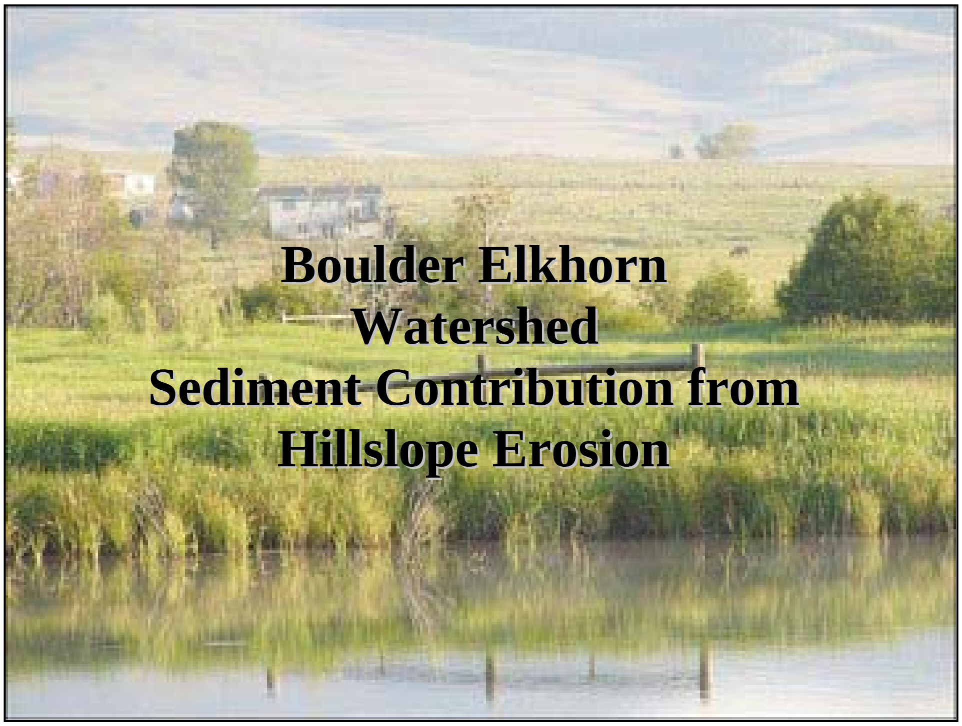

Boulder Elkhorn Watershed Sediment Contribution from Hillslope Erosion

Prepared For:

Montana Department of Environmental Quality
P.O. Box 200901
Helena, MT 59620-0901

Attn: Jim Bond

March 22, 2011

Prepared By:

CONFLUENCE incorporated

P.O. Box 1133
Bozeman, MT 59771-1133
406-585-9500
www.confluenceinc.com

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1.0 SEDIMENT CONTRIBUTION FROM HILLSLOPE EROSION

1.1 Introduction

Upland sediment loading due to hillslope erosion was modeled using the Universal Soil Loss Equation (USLE) and sediment delivery to the stream was predicted using a sediment delivery ratio. This model provided an assessment of existing sediment loading from upland sources and an assessment of potential sediment loading through the application of Best Management Practices (BMPs). The BMPs evaluated assumed modifications in upland management practices as well as improvements within the riparian buffer zone. When reviewing the results of the upland sediment load model, it is important to note that a significant portion of the sediment load is the “natural upland load” and not affected by the application of BMPs to the upland management practices.

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

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

where soil loss (A) is a function of the rainfall erosivity index (R), soil erodibility factor (K), overland flow slope and length (LS), crop management factor (C), and conservation practice factor (P) (Wischmeier and Smith 1978, Renard et al. 1997). USLE was selected for the Boulder Elkhorn watershed due to its relative simplicity and ease in parameterization and the fact that it has been integrated into a number of other erosion prediction models. These include: (1) the Agricultural Nonpoint Source Model (AGNPS), (2) Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS), (3) Erosion Productivity Impact Calculator (EPIC), (4) Generalized Watershed Loading Functions (GWLF), and (5) the Soil Water Assessment Tool (SWAT) (Doe, 1999). A detailed description of the general USLE model parameters is presented below.

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

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

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

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

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

The **P-factor** 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 (up-slope down-slope) farming practices with that of certain agriculturally based conservation practices.

1.2 Modeling Approach

Sediment delivery from hillslope erosion was estimated using a Universal Soil Loss Equation (USLE) based model to predict soil loss along with a distance and riparian health based sediment delivery ratio (SDR) to predict sediment delivered to the stream. This USLE based model is implemented as a watershed scale, grid format, GIS model using ArcView v 9.2 GIS software.

Desired results from the modeling effort include the following: (1) annual sediment load from each of the water quality limited segments on the state's 303(d) list, (2) the mean annual source distribution from each land category type, (3) annual potential sediment load from each of the water quality limited segments on the state's 303(d) list after the application of riparian buffer zone management BMPs, (4) annual potential sediment load from each of the water quality limited segments on the state's 303(d) list after the application of upland management BMPs, and (5) annual potential sediment load from each of the water quality limited segments on the state's 303(d) list after the application of riparian buffer zone management BMPs and upland management BMPs. Based on these considerations, a GIS- modeling approach (USLE) was formulated to facilitate database development and manipulation, provide spatially explicit output, and supply output display for the modeling effort.

1.3 Modeling Scenarios

Four management scenarios were evaluated for the Boulder Elkhorn watershed. They 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.

Erosion was differentiated into two source categories for each scenario: (1) natural erosion that occurs on the time scale of geologic processes and (2) anthropogenic erosion that is accelerated by human-caused activity. A similar classification is presented as part of the National Engineering Handbook Chapter 3 – Sedimentation (USDA, 1983). Differentiation is necessary for TMDL planning. Land cover categories considered to be affected by human-caused activity and therefore affected by BMPs within the Boulder Elkhorn watershed were developed (open space), developed (low intensity), developed (medium intensity), developed (high intensity), pasture/hay, grasslands/herbaceous, shrub/scrub, cultivated crops, and transitional (logging). All other land cover categories were considered to have “natural erosion.”

Well vegetated riparian buffers have been shown to act as filters that help to remove sediment from overland flow. In general, the effectiveness of vegetated riparian buffers is proportional to their width and overall health. A riparian health assessment was completed by the Montana Department of Environmental Quality (DEQ) for the Boulder Elkhorn Watershed. The DEQ riparian health assessment is used here to estimate further reduction in the quantity of eroded sediment that is ultimately delivered to the streams. These riparian areas are also considered to be affected by human-caused activity and are therefore subject to improved riparian health management.

1.4 Data Sources

The USLE model was parameterized using a number of published data sources. These include information from: (1) U.S. Geological Survey (USGS), (2) Spatial Climate Analysis Service (SCAS), and (3) Soil Conservation Service (SCS). Additionally, local information regarding specific land cover was acquired from the U.S. Forest Service (USFS) and the Natural Resource Conservation Service (NRCS). Specific GIS coverages used in the modeling effort included the following:

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

Polygon data of the **K-factor** were obtained from the NRCS General Soil Map (STATSGO) database and the NRCS Soil Survey Geographic (SSURGO) database. The USLE K factor is a standard component of the STATSGO soil survey, but has not been included for all polygons in the SSURGO soil survey. SSURGO data has higher resolution and is more current than the STATSGO dataset, however, the SSURGO data for the Boulder Elkhorn watershed did not contain the required K-factor for the entire watershed. STATSGO data was used to fill in the blanks. Soils polygon data were summarized and interpolated to grid format.

The **LS-factor** was derived from 30m USGS digital elevation model (DEM) grid data, interpolated to a 10m pixel. This factor is calculated within the model.

The **C-factor** was estimated using the National Land Cover (NLCD) dataset and using C-factor interpretations provided by the NRCS with input from MT DEQ. C-factors are intended to be conservatively representative of conditions in the Boulder Elkhorn watershed.

The **P-factor** was set to one, as per previous communication with the NRCS State Agronomist who suggested that this value is the most appropriate representation of current management practices in the Boulder Elkhorn watershed.

The **sediment delivery ratio** was derived by 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. This relationship was established by Megehan and Ketcheson (1996).

The **riparian health factor** was derived from a riparian health assessment completed by DEQ. Riparian health ratings of good, moderately good, fair, moderately fair, and poor were assigned according to the professional judgment of the assessment team. The percent of each sub-basin's area falling in each category was reported.

1.5 Modeling Methods

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

Specific parameterization of the USLE factors was performed as follows:

1.5.1 Sub-basins

The Boulder Elkhorn watershed boundary and the sub-basin boundaries were defined using the USGS 6th code Hydrologic Unit Codes (HUC). High Ore Creek, McCarty Creek, Nursery Creek, and Uncle Sam Gulch are 303(d) listed streams that were not represented in the 6th code HUCs. These sub-basins were cut from the larger HUC sub-basins using USGS topography as a guide to drainage divides. Additionally, the Elkhorn Creek sub-basin was divided into an upper and lower sub-basin, above and below Wood Gulch respectively.

Overall, the Boulder River watershed was divided into 4 sections: headwaters to Basin Creek (Headwaters), Basin Creek to the town of Boulder (Upper), the town of Boulder to Cottonwood Creek (Middle), and Cottonwood Creek to the mouth (Lower). The division between these sections coincided with HUC sub-basin boundaries except between the Upper and Middle sections. This division was made using the USGS topography as a guide.

Figure 1-1. Sub-basin polygons for the Boulder Elkhorn Watershed.

1.5.2 Boulder Elkhorn Watershed DEM

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

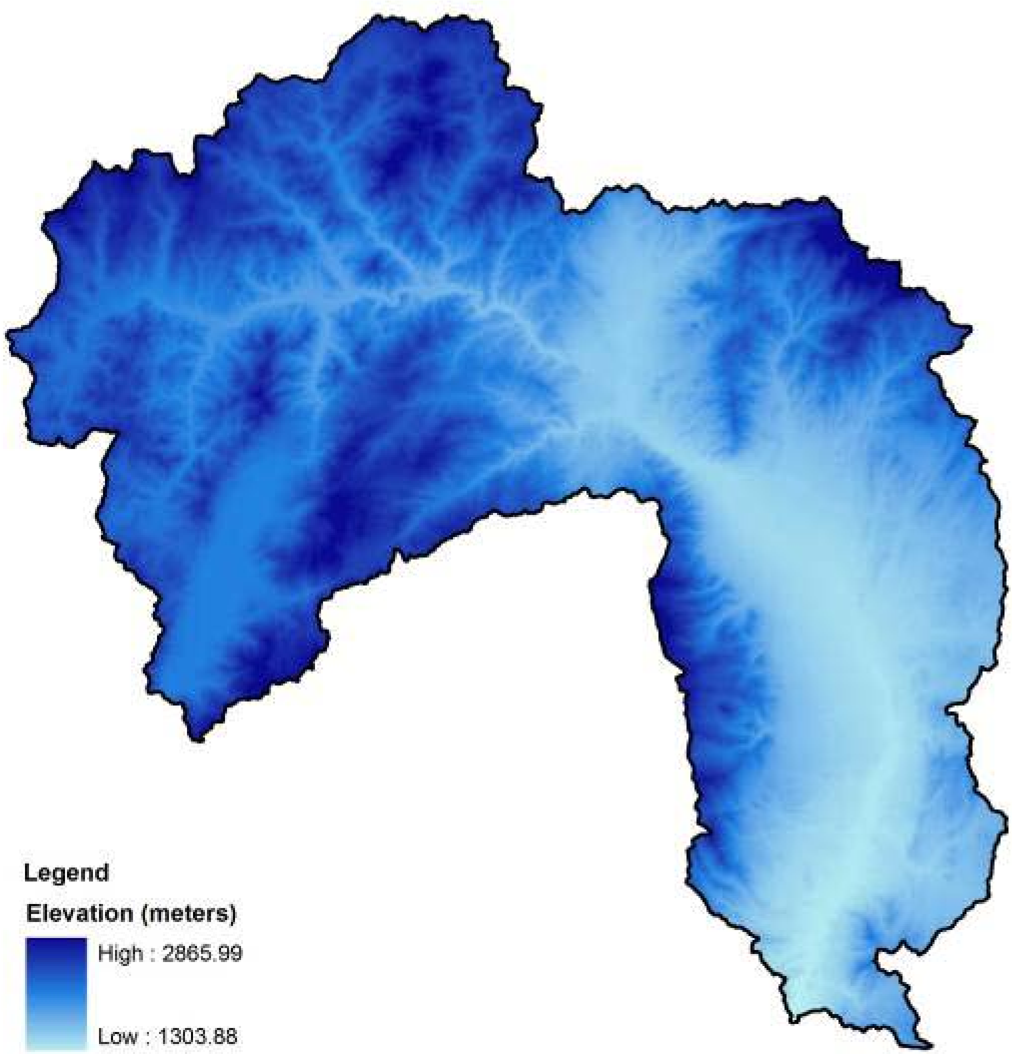

Figure 1-2. Digital Elevation Model (DEM) of the Boulder Elkhorn Watershed Prepared for Hydrologic Analysis.

1.5.3 Boulder Elkhorn Watershed Flow Network

The stream network for the watershed was derived from the 10m DEM, using hydrologic analysis methods developed by the Utah State University Hydrology Research Group, and implemented in the TauDEM (**T**errain **A**nalysis **U**sing **D**igital **E**levation **M**odels) software. These tools prepare a hydrologically correct surface from standard DEM data, filling errant sinks and ensuring positive drainage toward defined pour points. From this surface, a stream network is derived by calculating the watershed area for each pixel in the DEM, and assigning to the stream network those pixels that exceed a specified accumulation area threshold. The threshold is watershed specific, and is chosen in a manner whereby the resulting stream network satisfies the key elevation scaling laws (constant drop property and power law scaling of slope with area) that differentiate concentrated flow processes (channel erosion and transport) from the diffusive processes that characterize hillslope transport of sediment.

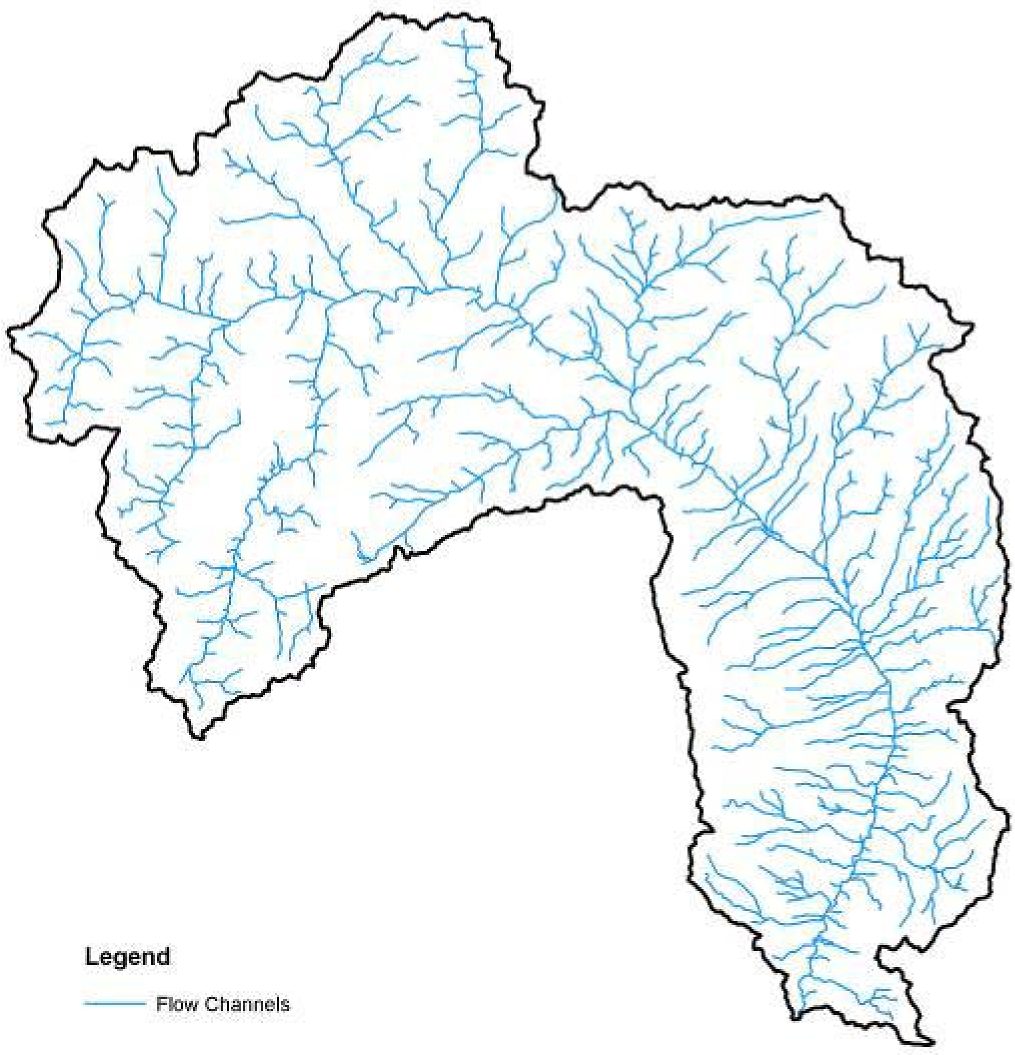

Figure 1-3. Flow network for the Boulder Elkhorn Watershed.

1.5.4 R-Factor

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

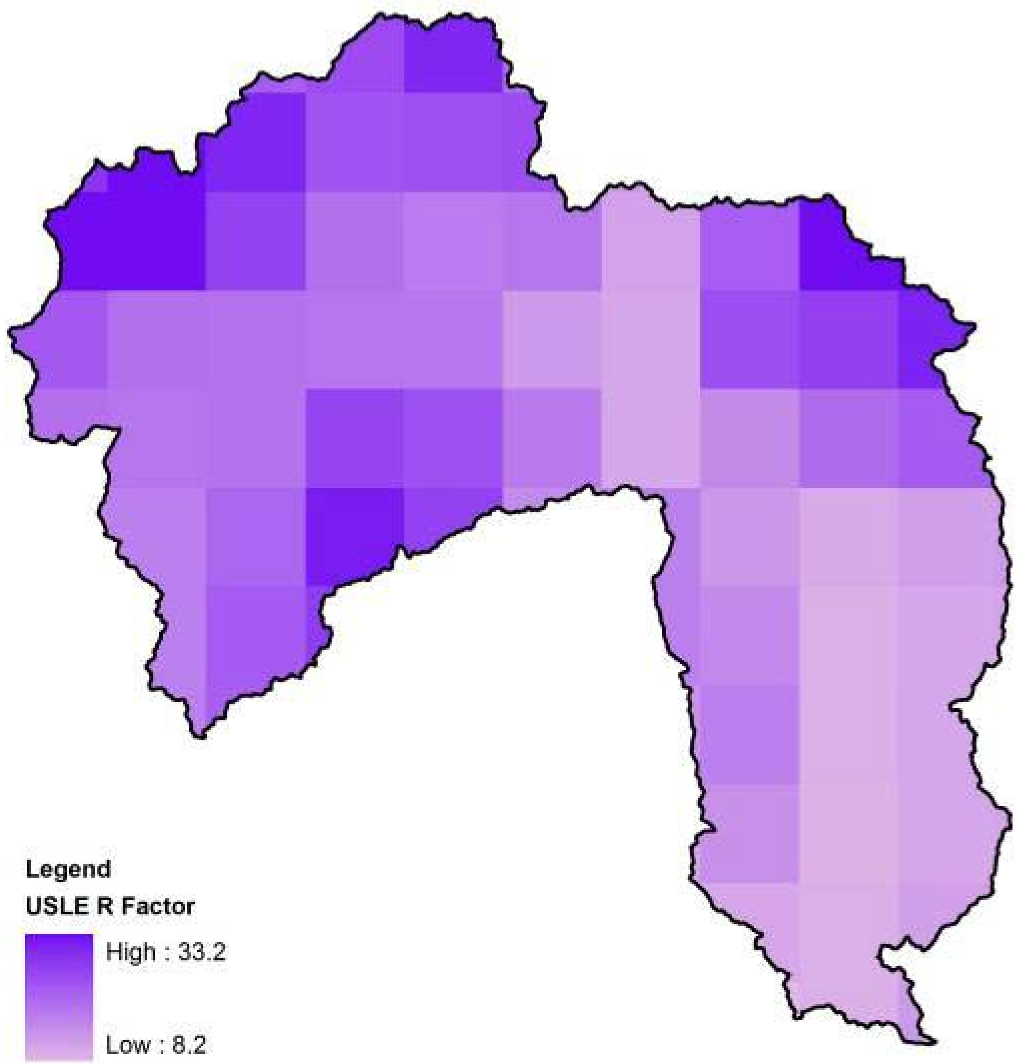

Figure 1-4. ULSE R-factor for the Boulder Elkhorn Watershed.

1.5.5 K-Factor

The soil erodibility factor grid was compiled from the 1:250K STATSGO and SSURGO data, as published by the NRCS. SSURGO data has higher resolution and is more current than the STATSGO dataset, however, the SSURGO data for the Boulder Elkhorn watershed did not contain the required K-factor for the entire watershed. STATSGO data was used to fill in the blanks. STATSGO and SSURGO database tables were queried to calculate a component weighted K value for all surface layers, which was then summarized by individual map unit. The map unit K values were then joined to a GIS polygon coverage of the map units, and the polygon coverage was converted to a 10m analytic grid for use in the model.

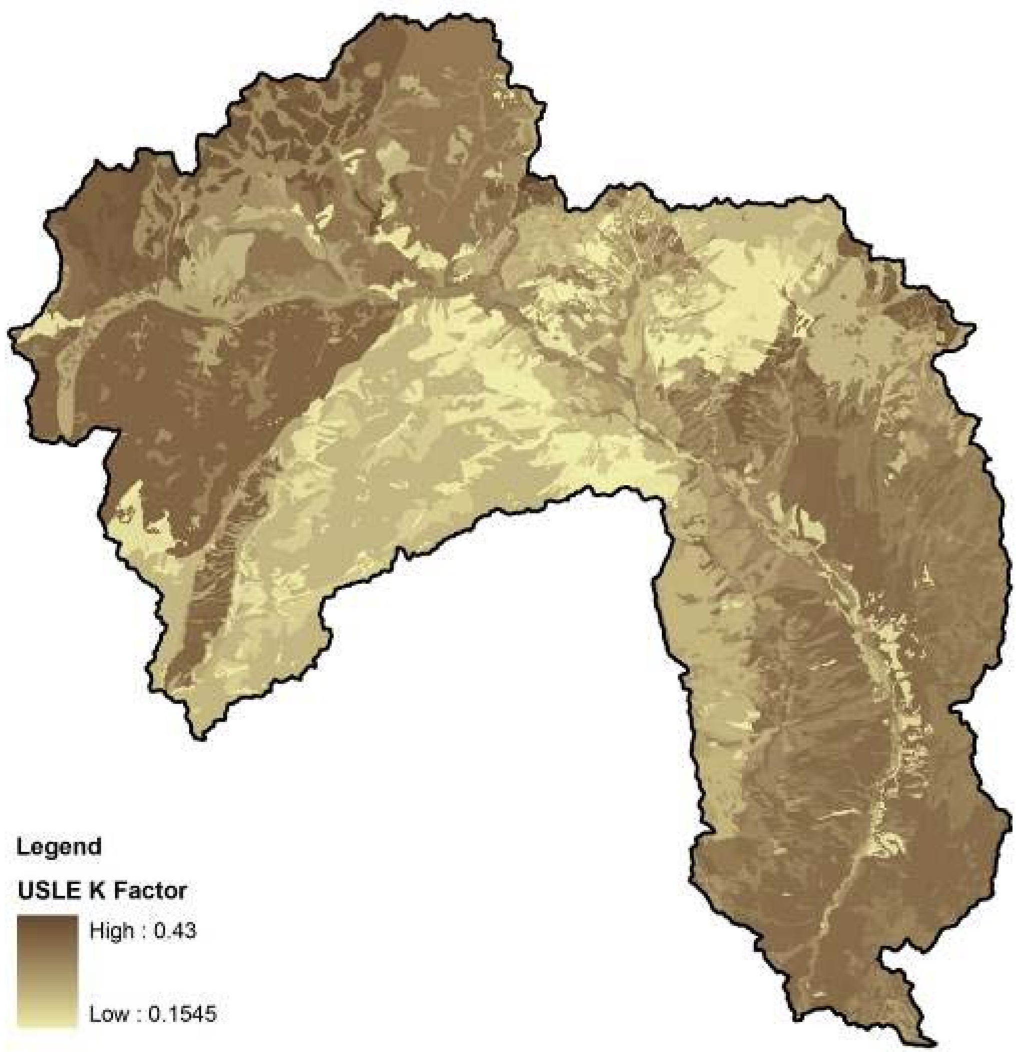

Figure 1-5. ULSE K-factor for the Boulder Elkhorn Watershed

1.5.6 LS-Factor

The equation used for calculating the slope length and slope factor was that given in the updated definition of RUSLE, as published in USDA handbook #703:

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

Where:

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

S_i = slope steepness factor for the ith segment.
$= 10.8 \sin\theta + 0.03$ for $\theta < 9\%$
$= 16.8 \sin\theta - 0.50$ for $\theta \geq 9\%$

m = a variable slope-length exponent.
$= \beta / (1 + \beta)$

and

B = ratio of rill to interrill erosion.
$= (\sin\theta / 0.0896) / [3.0 (\sin\theta)^{0.8} + 0.56]$

θ = slope angle as calculated by GIS based surface analysis procedures from the Boulder Elkhorn watershed DEM.

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

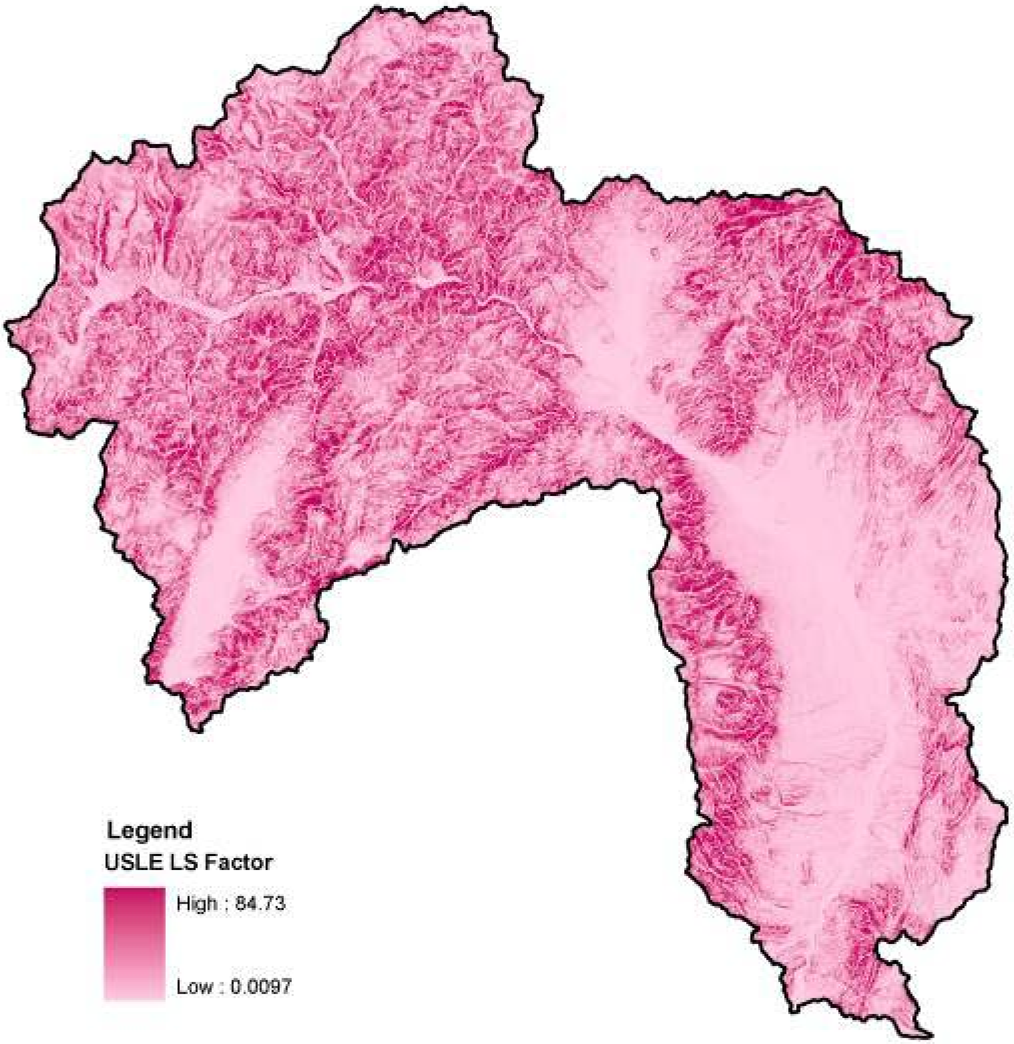

Figure 1-6. ULSE LS-factor for the Boulder Elkhorn Watershed

1.5.7 NLCD

The 2001 National Land Cover Dataset (NLCD) was obtained from USGS for use in establishing USLE C-factors for the Boulder Elkhorn watershed. The 2001 NLCD is the most current NLCD for the project are, and is a categorized 30 meter Landsat Thematic Mapper image shot in 2001. The NLCD image was reprojected to Montana State plane projection/coordinate system, and resampled to the project standard 10m grid. NLCD land cover classification codes for areas present in the Boulder Elkhorn watershed are described as follows:

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.

82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

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.

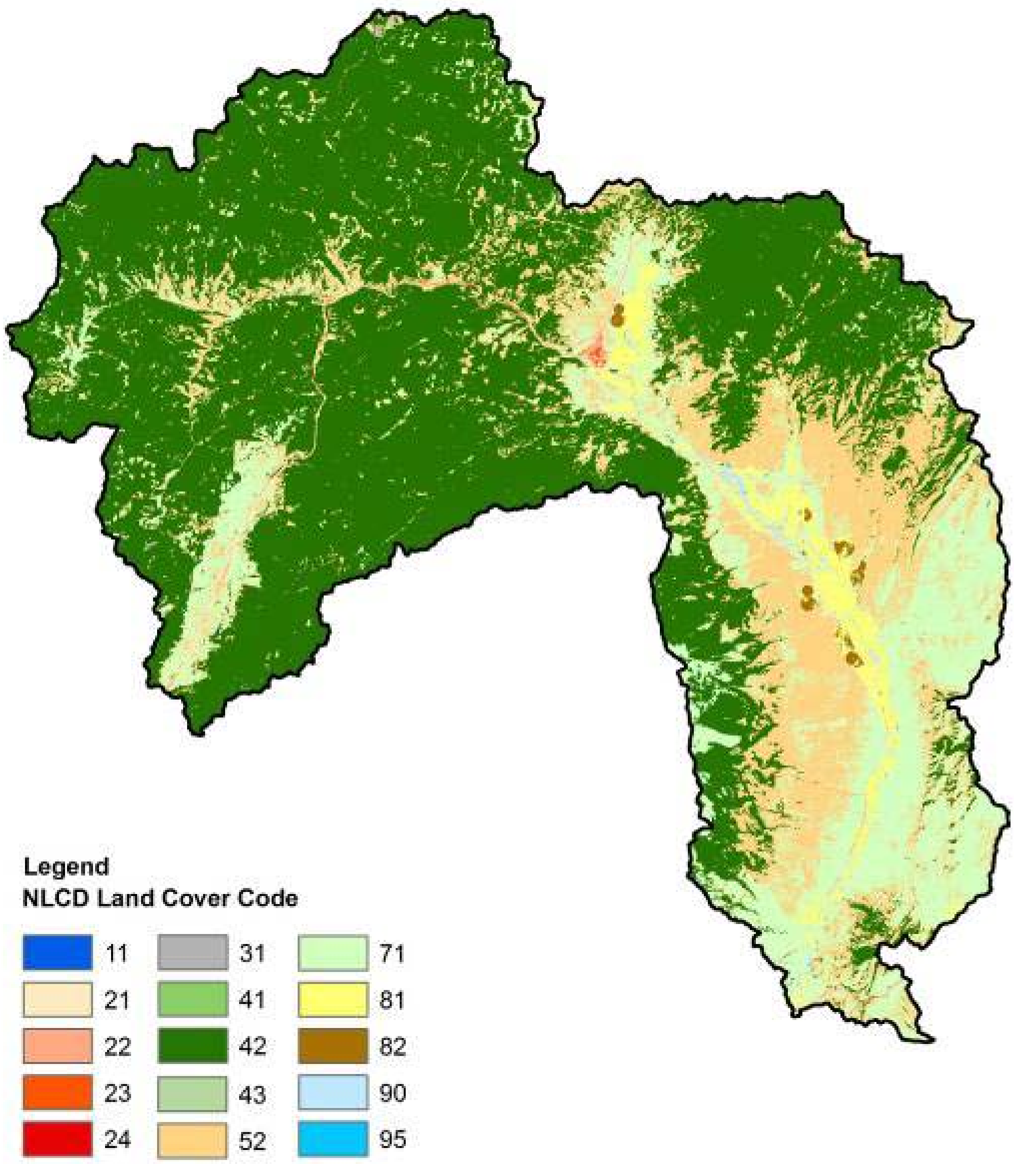

Figure 1-7. NLCD Landcover for the Boulder Elkhorn Watershed.

1.5.8 Logging and Fire Adjustment

In general, the land use classification of the NLCD was accepted as is, without ground truthing of original results or correction of changes that may have occurred since the NLCD image was shot. Given that we are looking for watershed and sub-watershed scale effects, the relative simplicity of the land use mix in the Boulder Elkhorn watershed, and the relative stability of that land use over the 10 years since the Landsat image that the NLCD is based on was taken, this was considered to be a reasonable assumption. One adjustment to the NLCD is necessary and appropriate, however. That is to quantify the amount of logging or fires that has occurred since 2001, and to also identify previously disturbed areas that are reforesting over that same period. As with other land uses in the valley, logging is a stable land use, but it is a land use that causes a land cover change that may affect sediment production.

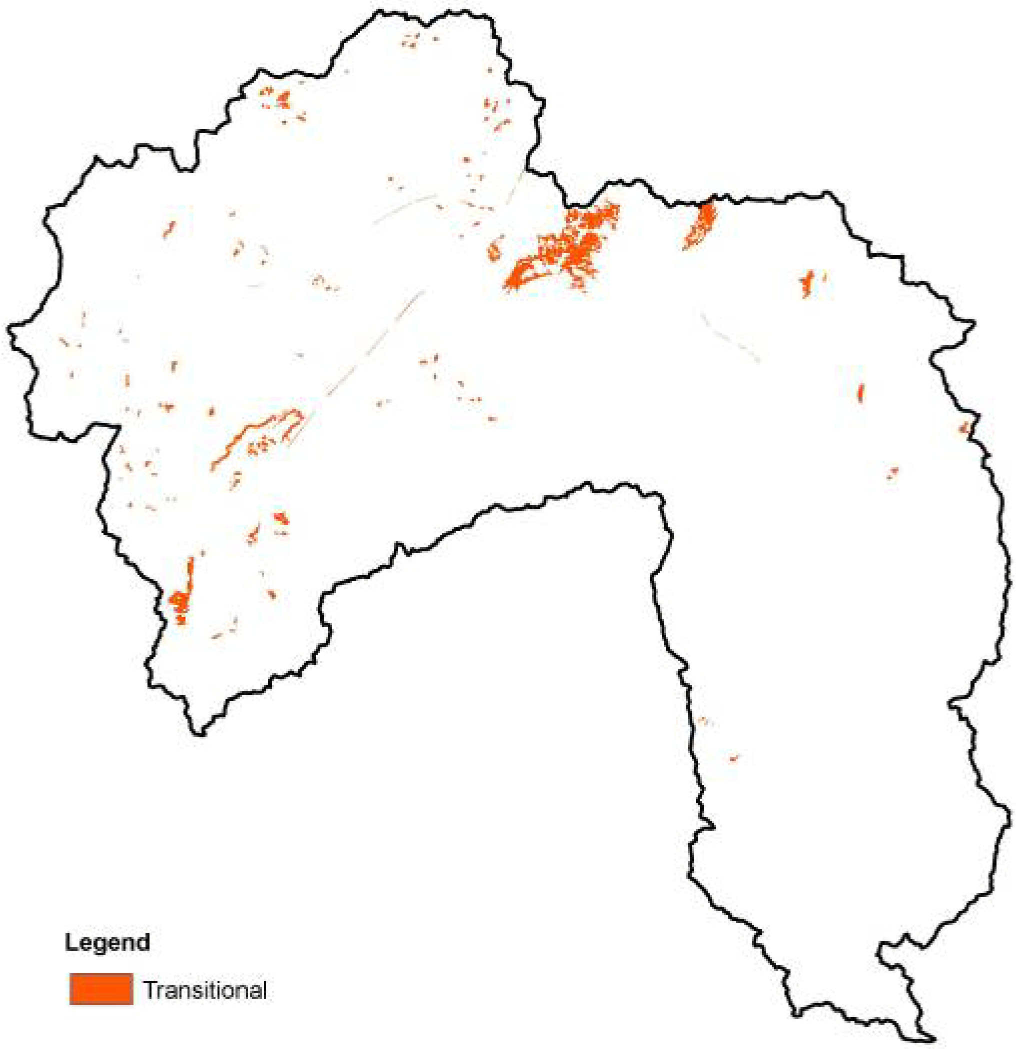

Figure 1-8. Transitional areas for the Boulder Elkhorn Watershed.

Adjustment for logging was accomplished by using fire and harvest record polygons provided by the U.S. Forest Service. Polygons with a harvest or fire date of 2001 or later were selected. There was a large fire north of the town of Boulder in 2000 that was also selected. Additionally, adjustment for logging was accomplished by comparing the 2001 NLCD grid for the Boulder Elkhorn Watershed with the 2009 NAIP aerial photography. Areas which were coded as a forest type (41, 42 or 43) on the NLCD were digitized and coded as Type 1 (logged) if they appeared to be other than forested (typically bare ground, grassland, or shrubland) on the NAIP photos, there were indications of logging activity (proximity to forest or logging roads, appearance of stands, etc), and they were located on non-USFS property. Conversely, areas which were coded something other than forest on the NLCD and appeared to have significant tree coverage on the NAIP photos were digitized and coded as Type 2 (regrowth). These areas were then grouped together into a transitional land cover category.

1.5.9 C-Factor Derivation

For purposes of the base (existing conditions) scenario, the following scheme of reclassification was used to derive annualized USLE C-factors from the NLCD land cover classes present in the Boulder Elkhorn watershed.

This reclassification is based on the NRCS table "C-Factors for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland" and was developed with the assistance and input of local NRCS employees. A narrative description of the professional judgment involved in the selection of these factors and the NRCS table are provided in Attachment A.

To estimate the potential reduction in sediment production that might be accomplished under the desired conditions scenario (application of best management practices), the model was re-run using a different C-factor reclassification scheme. Relative to the existing conditions C-factor scheme, the BMP C-factor for the 'transitional' land classification was changed to reflect the forest cover that most such areas are transitioning to in the Boulder Elkhorn watershed. The 'grasslands/herbaceous', 'shrub/scrub', 'pasture/hay', 'woody wetlands' BMP C-factors were conservatively changed to reflect a 10 percent increase in ground cover over existing conditions. The 'cultivated crops' BMP C-factor was changed to reflect a 20 percent increase in ground cover over existing conditions. No change was applied to the other land use types within the Boulder Elkhorn watershed from the existing conditions scenario.

The C-factors for the two scenarios are presented in **Table 1-1**.

Table 1-1 C-factors in the Boulder Elkhorn watershed.

NLCD Code	Description	C-Factor Existing Condition	C-Factor Desired Condition	Percent of Watershed
42	Evergreen forest	0.003	0.003	58.1%
52	Shrub/scrub	0.020	0.010	19.5%
71	Grassland/herbaceous	0.020	0.010	17.7%
81	Pasture/Hay	0.020	0.010	2.7%
N/A	Transitional	0.006	0.003	1.5%
21	Developed, open space	0.003	0.003	0.8%
90	Woody Wetlands	0.013	0.006	0.5%
82	Cultivated Crops	0.200	0.100	0.3%
22	Developed, low intensity	0.001	0.001	0.3%
23	Developed, medium intensity	0.001	0.001	0.1%
31	Barren land	0.001	0.001	0.03%
43	Mixed forest	0.003	0.003	0.02%
41	Deciduous forest	0.003	0.003	0.01%
24	Developed, high intensity	0.001	0.001	0.001%
95	Emergent Herbaceous Wetlands	0.003	0.003	0.001%

Table 1-2 Changes in percent ground cover for land cover types between existing and improved management conditions.

Land Cover	Existing % Ground Cover	Improved % Ground Cover
Shrub/scrub	75	85
Grasslands/Herbaceous	75	85
Pasture/Hay	75	85
Transitional	90	95-100
Woody Wetlands	80	90
Cultivated Crops	20	40

1.5.10 Riparian Health Assessment

Well vegetated riparian buffers have been shown to act as filters that remove sediment from overland flow. Because of this ability, the influence of riparian corridors on water quality is proportionately much greater than the relatively small area in the landscape they occupy. In general, the effectiveness of vegetated riparian buffers is proportional to their width and overall health. Thus, information regarding riparian zone health can be used to refine estimates of sediment delivery to streams from upstream sources. This section describes a riparian corridor quality assessment of the Boulder Elkhorn Watershed.

1.5.10.1 DEQ Riparian assessment

The riparian corridor quality assessment was provided by DEQ. The assessment was based on the results of the DEQ aerial assessment and reach delineation. 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 corridor condition was estimated using aerial photos, field notes, and best professional judgment. DEQ designated riparian corridor as having poor, moderately poor, fair, moderately good, or good quality. These determinations were made with consideration of adjacent land use, stream-side vegetation, and the presence or absence of human activities. The cumulative length of the reaches within each category was then tallied for each stream, and the percent of the length of stream in each category was calculated.

The results of the riparian corridor quality assessment from DEQ for the sub-basins are shown in **Table 1-3**.

Table 1-3 Percent of stream length in each riparian quality category.

Sub-basin	**Existing Conditions**					**BMP Conditions**				
	Good	**Moderately Good**	**Fair**	**Moderately Fair**	**Poor**	**Good**	**Moderately Good**	**Fair**	**Moderately Fair**	**Poor**
Basin Creek	32	66	0	0	2	98	0	2	0	0
Bison Creek	0	0	0	97	3	0	97	3	0	0
Boulder River Headwaters	10	0	90	0	0	100	0	0	0	0
Boulder River Upper	0	0	46.5	46.5	7	0	93	7	0	0
Boulder River Middle	0	0	81	0	19	28.4	52.6	19	0	0
Boulder River Lower	1	0	99	0	0	35.6	64.4	0	0	0
Cataract Creek	27	72	0	0	1	99	0	1	0	0
Elkhorn Creek Upper	24	0	71	0	5	95	0	5	0	0
Elkhorn Creek Lower	0	47	47	0	6	30.6	63.4	6	0	0
High Ore Creek	20	0	71	0	9	91	0	9	0	0
Little Boulder River	44	56	0	0	0	100	0	0	0	0
N.F. Little Boulder River	76	24	0	0	0	100	0	0	0	0
Lowland Creek	5	0	33.5	33.5	28	72	0	28	0	0
McCarty Creek	37	0	61	0	2	58.4	39.6	2	0	0
Muskrat Creek	41	0	0	59	0	41	59	0	0	0
Nursery Creek	0	100	0	0	0	65	35	0	0	0
Uncle Sam Gulch	26	74	0	0	0	100	0	0	0	0

1.5.11 Distance and Riparian Health Based Sediment Delivery Ratio

The USLE model upon which this model is founded is, as its name states, a soil loss (i.e. sediment production) model. Soil lost from one area due to erosive processes is typically redeposited a short distance downslope however, and most sediment produced from a hillslope erosion event does not travel so far as to be delivered to a stream channel. As TMDL questions deal specifically with sediment delivered to the stream, a method of accounting for redeposition and ultimate delivery to streams is required.

With USLE based models, this accounting of sediment redeposition is typically achieved through the application of a *sediment delivery ratio (SDR)*, a factor that estimates the percentage of sediment produced that is ultimately delivered to the stream. We apply a distance based sediment delivery ratio that reflects the relationship between downslope travel distance and ultimate sediment delivery.

Given that riparian zones can be effective sediment filters when wide and well vegetated, that riparian zone health is susceptible to anthropogenic impacts and thus to land management decisions, and that the effectiveness of riparian zones as sediment filters has been quantified in the literature, we incorporate riparian zone health and its effect on sediment delivery into our distance based sediment delivery ratio.

1.5.11.1 Distance based SDR

Megahan and Ketcheson (1996) found that the relationship between the percentage (by volume) of a sediment mass that travels a given percentage of the maximum sediment travel distance of that sediment mass is as shown in **Figure 1-9**.

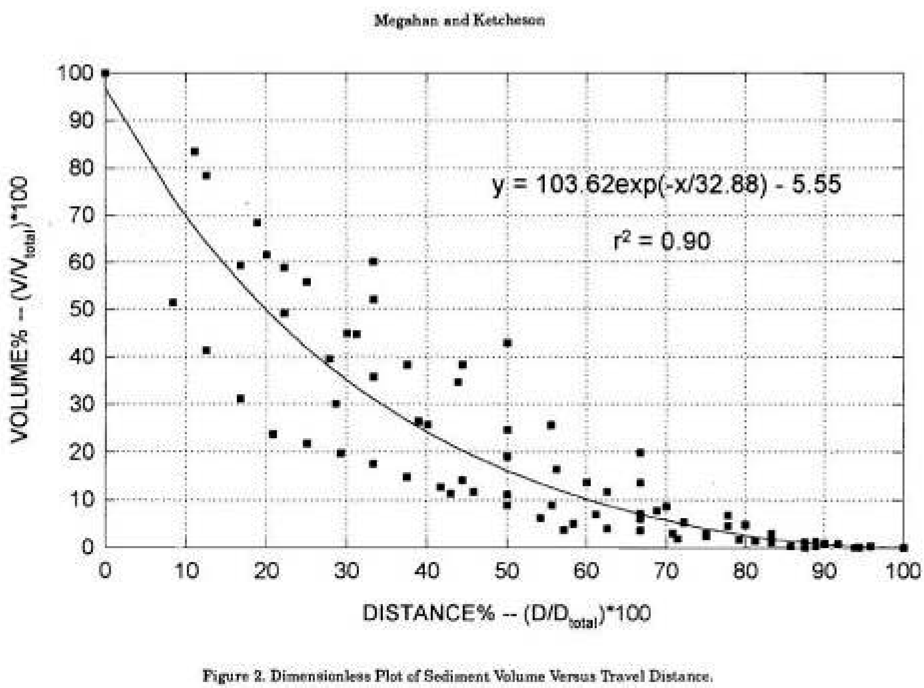

Figure 1-9. Figure 2 from Megahan and Ketcheson (1996), a dimensionless plot of sediment volume vs. travel distance.

This relationship was derived from a dataset of approximately 100 observations of sediment transport downslope from a known source (forest roads) that was not intercepted by a stream. It thus represents the 'typical' transport distribution along the maximum transport distance under a variety of field conditions.

Megahan and Ketcheson's logarithmic regression of the data permits this relationship to be expressed by the equation presented in Figure 1-8, which may be restated as a function of three variables:

*Volume % = 103.62*EXP(-((D/Dtotal)/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 this equation is dimensionless, to serve as an SDR it must first be scaled to the field conditions of the study area. This is accomplished by evaluating the equation with site specific values for D and Volume% at a single point, and solving for Dtotal. Having established a site specific Dtotal, the M&K equation reduces to two unknowns, the two variables that define a distance based SDR: distance and percent sediment delivered beyond that distance. This SDR may be used to estimate sediment delivery at all points on the sediment delivery path, from streambank to a distance Dtotal.

The derivation of site specific values of D and Volume % for use in scaling Megahan and Ketcheson's dimensionless equation is presented in section 1.5.11.2

1.5.11.2 Sub-basin 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 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 1.5.11.1) for use in predicting percent delivery from other distances.

Literature review (Wegner 1999, Knutson and Naef 1997) indicates that a 100 foot wide, well vegetated riparian buffer zone can be expected to filter 75-90% of incoming sediment from reaching its stream channel. Accordingly, this analysis conservatively assumes that a sediment reduction efficiency of 75% represents the performance of a 100 foot wide, high quality (good) vegetated riparian buffer in the Boulder Elkhorn watershed. Conversely, this analysis conservatively assumes that a 100 foot wide riparian zone without vegetation cover would only filter 10% of incoming sediment from reaching its stream. An approximately equal apportionment of the remaining range in sediment reduction efficiency between the 'poor', 'moderately fair, 'fair', and 'moderately good' riparian assessment categories results in the riparian health/sediment delivery relationship shown in **Figure 1-10**.

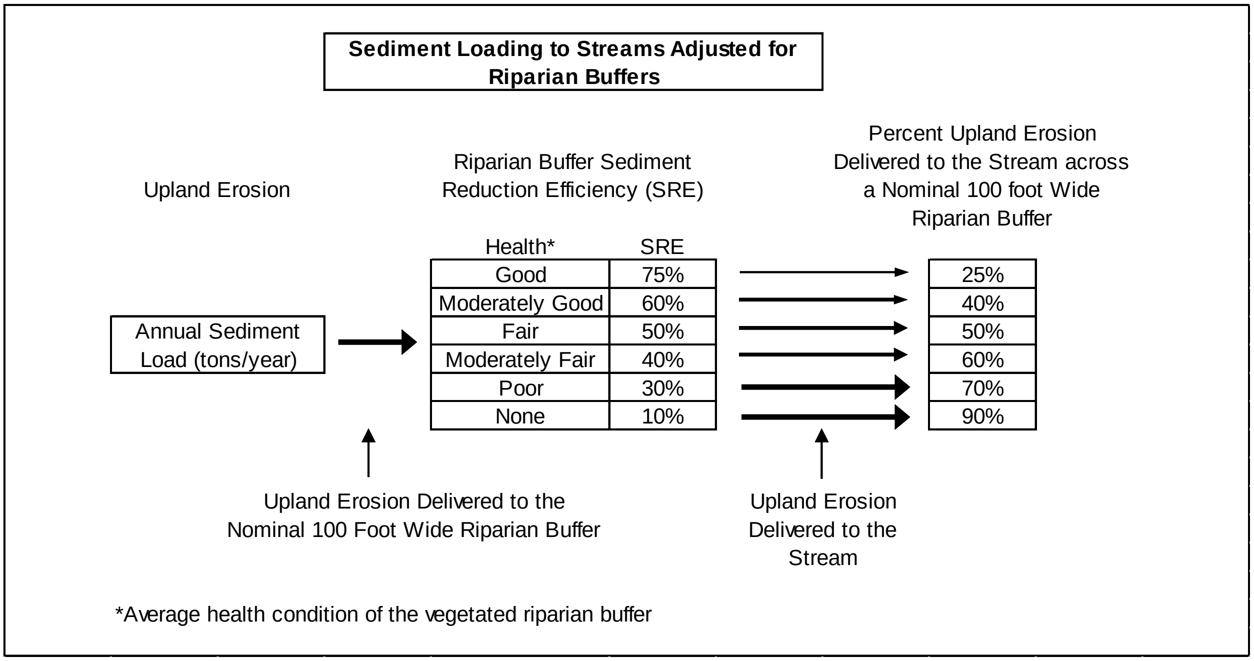

Figure 1-10. USLE Upland Sediment Load Delivery Adjusted for Riparian Buffer Capacity

Applying this relationship to the Boulder Elkhorn riparian assessment, we computed a riparian health score based sediment reduction percentage for each sub-basin of interest. This represents the percent reduction in delivery of sediment from a nominal 100 foot wide riparian zone. This was accomplished by taking the percentage of the stream length in each of the five riparian health classes, multiplying by the assumed sediment delivery efficiency reduction for each class (75% for good quality, 60% for moderately good quality, 50% for fair quality, 40% for moderately fair quality, and 30% for a poor quality) and summing for each stream.

The riparian health assessment based Sediment Reduction Percentage computed for each sub-basin of interest is presented in **Table 1-4.** Values are presented for both the existing conditions scenario and a BMP scenario. Under the BMP scenario, it is assumed that the implementation of BMPs on those activities that affect the overall health of the vegetated riparian buffer will increase an area with poor quality riparian health to fair quality. The increase for areas with an existing riparian health quality of better than poor varies for each sub-basin depending on the potential for improvement as determined by DEQ.

Table 1-4 Sediment reduction percentage based on riparian health assessment.

Sub-Basin	Riparian Quality	Percent of TMDL Stream Length for Existing Conditions	Weighted Sediment Reduction Percentage Existing Conditions	Percent of TMDL Stream Length for BMP Conditions	Weighted Sediment Reduction Percentage BMP Conditions	Change in Sediment Reduction Percentage	BMP Conditions
Bison Creek	Good						-Mod. Fair to Mod. Good -Poor to Fair
	Mod. Good			97	58.2		
	Fair			3	1.5		
	Mod. Fair	97	38.8				
	Poor	3	0.9				
	Total		**39.7**		**59.7**	**20.0**	
Lowland Creek	Good	5	3.8	72	54.0		-Fair to Good -Mod. Fair to Good -Poor to Fair
	Mod. Good						
	Fair	33.5	16.8	28	14.0		
	Mod. Fair	33.5	134				
	Poor	28	8.4				
	Total		**42.3**		**68.0**	**25.7**	
Boulder River Headwaters	Good	10	7.5	100	75.0		-Fair to Good
	Mod. Good						
	Fair	90	45.0				
	Mod. Fair						
	Poor						
	Total		**52.5**		**75.0**	**22.5**	
Basin Creek	Good	32	24.0	98	73.5		-Mod. Good to Good -Poor to Fair
	Mod. Good	66	39.6				
	Fair			2	1.0		
	Mod. Fair						
	Poor	2	0.6				
	Total		**64.2**		**74.5**	**10.3**	
Uncle Sam Gulch	Good	26	19.5	100	75.0		-Mod. Good to Good
	Mod. Good	74	44.4				
	Fair						
	Mod. Fair						
	Poor						
	Total		**63.9**		**75.0**	**11.1**	
Cataract Creek	Good	27	20.3	99	74.3		-Mod. Good to Good -Poor to Fair
	Mod. Good	72	43.2				
	Fair			1	0.5		
	Mod. Fair						
	Poor	1	0.3				
	Total		**63.8**		**74.8**	**11.0**	
High Ore Creek	Good	20	15.0	91	68.3		-Fair to Good -Poor to Fair
	Mod. Good						
	Fair	71	35.5	9	4.5		
	Mod. Fair						
	Poor	9	2.7				
	Total		**53.2**		**72.8**	**19.6**	

Table 1-4 Sediment reduction percentage based on riparian health assessment (continued).

Sub-Basin	Riparian Quality	Percent of TMDL Stream Length for Existing Conditions	Weighted Sediment Reduction Percentage Existing Conditions	Percent of TMDL Stream Length for BMP Conditions	Weighted Sediment Reduction Percentage BMP Conditions	Change in Sediment Reduction Percentage	BMP Conditions
Boulder River Upper	Good			93	55.8		-Fair to Mod. Good -Mod. Fair to Mod. Good -Poor to Fair
	Mod. Good						
	Fair	46.5	23.3	7	3.5		
	Mod. Fair	46.5	18.6				
	Poor	7	2.1				
	Total		**44.0**		**59.3**	**15.4**	
N. F. Little Boulder River	Good	76	57.0	100	75.0		-Mod. Good to Good
	Mod. Good	24	14.4				
	Fair						
	Mod. Fair						
	Poor						
	Total		**71.4**		**75.0**	**3.6**	
Little Boulder River	Good	44	33.0	100	75.0		-Mod. Good to Good
	Mod. Good	56	33.6				
	Fair						
	Mod. Fair						
	Poor						
	Total		**66.6**		**75.0**	**8.4**	
Nursery Creek	Good			65	48.8		-65% Mod. Good to Good
	Mod. Good	100	60.0	35	21.0		
	Fair						
	Mod. Fair						
	Poor						
	Total		**60.0**		**69.8**	**9.8**	
Muskrat Creek	Good	41	30.8	41	30.8		-Mod. Fair to Mod. Good
	Mod. Good			59	35.4		
	Fair						
	Mod. Fair	59	23.6				
	Poor						
	Total		**54.4**		**66.2**	**11.8**	
McCarty Creek	Good	37	27.8	58.4	43.8		-35% Fair to Good -65% Fair to Mod. Good -Poor to Fair
	Mod. Good			39.7	23.8		
	Fair	61	30.5	2	1.0		
	Mod. Fair						
	Poor	2	0.6				
	Total		**58.9**		**68.6**	**9.7**	
Elkhorn Creek Upper	Good	24	18.0	95	71.3		-Fair to Good -Poor to Fair
	Mod. Good						
	Fair	71	35.5	5	2.5		
	Mod. Fair						
	Poor	5	1.5				
	Total		**55.0**		**73.8**	**18.8**	

Table 1-4 Sediment reduction percentage based on riparian health assessment (continued).

Sub-Basin	Riparian Quality	Percent of TMDL Stream Length for Existing Conditions	Weighted Sediment Reduction Percentage Existing Conditions	Percent of TMDL Stream Length for BMP Conditions	Weighted Sediment Reduction Percentage BMP Conditions	Change in Sediment Reduction Percentage	BMP Conditions
Elkhorn Creek Lower	Good			30.5	22.9		-65% Mod. Good to Good -Fair to Mod. Good -Poor to Fair
	Mod. Good	47	28.2	63.5	38.1		
	Fair	47	23.5	6	3.0		
	Mod. Fair						
	Poor	6	1.8				
	Total		**53.5**		**64.0**	**10.5**	
Boulder River Middle	Good			28.4	21.3		-35% Fair to Good -65% Fair to Mod. Good -Poor to Fair
	Mod. Good			52.6	31.6		
	Fair	81	40.5	19	9.5		
	Mod. Fair						
	Poor	19	5.7				
	Total		**46.2**		**62.4**	**16.2**	
Boulder River Lower	Good	1	0.8	35.6	26.7		-35% Fair to Good -65% Fair to Mod. Good
	Mod. Good			64.4	38.6		
	Fair	99	49.5				
	Mod. Fair						
	Poor						
	Total		**50.3**		**65.3**	**15.0**	

1.5.11.3 Sediment Delivery Ratio - Example Calculation

To create a final, sub-basin specific SDR, Megahan and Ketcheson's dimensionless equation relating percent sediment volume to percent travel distance (**Figure 1-9**) was scaled to each sub-basin by using its riparian health assessment based 100 ft Sediment Reduction Percentage to derive a site specific maximum sediment travel distance. For each sub-basin, the following method was applied:

1 From the sub-basin's Riparian Health Assessment, determine the expected % sediment delivery across a nominal 100 foot wide riparian zone.

Example:
Per Table 1-4, the Bison Creek sub-basin's expected existing sediment delivery across a **100** foot wide riparian zone is (100% - 39.7% reduction) = **60.3%** delivered.

2 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 =

60.3% = 103.62exp(-((**100**/Dtotal)*100)/32.88) - 5.55

3 Solve the M&K equation for Dtotal to arrive at a representative maximum sediment travel distance for that sub-basin.

Example:
60.3% = 103.62exp(-((**100**/Dtotal)*100)/32.88) - 5.55

Dtotal = **100**/(-0.3288*ln((**60.3** + 5.55)/103.62))

Dtotal = **671** feet

4 Restate the M&K equation using the sub-basin's calculated maximum sediment travel distance (Dtotal) to arrive at an integrated Distance and Riparian Health based Sediment Deliver Ratio (SDR) for that sub-basin.

Example:
Within the Bison Creek sub-basin, 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/**671**)*100)/32.88) - 5.55

By this method, the Sediment Delivery Ratio for each analytical pixel in a Boulder Elkhorn watershed sub-basin is obtained by evaluating this equation:

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

Where:

SDR = the percentage 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 sub-basin specific Riparian Health derived maximum sediment travel distance.

1.5.12 Model Assumptions

The following assumptions are made, concerning the applicability and accuracy of the model with respect to the intended use of the results:

1. That the USLE model is sufficiently accurate for TMDL purposes. Discussion: The USLE model has been in widespread use for more than thirty years, and has been found to be sufficient for natural resources management decision making at the field scale.
2. That it is appropriate to extend the field scale USLE model to watershed scale. Discussion: Many watershed scale implementations of the USLE model have been developed and presented in the peer reviewed literature. This model is a similar gridded USLE implementation, and it faithfully executes the methodology specified in USDA Agriculture Handbook No. 703. It operates in field scale on a 10 meter

analytic pixel, and achieves watershed scale implementation through aggregation of field scale results.

3. That the data sources used are appropriate for USLE parameterization. Discussion: Data sources for USLE R and K factors were purpose built for that use. The USLE C factor is derived from Landsat thematic mapper imagery, classified by a rigorous process of peer reviewed methods into the NLCD landcover dataset. Specific assignment of C factors to landcover classes was performed under the guidance of natural resource professionals well versed in the application of USLE and USLE based sediment production models at the field scale. The USLE P factor was not used, as the best professional judgement of these same land managers is that the agricultural practices intended to be reflected by the USLE P factor are not in significant use in the Boulder Elkhorn watershed. The USLE L & S factors are mathematical constructs representing landform, and are derived here from Digital Terrain data. This analysis assumes that a 10 meter analytic pixel adequately describes the micro terrain slope and slope length at field scale. To the extent that this assumption is not met, results may deviate.
4. That the Riparian Health Assessment is of sufficient accuracy, resolution and coverage to serve as the basis for a sediment delivery ratio. Discussion: The Riparian Health Assessment only surveyed mainstem reaches. The condition of mainstem reaches is considered here to be broadly representative of overall watershed condition. To the extent that this assumption is not met, results may deviate proportionately.
5. That it is appropriate to use Megehan and Ketcheson's (1996) dimensionless equation relating sediment travel distance and delivered volume as the basis for a sediment delivery ratio. Discussion: Megehan and Ketcheson (1996) establishes that the purpose of the work is to provide an empirical alternative to process based modeling approaches for sediment delivery to streams. A decade later, Megehan and Ketcheson went on to produce the Washington Road Surface Erosion Model (WARSEM, 2004) which uses the Megehan and Ketcheson (1996) dimensionless equation as an SDR to account for delivery across fillslopes to streams. Here, we replicate Megehan and Ketcheson's use of the three variable dimensionless equation for the WARSEM SDR, evaluating that equation for a representative maximum sediment travel distance, and arriving at a scaled distance/sediment delivery relationship.

   A specific concern is that the Megehan and Ketcheson method, because it does not explicitly account for changes in vegetation as might be expected transitioning an upland/riparian zone boundary, may not adequately represent sediment delivery across a riparian zone. We note that whereas Megehan and Ketcheson used a single scaling of the dimensionless equation for all locations in an attempt to render the WARSEM model broadly applicable with minimum data collection needs, we take advantage of the available Boulder Elkhorn Riparian Health Assessment data to derive site-specific scalings of the dimensionless equation for Boulder Elkhorn sub-basins, based on riparian condition.

In this implementation, it is assumed that a significant difference in vegetation density between riparian and upland is unlikely to favor the upland, i.e. if there is a great difference, it is going to be a well vegetated near-stream zone paired with a sparsely vegetated upland. The most extreme instance of that would be reflected in this modeling approach as a 'good' riparian health category. For that category, we evaluate the dimensionless equation using the literature value of 75% sediment reduction at 100 feet, deriving a Dtotal value that may be used to estimate the percent sediment reduction at all distances. If failing to explicitly account for a significant change in vegetation produces a 'bust' in this procedure, it will be that it somewhat underestimates the sediment delivered from the upland portion of the delivery path. Given that:

- the maximum percent delivery for that portion of the path is 25%, declining to 0% at the outer bound, and
- that vegetation is only one component of the obstruction value, and
- that the obstruction value is only one of the factors predictive for sediment delivery,

we may conclude that the maximum effect of such a vegetation difference induced 'bust' is, in the most extreme case, some small fraction of 25%. Working down from that rare, most extreme case - if riparian condition and immediately adjacent upland condition are more similar, the potential magnitude of a 'bust' rooted in their difference becomes smaller as well. This places potential error in sediment due to the riparian transition well within the bounds of this effort.

6. That the uncalibrated watershed scale USLE model and sediment delivery ratio are sufficiently accurate for Boulder Elkhorn TMDL purposes. Discussion: The USLE is an empirical model developed initially for eastern US crop lands, but has been extended via revised C factors and other means to be more broadly applicable. The C factors used for this effort were chosen to be as representative of Boulder Elkhorn conditions as professional judgement allows. The Megehan and Ketcheson dimensionless equation was similarly developed as an empirical method for sediment delivery accounting in watersheds similar to the Boulder Elkhorn. The implementation of that SDR method used here is further fit to the Boulder Elkhorn project area with the use of site specific scaling factors. Both components of the model remain uncalibrated to local conditions however, in the sense that these attempts to better represent the Boulder Elkhorn watershed have not been tested empirically. Use of the results for relative comparison (as between sub-basins or alternative management scenarios) is well supported. Use of the results as predictors of absolute sediment load should be undertaken with care. Though both the USLE and the Megehan and Ketcheson SDR are currently in widespread use for absolute prediction of sediment load, local verification of predictive power is (as here) rarely undertaken.

1.6 Results

1.6.1 Management Scenarios

Figures 1-11 through 1-14 present the USLE based hillslope model's prediction of existing and potential conditions graphically. **Table 1-5** presents the prediction of existing and potential conditions numerically, broken out by 6th code HUC (as modified to represent the 303d listed streams) and existing land cover type. **Table 1-6** presents the delivered sediment load cumulative totals within the watershed. The cumulative totals for a sub-basin are a sum of the results for that sub-basin plus the sub-basins upstream of it. For example, Boulder River Headwaters is a sum of the results for that sub-basin plus the results for Bison Creek and Lowland Creek.

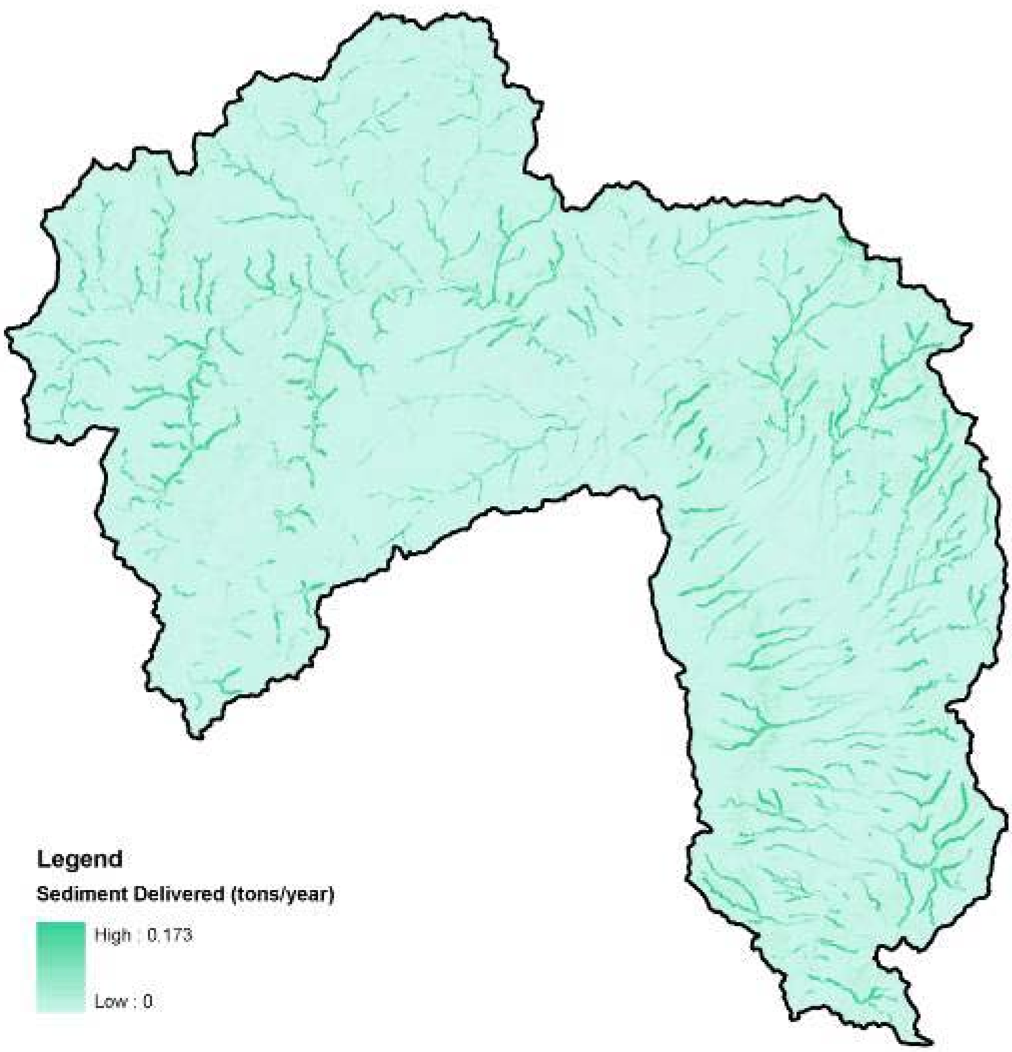

Figure 1-11. Upland Erosion Sediment Load for Existing Upland Conditions and Existing Riparian Health Conditions, Scenario 1.

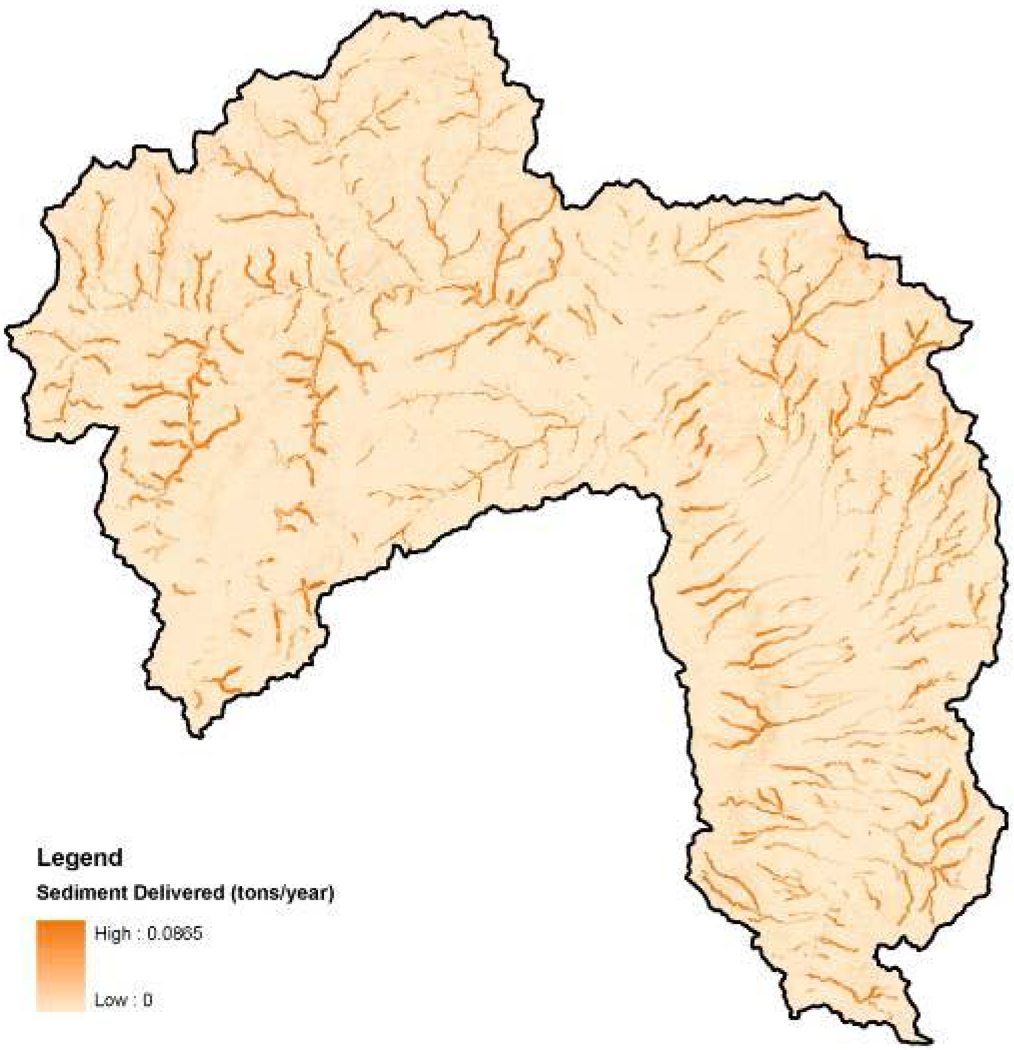

Figure 1-12. Upland Erosion Sediment Load for BMP Upland Conditions and Existing Riparian Health Conditions, Scenario 2.

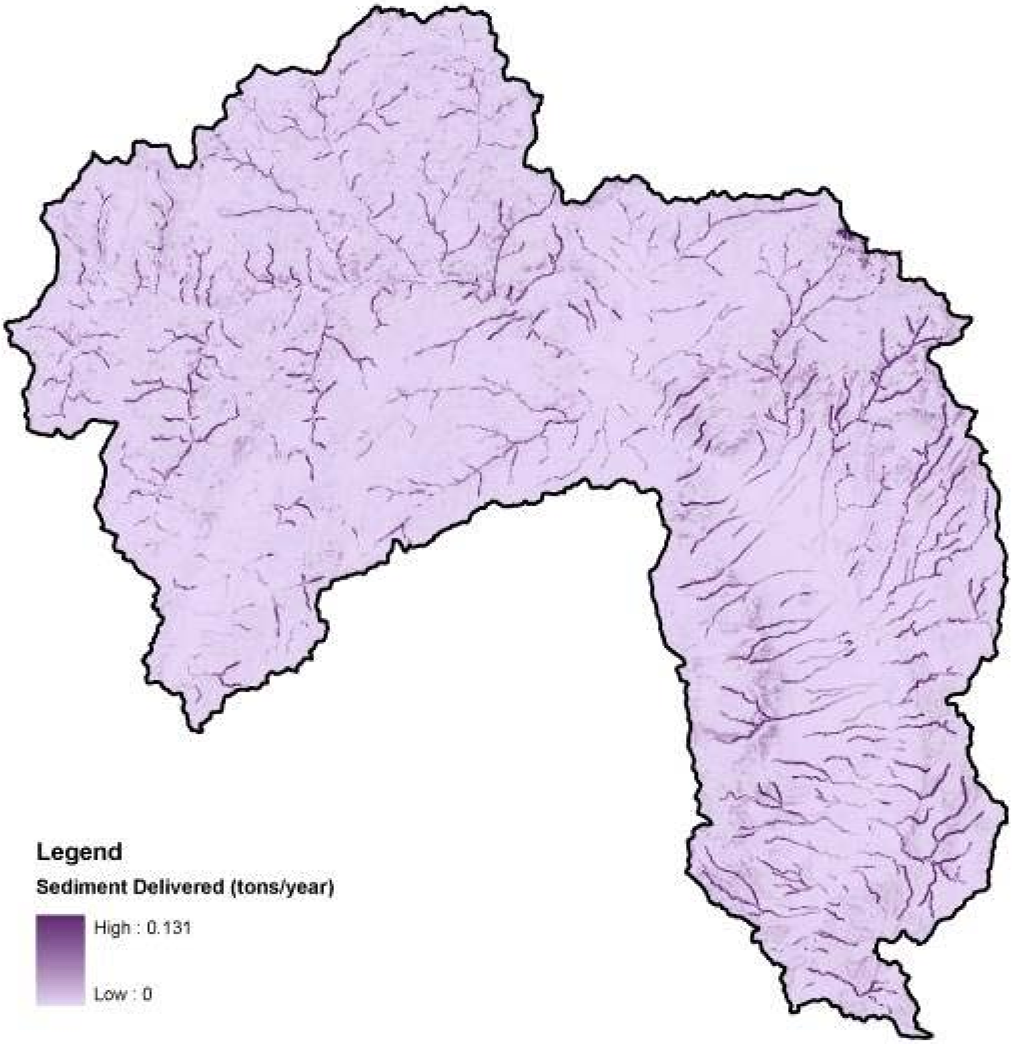

Figure 1-13. Upland Erosion Sediment Load for Existing Upland Conditions and BMP Riparian Health Conditions, Scenario 3.

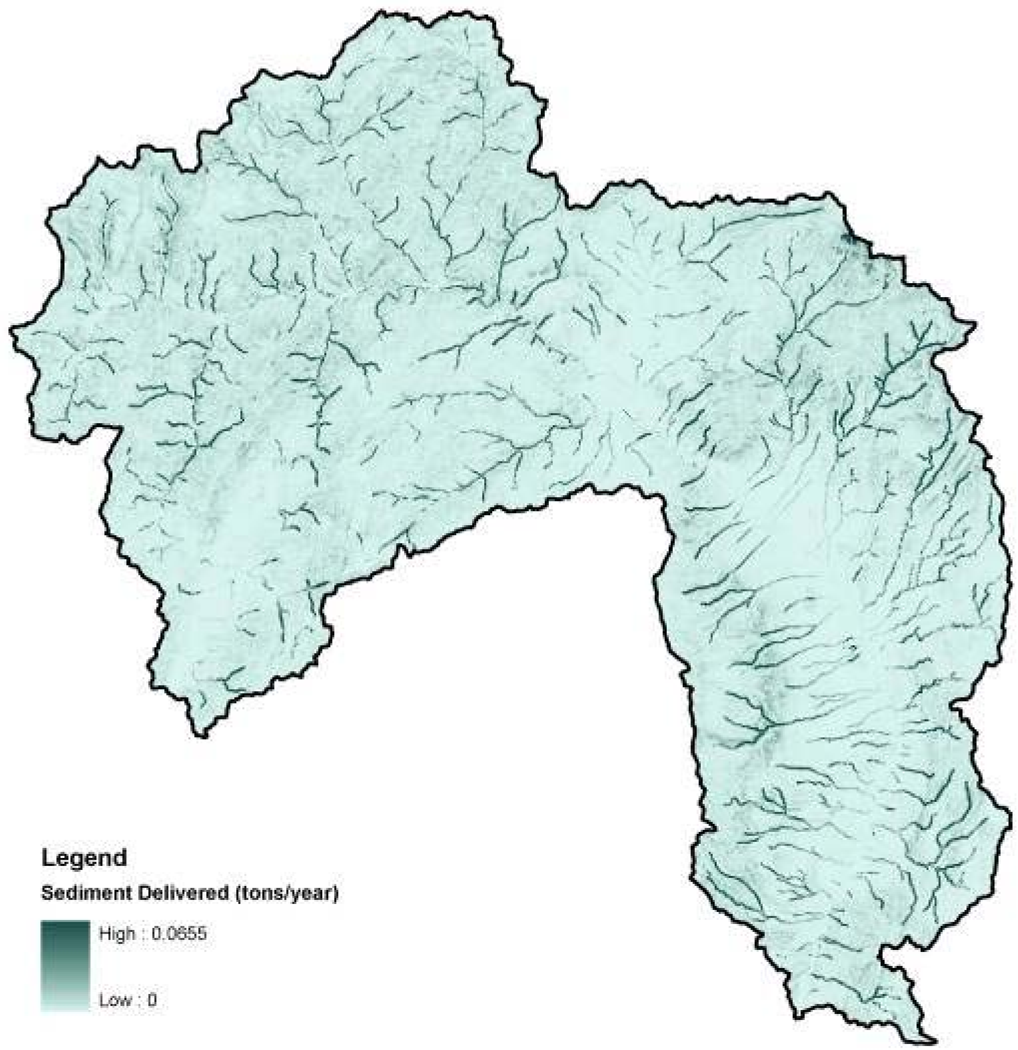

Figure 1-14. Upland Erosion Sediment Load for BMP Upland Conditions and BMP Riparian Health Conditions, Scenario 4.

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed.

			Scenario 1	**Scenario 2**		**Scenario 3**		**Scenario 4**	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Lowland Creek	Evergreen Forest	23,493.4	236.4	236.4	0%	115.1	51%	115.1	51%
	Shrub/Scrub	2,302.7	229.6	114.8	50%	92.3	60%	46.2	80%
	Grassland/Herbaceous	1,137.0	51.3	25.7	50%	20.7	60%	10.3	80%
	Pasture/Hay	0.8	<1	<1	0%	<1	0%	<1	0%
	Transitional	464.8	3.4	1.7	50%	2.0	42%	1.0	71%
	Woody Wetlands	3.6	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	27.1	<1	<1	0%	<1	0%	<1	0%
	Total	**27,429.5**	**521.0**	**378.8**	**27%**	**230.2**	**56%**	**172.7**	**67%**
Bison Creek	Evergreen Forest	34,841.6	298.3	298.3	0%	173.1	42%	173.1	42%
	Shrub/Scrub	4,123.6	76.5	38.3	50%	41.8	45%	20.9	73%
	Grassland/Herbaceous	7,867.5	40.9	20.5	50%	26.1	36%	13.1	68%
	Pasture/Hay	67.9	<1	<1	0%	<1	0%	<1	0%
	Transitional	1,399.8	10.6	5.3	50%	6.3	41%	3.1	70%
	Developed, open space	917.9	9.0	9.0	0%	3.9	57%	3.9	57%
	Woody Wetlands	10.7	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	49.0	2.3	1.1	50%	1.5	36%	0.7	68%
	Developed, low intensity	252.2	1.6	1.6	0%	0.5	66%	0.5	66%
	Developed, medium intensity	44.1	<1	<1	0%	<1	0%	<1	0%
	Barren Land	4.4	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	10.5	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.8	<1	<1	0%	<1	0%	<1	0%
	Total	**49,591.1**	**440.5**	**375.0**	**15%**	**253.8**	**42%**	**215.8**	**51%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Headwaters	Evergreen Forest	53,080.9	431.9	431.8	0%	257.0	40%	257.0	40%
	Shrub/Scrub	6,044.6	227.6	113.8	50%	123.8	46%	61.9	73%
	Grassland/Herbaceous	3,281.5	97.4	48.7	50%	53.2	45%	26.6	73%
	Pasture/Hay	97.8	1.4	0.7	50%	0.7	48%	0.4	74%
	Transitional	309.0	6.7	3.3	50%	3.1	53%	1.6	77%
	Developed, open space	74.9	1.2	1.2	0%	0.5	63%	0.5	63%
	Woody Wetlands	107.5	1.1	0.5	54%	0.6	45%	0.3	74%
	Cultivated Crops	76.9	11.9	6.0	50%	6.5	45%	3.3	73%
	Developed, low intensity	82.6	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	6.9	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	13.5	<1	<1	0%	<1	0%	<1	0%
	Total	**63,176.1**	**779.9**	**606.8**	**22%**	**445.8**	**43%**	**351.7**	**55%**
Basin Creek	Evergreen Forest	24,709.7	143.6	143.6	0%	114.1	20%	114.1	20%
	Shrub/Scrub	1,009.3	39.3	19.6	50%	29.6	25%	14.8	62%
	Grassland/Herbaceous	332.3	9.5	4.7	50%	7.6	20%	3.8	60%
	Pasture/Hay	8.3	<1	<1	0%	<1	0%	<1	0%
	Transitional	359.1	1.6	0.8	50%	1.4	11%	0.7	56%
	Developed, open space	0.5	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	4.0	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	1.3	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	6.4	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	6.2	<1	<1	0%	<1	0%	<1	0%
	Barren Land	135.2	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	2.4	<1	<1	0%	<1	0%	<1	0%
	Total	**26,574.6**	**194.6**	**169.1**	**13%**	**153.3**	**21%**	**133.8**	**31%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	**Scenario 2**		**Scenario 3**		**Scenario 4**	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Uncle Sam Gulch	Evergreen Forest	1,776.3	11.1	11.1	0%	8.7	21%	8.7	21%
	Shrub/Scrub	102.1	2.4	1.2	50%	2.1	10%	1.1	55%
	Grassland/Herbaceous	41.6	<1	<1	0%	<1	0%	<1	0%
	Transitional	2.0	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	1.1	<1	<1	0%	<1	0%	<1	0%
	Total	**1,923.2**	**14.2**	**12.7**	**11%**	**11.5**	**19%**	**10.1**	**29%**
Cataract Creek	Evergreen Forest	16,577.2	93.9	93.9	0%	74.1	21%	74.1	21%
	Shrub/Scrub	1,393.5	37.5	18.7	50%	29.0	23%	14.5	61%
	Grassland/Herbaceous	1,199.7	17.5	8.7	50%	14.2	19%	7.1	60%
	Pasture/Hay	2.0	<1	<1	0%	<1	0%	<1	0%
	Transitional	297.9	1.9	0.9	50%	1.7	8%	0.9	54%
	Developed, open space	3.0	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	2.4	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	1.2	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	12.8	<1	<1	0%	<1	0%	<1	0%
	Total	**19,489.8**	**150.8**	**122.4**	**19%**	**119.0**	**21%**	**96.6**	**36%**
High Ore Creek	Evergreen Forest	3,845.4	40.1	40.1	0%	22.7	43%	22.7	43%
	Shrub/Scrub	1,227.4	66.3	33.2	50%	39.6	40%	19.8	70%
	Grassland/Herbaceous	297.2	18.4	9.2	50%	10.7	42%	5.4	71%
	Transitional	273.6	1.1	0.6	50%	1.0	10%	0.5	55%
	Barren Land	1.2	<1	<1	0%	<1	0%	<1	0%
	Total	**5,644.9**	**126.0**	**83.0**	**34%**	**74.1**	**41%**	**48.4**	**62%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Upper	Evergreen Forest	10,710.3	93.6	93.6	0%	56.6	40%	56.6	40%
	Shrub/Scrub	4,014.9	127.3	63.6	50%	79.3	38%	39.7	69%
	Grassland/Herbaceous	1,394.9	33.4	16.7	50%	20.6	38%	10.3	69%
	Pasture/Hay	28.2	<1	<1	0%	<1	0%	<1	0%
	Transitional	1,133.6	12.4	6.2	50%	7.8	37%	3.9	69%
	Developed, open space	317.6	3.5	3.5	0%	1.8	47%	1.8	47%
	Woody Wetlands	18.0	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	428.0	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	132.9	<1	<1	0%	<1	0%	<1	0%
	Barren Land	0.1	<1	<1	0%	<1	0%	<1	0%
	Developed, high intensity	1.3	<1	<1	0%	<1	0%	<1	0%
	Total	**18,179.9**	**272.2**	**185.4**	**32%**	**167.3**	**39%**	**113.3**	**58%**
North Fork Little Boulder River	Evergreen Forest	10,863.2	34.8	34.8	0%	31.8	9%	31.8	9%
	Shrub/Scrub	707.3	10.8	5.4	50%	9.7	10%	4.9	55%
	Grassland/Herbaceous	239.4	2.8	1.4	50%	2.6	8%	1.3	54%
	Pasture/Hay	1.0	<1	<1	0%	<1	0%	<1	0%
	Transitional	73.7	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	5.1	<1	<1	0%	<1	0%	<1	0%
	Total	**11,889.7**	**48.8**	**41.8**	**14%**	**44.4**	**9%**	**38.1**	**22%**
Little Boulder River	Evergreen Forest	22,741.2	100.7	100.7	0%	81.3	19%	81.3	19%
	Shrub/Scrub	1,538.0	38.3	19.2	50%	28.9	25%	14.5	62%
	Grassland/Herbaceous	842.3	12.6	6.3	50%	9.4	26%	4.7	63%
	Pasture/Hay	166.6	1.9	1.0	50%	1.7	12%	0.8	56%
	Developed, open space	90.9	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	31.4	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	1.3	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	23.7	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	2.5	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.3	<1	<1	0%	<1	0%	<1	0%
	Total	**25,439.3**	**154.3**	**127.6**	**17%**	**121.8**	**21%**	**101.6**	**34%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Nursery Creek	Evergreen Forest	325.5	1.3	1.3	0%	1.2	14%	1.2	14%
	Shrub/Scrub	25.4	<1	<1	0%	<1	0%	<1	0%
	Grassland/Herbaceous	4.2	<1	<1	0%	<1	0%	<1	0%
	Pasture/Hay	0.9	<1	<1	0%	<1	0%	<1	0%
	Transitional	306.9	3.4	1.7	50%	2.6	21%	1.3	61%
	Total	**662.9**	**5.2**	**3.3**	**37%**	**4.2**	**18%**	**2.7**	**48%**
Muskrat Creek	Evergreen Forest	10,655.4	66.2	66.2	0%	47.8	28%	47.8	28%
	Shrub/Scrub	4,576.7	44.0	22.0	50%	35.1	20%	17.5	60%
	Grassland/Herbaceous	4,438.4	28.3	14.2	50%	21.3	25%	10.7	62%
	Pasture/Hay	2,072.0	5.8	2.9	50%	4.6	21%	2.3	60%
	Transitional	2,016.5	7.4	3.7	50%	6.5	11%	3.3	56%
	Developed, open space	479.3	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	178.7	1.4	0.6	54%	1.2	14%	0.5	61%
	Cultivated Crops	225.0	7.7	3.8	50%	5.7	25%	2.9	63%
	Developed, low intensity	118.1	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	13.0	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	1.1	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	19.0	<1	<1	0%	<1	0%	<1	0%
	Total	**24,793.3**	**161.0**	**113.7**	**29%**	**122.4**	**24%**	**85.1**	**47%**
McCarty Creek	Evergreen Forest	2,950.4	10.8	10.8	0%	8.6	20%	8.6	20%
	Shrub/Scrub	603.2	6.6	3.3	50%	5.2	21%	2.6	61%
	Grassland/Herbaceous	198.3	1.9	0.9	50%	1.4	25%	0.7	62%
	Pasture/Hay	37.4	<1	<1	0%	<1	0%	<1	0%
	Transitional	7.1	<1	<1	0%	<1	0%	<1	0%
	Developed, open space	14.4	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	3.1	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	1.5	<1	<1	0%	<1	0%	<1	0%
	Total	**3,815.6**	**19.5**	**15.2**	**22%**	**15.4**	**21%**	**12.0**	**39%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Elkhorn Creek Upper	Evergreen Forest	16,084.0	141.8	141.8	0%	89.6	37%	89.6	37%
	Shrub/Scrub	2,196.5	131.7	65.9	50%	83.4	37%	41.7	68%
	Grassland/Herbaceous	455.1	16.0	8.0	50%	9.8	39%	4.9	69%
	Pasture/Hay	22.0	<1	<1	0%	<1	0%	<1	0%
	Transitional	185.7	3.0	1.5	50%	1.6	45%	0.8	73%
	Woody Wetlands	9.8	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	13.1	4.1	2.1	50%	2.9	30%	1.5	65%
	Barren Land	1.6	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	3.3	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.1	<1	<1	0%	<1	0%	<1	0%
	Total	**18,972.2**	**297.2**	**219.5**	**26%**	**187.7**	**37%**	**138.7**	**53%**
Elkhorn Creek Lower	Evergreen Forest	1,341.3	10.3	10.3	0%	8.0	22%	8.0	22%
	Shrub/Scrub	1,615.7	45.8	22.9	50%	34.1	26%	17.1	63%
	Grassland/Herbaceous	383.0	14.2	7.1	50%	11.4	20%	5.7	60%
	Pasture/Hay	156.4	1.6	0.8	50%	1.3	21%	0.6	60%
	Developed, open space	50.2	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	90.8	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	2.0	<1	<1	0%	<1	0%	<1	0%
	Total	**3,639.5**	**72.3**	**41.3**	**43%**	**55.1**	**24%**	**31.6**	**56%**

Table 1-5 Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	**Scenario 2**		**Scenario 3**		**Scenario 4**	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Middle	Evergreen Forest	33,776.8	330.6	330.6	0%	213.1	36%	213.1	36%
	Shrub/Scrub	52,488.6	1,344.2	672.1	50%	841.4	37%	420.7	69%
	Grassland/Herbaceous	46,764.8	727.2	363.6	50%	463.5	36%	231.8	68%
	Pasture/Hay	9,278.4	20.9	10.4	50%	13.3	36%	6.7	68%
	Transitional	223.7	1.1	0.5	50%	1.0	12%	0.5	56%
	Developed, open space	1,490.5	1.1	1.1	0%	0.7	37%	0.7	37%
	Woody Wetlands	1,542.9	1.7	0.8	54%	1.1	38%	0.5	71%
	Cultivated Crops	1,001.9	31.6	15.8	50%	21.1	33%	10.5	67%
	Developed, low intensity	386.8	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	44.5	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	6.0	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	10.7	<1	<1	0%	<1	0%	<1	0%
	Developed, high intensity	3.1	<1	<1	0%	<1	0%	<1	0%
	Emergent Herbaceous Wetlands	4.0	<1	<1	0%	<1	0%	<1	0%
	Total	**147,022.7**	**2,458.4**	**1,395.1**	**43%**	**1,555.3**	**37%**	**884.5**	**64%**
Boulder River Lower	Evergreen Forest	7,215.9	63.3	63.3	0%	43.9	31%	43.9	31%
	Shrub/Scrub	10,111.3	265.8	132.9	50%	173.8	35%	86.9	67%
	Grassland/Herbaceous	16,216.9	255.9	127.9	50%	171.5	33%	85.8	66%
	Pasture/Hay	1,335.7	5.5	2.7	50%	3.3	40%	1.6	70%
	Developed, open space	416.3	1.5	1.5	0%	1.0	37%	1.0	37%
	Woody Wetlands	404.5	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	10.7	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	252.2	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	12.8	<1	<1	0%	<1	0%	<1	0%
	Total	**35,976.2**	**593.7**	**329.3**	**45%**	**394.5**	**34%**	**219.7**	**63%**

Table 1-6 Cumulative Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed.

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Headwaters Total (Lowland Ck, Bison Ck, and Boulder River Headwaters)	Evergreen Forest	111,415.9	966.5	966.5	0%	545.1	44%	545.1	44%
	Shrub/Scrub	12,470.9	533.7	266.8	50%	257.9	52%	128.9	76%
	Grassland/Herbaceous	12,286.0	189.7	94.8	50%	100.0	47%	50.0	74%
	Pasture/Hay	166.6	1.8	0.9	50%	0.9	49%	0.5	74%
	Transitional	2,173.6	20.7	10.4	50%	11.4	45%	5.7	73%
	Developed, open space	992.8	10.2	10.2	0%	4.3	58%	4.3	58%
	Woody Wetlands	121.7	1.4	0.7	54%	0.8	42%	0.4	73%
	Cultivated Crops	126.0	14.2	7.1	50%	8.0	44%	4.0	72%
	Developed, low intensity	334.9	2.2	2.2	0%	0.8	64%	0.8	64%
	Developed, medium intensity	51.0	<1	<1	0%	<1	0%	<1	0%
	Barren Land	4.4	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	51.1	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.8	<1	<1	0%	<1	0%	<1	0%
	Total	**140,196.7**	**1,741.3**	**1,360.5**	**22%**	**929.7**	**47%**	**740.2**	**57%**
Cataract Creek Total (Uncle Sam Gulch and Cataract Ck)	Evergreen Forest	18,353.5	105.0	105.0	0%	82.8	21%	82.8	21%
	Shrub/Scrub	1,495.6	39.8	19.9	50%	31.1	22%	15.5	61%
	Grassland/Herbaceous	1,241.4	18.3	9.1	50%	14.9	19%	7.4	59%
	Pasture/Hay	2.0	<1	<1	0%	<1	0%	<1	0%
	Transitional	299.9	1.9	0.9	50%	1.7	8%	0.9	54%
	Developed, open space	3.0	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	2.4	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	1.2	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	14.0	<1	<1	0%	<1	0%	<1	0%
	Total	**21,412.9**	**165.1**	**135.0**	**18%**	**130.5**	**21%**	**106.7**	**35%**

Table 1-6 Cumulative Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Upper Total (Basin Ck, Cataract Ck Total, High Ore Ck, and Boulder River Upper)	Evergreen Forest	57,618.9	382.2	382.2	0%	276.2	28%	276.2	28%
	Shrub/Scrub	7,747.2	272.7	136.4	50%	179.7	34%	89.8	67%
	Grassland/Herbaceous	3,265.8	79.6	39.8	50%	53.8	32%	26.9	66%
	Pasture/Hay	38.5	<1	<1	0%	<1	0%	<1	0%
	Transitional	2,066.2	17.0	8.5	50%	11.9	30%	6.0	65%
	Developed, open space	321.1	3.5	3.5	0%	1.8	47%	1.8	47%
	Woody Wetlands	22.0	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	1.3	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	436.8	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	140.3	<1	<1	0%	<1	0%	<1	0%
	Barren Land	136.5	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	16.4	<1	<1	0%	<1	0%	<1	0%
	Developed, high intensity	1.3	<1	<1	0%	<1	0%	<1	0%
	Total	**71,812.3**	**757.9**	**572.7**	**24%**	**525.2**	**31%**	**402.1**	**47%**
Little Boulder River Total (N.F. Little Boulder River and Little Boulder River)	Evergreen Forest	33,604.4	135.6	135.6	0%	113.0	17%	113.0	17%
	Shrub/Scrub	2,245.4	49.1	24.6	50%	38.7	21%	19.3	61%
	Grassland/Herbaceous	1,081.7	15.4	7.7	50%	11.9	23%	6.0	61%
	Pasture/Hay	167.6	2.0	1.0	50%	1.8	13%	0.9	56%
	Transitional	73.7	<1	<1	0%	<1	0%	<1	0%
	Developed, open space	90.9	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	31.4	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	6.4	<1	<1	0%	<1	0%	<1	0%
	Developed, low intensity	23.7	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	2.5	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.3	<1	<1	0%	<1	0%	<1	0%
	Total	**37,329.0**	**203.2**	**169.5**	**17%**	**166.2**	**18%**	**139.7**	**31%**

Table 1-6 Cumulative Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	Scenario 2		Scenario 3		Scenario 4	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Muskrat Creek Total (Nursery Ck and Muskrat Ck)	Evergreen Forest	10,980.9	67.5	67.5	0%	48.9	28%	48.9	28%
	Shrub/Scrub	4,602.1	44.2	22.1	50%	35.2	20%	17.6	60%
	Grassland/Herbaceous	4,442.6	28.4	14.2	50%	21.4	25%	10.7	62%
	Pasture/Hay	2,073.0	6.0	3.0	50%	4.8	20%	2.4	60%
	Transitional	2,323.4	10.7	5.4	50%	9.2	15%	4.6	57%
	Developed, open space	479.3	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	178.7	1.4	0.6	54%	1.2	14%	0.5	61%
	Cultivated Crops	225.0	7.7	3.8	50%	5.7	25%	2.9	63%
	Developed, low intensity	118.1	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	13.0	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	1.1	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	19.0	<1	<1	0%	<1	0%	<1	0%
	Total	**25,456.2**	**166.2**	**116.9**	**30%**	**126.6**	**24%**	**87.8**	**47%**
Elkhorn Creek Total (Elkhorn Ck Upper and Elkhorn Ck Lower)	Evergreen Forest	17,425.3	152.0	152.0	0%	97.6	36%	97.6	36%
	Shrub/Scrub	3,812.1	177.5	88.8	50%	117.5	34%	58.8	67%
	Grassland/Herbaceous	838.2	30.2	15.1	50%	21.2	30%	10.6	65%
	Pasture/Hay	178.4	1.9	1.0	50%	1.5	24%	0.7	62%
	Transitional	185.7	3.0	1.5	50%	1.6	45%	0.8	73%
	Developed, open space	50.2	<1	<1	0%	<1	0%	<1	0%
	Woody Wetlands	100.5	<1	<1	0%	<1	0%	<1	0%
	Cultivated Crops	13.1	4.1	2.1	50%	2.9	30%	1.5	65%
	Developed, low intensity	2.0	<1	<1	0%	<1	0%	<1	0%
	Barren Land	1.6	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	3.3	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	1.1	<1	<1	0%	<1	0%	<1	0%
	Total	**22,611.7**	**369.5**	**260.8**	**29%**	**242.8**	**34%**	**170.2**	**54%**

Table 1-6 Cumulative Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	**Scenario 2**		**Scenario 3**		**Scenario 4**	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Middle Total (Little Boulder River Total, Muskrat Ck Total, McCarty Ck, Elkhorn Ck Total, and Boulder River Middle)	Evergreen Forest	65,133.5	560.9	560.9	0%	368.2	34%	368.2	34%
	Shrub/Scrub	61,506.0	1,572.5	786.2	50%	999.4	36%	499.7	68%
	Grassland/Herbaceous	52,243.9	787.6	393.8	50%	507.5	36%	253.7	68%
	Pasture/Hay	11,567.2	29.0	14.5	50%	19.7	32%	9.9	66%
	Transitional	2,739.9	14.8	7.4	50%	11.8	20%	5.9	60%
	Developed, open space	2,034.3	1.5	1.5	0%	1.0	34%	1.0	34%
	Woody Wetlands	1,825.3	3.7	1.7	54%	2.7	27%	1.2	66%
	Cultivated Crops	1,240.0	43.4	21.7	50%	29.7	31%	14.9	66%
	Developed, low intensity	506.9	<1	<1	0%	<1	0%	<1	0%
	Developed, medium intensity	57.5	<1	<1	0%	<1	0%	<1	0%
	Barren Land	1.6	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	12.0	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	30.8	<1	<1	0%	<1	0%	<1	0%
	Developed, high intensity	3.1	<1	<1	0%	<1	0%	<1	0%
	Emergent Herbaceous Wetlands	4.0	<1	<1	0%	<1	0%	<1	0%
	Total	**198,906.1**	**3,013.6**	**1,787.9**	**41%**	**1,940.1**	**36%**	**1,154.6**	**62%**

Table 1-6 Cumulative Delivered Sediment Load by Land Cover Type for the Boulder Elkhorn Watershed (continued).

			Scenario 1	**Scenario 2**		**Scenario 3**		**Scenario 4**	
Sub-basin	**Land Cover Classification**	**Area (acres)**	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 Change from Existing**	Upland Erosion Sediment Load for **Existing** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**	Upland Erosion Sediment Load for **BMP** Conditions and **BMP** Riparian Health **(tons/year)**	**Percent Change from Existing**
Boulder River Total (Boulder R Headwaters Total, Boulder R Upper Total, Boulder R Middle Total, and Boulder R Lower)	Evergreen Forest	241,384.2	1,973.0	1,973.0	0%	1,233.5	37%	1,233.5	37%
	Shrub/Scrub	91,835.4	2,644.7	1,322.3	50%	1,610.7	39%	805.3	70%
	Grassland/Herbaceous	84,012.6	1,312.8	656.4	50%	832.8	37%	416.4	68%
	Pasture/Hay	13,108.0	36.7	18.4	50%	24.2	34%	12.1	67%
	Transitional	6,979.7	52.6	26.3	50%	35.1	33%	17.6	67%
	Developed, open space	3,764.6	16.7	16.7	0%	8.1	52%	8.1	52%
	Woody Wetlands	2,373.6	6.2	2.9	54%	4.3	32%	2.0	69%
	Cultivated Crops	1,378.0	58.6	29.3	50%	38.5	34%	19.2	67%
	Developed, low intensity	1,530.8	3.3	3.3	0%	1.4	58%	1.4	58%
	Developed, medium intensity	261.6	1.4	1.4	0%	0.7	49%	0.7	49%
	Barren Land	142.5	<1	<1	0%	<1	0%	<1	0%
	Mixed Forest	79.4	<1	<1	0%	<1	0%	<1	0%
	Deciduous Forest	32.6	<1	<1	0%	<1	0%	<1	0%
	Developed, high intensity	4.5	<1	<1	0%	<1	0%	<1	0%
	Emergent Herbaceous Wetlands	4.0	<1	<1	0%	<1	0%	<1	0%
	Total	**446,891.3**	**6,106.5**	**4,050.4**	**34%**	**3,789.5**	**38%**	**2,516.6**	**59%**

1.7 References

Knutson, K and Naef, V. 1997. Management Recommendations for Washington's Priority Habitats Riparian. Washington Department of Fish and Wildlife.

Megahan, W.F.; Ketcheson, G.L. 1996. Predicting downslope travel of granitic sediments from forest roads in Idaho. Water Resources Bulletin. 32: 371-382.

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

Wenger, S. 1999. A review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. Prepared for the Office of Public Service and Outreach, University of Georgia.

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

Attachment A – Assignment of USLE C-factors to NLCD Landcover Values

The NRCS table "C-Factors for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland" (Figure A-1) was used to develop C-factors for the various land use types as defined by the NLCD database within the Boulder Elkhorn watershed. This table uses four sub-factors: the vegetative canopy type and height, the vegetative canopy percent cover, the type of cover that contacts the soil surface, and the percent ground cover to derive a C-factor. The resulting C-factor is very sensitive to the type and percent of ground cover and less sensitive to the type and percent of canopy cover.

The type and percent of canopy cover were determined based on the NLCD land use definition. In some cases the minimum percent canopy cover specified in the land use definition was used and resulted in a conservative C-factor. The type of ground cover was considered to be G (cover is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep) for all of the land uses in the Boulder Elkhorn watershed. The percent ground cover not only includes the basal plant material, but also gravel and plant litter. The percent ground cover for each of the land uses within the Boulder Elkhorn watershed was estimated by Confluence.

Table A-1 provides the C-factors for all land use types within the sub-basins of interest in the Boulder Elkhorn watershed for the existing conditions. The C-factors for the 'barren land', 'developed, low intensity', 'developed, medium intensity', and 'developed, high intensity' land uses are the same C-factors previously recommended by Richard Fasching, the former Montana State Agronomist, for other hillslope USLE modeling efforts.

Table A-2 provides the C-factors for all land use types within the sub-basins of interest in the Boulder Elkhorn watershed for the desired well managed scenario. The percent ground cover was increased by 10% over the existing percentage for the 'shrub/scrub', 'grassland/herbaceous', 'pasture/hay', and 'woody wetlands' land uses to reflect a decrease in grazing. For the 'cultivated crops' land use, the percent ground cover was increased by 20% over the existing percentage to reflect improved agricultural practices. For the 'transitional' land use, the desired scenario assumed a return to a forest land use. The C-factors for the other land use types were not changed. This is similar to the methods used by the DEQ for the Shields River watershed TMDL and by Confluence for other hillslope USLE modeling efforts.

These tables were reviewed and approved by Ronnie Maurer, an NRCS employee familiar with the Boulder Elkhorn watershed.

Exhibit MT510.03

"C" Factors for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland 1/

Vegetal Canopy			Cover that Contacts the Surface (Vegetation, living and dead)					
Type and Height of Raised Canopy 2/	Canopy Cover 3/ %	Type 4/	Percent Ground Cover					
			0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall grass, weeds or brushes with average drop fall height of less than 3 feet 5/	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

1/ All values shown assume: 1) random distribution of mulch or vegetation, and 2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years. Also to be used for burned forest land and forest land that has been harvested less than three years ago.

For grazed woodland with high buildup of organic matter in the topsoil under permanent forest conditions, multiply the table values by 0.7.

2/ Average fall height of waterdrops from canopy to soil surface: m = meters.

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.
W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface), and/or undecayed residue.

5/ The portion of a grass or weed cover that contacts the soil surface during a rainstorm and interferes with water flow over the soil surface is included in "cover at the surface." The remainder is included in canopy cover.

Figure A-1. NRCS C-factor table

Table A-1 C-factors for land cover types in the Boulder Elkhorn watershed for existing conditions.

NLCD #	Name	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-factor
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	75	0.020
71	Grassland/herbaceous	no appreciable canopy	-	G	75	0.020
81	Pasture/Hay	no appreciable canopy	-	G	75	0.020
82	Cultivated Crops	no appreciable canopy	-	G	20	0.200
90	Woody Wetlands	trees	25	G	80	0.013
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003
99	Transitional	trees	25	G	90	0.006

Notes:

1) Canopy cover percents were selected based on the land cover class definition.
2) Low, medium, and high intensity development land uses are assumed to be the same as barren land.
3) Deciduous and mixed forest land uses are assumed to be the same as evergreen forest.

Table A-2 C-factors for land cover types in the Boulder Elkhorn watershed for BMP conditions.

NLCD #	Name	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-factor
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	0.010
71	Grassland/herbaceous	no appreciable canopy	-	G	85	0.010
81	Pasture/Hay	no appreciable canopy	-	G	85	0.010
82	Cultivated Crops	no appreciable canopy	-	G	40	0.100
90	Woody Wetlands	trees	25	G	90	0.006
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003
99	Transitional	trees	75	G	95-100	0.003

Notes:

1) Canopy cover percents were selected based on the land cover class definition.
2) Low, medium, and high intensity development land uses are assumed to be the same as barren land.
3) Deciduous and mixed forest land uses are assumed to be the same as evergreen forest.