APPENDIX H
UPLAND SEDIMENT MODELS

RUBY RIVER WATERSHED

AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT (AGWA) MODEL SEDIMENT YIELD ASSESSMENT

Submitted to:

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1.0 INTRODUCTION

The Ruby River Watershed is a 620,000 acre watershed located in Madison County, southwestern Montana (Figure 1). The watershed includes a narrow valley surrounded by the Tobacco Root Mountains, Ruby Mountains, Gravelly Range, and Snowcrest Mountains. The headwaters of the mainstem Ruby River originate in the Gravelly and Snowcrest Mountains of the Beaverhead - Deer Lodge National Forest. Land use in the watershed is currently rural-agricultural, but also includes tourism associated with historic Virginia City and minor mining and logging operations (Ruby Watershed Council 2003). Livestock grazing is a major land use throughout the watershed. A detailed description of the physical and biological characteristics of the Ruby River Watershed is provided in the watershed characterization section of the Ruby River Watershed Total Maximum Daily Load (TMDL) report (Watershed Consulting, in progress).

In 1997, the Montana Department of Environmental Quality (DEQ) was tasked with restoring the water quality of streams and lakes in Montana that do not support irrigation, fisheries and recreation; or provide drinking water, stockwater and wildlife habitat. These impaired waterbodies are placed on a State of Montana 303(d) list for impaired waterbodies until water quality clean up plans (TMDLs) are developed. There are currently 27 303 (d)-listed impaired waterbodies in the Ruby River Watershed that need to be addressed through TMDL planning activities. All of these waterbodies are listed for impairment caused by sediment or sediment sources. Although sediment occurs naturally, excess sediment in a lake or stream bed can cloud the stream, reducing sunlight, impacting biological communities and transporting nutrients, pathogens, and heavy metals.

A Ruby River Watershed Sediment Total Maximum Daily Load is currently being developed to address the sediment impairments of the 303(d) - listed waterbodies (Watershed Consulting, in press). The sediment yield analysis presented herein was completed as a component of the on-going TMDL assessment. This assessment is designed as a screening level model for determining relative sediment source potential of upland areas within the Ruby River watershed. Golder Associates (Golder) was retained by Watershed Consulting LLC to conduct this assessment.

Specific objectives of the Ruby River Watershed Sediment Yield Assessment effort were:

1. Determine which sub-basins containing 303(d) sediment impaired streams contribute the highest relative sediment yields in the watershed under existing conditions. The modeling results from this assessment will be used in conjunction with field assessments to help identify the extent and magnitude of sediment sources originating within each sub-basin.
2. Model various land and water management scenarios to determine effects of these practices on sub-basin sediment contributions to the Ruby River Watershed. Modeling scenarios concentrate on sediment management effects of roads, enhanced riparian buffer conditions, and in-channel ponds.

To achieve Objective 1 of the assessment, sediment yields were modeled on the sub-basin scale for the Upper and Lower Ruby River mainstem and 14 tributary sub-basins containing 303(d) sediment listed streams. The detailed, event-based sediment yield modeling was completed using the KINEROS2 component of the Automated Geospatial Watershed Assessment (AGWA) model. Using the model, relative sediment yields were determined among sub-basins and within individual sub-basin areas.

For Objective 2 of the assessment, the baseline condition and various land management scenarios were modeled to determine changes in sediment yields. Modeling of two scenarios, road removal and riparian enhancement, was completed for the 14 tributary sub-basins. A third scenario, on-channel pond placement, was completed for two tributary sub-basins, Alder Gulch and Warm Springs. These two representative sub-basins were selected as being of similar characteristics but having different levels of sediment yield under existing conditions. The detailed, event-based sediment yield modeling was completed using the KINEROS2 component of the Automated Geospatial Watershed Assessment (AGWA) model on the sub-basin scale. Relative changes in total sediment yield and percent change in sub-basin sediment yields were calculated to determine the effect of the scenarios on sediment.

2.0 MODEL DESCRIPTION AND SELECTION RATIONALE

2.1 The Automated Geospatial Watershed Assessment (AGWA) Model

Sediment models may be used as investigative, explanatory, or predictive tools. Often, they are applied as preliminary investigations so that field resources can be more effectively directed. Many erosion models have been developed during the last four decades to predict the impacts of soil loss and sediment yield in watersheds. Applicability of a model is often determined based on the temporal and spatial goals of the project and the data inputs available. Development of a sediment analysis of the Ruby River Watershed was constrained by the limited availability of existing quantitative sediment and hydrology information and the numerous sub-basins of interest within the Ruby River Watershed. Based on the data available and the goals of the project, the Automated Geospatial Watershed Assessment model (AGWA) software was selected to achieve the objectives of the project.

AGWA is a Geographic Information Systems (GIS) interface developed by the USDA-ARS Southwest Watershed Research Center in cooperation with the US EPA Office of Research and Development. AGWA is an ArcView extension designed to provide qualitative estimates of runoff and erosion relative to landscape change. Key components of AGWA are the hydrological models used to evaluate the effects of land cover and land use on watershed response. AGWA uses readily available data including: digital elevation models (DEMs), land cover grids, soils data, and precipitation data. The user selects a starting point from which AGWA delineates the watershed using the Digital Elevation Model (DEM). AGWA intersects the soil, land cover, and precipitation data layers with the selected watershed area to derive the essential hydrological model input parameters. The hydrological model is then run, and the results are imported back into AGWA for visual display. The use of the GIS-based data allows for easy adaptation for modeling various land management scenarios. Outputs are highly visual for ease of conveying information to stakeholder groups.

AGWA contains two well-established hydrologic models: Soil Water Assessment Model (SWAT) and the Kinematic Runoff and Erosion (KINEROS2) model. Both KINEROS2 and SWAT are considered deterministic watershed models. Deterministic models are models in which no random variables are used, i.e. for each unique set of input data the model will compute fixed, repeatable results. If desired, both models can be used conjunctively to analyze watersheds at different spatial and temporal scales within the AGWA model. However, due to budget limitations only a single model could be used to model Ruby River sediment yields. A description of the two hydrologic models is presented below. A tabular comparison of the two models is presented in Table 1.

2.1.1 Soil Water Assessment Tool (SWAT)

SWAT is a river basin scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in very large, complex watersheds (Arnold et. al. 1994). It is widely accepted and has been validated in watersheds in numerous geographies. The SWAT model is comprised of predominantly empirical equations and uses readily available inputs. SWAT operates on a daily time step and can simulate long periods of time (100+ years). The hydrology of SWAT is based on the water balance equation. Major components of the hydrologic balance and their interactions are simulated including surface runoff, lateral flow in the soil profile, groundwater flow, evapotranspiration, channel routing, and pond and reservoir storage. Surface runoff from daily precipitation is estimated in SWAT using the SCS curve number method. The curve number method combines infiltration losses, depression storage, and interception into a potential maximum storage parameter. Infiltration is calculated in SWAT as precipitation minus runoff.

TABLE 1

Comparison of SWAT and KINEROS2 Sediment Models

Characteristics	SWAT	KINEROS2
Temporality	Continuous (designed to predict long term impacts)	Event-based.
Equations	Semi -Empiric (based on USLE)	Physically-based.
Requirements	Moderate input parameters	Many input parameters.
Scale	Basin-scale	Plots, hillslopes, small catchments and channel (best for areas (<100 km^2).
Hydrology	Water balance equation. Curve Number method.	One dimensional kinematic equations; Smith –Parlange for infiltration
Sediment Yield	USLE; MUSLE	Mass balance equation similar to that for kinematic water flow (Bennett, 1974). Net upland erosion is a sum of splash erosion rate and hydraulic erosion rate.
Sediment Size	Yes	Yes
General	Quasi distributed used to predict the impact of land management practices on water, sediment and agricultural chemical yields in large (basin scale) complex watersheds with varying soils, land use and management conditions over long periods of time (> 1 year). Not designed for detailed single event. Uses daily averages	Unlike SWAT, KINEROS2 is based on physical processes rather then empirical equations and is designed to simulate runoff and erosion for single storm events. Eight hydrologic processes exist within the KINEROS2 model: rainfall, interception, infiltration, overland flow, open channel flow, erosion, sediment transport, and reservoir routing and sedimentation.
Outputs	• Evapotranpiration; • Percolation; • Runoff; • Water yield; • Transmission loss; and • Sediment yield	• Channel infiltration; • Plane infiltration; • Runoff; • Sediment yield; • Peak flow; • Sediment discharge; and • Channel scour.

The Universal Soil Loss Equation (USLE) is used in SWAT to estimate initial soil detachment and upland erosion. Sediment yield is determined from the Modified Universal Soil Loss Equation (MUSLE) developed by Williams and Berndt (1977) (Arnold, 1992). Both USLE and MUSLE are empirical soil equations.

Outputs of SWAT include:

- Evapotranpiration;
- Percolation;

- Runoff;
- Water yield;
- Transmission loss; and
- Sediment yield.

2.1.2 Kinematic Runoff and Erosion Model (KINEROS2)

The KINEROS2 model was developed by the USDA-Agricultural Research Service and is supported by the Southwest Watershed Research Center in Tucson, Arizona. KINEROS2 is designed to model hydrological and erosional processes of small watersheds less than about 100 km^2. Application and testing of KINEROS2 is well-documented (Smith et. al 1995). Unlike SWAT, KINEROS2 is based on physical processes rather then empirical equations and is designed to simulate runoff and erosion for single storm events. Eight hydrologic processes exist within the KINEROS2 model: rainfall, interception, infiltration, overland flow, open channel flow, erosion, sediment transport, and reservoir routing and sedimentation.

KINEROS2 represents the watershed as a cascade of planes and channels. Runoff is modeled with one-dimensional kinematic equations to route water over the rectangular planes and through the trapezoidal open channels. The Smith-Parlange infiltration equation is used to calculate infiltration (Smith and Parlange, 1978). The Smith-Parlange infiltration is more detailed than the CN method for infiltration in that it provides variability in infiltration as a precipitation event extends over time.

The KINEROS2 model simulates the movement of eroded soil along with the movement of surface water. This separation of flows by overland and channel components within the model provides the details for effective process-based erosion predictions. This is completed by various equations that account for upland erosion, splash erosion, and channel transport capacity (affecting sediment deposition).

Outputs of KINEROS2 include:

- Channel infiltration;
- Plane infiltration;
- Runoff;
- Sediment yield;
- Peak flow;
- Sediment discharge; and
- Channel scour.

2.2 Rationale for Model Selection

Using the AGWA model framework, both SWAT and KINEROS2 utilize primarily the same readily available data sets and require similar levels of effort for model set-up and implementation. The modeling processes of both SWAT and KINEROS2 are appropriate for sediment yield analysis in general. However, important drivers in model selection are the spatial and temporal scales of interest. Based on spatial and temporal scale considerations, KINEROS2 is the most appropriate model to fulfill the specific objectives for the analysis as outlined in Section 1.0 of this report.

KINEROS2 was selected for the following reasons:

- **Appropriate spatial scale.** The spatial scale for which a model is designed can play a significant role in how specific processes are treated. Runoff in large river basin scale watersheds (> 1000 km^2), for instance, is dominated by channel storage. In contrast, runoff from small tributary watersheds (< 100 km^2) is dominated by overland flow. The majority of sub-basins (10 of 14) delineated in this analysis were smaller than 100 km^2. The remaining four sub-basins: Alder Gulch (253 km^2), Sweetwater Creek (332 km^2), Upper Ruby River Headwaters (242 km^2), and Warm Springs Creek (132 km^2) were of an intermediate size that is not ideal for either the KINEROS2 model or the SWAT model. The KINEROS2 model was chosen because it was appropriate for the size of the majority of the sub-basins. To retain model consistency, the KINEROS2 model was used for the remaining four sub-basins.
- **Appropriate time scale.** Hydrologic processes occur at different time scales, therefore choosing the time scale necessary to achieve project objectives is important. In smaller, headwaters sub-basins, runoff is generally dominated by overland flow and single events primarily drive sediment yields. The Curve Number runoff method of SWAT is not designed to simulate detailed, single event routing. KINEROS2 was selected based on its ability to model detailed single events.
- **Other.** Additional benefits for selecting the KINEROS2 model include a higher level of detail in the hydrologic and sediment computations (physical process based rather than empirical) and more relevant outputs. The physical process of runoff and sediment movement are captured in more detail, separating out the processes of rainfall, interception and infiltration, in KINEROS2 than in SWAT.

2.3 Model Limitations

Though KINEROS2 is the most appropriate model for the objectives of this assessment, it is not without its limitations. These limitations include the following:

- KINEROS2 is an event-based model; therefore long periods of soil water redistribution, plant growth, and other inter-storm changes are not treated. Appropriately for an event-based model, evapotranspiration is also not considered.

  Since the time scale of interest in this analysis is event-based, these particular limitations are not an issue.

- Though the KINEROS2 model provides a high level of detail in landscape features by discretizing the watershed into planes and channels, it still retains some limitations in this arena. As with any model, KINEROS2 does not specifically include all important landscape features that may influence runoff routing (e.g., gullies, ditches, cutbanks, paths, Horton Overland Flow directed at hillsides, etc).

  Important landscape features that could influence routing of runoff in the sub-basins at the northern (downstream) portion of the watershed are the irrigation ditches that run parallel to the Ruby River and cross the lower portions of some of the sub-basins perpendicularly. To limit the effect of this issue on the modeling, delineation of these northern sub-basins was begun at a point upstream of the major ditches. This eliminated a small portion of the sub-basin from analysis.

- While KINEROS2 performs equations that account for upland erosion, splash erosion and sediment deposition and suspension in channel routing, it does not take into account streambank erosion associated with lateral channel migration and other geomorphic processes. Therefore, the simulation produces only relative results from differences in soil, land cover, topographic and hydrological properties.

  The modeled sub-basins in this assessment were generally small. Small watersheds are dominated by the land phase and overland flow and have relatively less conspicuous channel phase, limiting the effect of this issue in the model results. Since the objectives of this assessment were aimed at only obtaining relative differences in sediment yield this limitation is acceptable for this assessment. Bank erosion is considered in field assessments conducted in the Ruby River Sediment TMDL.

- Finally, the model is limited to the scale and the level of resolution of its input data (described in the following section).

  The data inputs are of uniform scale throughout the watershed. This produces effective relative sediment yields. The objectives of the assessment were aimed at only obtaining relative difference in sediment yield. For these reasons, this limitation is acceptable for this assessment. If more detailed quantitative data becomes necessary, higher resolution input data should be obtained.

3.0 APPROACH

The approach used to perform the AGWA sediment modeling of the Ruby River watershed included four major steps:

3.1 Data Gathering and Pre-processing

In this step, the appropriate data inputs were assembled. Three main GIS data sets were used for model inputs: land cover, soils, and topography. A separate non-GIS precipitation input file was also obtained. Table 2 provides details of the type, name, source, resolution, and year associated with the GIS baseline data inputs used for this modeling effort. Pre-processing of GIS data for use in the AGWA modeling software was completed for each data set as described in Table 2.

3.1.1 Land Cover Data

The land cover data set was obtained from the National Land Cover Database (NLCD) and has been interpreted from 1992 LANDSAT Thematic Mapper satellite images with 30 meter resolution. Because of the scale of these satellite images, the land cover information is effectively the average of the land cover per 30 square meter pixels across the watershed. User's accuracy for the data set is estimated to be between 57% and 93% for land use classes with overall average accuracy of 83%. This land cover information can be used to provide an understanding of overall land cover distribution in the watershed in 1992, but is not expected to be accurate at a small scale.

Land cover from the NLCD is presented in various categories. The transitional category contains areas with disturbed land cover, and can be used in forest regions to indicate areas where the forest has not yet recovered from clear-cut logging practices. Selective logging practices are not likely to be apparent in the transitional land cover category. Developed land cover categories can include agriculture/orchards, transitional, and residential/commercial. Other land cover categories presented are forested uplands, water, barren, shrublands, and wetlands; these categories may or may not show effects of human land use.

3.1.2 Soils Data

Soil maps for the State Soil Geographic (STATSGO) database are produced by generalizing the detailed soil survey data. Has been done by line segment (vector) format in accordance with Natural Resources Conservation Service (NRCS) digitizing standards. The base map used is the U.S. Geological Survey (USGS) 1:250,000 topographic quadrangles. The number of soil polygons per quadrangle map is between 100 and 400. The minimum area mapped is about 1,544 acres.

Each STATSGO map is linked to the Soil Interpretations Record (SIR) attribute database. The attribute database gives the proportionate extent of the component soils and their properties for each map unit. The STATSGO map units consist of 1 to 21 components each. The Soil Interpretations Record database includes over 25 physical and chemical soil properties, interpretations, and productivity. Examples of information that can be queried from the database are available water capacity, soil reaction, salinity, flooding, water table, bedrock, and interpretations for engineering uses, cropland, woodland, rangeland, pastureland, wildlife, and recreation development.

TABLE 2

Description of Model Input Data

Data Type	**Name**	**Source**	**Resolution**	**Data**	**Pre-processing Performing**
Topography	Digital Elevation Model (DEM)	USGS National Elevation Dataset	7.5 minute, 30 meter	NA	Merged; Re-projected to Montana State Plane; Clipped to Project area size.
Soils	STATSGO Soil Survey	USGS	1:250,000	1994	Merged; Re-projected to Montana State Plane; Clipped to Project area size.
Land Cover	National Land Cover Database (NLCD)	USGS	7.5 minute, 30 meter	1992	Re-projected to Montana State Plane; Clipped to project area size.
Precipitation	NOAA Atlas 2	National Weather Service (NOAA)	15 sec	1973	Re-projected to Montana State Plane; Clipped to project area.

3.1.3 Topography Data

Digital Elevation Models (DEMs) consist of a raster grid of regularly spaced elevation values that have been primarily derived from the USGS topographic map series. DEMs are available in Native format, written as ANSI-standard ASCII characters in fixed-block format. 7.5-Minute DEMs correspond to the USGS 1:24,000- and 1:25,000-scale topographic quadrangle maps. The files used in this analysis have a grid spacing of 30 meters.

3.1.4 Precipitation Data

Precipitation input was derived from the NOAA Atlas2 (1972). Each volume of this Atlas contains precipitation-frequency maps for 6- and 24-hr durations for return periods from 2 to 100 years for one of the 11 western states (west of about 103" W.). The 2-year, 6-hour event was used for this analysis. This series of maps differs from previous publications through greater attention to the relation between topography and precipitation-frequency values. This relation is studied objectively through the use of multiple regression screening techniques, which develop equations used to assist in interpolating values between stations in regions of sparse data. The maps were drawn on a scale of 1:1,000,000 and reduced to 1:2,000,000 for publication.

3.1.5 Pre-processing

In general, pre-processing included reviewing the data layer for completeness, merging or creating mosaics of individual data files into one file to cover the entire project area, re-projecting the file to Montana State Plane, and clipping the files to fit the project area. In addition, a 1992 TIGER roads coverage and a detailed forest lands road coverage obtained from the US Forest Service Beaverhead-Deer Lodge National Forest was integrated into the baseline NLCD land cover data layer. The roads coverage was converted from shapefile format into ESRI grid format with a cell size of 30 meters and merged with the NLCD 30 meter coverage. To truth the NLCD layer, the cover types of 30 meter grids were modified by Watershed Consulting to reflect the current conditions of the watershed based on aerial photograph review and 2003 field data. Other than those changes listed above, source data were not directly altered.

Limitations associated with data sets are often related to time and scale. Date of origination of the data layer does not appear to be a confounding factor for this modeling assessment. The age of the NLCD land use data set (1992) is unlikely to be an issue because land use has not changed markedly in the watershed over the last 10 years. In addition, the age of the precipitation file (1972) is also unlikely to be an issue because the period of record associated with that data set (1897-1970) is long enough to span a wide range of climatic conditions.

The major limitation of the data used in this analysis is its coarse scale. Finer scale data sets than the ones used in this analysis (e.g. SSURGO soil data sets (1:24,000)) often exist in readily available format. However, in the case of the Ruby River Watershed, these more detailed data sets were not available for the entire areas to be modeled. The data sets used in this analysis represent the smallest scale of readily available data present for the entire Ruby River Watershed.

Given the coarse level of resolution of the data inputs used for this model analysis, the model has the greatest applicability as a screening level tool. Used at the screening level, the modeling results can be compared among sub-basins on a relative scale because the data resolution is the same across the entire watershed. These results can then be used to target quickly the areas of high sediment yield for further investigation through on site field review.

3.2 Model Development

This step included the creation of the framework for running the AGWA model. The first task involves the use of AGWA to delineate sub-basins for modeling. For this task, the modeler designated an outlet (pour point) at the downstream end of each sub-basin study area. From the outlet, AGWA created an outline of the sub-basin and a grid based on the directional accumulated flow to the designated outlet. The Upper and Lower Ruby River mainstem and 14 individual tributary sub-basins containing the 303(d) listed streams were delineated in this manner.

Due to budget limitations, sub-basin delineations could not be completed for all 303(d) listed streams separately. As a result, some sub-basins contain more than one 303(d) listed streams. For instance, when a network of small 303(d) listed streams were located in close proximity to each other and within similar landscape conditions (e.g. small streams of the Upper Ruby River Headwaters sub-basin) or when 303(d) listed tributaries drained to other larger order 303(d) listed streams (e.g. Harris and California Creeks), they were grouped into a single sub-basin. The 14 delineated sub-basins are listed in Table 3 and depicted in Figure 2.

The second task in this step entailed sub-dividing the sub-basins into surface drainage and channel networks. Surface drainage and channel network configuration are important landscape attributes for hydrologic modeling of runoff processes. The AGWA model used DEM topography data to build a polygon shapefile from the sub-basin outline and extract a drainage network. The sub-basin was then divided into combinations of overland flow planes (upland areas) and interconnected channel elements. The channel elements were connected into a stream network based on the topography. Upland areas were used to model overland flow to the channel elements.

When the Upper and Lower Ruby mainstem sub-basins were sub-divided, upland areas derived by the model were distinct from the 14 tributary sub-basins. Figure 2 and Figures 5 – 18 depict divisions of each sub-basin into individual plane and channel elements.

TABLE 3

Modeled Sub-basins and Associated 303(d) Sediment-listed Waterbodies

Sub-Basin	303 (d) Listed Water Bodies in Sub-Basin
Alder Gulch	Alder Gulch Mill Gulch
Burnt Creek	Burnt Creek
California Creek	California Creek Harris Creek
Cottonwood Creek	Cottonwood Creek
Garden Creek	Garden Creek
Greenhorn Creek	N. Fork Greenhorn Creek
Indian Creek	Indian Creek
Lower Ruby River mainstem	Lower Ruby River mainstem
Mill Creek	Mill Creek
Mormon Creek	Mormon Creek
Ramshorn Creek	Ramshorn Creek Currant Creek
Sweetwater Creek	Sweetwater Creek
Warm Springs Creek	Warm Springs Creek
Wisconsin Creek	Wisconsin Creek
Upper Ruby River mainstem	Upper Ruby River mainstem
Upper Ruby Headwaters	Basin Creek Coal Creek East Fork Ruby River Hawkeye Creek Poison Creek Shovel Creek West Fork Ruby River

3.3 Scenario Development

Watershed hydrology can be modified by land cover changes in the watershed, such as land clearing, agriculture, urbanization, or construction of infrastructure. Anthropogenic land cover changes due to different land uses can also increase or decrease the rate at which surface geomorphologic and hydrologic processes take place or change the impact of the forces of these processes relative to each other.

Watershed hydrology and sediment are driven by the way that precipitation, surface water, and groundwater move through the watershed system. Water generally enters the system as precipitation, which may then be infiltrated to the soil, intercepted by vegetation, evaporated, or moved across the landscape as surface runoff. Watershed land cover can affect the percentage of water that moves through the landscape in each of these processes. In areas with dense vegetation, more water is intercepted or infiltrated than moves across the surface as runoff. In areas with less vegetation, a higher percentage of the water becomes surface runoff. The change in hydrologic regime due to land cover change has repercussions in the geometric shape of the stream channel, instantaneous rate of flow, the annual hydrograph, and the stream ecosystem itself.

Changes to the land cover (NLCD) data inputs can create hypothetical scenarios of land management. In this step of the modeling process, the context of the land cover (scenario) for each model run was developed. Modeling of the 2-year, 6-hour event was conducted for the baseline (existing) sub-basin condition and for three different land management scenarios. These scenarios included:

- Baseline (existing) condition (Upper and Lower Ruby River mainstem and 14 sub-basins);
- Without roads (14 sub-basins);
- With enhanced riparian buffers (14 sub-basins); and
- With on-channel ponds (2 sub-basins).

All scenarios included the four basic GIS data sets described in Table 2. The only data set that was altered for each scenario model run was the land cover (NLCD) data set. Details on the rationale for each scenario, how it is used to meet the objectives of the study, what modifications were made to the land use (NLCD) data set, and assumptions specific to each scenario are provided in the following discussion.

3.3.1 Baseline (existing) condition scenario

The baseline condition scenario utilized the current (1992) NLCD land use data coverage integrated with the TIGER and Forest Service roads coverage. The method by which these data sets were integrated has been described previously in Section 3.1. This land cover was used to represent the existing land cover in the watershed. An existing conditions model run was conducted for the Upper and Lower Ruby River mainstems and each of the 14 303(d) - listed sub-basins.

3.3.2 Sub-basins without roads scenario

Roads built in certain areas can pose sediment risks. Often, roads are built along streams because topographically road construction is easier in these flatter areas. Generally, forest roads in the watershed can be related to mass wasting events. Forest roads can contribute to landslides and occasionally cause large debris flows. Roads that cross the same stream channel two or more times are particularly prone to causing these problems. Rapid sediment source inventories conducted in 2003 through the Ruby River Sediment TMDL Assessment indicated that roads are a significant source of sediment to several 303(d) - listed waterbodies in the Ruby River Watershed (Watershed Consulting, in press). Based on field assessments, streams in the Tobacco Root Mountains appear to have an especially high relative sediment contribution due to roads, compared to natural sediment sources. The influence of roads on sediment yields was developed as a model scenario in order to determine which sub-basins are highly influenced by roads.

The effect of the road cover class within the model was created by changing the individual land cover classes of the 30 meter grid cells for all roads except paved roads. Road cover classes were changed to that of the surrounding landscape within the sub-basin. Although total road removal within a watershed is not considered a reasonable management alternative, the objective of the scenario assessment was to determine the proportion of relative sediment yield within each sub-basin contributed by the road cover class of secondary roads within the model. The sub-basins without roads scenario was completed for each of the 14 303(d)-listed sub-basins.

The data inputs for AGWA for this scenario are based on a 30 meter resolution, and thus AGWA analysis considers roads to have a minimum 30 meter (~100 foot) width. Since this over-represents the actual road widths of native forest surface roads (generally < 20 feet), it is likely that the model results would over-predict the effect of roads on sediment yields. Over-representation of road widths would have a greater effect on sub-basins containing more road miles.

To compensate for this effect, the difference in erosion magnitude for roads of varying widths needed to be determined. The general magnitude of difference in sediment yield between a 30 meter road and a five meter road was determined using the WEPP (Water Erosion Prediction Project): ROADS calculator. This quick calculator was developed by the US Forest Serviced to determine amounts of sediment yield from sections of roads within a watershed. To address the road width difference issue, the sediment yields for a 30 meter long, representative rutted, native surface road in clay loam in southwestern Montana was calculated at both a 30 meter and five meter width at various slopes. The calculator results indicate that the sediment yields increased by a magnitude of seven times for the 30 meter road over the five meter road. As a result, the sediment yields obtained in the AGWA modeled sub-basins were adjusted by a factor of seven to more accurately represent the roads effect of overall sediment yield in the sub-basin.

This modeling scenario did not distinguish among detailed road characteristics such as road types or use levels, but does provide a framework for targeting transportation management and improving road design using effective BMPs. The AGWA modeling provides an estimate of the sediment contribution due to the hydrological effects of the road cover class in the model, but does not address specific sediment routing sites, where roads drain to stream corridors or the effects of the surface condition, road fill slope and width on sediment yields. This analysis should be coupled with the more detailed estimate of sediment contributions from the Ruby River Watershed Sediment TMDL (Watershed Consulting in press). That assessment measured and mapped sediment delivery sites on roads along sediment-impaired streams.

3.3.3 Sub-basins with riparian buffer enhancement

Riparian areas are the stretches of land area that are the margin between land and freshwater. They are the location where terrestrial ecosystems and watershed land uses meet and affect the stream ecosystem. Riparian areas serve many functions important to the watershed as a whole. Plants and moist soil filter nutrients, sediment, and toxins from runoff before they reach the stream channel (Manci, 1989). Root structures and ground cover decrease stream bank erosion and stream sediment load. Streamside vegetation increases roughness, dissipating flood water velocity. Deep-rooted trees increase ground porosity and capillarity, and improve infiltration (Tabacchi et. al, 2000).

Riparian areas are often cleared to make way for human land uses, and benefits to the entire watershed system are lost. Any land clearing or land conversion activity including logging, agriculture, residential development, and general urbanization can result in riparian area degradation and lost function in controlling sediment inputs. The riparian buffer enhancement scenario was developed to determine what areas are most prone to sediment inputs due to overland flow and to what extent increasing riparian vegetation can reduce inputs due to overland flow. The riparian buffer enhancement scenario was completed for each of the 14 303(d)-listed sub-basins.

The riparian buffer enhancement scenario was created by reclassifying NLCD 30 meter riparian buffer grid cells along streams to the reference riparian condition for that sub-basin. The reference condition was determined by Watershed Consulting through 2003 field data collection of riparian type and condition.

Due to the scale of resolution of the data inputs, the modeling analysis assumes a baseline and scenario buffer width of 30 meters (~100 ft). If buffers are actually enhanced to a narrower width than 30 meters, it is likely that the effect on sediment yields would be less than presented. In addition, the AGWA model does not consider the riparian vegetation effect on streambank erosion; however, a rapid sediment source inventory conducted in 2003 provides detailed information about sediment sources related to streambank erosion. The results of this assessment will be combined with the field investigation in development of the Ruby River Sediment TMDL (Watershed Consulting, in press).

3.3.4 Sub-basins with ponds

Historic accounts mention high populations of beaver on streams throughout the Rocky Mountains and document severe declines in beaver populations after wide-spread trapping. Removal of beaver and past land uses involving placer mining and overgrazing have led to removal of riparian vegetation on floodplains, lowered water tables, and stream incisement in several areas of the Ruby watershed (Watershed Consulting, in press). According to riparian assessments conducted in 2003, beaver have restored water tables and floodplain vegetation at several of these sites (Watershed Consulting, in press). Water supply, quality and quantity of riparian and aquatic habitat, and water quality are all affected by beaver activity, thus opportunities for restoration could be linked to restoring beaver populations. The pond effects scenario was developed because many of the stream channels in the Ruby watershed exhibit influences of past beaver activity, yet currently have little activity and little available beaver habitat (Watershed Consulting, in press).

The pond effects scenario models the potential of pond complexes (similar in size and structure to beaver ponds) to reduce sediment yields. Due to budget limitations and the complexities of running this scenario, the ponds scenario was completed for 2 of the 303(d) listed sub-basins (Alder Gulch and Warm Springs Creek). Sub-basins for this scenario were chosen for the following characteristics:

- Streams of 1.5 % to 2.5 % gradient for location of pond;
- Watersheds above the pond location of similar size; and
- Different relative sediment yield classifications.

This scenario involved placement of small pond complexes directly on the stream channel of the sub-basins of interest. KINEROS2 within AGWA has a pond routing sub-routine that allows for placement of a pond on a channel within a watershed. The pond complexes were designed as a series of three small shallow ponds, with each pond 10 meters wide by 30 meters long, with an average depth of 1 meter. The pond was placed on the channel and the sediment yield for the sub-basin was calculated with and without the pond to obtain the change in sediment yields from ponds.

Currently, few areas exist in the Ruby River watershed with the potential to sustain beaver populations long enough to achieve channel restoration or avoid conflicts with current land management (Watershed Consulting, in press). Therefore, the modeled pond scenario addresses the potential of beaver complexes to mitigate high flow and sediment delivery, but does not address management requirements for restoring beaver habitat and populations in tributaries of the Ruby watershed.

3.4 Data Analysis and Reporting

The first task in the models data analysis entailed deriving input parameters from land cover and soil GIS coverages. In this process, AGWA intersected soil and land cover GIS data files with the sub-basin boundary. Parameters necessary for the hydrological model runs were collected from the GIS data files by AGWA. For KINEROS2 sediment yields, AGWA is primarily concerned with the uppermost 9 inches of soil because of its dominant influence on event runoff. As a result, parameter values associated with soil textures within the uppermost nine inches of a component soil were weighted by depth/thickness to get an average value. These average values were then used to derive the information for the model, such as percentages of sand, silt, clay, and rock, following programming scripts based on procedures outlined in the KINEROS manual and Rawls et al. (1982). AGWA then updated the feature attribute table for each sub-basin with this information.

Rainfall input files were built for the AGWA framework. Due to limited available rainfall gage data and budget limitations, the NOAA 2-year, 6-hour event was used for this modeling assessment, as this is an event with a high frequency of occurrence. For this task, AGWA intersected the NOAA grid with the watershed centroid to get the storm total depth value. The depth value was then converted to a type II distribution using the SCS methodology (SCS, 1973). The type II distribution is appropriate for deriving the time distribution of rainfall for most of the country (SCS, 1986). For the 11 Western states where rainfall data are available, the entire interior West is characterized by the type II curve.

The KINEROS2 hydrological model was run after all input data were prepared. An existing conditions model analysis was conducted for the Upper and Lower Ruby River mainstem and each of the 14 303(d) listed tributary sub-basins. As stated previously, when the Upper and Lower Ruby mainstem sub-basins were sub-divided, upland areas derived by the model were distinct from the 14 tributary sub-basins. Relative sediment yields for all upland areas in the entire watershed were compared to one another to derive relative sediment yields for upland areas affecting the Upper and Lower Ruby River mainstem. For this reason, relative rankings for Upper and Lower Ruby River mainstem sediment yields should be viewed in a separate context from the relative rankings modeled for the 14 tributary sub-basins.

At the end of the model run, AGWA automatically imported the model results and added them to the polygon and stream maps' tables for display. Sediment yield results for each sub-basin under existing conditions were produced in these model runs. A separate module controlled the visualization of model results. This enables problem areas of high sediment yield among and within sub-basins to be identified visually.

The main output of KINEROS2 used and reported in this analysis was sediment yield (kg/ha) and particle size distribution (mm) produced by each sub-basin and each upland area within a sub-basin. The general equation used in KINEROS2 to describe the sediment dynamics at any point along a surface flow path was a mass balance equation similar to that for kinematic water flow (Bennett, 1974). Net upland erosion was a sum of splash erosion rate and hydraulic erosion rate. The above series of erosion relations were applied to each of up to five particle size classes, which are used to describe a soil with a range of particle sizes. Particle settling velocity was calculated from particle size and density, assuming the particles have drag characteristics and terminal fall velocities similar to those of spheres (Fair and Geyer, 1954). In larger particles on stream bottoms, armoring will ultimately occur when smaller more transportable particles are selectively removed, leaving behind an "armor" of large particles.

To determine the magnitude of relative sediment yields, a sediment yield classification system was devised. The sediment yield result for each tributary sub-basin was classified into one of five relative sediment yield classification categories. The classification system allows the baseline sediment yields to be presented relative to one another as:

- Low (0-20 %);
- Medium Low (20-40 %);
- Medium (40-60 %);
- Medium High (60-80 %); and
- High (80-100 %).

The uppermost end of the "high" category (100%) was equivalent to the highest sub-basin sediment yield produced from the 14 sub-basins. The remaining percentages that define the boundaries of the categories were calculated as a proportion of the highest sediment yield. For example, if the highest sub-basin sediment yield produced were 100 kg/ha, sub-basins with sediment yields of 80 to 100 kg/ha would rank "high"; sub-basins with 60 to 80 kg/ha would rank "medium high" and so forth. The same process for sediment yield classification was also completed for the individual upland areas of the Upper and Lower Ruby River basins.

Detailed calibration and model validation was not performed as the objectives of the project were to determine qualitative, relative sediment yields. However, modeled water balances for the 2-year event were analyzed to review the error associated with modeled hydrologic processes. Error associated with inflow and outflow of the water balance was determined for each of the 14 sub-basins. Twelve of the 14 sub-basins were determined to have errors of less than 0.8 % in water balance. Indian and Mill Creek sub-basins had errors of 7.86% and 3.4 % respectively.

A model check was also performed for the larger sub-basins that exceeded the size assumption of the KINEROS 2 model. Four of the sub-basins (the four largest: Sweetwater Creek, Alder Gulch, Warm Springs Creek, and Upper Ruby Headwaters) were generally larger in size than that typically modeled by KINEROS2. However, KINEROS 2 was used to model all sub-basins for consistency purposes in this analysis. To determine if there were relative errors in KINEROS2 modeled sediment yields for large, ungaged sub-basins, another erosion model, SEDCAD, was used to model the sub-basins using the same input data.

The SEDCAD model utilizes the SCS Curve Number method for runoff, like SWAT, which is generally used for basins of large area. Overall, the larger sub-basins produced runoffs that were larger with KINEROS2 than with SEDCAD (though this could be controlled with some adjustments to parameterized values in KINEROS2). The relative rank of outputs for the four largest sub-basins, however, was similar between both models. This indicated that quantitative results of the larger sub-basins with uncalibrated KINEROS2 may lose accuracy due to model assumptions, but relative results remained similar. Due to the limits of calibration of the model for the larger sub-basins, it should be emphasized again that model results should only be used in a qualitative, relative manner for planning level purposes.

4.0 RESULTS

4.1 Baseline Conditions

The Upper and Lower Ruby River and the 14 303(d) listed tributary sub-basins were modeled using the baseline condition scenario for existing land cover to determine relative sediment.

4.1.1 Upper and Lower Ruby River

For the Upper and Lower Ruby River mainstems, the baseline sediment yields of each individual upland area were classified in one of the five sediment yield classification categories. As stated in Section 3.0, when the Upper and Lower Ruby mainstem sub-basins are analyzed, the upland areas derived by the model are separate from the 14 tributary sub-basins.

Results of relative sediment yield areas for the Upper and Lower Ruby River mainstems are presented in Figure 3. Illustrating relative sediment yields on this scale provides an overview of the sediment yield risk from all individual areas within the basin. This information can be used to predict more closely which areas within the watershed are causing the highest proportion of the sediment yield.

Examining Figure 3, areas between and including Warm Springs Creek and the East Fork of the Ruby River had the highest relative sediment yields. High relative sediment yields can also be noted in the Robb Creek drainage, the southern portion of the Sweetwater Creek drainage, and the Cottonwood, Mormon, and Garden Creek drainages (Figure 3).

Areas with high relative sediment yields were characterized by similar watershed characteristics. In particular, areas with high sediment yields universally had lower soil hydraulic conductivity than those areas experiencing low sediment yields. Areas with relatively low sediment yields, such as in the northeastern corner of the watershed, generally have relatively higher soil hydraulic conductivity.

Hydraulic conductivity was determined within the model based on soil texture input information in the SSTASGO file. Hydraulic conductivity measures the ease with which water moves through the soil. Areas characterized by low hydraulic conductivity will generally have less water entering and moving through the soil and more water moving on top of the soil. More water moving on top of the soil can create greater sediment detachment from overland flow.

For areas with similar hydraulic conductivities, sediment yield results from the model indicate a secondary effect from land cover. For cover, the model assigns various land classifications a cover value. For example, cover values of 50 % are assigned to forest lands, 25 % to shrublands and grasslands, and 2 % to bare ground. In the model, areas characterized by land cover types with high assigned cover values (i.e. forest lands) tend to have lower sediment yields than those with low assigned cover values (i.e. grasslands). In a landscape devoid of vegetation, the rate of surface runoff is greater than in a forested landscape. Higher rates of surface runoff increase the erosion capability of water as it moves across the land surface, and yields more water in the stream at any one time, making streamflows “flashy.” These flashier flows result in more water in the stream channel that moves faster, increasing the scouring capability of streams. Land clearing can also yield other problems including reduction of the filtering ability from the landscape that would intercept sediment.

Slope of the sub-basin is another secondary characteristic driving sediment yields within the model. Those areas with similar soil hydraulic conductivities produced higher relative sediment yields when the sub-basin slope was higher.

These factors act singly and in combination to produce high sediment yields. The highest sediment yields from the model result from areas characterized by relatively lower soil hydraulic conductivity, lower land cover, and higher slopes. For example, low hydraulic conductivity of the soils coupled with high slopes (>30 %) in the area between Warm Springs and the East Fork of the Ruby River contribute to the modeled high sediment yields for this area. The upper portions of the basin contain approximately 50 % forest lands, thus mitigating sediment yields in those areas.

Soil hydraulic conductivities and slope are inherent features to individual sub-basins. Cover is the one variable that can be most affected by various land management activities. It can be altered by changes in dominant vegetation types or through the cover reduction effects of fire, grazing, mining, timber harvest, roads and other vegetation removal. For example, reduction of cover in the high sediment yield areas between Warm Springs Creek and the East Fork of the Ruby River would result in higher sediment yields than those currently present. Reduction in forest cover may result from wildfire, insect attack, blowdown, and timber harvest. Of these, timber harvest is the only process that can be planned to help mitigate the potential effects of increased water available for runoff during rain on snow events.

It is likely that severe reductions in cover for high sediment yield areas of the watershed (i.e. as a result of fire, creation of large areas of bare ground, overgrazing, timber harvest, mining, etc) would produce extremely high sediment yields due to the other inherent watershed characteristics. Conversely, increases in cover by reducing areas of bare ground, increasing grass height and density, etc. would have a positive impact on sediment yields in these areas.

4.1.2 Tributary Sub-basins

For the 303 (d)-listed tributary sub-basins, Warm Springs Creek sub-basin had the highest relative sediment yield under baseline (existing) condition (Table 4). Burnt and Garden Creeks sub-basins ranked medium, Mormon Creek and Cottonwood Creek ranked medium low, and the remaining nine sub-basins ranked low, producing 0 to 20 % the amount of sediment yield as the Warm Springs Creek sub-basin hillslopes (Table 4). Figure 5 provides a color-coded comparison of the relative sediment yields under baseline (existing) condition for the 14 sub-basins.

TABLE 4

Relative Sediment Yield Comparisons for Ruby River Watershed
Sub-basins under the Baseline (Existing) Condition Scenario

Sub-basin Name	Sediment Yield Classification
Alder Gulch	Low
Burnt Creek	Medium
California Creek	Low
Cottonwood Creek	Medium Low
Garden Creek	Medium
Greenhorn Creek	Low
Indian Creek	Low
Mill Creek	Low
Mormon Creek	Medium Low
Ramshorn Creek	Low
Sweetwater Creek	Low
Upper Ruby Headwaters	Low
Warm Springs Creek	High
Wisconsin Creek	Low

As described for the Upper and Lower Ruby River mainstems, soil characteristics had the dominant effect on sub-basin sediment yields. Among the 14 sub-basins analyzed, sub-basins with relatively lower soil hydraulic conductivity produced the highest sub-basin sediment yields. In general, those basins and sections of sub-basins with lower sediment yields generally had higher soil conductivity.

Within areas containing similar soil types; cover was an important factor in sediment yields. The percentage of various cover types for each of the 14 sub-basins is presented in Table 5. When sections of sub-basins with similar soil types are considered, areas with higher amounts of cover had lower sediment yields. Those sections of sub-basins with larger amounts of forest cover, for example, produced lower sediment yields than those with lesser amounts of forest cover. The effect of cover, however, was superseded by the effect of soil characteristics, wherever soil characteristics were different.

Within each of the TMDL sub-basins, the baseline sediment yields of each individual upland area were also classified in one of the five sediment yield classification categories. Relative sediment yield rankings within sub-basins are presented in Figures 5 though 18 as follows:

- Alder Gulch (Figure 5);
- Burnt Creek (Figure 6);
- California Creek (Figure 7);
- Cottonwood Creek (Figure 8);
- Garden Creek (Figure 9);
- Greenhorn Creek (Figure 10);
- Indian Creek (Figure 11);
- Mill Creek (Figure 12);
- Mormon Creek (Figure 13):
- Ramshorn Creek (Figure 14);
- Sweetwater Creek (Figure 15);
- Upper Ruby Headwaters (Figure 16);
- Warm Springs Creek (Figure 17); and
- Wisconsin Creek (Figure 18).

TABLE 5

Land Cover of Sub-basins

	Alder Gulch	Burnt	California	Cottonwood	Garden	Greenhorn	Indian	Mill	Mormon	Ramshorn	Sweetwater	Ruby HW	Warm Springs	Wisconsin
Land Use Classifications														
Bare Rock/Sand/Clay	0%	0%	0%	0%	0%	0%	2%	1%	0%	0%	0%	0%	0%	2%
Deciduous Forest	1%	1%	0%	0%	29%	0%	2%	3%	0%	1%	0%	0%	2%	2%
Evergreen Forest	33%	57%	22%	9%	28%	66%	62%	50%	14%	34%	2%	37%	50%	31%
Shrubland	13%	20%	12%	28%	0%	9%	9%	10%	24%	15%	35%	22%	15%	11%
Grasslands/Herbaceous	53%	22%	60%	62%	42%	22%	19%	31%	60%	40%	61%	39%	32%	35%
Pasture/Hay	0%	0%	3%	0%	0%	1%	6%	5%	0%	6%	2%	0%	0%	12%
Small Grains	0%	0%	2%	0%	0%	1%	0%	0%	0%	3%	0%	0%	0%	5%
Other classifications	1%	0%	1%	0%	0%	1%	0%	1%	0%	100%	0%	1%	0%	2%
Soil Hydraulic Continuity (Ks)	4.1	2.4	4.1	2.5	3.2	7.2	7.5	7.3	2.7	4.9	2.8	4.4	2.3	5.8

Illustrating the sub-basins on this scale provides a more detailed review of the sediment yield risk from each individual area within the sub-basin. For instance, in the Upper Ruby Headwaters sub-basin (Figure 16), higher sediment yields are being contributed by the eastern one-third of this sub-basin, particularly the area of the East Fork of the Ruby River, due to lower soil hydraulic conductivities in this area. In the Warm Springs Creek sub-basin (Figure 17), sediment yield contributions are more evenly distributed, but are primarily a result of the upper tributary areas of the sub-basin. Examining Figures 5 through 18, one can predict more closely which areas within the individual sub-basins are causing the highest proportion of the sediment yield, and thus pose the highest sediment risk.

Those portions of the sub-basins that were forested generally had lower sediment yields than those that were covered by shrubland or grasslands if the soil types were similar. Areas with bare ground, transitional habitat, quarries/mining, residential and commercial areas and fallow fields, in turn, produce higher sediment yields than forest, grassland and shrubland due to less overall percent cover.

4.1.3 Particle Size Distribution

The model outputs predict the soil particle size class distribution for the individual sub-basin sediment yields. Results of the particle size distribution are presented in Table 6.

TABLE 6

Sediment Yield Particle Size Composition for Sub-basins

Basin Name	Sediment Yield Classification	Particle size < 0.250 mm (%)	Particle size < 0.033 mm (%)	Particle size < 0.004 mm (%)
Alder Gulch	Low	5	37	58
Burnt Creek	Medium	44	44	12
California Creek	Low	21	55	24
Cottonwood Creek	Medium Low	38	48	14
Garden Creek	Medium	39	47	14
Greenhorn Creek	Low	25	58	17
Indian Creek	Low	11	52	37
Mill Creek	Low	9	48	43
Mormon Creek	Medium Low	38	48	15
Ramshorn Creek	Low	6	46	48
Sweetwater Creek	Low	24	58	18
Upper Ruby Headwaters	Low	35	52	13
Warm Springs Creek	High	33	53	14
Wisconsin Creek	Low	3	23	74

Model results indicate variability in the particle size composition of sediment transported by individual sub-basins. Sediment was composed of a much higher proportion of the very fine particle size in Wisconsin Creek, Ramshorn Creek, and Alder Gulch compared to other sub-basins. Indian Creek and California Creek sediment yields were composed primarily of the two smallest particle size classes, while the sediment yields in the remaining sub-basins were composed predominantly of the largest and medium particle size classes.

The type of sediment (fine or coarse) moving through a system affects the overall sediment yield weight. In general, those sub-basins with a higher percentage ($\geq$ 38 %) of the larger size particles had somewhat higher sediment yields than those with primarily smaller particle sizes.

The type of sediment contributed by each sub-basin is a factor of sub-basin characteristics. Sub-basins in the northeastern portion of the watershed had sediment yields composed predominantly of smaller particle sizes. This is likely a factor of soil type, geology and high hydraulic conductivity.

4.2 Scenario 1: Road Removal

The 14 303(d)-listed sub-basins were modeled to determine the relative sediment yield reduction created when the land cover of roads in the sub-basin was altered. As described in Section 3.0, the road effects scenario was created by changing the land cover class of all roads in the model inputs except paved roads. It is reiterated here that removal of all roads is not a considered a reasonable restoration/land management approach.

A representation of the percent change of sediment yield within subbasins as a result of removing the road cover class for the 2-year, 6-hour event is presented in Figure 19. Numerical percent changes in sediment yields due to the road cover class are provided in Table 7. Total sediment yields and percent change results are those corrected to typical road widths as described in Section 3.0.

TABLE 7

Relative Changes in Sediment Yield for Road Removal Scenario

Sub-basin	Baseline Sediment Yield Classification	Length of Roads (m)	Road Density (m/ha)	Classification of Total Amount of Sediment Yield from Roads	Percent Change in Overall Sub-basin Sediment Yield from Roads
Alder Gulch	Low	184058	7.3	Low	3%
Burnt Creek	Medium	3538	1.9	Low	<1%
California Creek	Low	55773	8.7	Low	3%
Cottonwood Creek	Medium Low	23874	8.2	Low	<1%
Garden Creek	Medium	21330	6.3	Low	1%
Greenhorn Creek	Low	14906	2.6	Low	1%
Indian Creek	Low	18852	4.8	Low	4%
Mill Creek	Low	49427	6.4	Low	4%
Mormon Creek	Medium Low	1830	1.2	Low	<1%
Ramshorn Creek	Low	57255	9.6	Low	2%
Sweetwater Creek	Low	218180	6.6	Medium	1%
Upper Ruby Headwaters	Low	48718	2.0	Low	<1%
Warm Springs Creek	High	47536	3.6	High	<1%
Wisconsin Creek	Low	69552	7.1	Low	4%

In total, road removal for the 14 sub-basins resulted in a <1 % reduction in total sediment yield. This is determined as the proportion of the total road sediment yield to the overall total sediment yield for the 14 sub-basins. Due to the limitations by which the model represents the physical characteristics of roads, it is likely that actual contribution from roads is higher than this result.

Total sediment yield due to the roads cover class was highest in the Warm Springs Creek sub-basin and medium in the Sweetwater Creek sub-basin. Overall total sediment yield due to the road cover class was low in the remainder of the sub-basins.

In the model, the total sediment yield due to the road cover class appears to be primarily a factor of the land cover class to which the road land cover is changed. In the model scenario, the bare ground (2 % cover) on roads was replaced with the cover of the adjacent land areas, therefore the higher the cover present in the adjoining areas and the greater area to which it is applied, the more pronounced the effect of the road removal scenario. For example, in the Warm Springs sub-basin the adjacent cover generally included forest lands (50 % cover). As a result, these sub-basins experienced a higher reduction in sediment yields than those sub-basins in which the surrounding land cover was shrubland or grassland. A secondary factor affecting total sediment yields due to road cover was the proportion of the sub-basin that was covered by the road cover class. The higher the percentage of the road cover within the sub-basin the higher the total road sediment yield

The effects of the road cover class as a percentage of total sub-basin sediment yields, however, is a factor of the cover type, road density and overall baseline sediment yields. Assuming a similar cover class change, those sub-basins with the lowest initial baseline sediment yield and the highest road densities would have the highest proportional change in sediment yield due to roads. These effects are most apparent in those sub-basins of the northeastern portion of the watershed. Sediment yield reductions were 3 to 4 % for the Indian, Mill, Wisconsin, California, and Alder Gulch sub-basins. Except for difference in cover, these sub-basins had generally lower sediment yields to start and high road densities. Thus the overall impact of changes in road cover class in these sub-basins generally had a greater effect in the percent reduction of sediment yield than for sub-basins with higher overall sediment yields.

Remaining sub-basins had a much lower proportion of the total sediment yield related to roads, with Burnt Creek, Mormon Creek, and the Upper Ruby Headwaters sub-basins affected the least by removing the road cover class. In these sub-basins there was a low proportion of road sediment yields to total sediment yields, primarily as a result of the low road density.

In summary, the type of alternate cover, baseline sediment yield, and road density affected the total sediment yield and percent contribution of the road cover class in the model. Many characteristics of roads could not be accounted for in the model such as detailed road surface characteristics and texture, road condition, and fill width and slope. As a result, it is expected that these modeling results will be combined with detailed field verification of road characteristics to provide finer resolution of the affects of roads on sediment in these sub-basins.

4.3 Scenario 2: Riparian Buffer Enhancement

The 14 303(d) listed sub-basins were modeled to determine relative sub-basin sediment yield due to enhanced riparian buffers in the sub-basin. As described in Section 3.0, the riparian buffer enhancement scenario was created by adding and reclassifying riparian buffer along streams to the model data inputs. The objective of the scenario assessment was to determine the proportion of relative sediment yield affected by enhancing riparian buffers within each sub-basin to the reference riparian condition for that sub-basin.

Figure 20 illustrates the percent reduction of sediment yield as a result of riparian buffer enhancement for the 2-year, 6-hour precipitation event. Numerical percent changes in sediment yields due to riparian buffer enhancement are provided in Table 8.

TABLE 8

Relative Changes in Sediment Yield for Riparian Enhancement Scenario

Sub-basin	Baseline Sediment Yield Classification	Classification of Total Sediment Yield from Riparian Buffer Enhancement	Percent Change in Overall Sediment Yield (%)
Alder Gulch	Low	Low	3 %
Burnt Creek	Medium	High	7 %
California Creek	Low	Low	0 %
Cottonwood Creek	Medium Low	Low	-1 %
Garden Creek	Medium	Low	0 %
Greenhorn Creek	Low	Low	-1 %
Indian Creek	Low	Low	13 %
Mill Creek	Low	Low	23 %
Mormon Creek	Medium Low	Low	2%
Ramshorn Creek	Low	Low	3%
Sweetwater Creek	Low	Low	-1 %
Upper Ruby Headwaters	Low	High	3 %
Warm Springs Creek	High	Low	<1%
Wisconsin Creek	Low	Low	-4 %

* Negative results indicate a positive increase in sediment yield.

Overall riparian buffer enhancement for the 14 sub-basins had a very limited effect on sediment yields, resulting in an overall <1 % reduction in total sediment yield for all sub-basins combined.

Total amount of sediment yield that was reduced due to the riparian buffer enhancement was highest in the Upper Ruby Headwaters sub-basin and Burnt Creek sub-basin. Overall total sediment yield that was reduced due to the riparian buffer enhancement was low in the remainder of the sub-basins. As with roads, overall changes in sediment yields for riparian buffer enhancement scenarios were largely a result of changes in the cover of the vegetation type.

Those sub-basins in which the riparian buffer was changed from a lesser amount (i.e grassland with 25 % cover) to a higher cover type (i.e woody wetlands with a 70% cover type) experienced the largest reductions in sediment yields. On the other hand those sub-basins in which the cover type changed from a greater amount (urban/recreational grasses with a cover type of 90 %) to a lower cover type (woody wetlands with a 70 % cover) actually experienced a gain in sediment yields from overland flow.

The largest reduction in sediment yield as a result of riparian enhancement occurred in the Mill Creek (23 %), Indian Creek (13 %) and Burnt Creek (7 %) sub-basins. The remaining sub-basins had much less sediment yield improvement related to riparian enhancement. As with the roads scenario, this is primarily a factor of the change in land cover, the amount of baseline sediment yield and the amount of buffer enhanced. In those sub-basins, where riparian cover change was similar, areas with the lowest baseline sediment yields and the largest riparian area enhanced tended to have greater overall percentages of sediment yield reductions. The cover changes in the Mill, Indian, and Burnt Creek sub-basins were the highest over the greatest area.

In summary, riparian buffer enhancement that involved changes to denser cover classes had the highest reductions in sediment yields. The overall percent reduction in total sediment yield is a factor of the cover class change, the baseline sediment yield and the amount of area enhanced. As discussed in Section 3.0, due to the scale of resolution of the data inputs, the modeling analysis assumes a baseline and scenario buffer width of 30 meters (~100 ft). If buffers are actually enhanced to a narrower width than 30 meters, it is likely that the percent reduction would be less than presented. It should also be noted that the modeling effort only reflects the effects of enhanced buffers to overland sediment yield entering the stream. The model results do not take into account other soil stabilizing vegetative characteristics of riparian vegetation, including deep binding root structures to stabilize streambank soil particles. The TMDL field monitoring conducted in 2003 provides information for estimating bank erosion in source assessment and loading estimates.

4.4 Scenario 3: Pond Placement

The third scenario involved placement of small sediment storage ponds on the mainstem channel of two-303 (d)-listed streams (Alder Gulch and Warm Springs Creek). This scenario simulated the effects of sediment storage provided by beaver pond complexes. The objective of this scenario was to determine the effect of pond placement on the relative percentage of sediment yield.

Modeling results of the scenario were compared to the baseline condition for the 2-year, 6-hour precipitation event to derive percent changes in sediment yield due to placement of beaver ponds. Numerical percent changes in sediment yield are provided in Table 9.

TABLE 9

Relative Changes in Sediment Yield
for In-channel Pond Placement Scenario

Basin Name	Baseline Sediment Yield Classification	Percent Reduction in Sediment Discharge
Alder Gulch	Low	<1 %
Warm Springs Creek	High	3 %

As only two sites were modeled for pond placement, the interpretation of the baseline sediment yield classification and other sub-basin characteristics on the percent reduction in sediment from ponds is limited. However, some general conclusions can be made. Percent reduction in sediment yield was higher in Warm Springs Creek than in Alder Gulch. For Warm Springs Creek, the placement of one small pond complex had a larger impact in sediment yield reduction in the watershed than either of the other two watershed scale scenarios (riparian enhancement or road effects). For Alder Gulch, the pond reduction of sediment from one pond complex was smaller relative to the reduction in sediment yield through road removal and riparian enhancement, but this was the result of only one pond complex.

Large-scale placement of multiple small ponds throughout the watershed (as generally occurs with natural beaver pond complexes) was not modeled, due to budget constraints. However, it is likely that such a scenario would reduce peak sediment discharge by a larger amount than was predicted for only one pond complex. The reduction in sediment from just one in-channel pond complex suggests that the sediment reduction due to pond complexes could be substantial over an entire watershed.

5.0 CONCLUSIONS

In the context of the entire Ruby River watershed, areas in the southeastern portion of the watershed, between and including Warm Springs Creek and the East Fork of the Ruby River, had the highest relative sediment yields. High relative sediment yields can also be noted in the Robb Creek drainage, the southern portion of the Sweetwater Creek drainage, and the Cottonwood, Mormon, and Garden Creek drainages. Sediment yield classifications among 14 individual 303(d)-listed tributary sub-basins, indicated that Warm Springs Creek had the highest relative sediment yield under baseline (existing) condition. Burnt and Garden Creeks sub-basins ranked medium, Mormon Creek and Cottonwood Creek ranked medium low, and the remaining nine sub-basins ranked low, producing only 0 to 20 % of the sediment yield in the model produced by the Warm Springs Creek sub-basin.

The modeled tributary sub-basins are generally small and dominated by overland flow on the upland areas. As result, a variety of upland characteristics affected sediment yields. Soil characteristics in particular played primary roles in producing various magnitudes of sediment yield in the model. The highest sediment yields from the model result from areas characterized primarily by low soil hydraulic conductivity (from soils) and secondarily by low land cover and high slopes. The highest relative sediment yields extend on the southeastern portion of the watershed from Warm Springs Creek sub-basin southward through the eastern half of the Upper Ruby Headwaters sub-basin. These high relative sediment yields are due primarily to the low hydraulic conductivities of the soils of this area. These modeling results indicate that inherent soils characteristics play an important part in high sediment yield areas produced by the model in the watershed.

Vegetative cover plays a secondary role in the relative magnitude of sediment yields produced in the model assessment, but it is the characteristic of the sub-basin that can be changed through land management actions. Locations within the Warm Springs to East Fork Ruby River area of the watershed contain higher percentages of vegetative land cover in some areas that help mitigate high sediment yields. Increasing vegetative cover on the uplands of all the Ruby River sub-basins is an important factor in ameliorating high sediment yields or further reducing areas of relatively low sediment yields. To manage for sediment yields within high risk sediment sub-basins, vegetative cover could be increased to the extent possible.

Three scenarios for land management were modeled within this assessment. Overall, in the road effects scenario, total sediment yield for the 14 sub-basins resulted in <1 % of the total sediment yields produced by all sub-basins. This is likely lower than actual due to the assumptions and limitations of how the model represents roads. The effect of the road cover class as a percentage of total sub-basin sediment yields is a factor of the cover type, road density and baseline sub-basin sediment yield. In the model, the total sediment yield due to the road cover class appears to be primarily a factor of the land cover class to which the road land cover is changed.

Overall riparian buffer enhancement to a 30 meter width for all streams for the 14 sub-basins resulted in an overall <1 % reduction in total sediment yield for all sub-basins combined. As with roads, overall changes in sediment yields for riparian buffer enhancement scenarios were largely a result of changes in the cover of the vegetation type and the amount of buffer enhanced relative to watershed area.

The third scenario for the placement of on channel ponds was limited to two sub-basins, and showed a 1 to 3 % reduction in sediment yields in these sub-basins. This was for the placement of a small series of ponds on the channel in one location in the watershed. It is likely that increased placement of ponds would have an increased effect on reduction of sediment yields. The pond scenario could be a promising management option for reducing sediment yields if investigated in more detail.

Applying these management options on a sub-basin scale could be focused in a variety of ways. If the overall goal is to manage the sub-basin sediment on an individual sub-basin level, management actions could focus on the sub-basins with the highest proportional change of total sediment yield. Roads contributed the highest proportion (up to 4 %) of total sediment in the streams of the Tobacco Root Mountains landscape of the northeastern portion of the watershed (Indian, Mill, Alder Gulch, Wisconsin, and California Creeks). The riparian buffer enhancement reduced the highest proportion of sediment in the streams of Indian and Mill Creeks. However, these sub-basins generally have lower sediment yields as a baseline condition, and thus the total sediment yield reduced in these sub-basins is actually low.

If the overall goal is to reduce as much sediment as possible entering the Ruby River mainstem, management should focus on those sub-basins that had the highest total reduction in sediment yield. This would include Warm Springs Creek sub-basin and Sweetwater Creek sub-basin for the roads scenario and the Upper Ruby Headwaters sub-basin and Burnt Creek sub-basin for the riparian buffer enhancement scenario. Most of these are large sub-basins in which the sediment from the scenario represents a small portion of the total sub-basin sediment yields. As a result, these management actions could be coupled with management actions that increase vegetative cover in the uplands to further maximize the reduction in sub-basin sediment yields.

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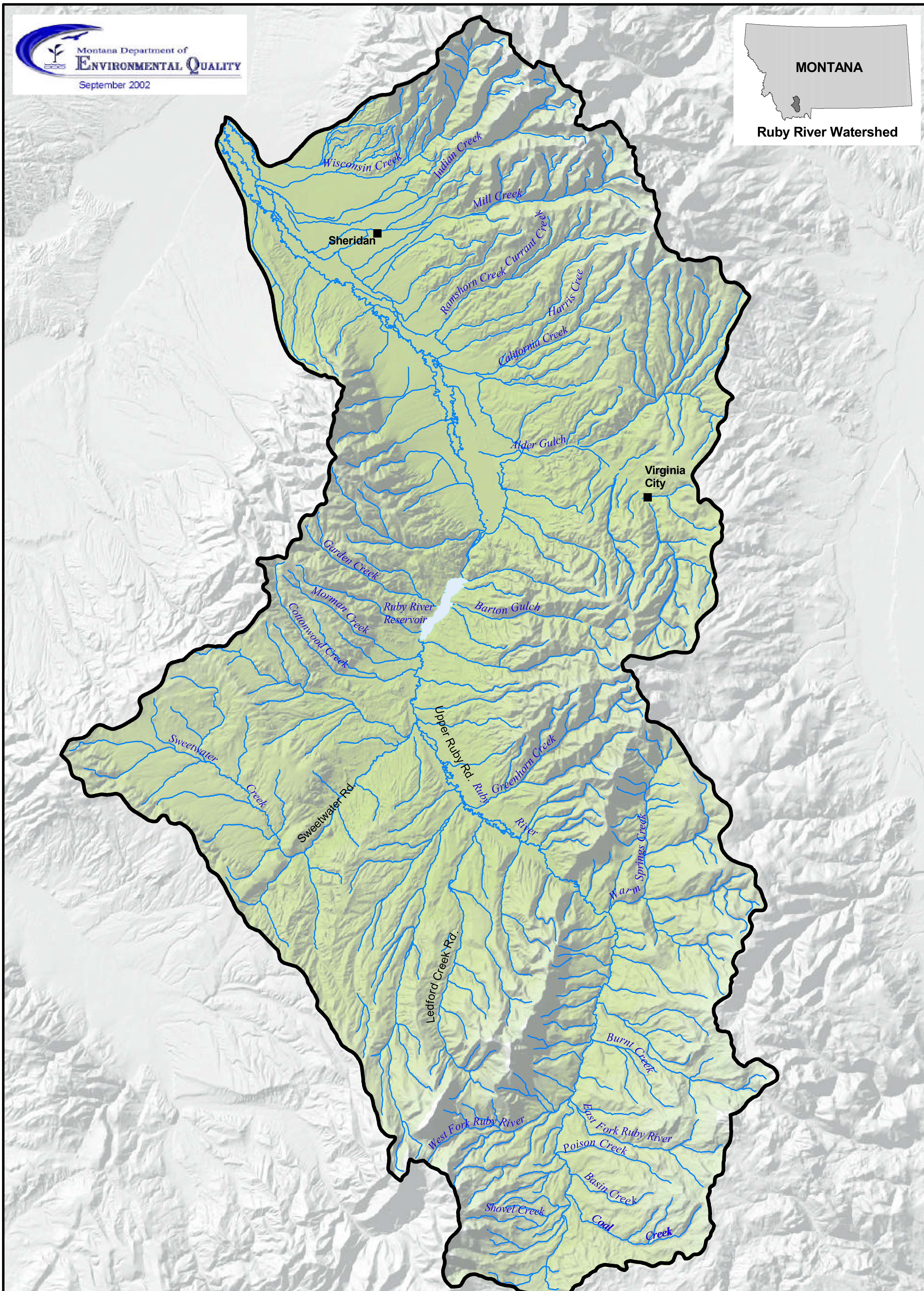
FIGURES



LEGEND

Ruby River Watershed Boundary	Lakes
HUC 5 Boundaries	Rivers and Streams
Cities	
Roads	

0 4
Scale 1" = 4 Miles

Map Projection:
Montana State Plane NAD 83
Meters
Source: NRIS, USGS
US CENSUS

N

Figure 1
Ruby River Watershed Overview

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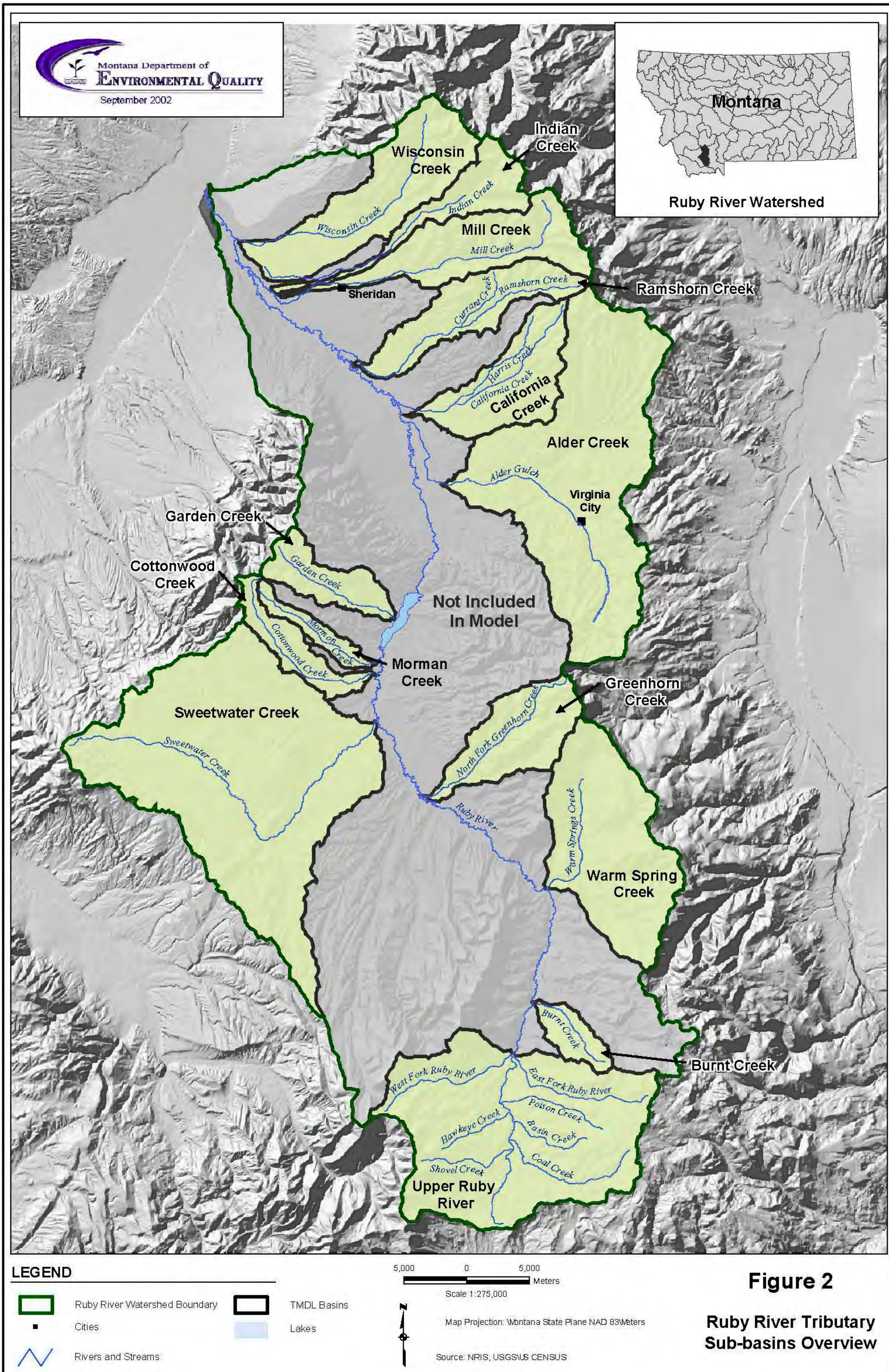
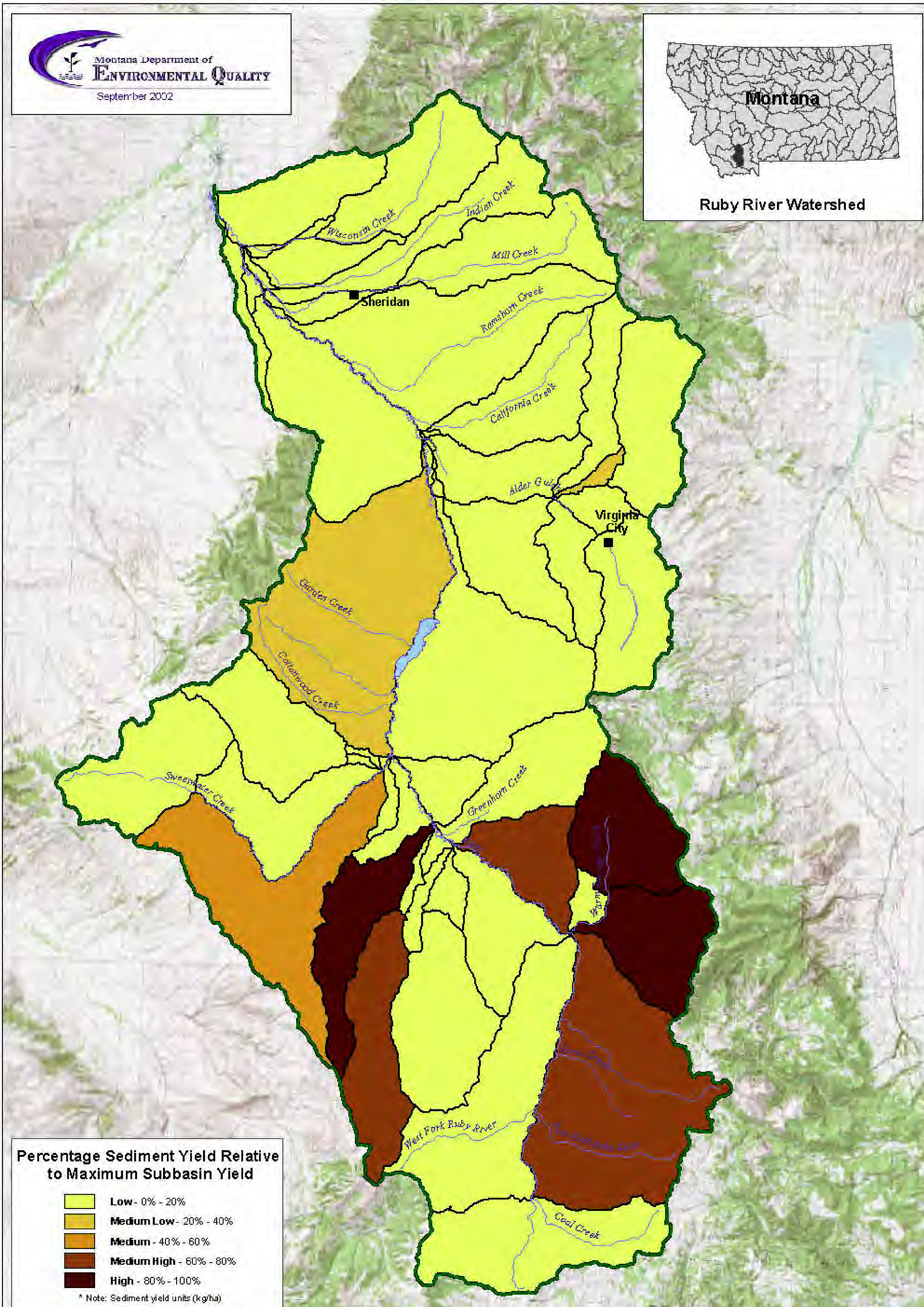


Figure 2

Ruby River Tributary Sub-basins Overview



LEGEND

Ruby River Watershed Boundary

Cities

Lakes

Rivers and Streams

5,000 0 5,000 Meters

Scale 1:275,000

N

Map Projection: Montana State Plane NAD 83 Meters

Source: NRIS, USGS US CENSUS

Figure 3

Ruby River Watershed Relative Sediment Yield

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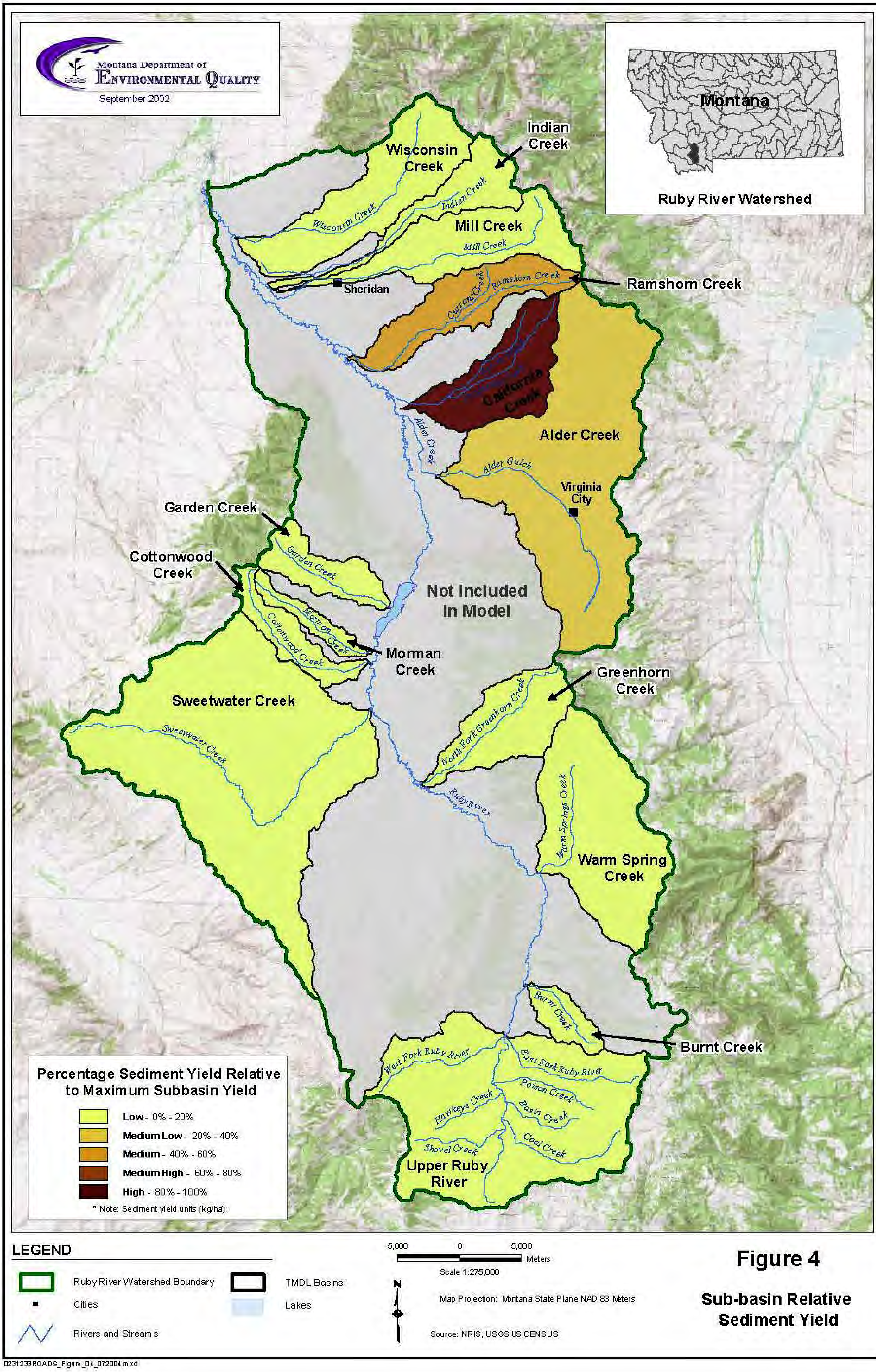
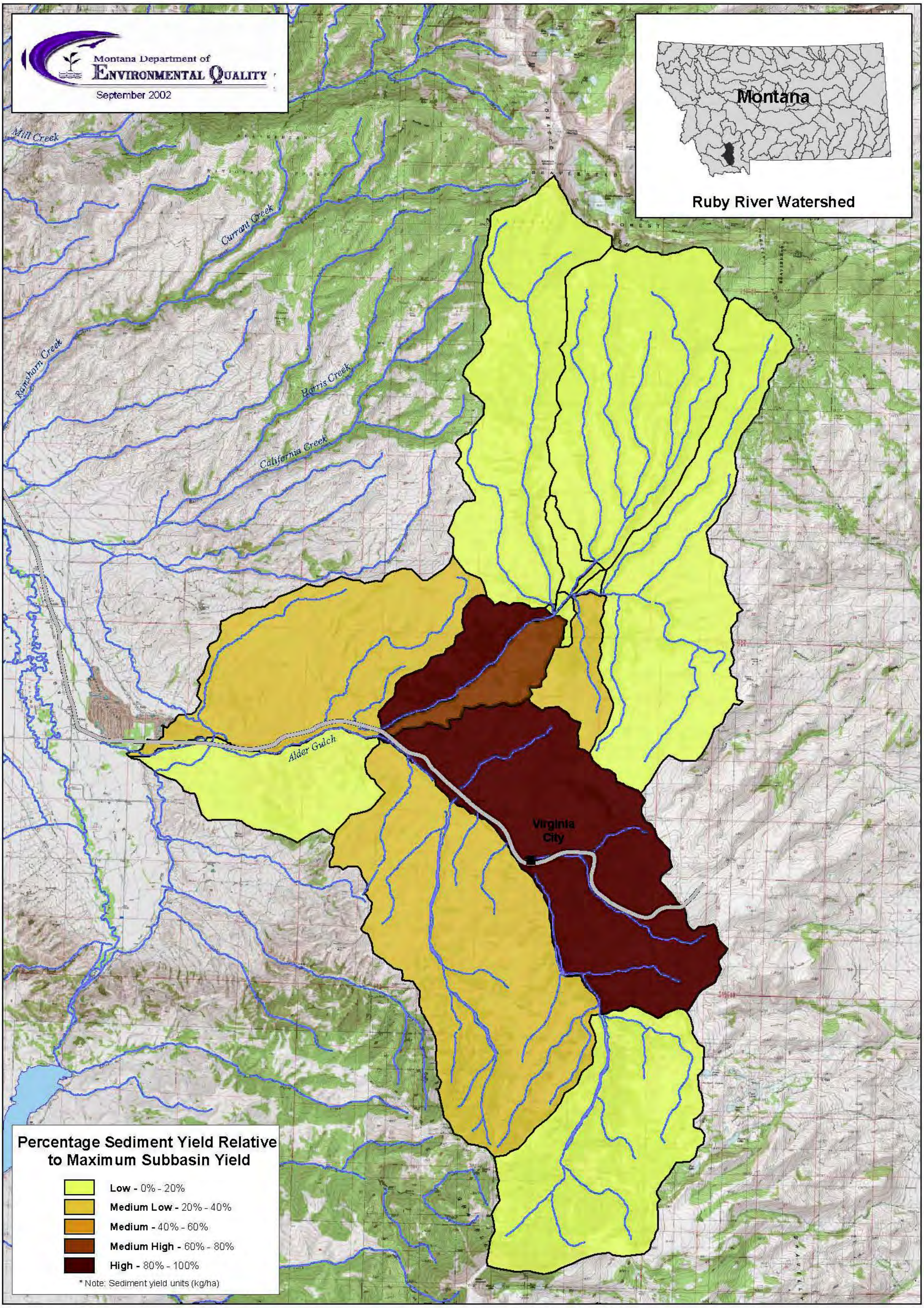


Figure 4

Sub-basin Relative Sediment Yield



LEGEND

Cities

Lakes

Roads

Rivers and Streams

2,000 0 2,000 Meters

Scale 1:100,000

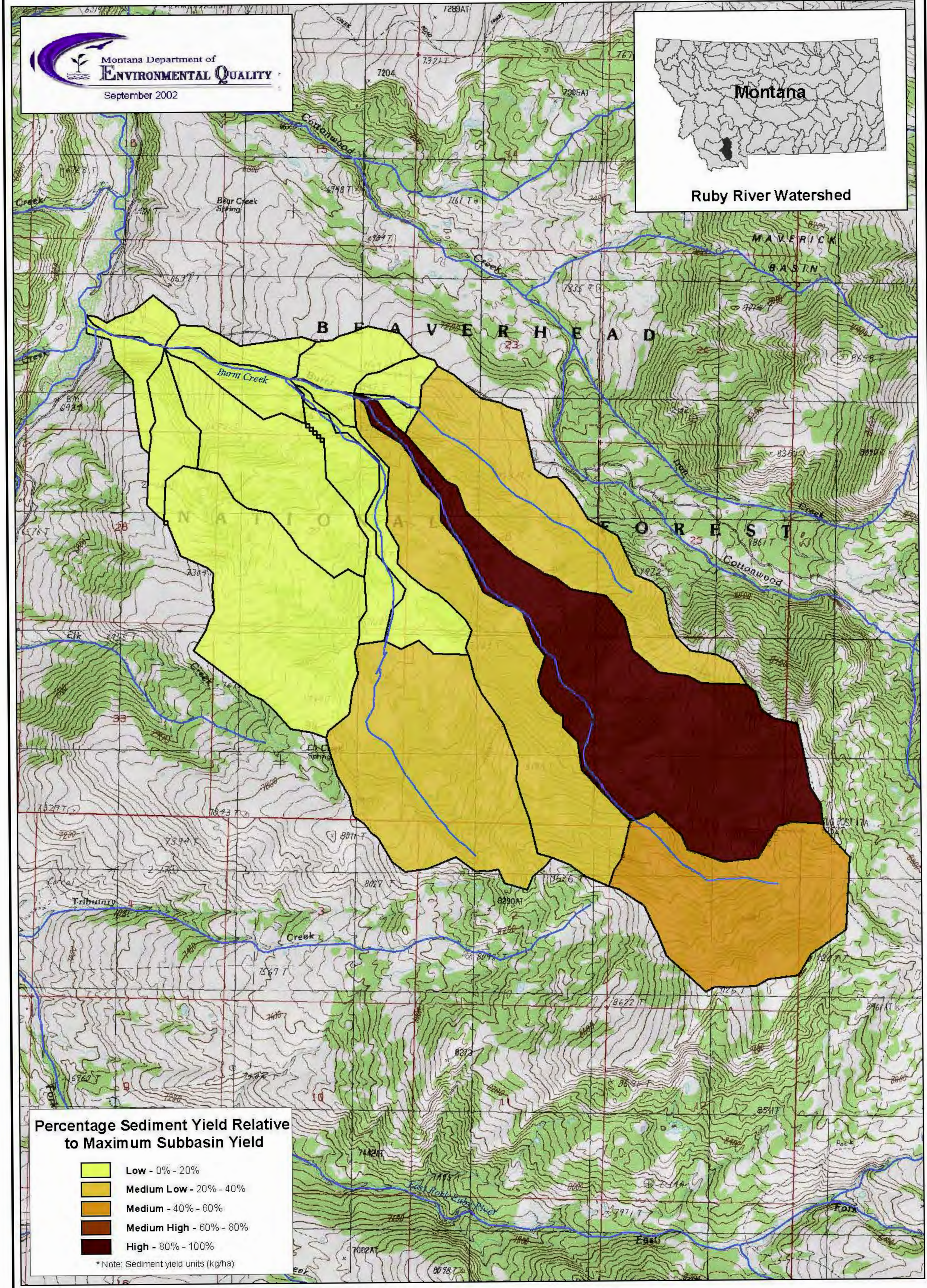
Map Projection: Montana State Plane NAD 83 Meters

Source: NRIS, USGS US CENSUS

Figure 5

Ruby River Watershed Alder Gulch Relative Sediment Yield

0231233ROADSF02R0.mxd



LEGEND

- Cities
- Lakes
- Roads
- Rivers and Streams

1,000 0 1,000 Meters

Scale 1:30,000

Map Projection: Montana State Plane NAD 83 Meters

Source: NRIS, USGS US CENSUS

Figure 6

Ruby River Watershed
Burnt Creek
Relative Sediment Yield

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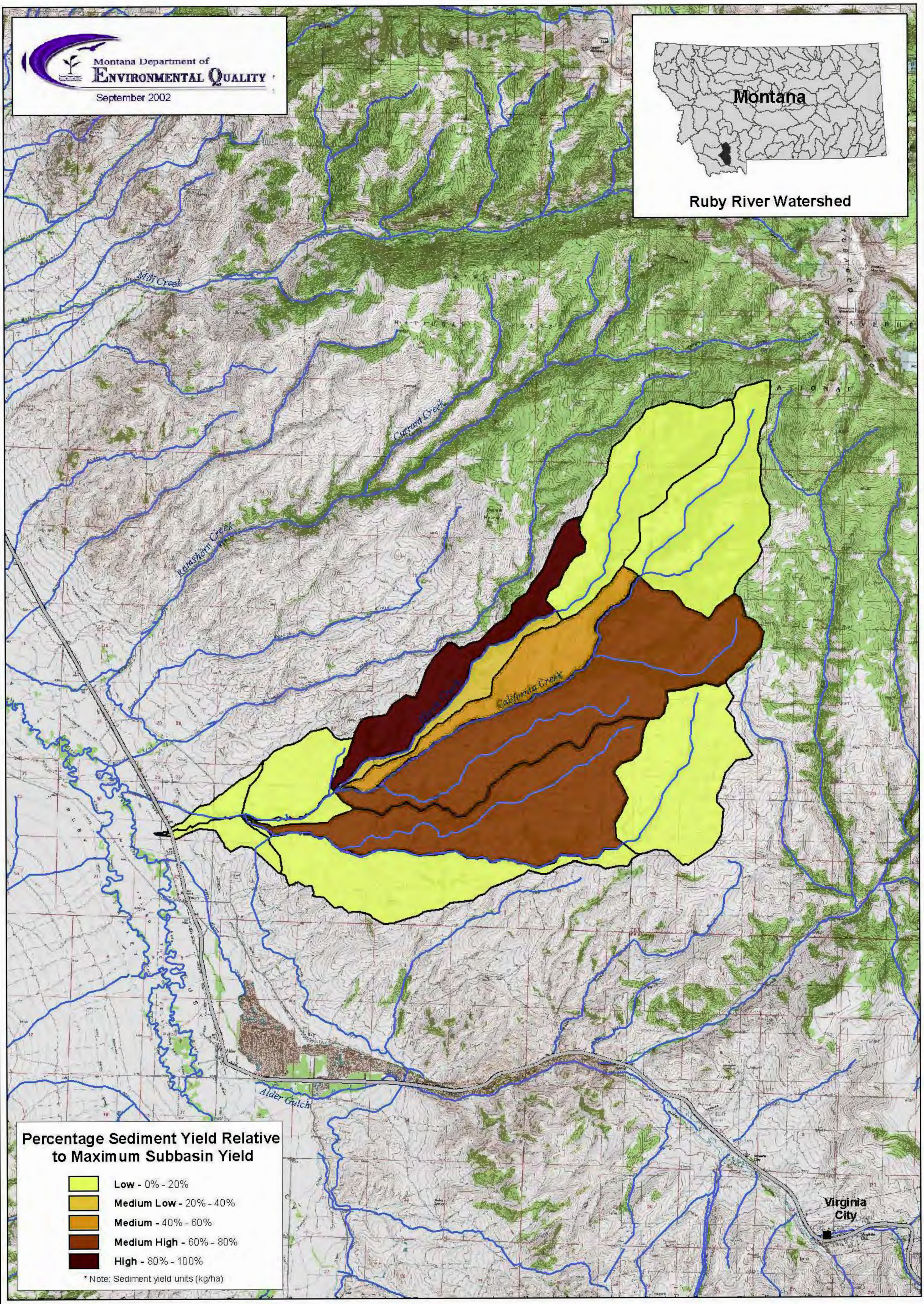


LEGEND

Cities

Lakes

Roads

Rivers and Streams

2,000 0 2,000 Meters

Scale 1:75,000

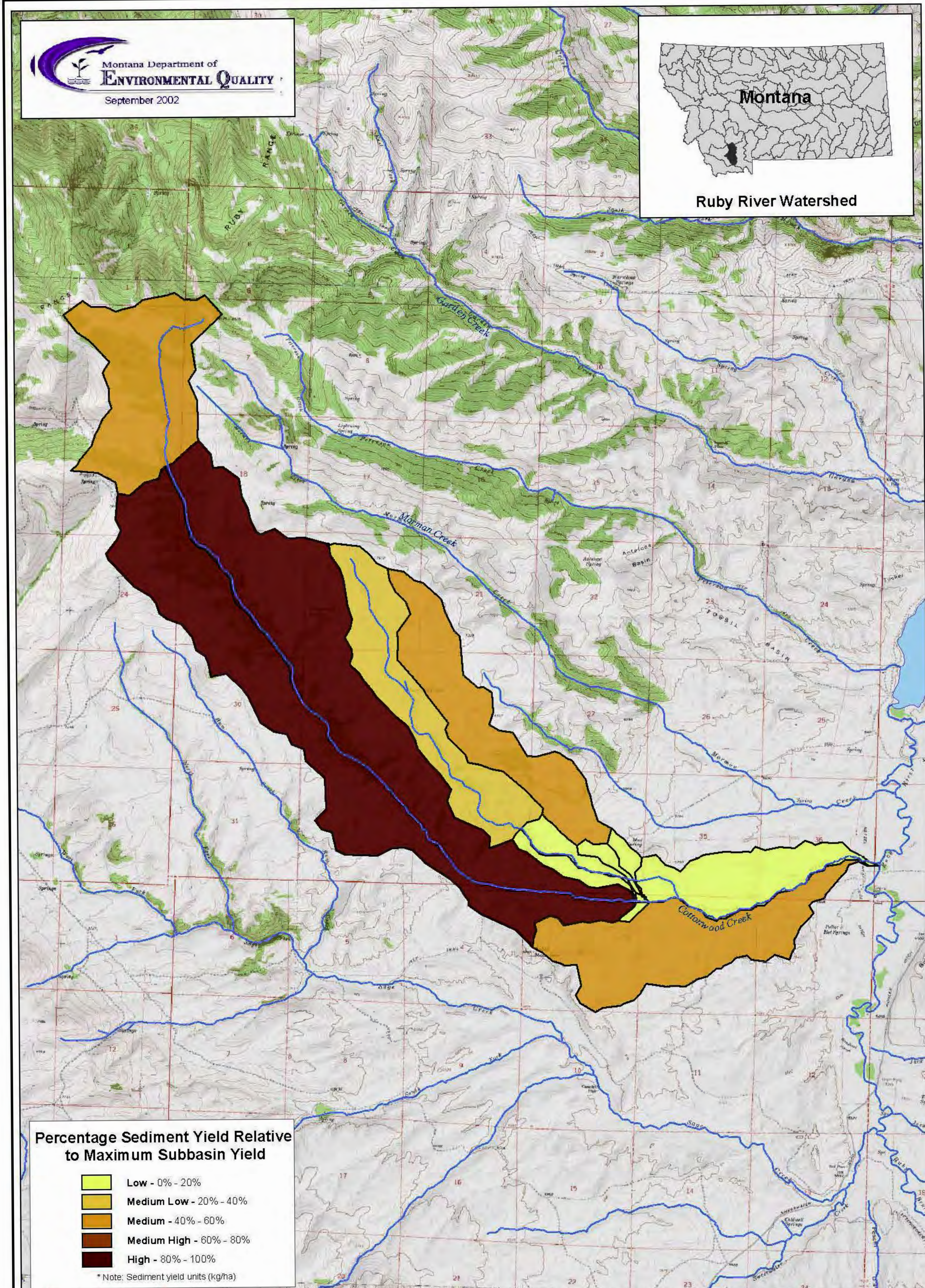
Map Projection: Montana State Plane NAD 83 Meters

Source: NRIS, USGS US CENSUS

Figure 7

Ruby River Watershed
California Creek
Relative Sediment Yield

0231233ROADSF04R0.mxd



LEGEND

Cities
Lakes
Roads
Rivers and Streams

1,000 0 1,000 Meters

Scale 1:50,000

Map Projection: Montana State Plane NAD 83 Meters

Source: NRIS, USGS US CENSUS

Figure 8

**Ruby River Watershed
Cottonwood Creek
Relative Sediment Yield**

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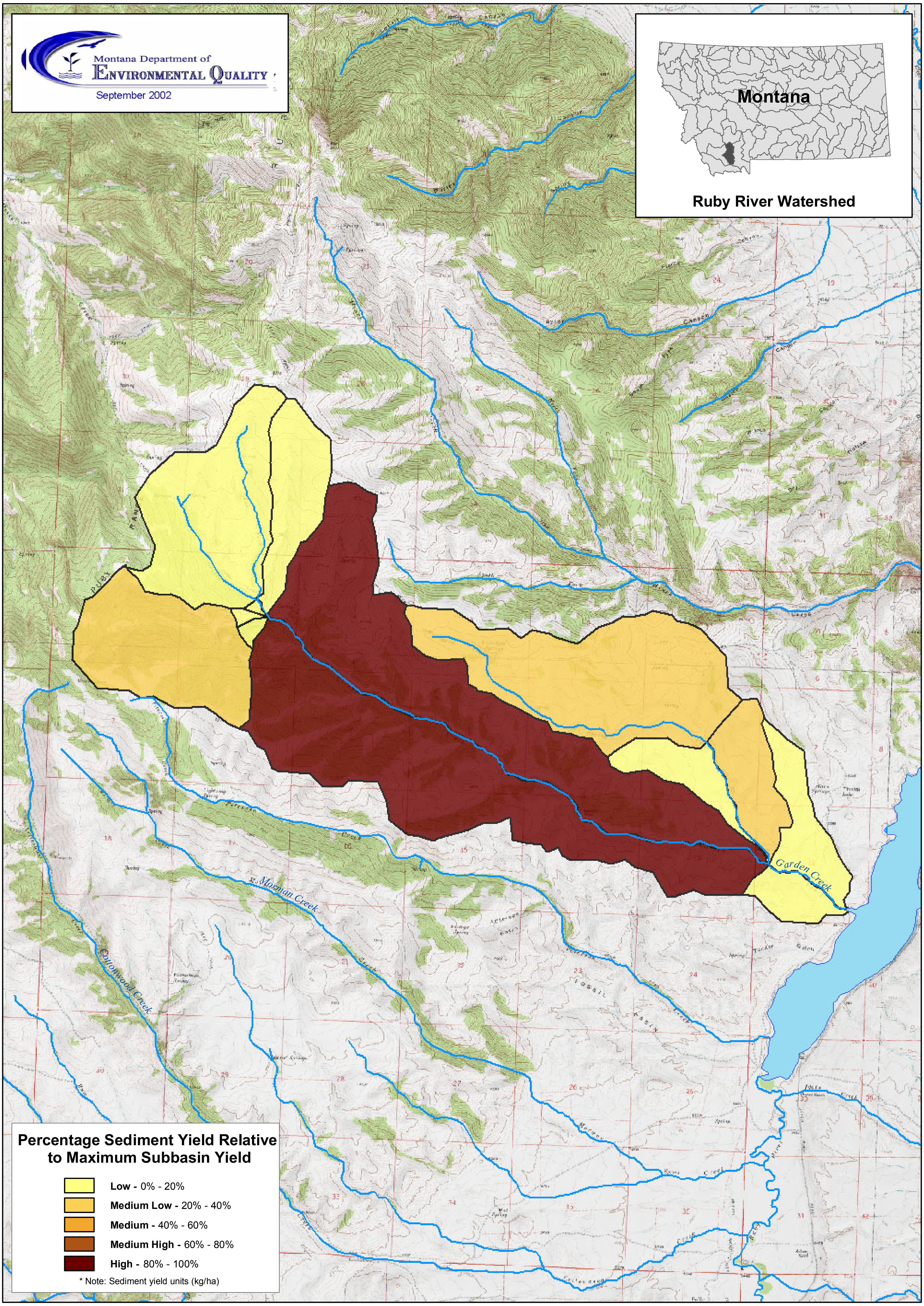


LEGEND

Cities	Lakes
Roads	Rivers and Streams

1,000 0 1,000 Meters

Scale 1:50,000

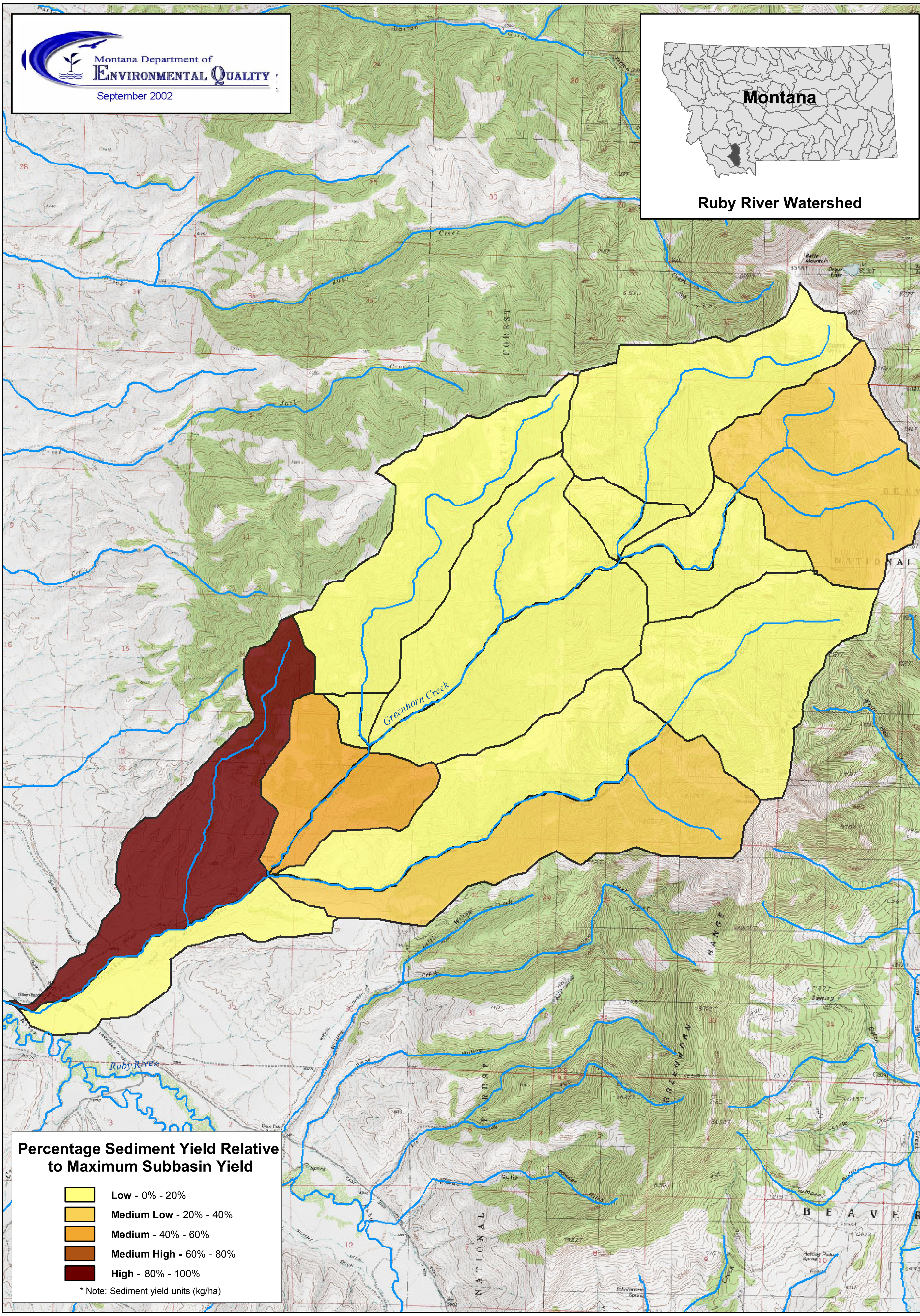
Map Projection:
Montana State Plane NAD 83
Meters

Source: NRIS, USGS
US CENSUS

Figure 9

Ruby River Watershed
Garden Creek
Relative Sediment Yield

0231233ROADSF06.mxd



LEGEND

- Cities
- Lakes
- Roads
- Rivers and Streams

1,000 0 1,000 Meters

Scale 1:50,000

N

Map Projection:
Montana State Plane NAD 83
Meters

Source: NRIS, USGS
US CENSUS

Figure 10

Ruby River Watershed
Greenhorn Creek
Relative Sediment Yield

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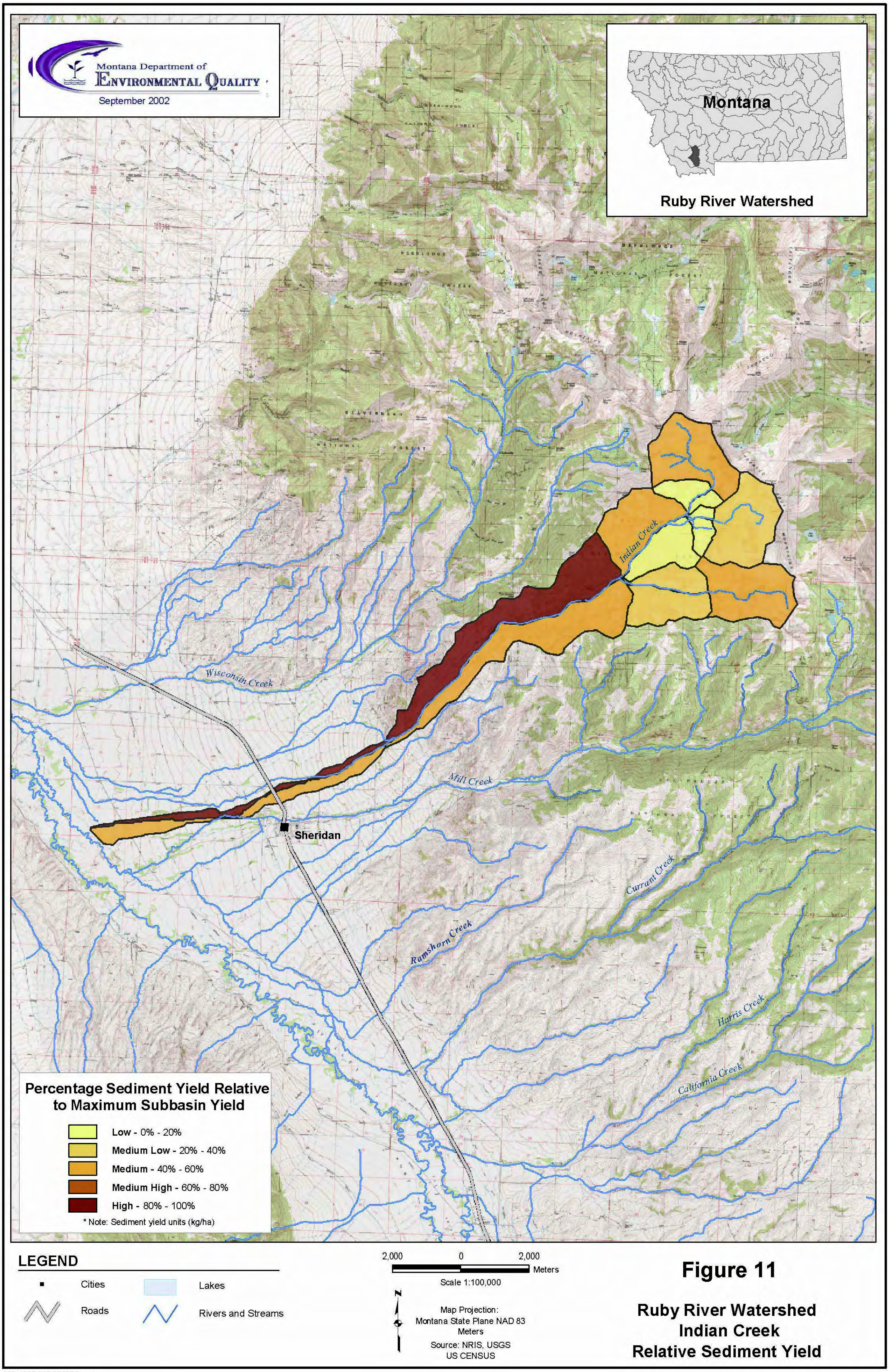

Figure 11

**Ruby River Watershed
Indian Creek
Relative Sediment Yield**

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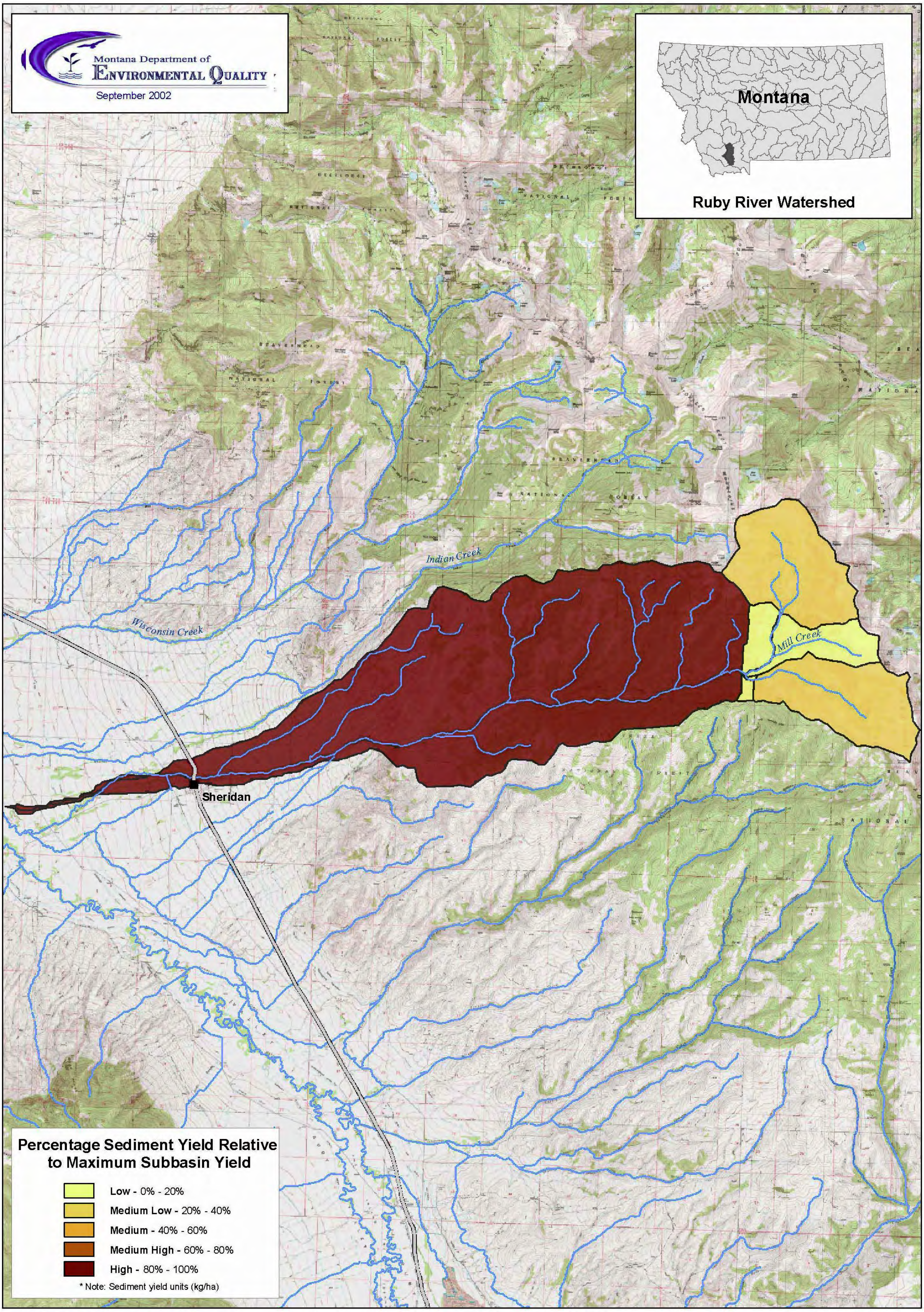

LEGEND

Cities

Roads

Lakes

Rivers and Streams

2,000 0 2,000 Meters

Scale 1:100,000

N

Map Projection:
Montana State Plane NAD 83
Meters

Source: NRIS, USGS
US CENSUS

Figure 12

Ruby River Watershed
Mill Creek
Relative Sediment Yield

0231233ROADSF09R0mxd

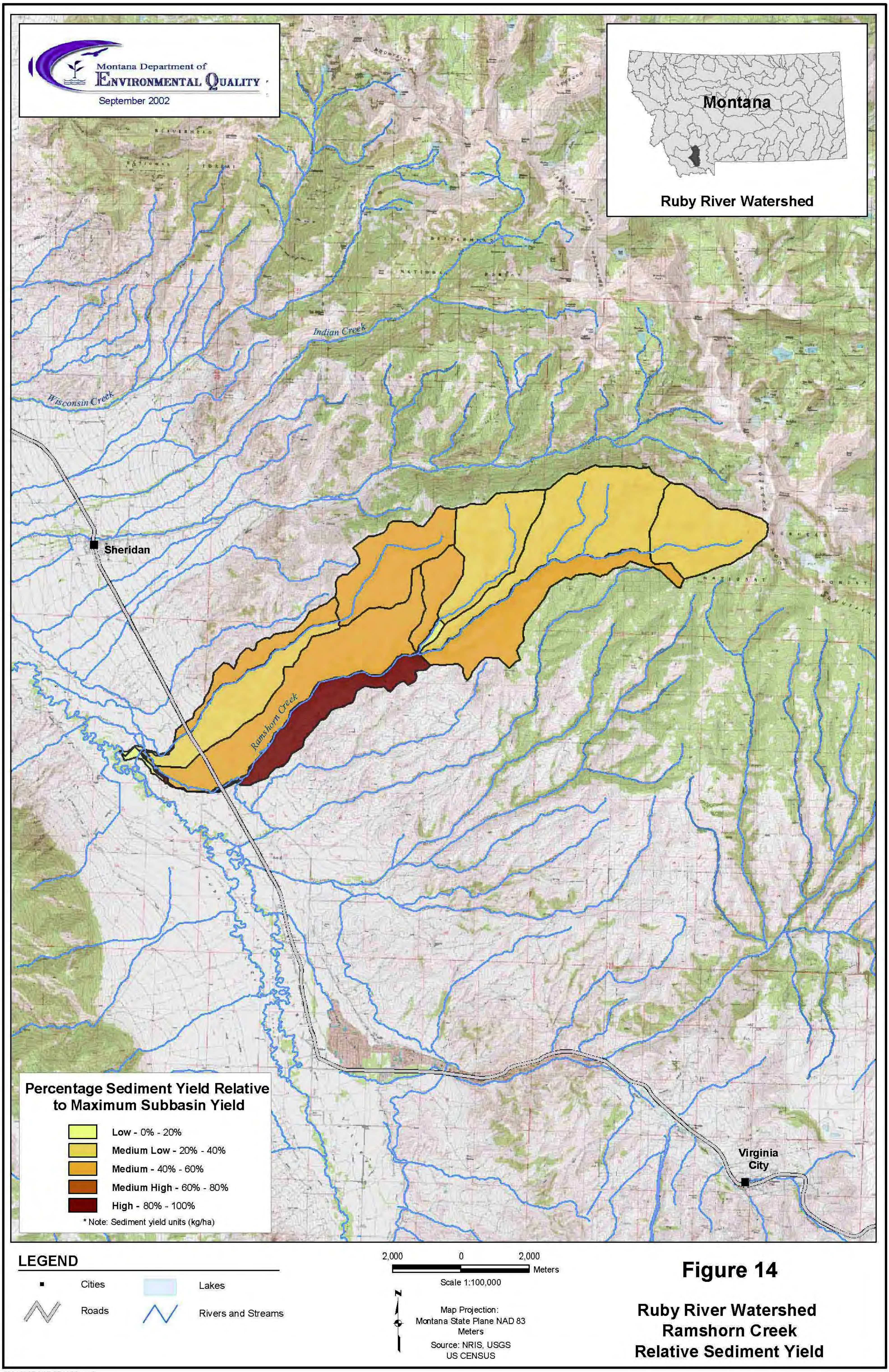

Figure 14

Ruby River Watershed
Ramshorn Creek
Relative Sediment Yield

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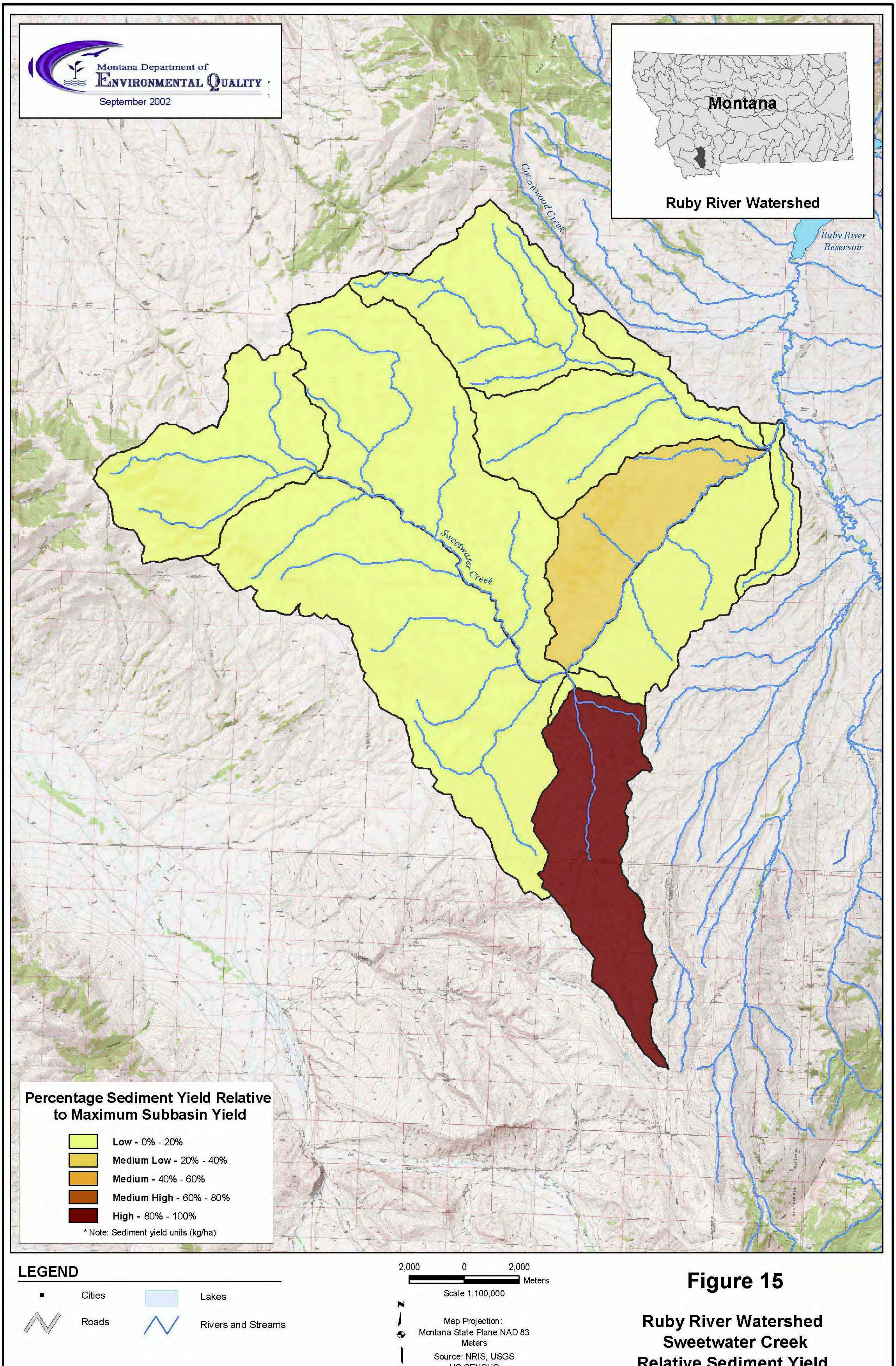

Figure 15

**Ruby River Watershed
Sweetwater Creek
Relative Sediment Yield**

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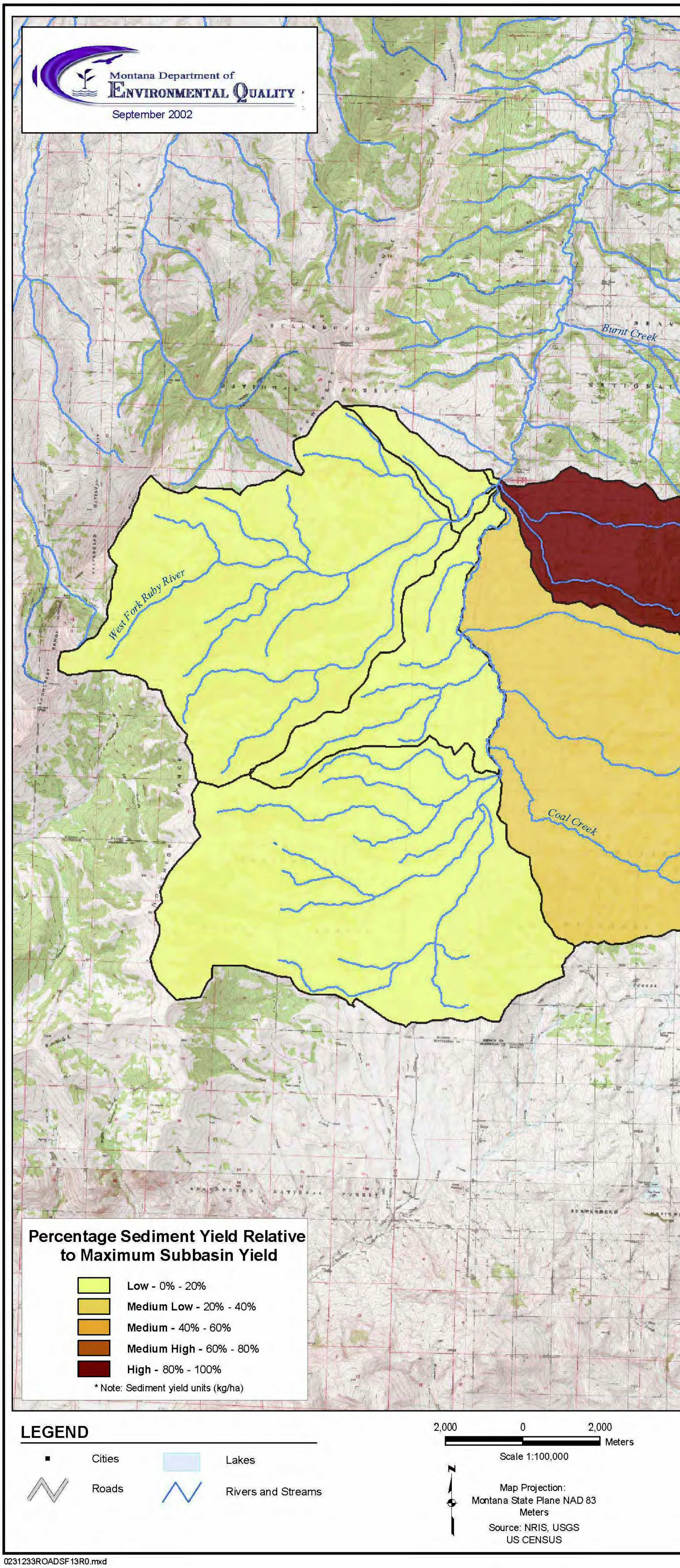

Figure 16

Ruby River Watershed
Upper Ruby River Watershed
Relative Sediment Yield

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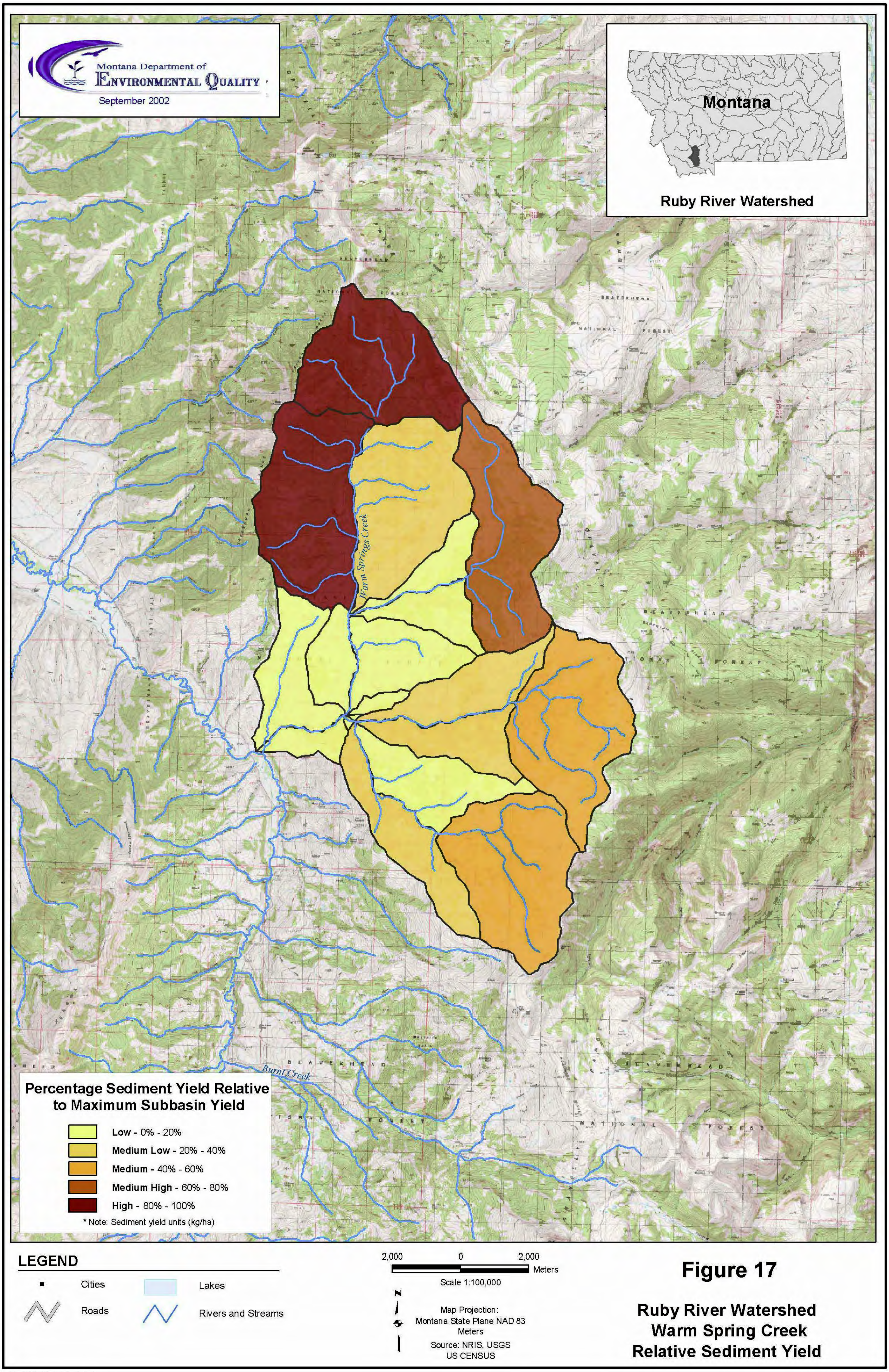

Figure 17

Ruby River Watershed Warm Spring Creek Relative Sediment Yield

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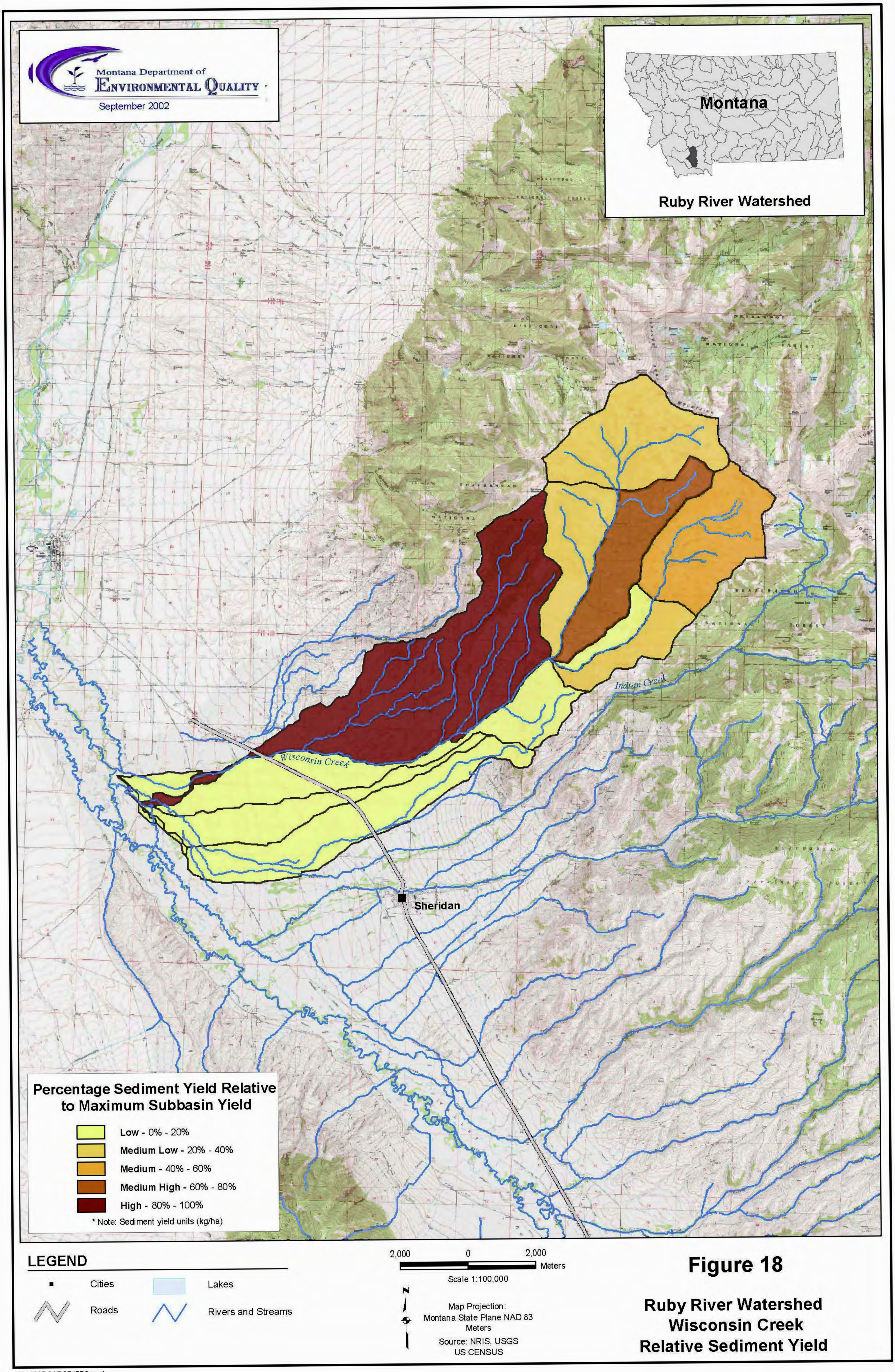

Figure 18

**Ruby River Watershed
Wisconsin Creek
Relative Sediment Yield**

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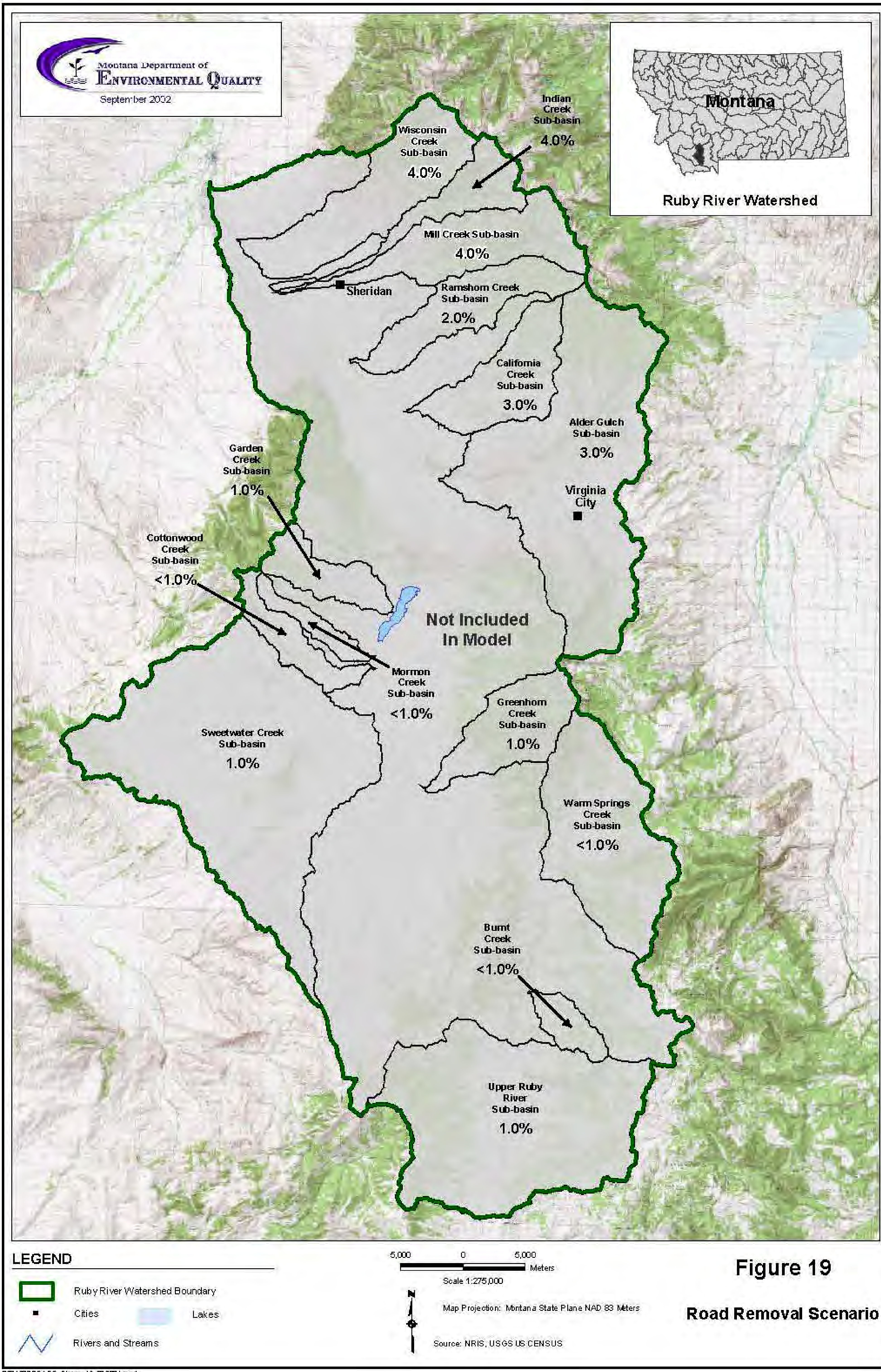

Figure 19

Road Removal Scenario

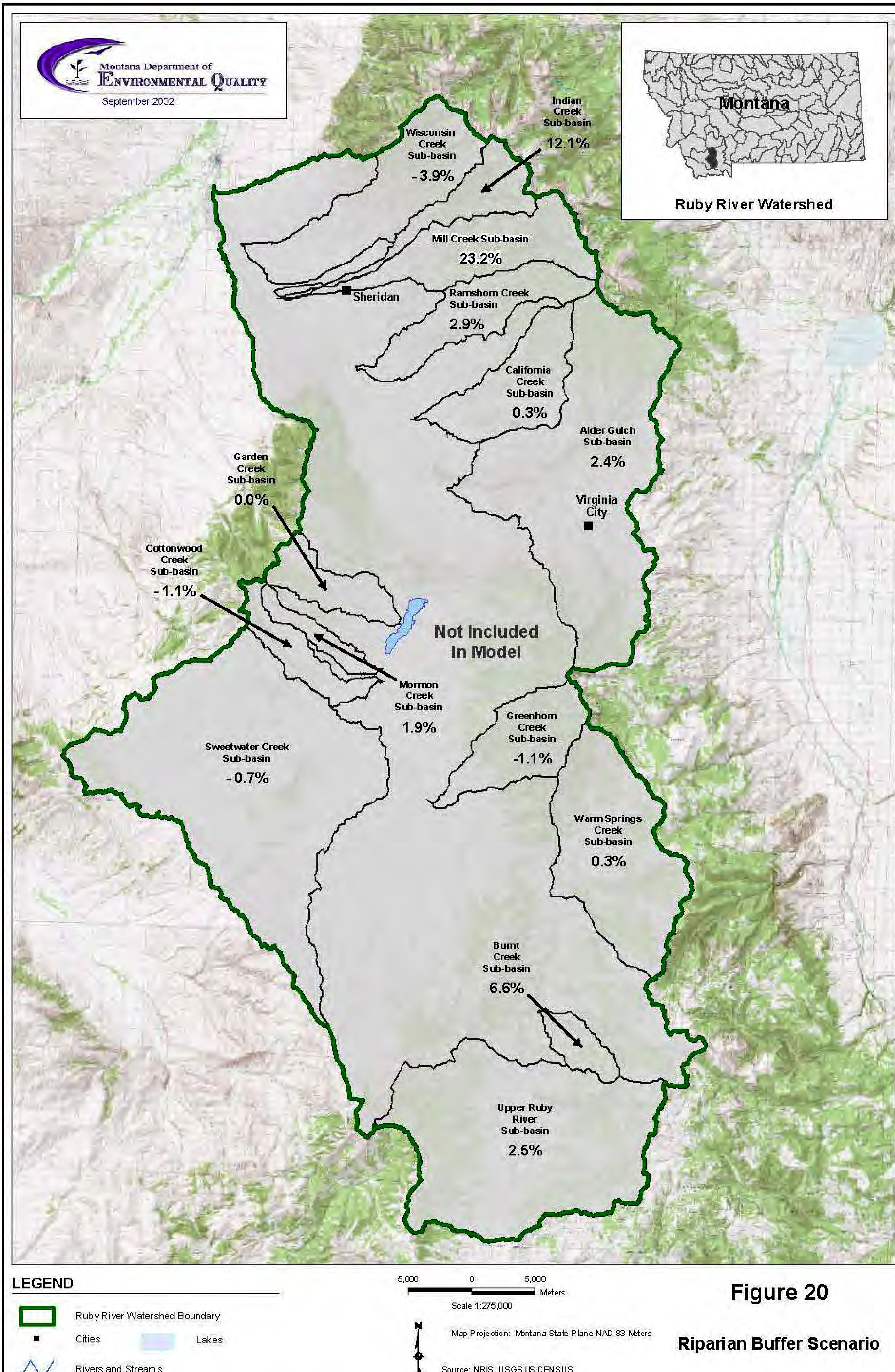

Figure 20

Riparian Buffer Scenario

RUBY RIVER WATERSHED SOIL EROSION MODELING

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ABSTRACT

A version of the Universal Soil Loss Equation model (USLE 3-D) was used to estimate sediment yield in 38 contiguous watersheds of the Ruby River Watershed as part of the Total Maximum Daily Load (TMDL) program. ArcGIS™ zonal queries were implemented to establish the annual erosion rates and differentiate between sediment yield and erosion source categories on a subwatershed basis. Results of the raster modeling include: (1) annual loads at specified outlet points in the watershed, (2) major and minor sediment source categories on a subwatershed scale, (3) the overall sediment load entering the Ruby Reservoir, and (4) the overall sediment load exiting the Ruby River Watershed.

Based on the results of the modeling effort, grassland / herbaceous land cover was identified as the predominant upland sediment source category in the watershed with a mean erosion rate of 0.63 tons acre^{-1} year^{-1}. Annual delivery to the mouth of Ruby River from grassland was 7,156 tons per year. Shrubland (e.g. brush covered lands) was the second largest contributor exhibiting an erosion rate of 0.54 tons acre^{-1} year^{-1} and contributing 2,384 tons of sediment annually. The overall upland sediment load entering the Ruby Reservoir was 18,263 tons per year and the total annual sediment yield in the watershed is 10,684 tons per year (based on an estimated five percent reservoir flow-through of sediment; Van Mullem, 2000). All erosion estimates assume that eroded sediment migrates through the fluvial system on an annual basis.

INTRODUCTION

The Ruby River Watershed is located in Madison and Beaverhead Counties on the eastern portion of the Rocky Mountains in southwestern Montana (Figure-1). Consisting of the Ruby River TMDL Planning Area (TPA), the watershed comprises approximately 966 square miles of drainage area and is part of United States Geological Survey (USGS) 4th field Hydrologic Unit Code (HUC) 10020003. Currently 26 stream and river segments and one reservoir must be addressed as part of the Montana TMDL Program.

The Montana Department of Environmental Quality (DEQ) has funded the development of a USLE-based sediment model to support the TMDL planning effort. The goal of the modeling effort is to establish net hillslope erosion estimates and relative source contributions from various landcover types. Results of the modeling will be used in cooperation with road and stream bank erosion source estimates to provide a comprehensive sediment source assessment of the watershed.

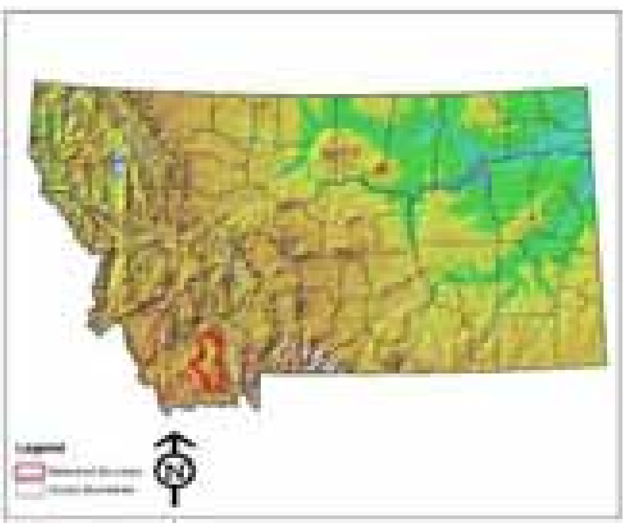
HYDRO-CLIMATIC SETTING

Hydrology in the Ruby River Watershed is primarily snowmelt dominated. The snowpack ripens in early summer causing high stream flow events during the months of May and June. Baseflow is maintained by subsequent groundwater infiltration and recharge to the surface water. The southern portion of the Ruby River drains the Gravelly, Snowcrest, and Ruby Ranges while the northeast corner originates in the Tobacco Root Mountains (Woods, et. al. 1999). The main-stem river flows approximately 80 miles including a brief detainment in the Ruby Reservoir south of Alder, MT. The headwaters begin at nearly 10,655 feet near Hogback Mountain and reach an endpoint at the confluence with the Beaverhead River near 4,360 feet (WCLLC, 2002).

Climate in the Ruby is highly seasonal. The most detailed climatological station in the watershed is Cooperative Observer (COOP) station number 240110-2 (Alder 17S), maintained by the National Weather Service (NWS). It is located 17 miles south of Alder, Montana at an elevation of 5,800 feet. Review of the site record indicates that precipitation occurs as both rainfall and snowfall. Average annual precipitation is 13.3 inches and mean annual snowfall is 51 inches (1956-2000). Most of the snow occurs between the months of November and April (WCLLC, 2002).

Two USGS gauging stations are in operation on the Ruby River, one upstream, and one downstream of the reservoir (1938-present). Mean annual streamflow upstream of the reservoir closely resembles natural drainage hydrology and is approximately 180 cubic feet per second (cfs). Average annual peak flow is ~1,110 cfs. The reservoir itself contains 38,000 acre-foot of storage at full pool. It is used primarily for irrigation water storage and flood control (MFWP 1989).

FIGURE-1. RUBY RIVER TMDL PLANNING AREA



PREVIOUS STUDIES

A number of suspended sediment studies have been completed in the Upper Ruby River Watershed for the purpose of monitoring deposition rates in the Ruby Reservoir. Specific projects identified by the Montana DEQ include the following:

- Sediment Yields from Rangelands in the Upper Ruby River Drainage, Southwestern Montana (Page, 1975)
- Ruby River Sediment Study and Action Plan (USDA, 1979)
- Ruby River Watershed Water Quality Monitoring Data Report (NRCS, 1998)
- Suspended Sediment in the Ruby River Above Ruby River Reservoir (Van Mullen, 2000)

Annual loads to a number of tributaries were reported in these studies and include the following: Ruby River mainstem to the reservoir, Coal Creek, Basin Creek, Poison Creek, East Fork of the Ruby River, West Fork of the Ruby River, Middle Fork of the Ruby River, Burnt Creek, Cottonwood Creek, and Warm Springs Creek. Comparison of these results against the USLE erosion estimate is presented as part of the modeling discussion.

UNIVERSAL SOIL LOSS EQUATION (USLE)

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

(1) $A = RK(LS)CP$ (in tons acre^{-1} year^{-1})

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

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

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

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

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

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

The **P-factor** (conservation practice factor) is a function of the interaction of the supporting land management practice and slope. It incorporates the use of erosion control practices such as 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.

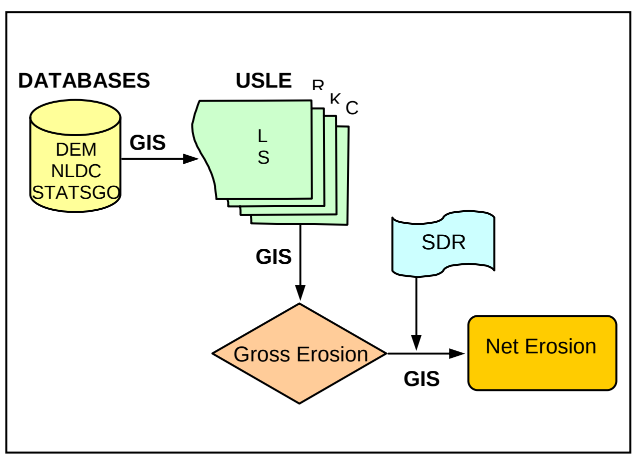
MODELING APPROACH

Desired results from the modeling effort include the following: (1) the annual sediment load for the Ruby River Watershed, (2) total annual sediment load into the Ruby Reservoir, (3) annual sediment load from each of the water quality limited segments on the state's 303(d) list, and (4) the mean annual source distribution from each land category type. Based on these considerations, a GIS- modeling approach (USLE 3-D) was formulated to facilitate database development and manipulation, provide spatially explicit output, and supply output display for the modeling effort.

UNIVERSAL SOIL LOSS EQUATION-3D

USLE 3-D is a spatially distributed adaptation of the standard USLE modeling procedure described previously. It is capable of estimating net hillslope erosion on a watershed scale and divides the watershed into 30 x 30 m grid cells to predict gross and net soil erosion on a cell-by-cell basis. The conceptual diagram for the model is predicated on several GIS processing routines where USLE input parameters and gross and net erosion are calculated successively from project databases (Figure-2). Gross erosion is reflective of the erosion rate in each raster cell while net erosion is the actual mass of sediment eroded from that cell. The use of a sediment delivery ratio (SDR) is required to differentiate between gross and net erosion.

FIGURE-2. USLE 3-D MODELING APPROACH



Loosely termed USLE 3-D by Montana DEQ, the hybrid approach is applicable to detachment-limited environments and incorporates the following: (1) an LS-factor modification proposed by Mitasova (1996) in U.S. Army Corps of Engineers DACA88-99-D-0002 for application in Geographic Information Systems (GIS), (2) the addition of a spatially explicit rainfall erosivity factor (R-factor) to vary rainfall intensity and rain drop impact kinetic energy across the watershed, and (3) the use of gridded C- and K-factors to determine erosion on a 30 x 30 m grid. Specific modifications to USLE 3-D from the original USLE equation are described below.

LS – The slope-length parameter of USLE 3-D is based on a flow accumulation raster of the project site and forms a continuous representation of the LS-factor over complex terrain. It is applicable to areas where transport capacity exceeds detachment capacity, and where erosion is limited primarily by the capacity of rainfall to detach sediment (Mitasova, 1996).

Since sediment production is thought to be primarily detachment-limited in the Ruby due to arid climatic conditions, steeply sloped mountainous terrain, and active tectonic uplift (Page 1978, USDA 1979, NRCS 1998, USDA Forest Service 1992 and Alt 1986), the modified LS-factor was deemed an appropriate methodology for the USLE-3D study. Additionally, the fact that the bank erosion and road sediment estimates are predicated on net-erosion, make the modified LS approach especially applicable (LS is net-erosion based).

R – According to Bales (2004), the spatial and temporal distribution of hydrometerological conditions in mountainous environments is highly variable. Even so, a number of published USLE studies continue to use a lumped R-factor even for expansive watersheds or areas with significant orographic influence (Sun 1998, Engel 1999, Shi et al. 2002, Zaluski et al. 2004). In order to avoid the shortcoming of using a single rainfall erosivity parameter across the entire Ruby River Watershed, a spatially derived R-factor grid was used in the USLE-3D analysis.

The R-factor grid was compiled by the Spatial Climate Analysis Service as part of U.S. Environmental Protection Agency (EPA) contract #OV1062NAEX with Oregon State University (SCAS, 2002). The use of a commercially distributed layer was thought to be the most acceptable resource for the modeling effort.

K, C – Spatially distributed K- and C-factors were assigned to the 30 x 30 meter grid based on the State Soil Geographic (STATSGO) database from the Soil Conservation Service (SCS) and NLCD from USGS. No changes were made in the standard USLE approach for the development of these parameters.

MODELING SCENARIOS

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

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

DATA SOURCES

The USLE-3D model was parameterized using a number of published data sources. These include information from: (1) USGS, (2) Spatial Climate Analysis Service (SCAS), and (3) National Resource Conservation Service (NRCS). Additionally, local information regarding specific land use management and cropping practices was acquired from the Montana Agricultural Extension Service and Ruby Valley Natural Resource Conservation Service (NRCS) (verbal communication 2005). Specific GIS coverages used in the modeling effort included the following:

- **R-factor Grid** – The Spatial Climate Analysis Services (SCAS) provides a 4-km R-factor grid based on the PRISM precipitation model.
- **National Elevation Dataset (NED)** – The USGS NED is a 1:24,000 scale 30m high-resolution compilation of elevation data used in watershed delineation, flow accumulation processing, and slope determination.

- **National Land Cover Dataset (NLDC)** – The NLCD 1992 is a 21-category land cover classification (30m grid) that has been applied consistently over the conterminous U.S. for developing gridded C-factor coverage.
- **STATSGO Soils** – The STATSGO soil map is a 1:250,000 scale generalization of detailed soil survey data that was used to determine K-factors for USLE 3-D.
- **Ortho/Digital Quads -** USGS Digital Raster Graphics (DRGs) and Orthophoto Quarter-Quadrangles (DOQQs) were used in refining the subbasin discretization and estimating C-factors.

The State of Montana Natural Resource Information System (NRIS) provides access to all sources identified above (with the exception of the R-factor grid that is maintained by SCAS). Modeling data typically includes Quality Assurance / Quality Control (QA / QC) information, acknowledgement and (or) use restrictions, and all associated metadata.

WATERSHED DISCRETIZATION

The watershed discretization scheme for the Ruby River Watershed USLE 3-D model was based on the following criteria: (1) that all water quality limited stream segments be separated into their own subwatershed for reporting, (2) reservoir breakpoints be included in the model definition, and (3) any other notable hydrologic features within the drainage area be defined. The delineation was completed using a USGS 30-meter 1:24,000 Digital Elevation Model (DEM) mosaic in NAD83 coordinate system with 1-meter vertical resolution (Figure-3).

The surface elevation of the DEM was adjusted using AGREE surface reconditioning in order to provide consistency with the specified 303(d) stream segment vector coverage. The resultant lowering (burning) and raising (fencing) of the DEM ensures that the subbasin outlets are geo-located with respect to the USGS digital quadrangle map and that the calculation of watershed drainage areas are optimized. Following the terrain pre-processing, Topographic Parameterization Software (TOPAZ) was used to complete automated watershed delineation of the study area. The result was a final delineation of 38 subbwatersheds (Figure-4).

FIGURE-3. USGS DIGITAL ELEVATION MODEL

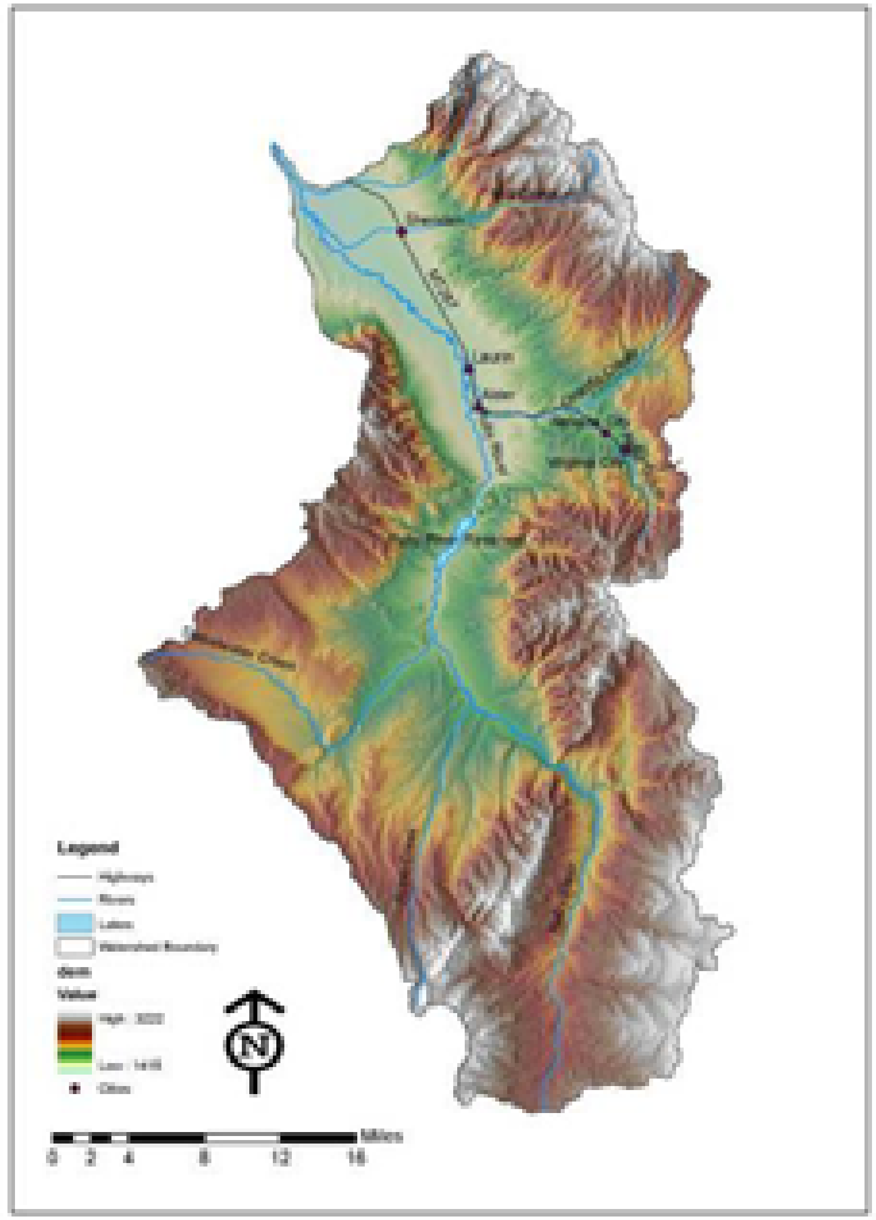


FIGURE-4. RUBY RIVER SUBBASIN DISCRETIZATION

WATERBODY	ID	AREA_MILES
Wisconsin Creek	1	30.0709
Indian Creek	2	25.5216
Mill Creek	3	34.9655
Currant Creek	4	3.2240
Ramshorn Creek	5	21.1451
Harris Creek	6	4.9688
Ruby River-01	7	35.9768
Mill Gulch	8	10.6959
California Creek	9	22.1776
Granite Creek	10	31.0674
Ruby River-02	11	37.9827
Ruby River-03	12	51.3980
Garden Creek	13	13.1460
Peterson Creek	14	5.6369
Alder Gulch Creek	15	64.4356
Mormon Creek	16	6.0570
Ruby Reservoir	17	28.2480
Cottonwood Creek	18	12.7151
Ruby River-04	19	28.8665
Greenhorn Creek	20	22.1514
Ruby River-05	21	14.4353
Sweetwater Creek-01	22	49.1105
Warm Springs Creek	23	51.1626
Sweetwater Creek-02	24	79.4392
Ruby River-08	25	9.6136
Ruby River-06	26	76.8046
Burnt Creek	27	6.9695
Ruby River-07	28	45.8425
Robb Creek	29	49.3465
Poison Creek	30	4.1344
E. Ruby River	31	16.3609
Ruby River-09	32	5.3141
Basin Creek	33	5.5869
W. Ruby River	34	21.8435
Hawkye Creek	35	3.2829
Shovel Creek	36	5.3679
Coal Creek	37	15.2257
M. Ruby River	38	16.4353

R- FACTOR DETERMINATION

R-factor input for USLE 3-D is based on the Parameter-elevation Regressions on Independent Slopes Model (PRISM) model, which uses point data and a DEM to generate gridded estimates of climate parameters. PRISM is especially well suited to mountainous regions because the effect that terrain plays on climate (Daly et al., 1994). The PRISM R-factor grid was provided by the Oregon State SCAS laboratory and was developed by: (1) obtaining the input station data, (2) applying PRISM to develop spatially varying regression functions between R-factor and gridded MAP in log10 space, and (3) converting the PRISM prediction grids from log10 space back to real space (Daly, 2002). The result is a 2.5-minute (~4 km) grid of the annual R-factor for the conterminous United States (Figure-5). Based on the PRISM grid, R-factor values in the Ruby River watershed range from 7.3 to 36.4 100's foot-tons-force inches per hour per acre per year.

Precipitation data supporting the PRISM model originate from the National Weather Service Cooperative Observer Program and were collected and analyzed by a team at the Illinois State Water Survey (2001). Over 1,840 stations were used in the development of the coverage. Units are recorded in English hundreds of foot-tons-force inches per hour per acre per year.

K-FACTOR ASSIGNMENT

Soil erodibility factors (K-factors) for the Ruby River Watershed were determined by classifying map unit identification (MUID) values from the 1:250,000 STATSGO database with the corresponding rock-fragment free soil erodibility factors. Since raw STATSGO tables are not readily formatted for USLE modeling, the Blackland Research Center STATSGO database annotation (BRC, 2001) was used to determine the K-factor for each grid unit. BRC tables have been compiled for the express purpose of USLE modeling.

Because the original BRC annotation uses only the dominant MUID soil type to determine the K-factor, Montana DEQ further refined the tables for the Ruby River TMDL modeling effort. Weighted averages of soil erodibility factor for each MUID were determined by using the composition percentage (CMPPCT) to find a composite soil erodibility factor for each MUID. Values were then assigned to the STATSGO raster grid and ranged from 0.11 to 0.34. (Figure-6).

LS-FACTOR DETERMINATION

To incorporate the impact of flow convergence in complex terrain, the standard USLE hillslope length factor was replaced by a method proposed by Moore and Burch (1986), Mitasova et al. (1996), and Desmet and Govers (1996) that uses upslope contributing area. The modified equation computes the LS factor in a finite difference form where each grid cell represents a hillslope segment. The continuous form of the LS equation is shown in Equation-2 where $A_{(r)}$ is upslope contributing area per unit contour width (cannot exceed normal overland flow length conditions), $b_{(r)}$ is the slope in radians, m and n are experimentally determined coefficients, and a_0 and b_0 are the length and slope of the standard USLE plot [72.6ft (22.13m) and 9%] (Mitasova, 1996)

$$(2)\quad LS_{(r)} = (m+1)\ [\ A_{(r)} / a_0\ ]^m\ [\ \sin b_{(r)} / b_0\ ]^n$$

Typical values for m and n are between 0.4-0.6 and 1.0-1.4 depending on the prevailing type of flow. Lower magnitudes of m and n are used in areas with dispersed flow such as those well covered with vegetation. Higher values are used for areas with more turbulent flow that is caused by existing rills or disturbed areas (Mitasova, 1996). The exponents of m=0.4 and n=1 were selected for the Ruby USLE 3-D model due to the fact that the project site is well-vegetated and that overland flow is distributed across the land surface. Given this assumption, LS parameters in the Ruby River Watershed range from 0.0 to 26.7 (Figure-7).

C-FACTOR ASSIGNMENT (OR VM-FACTOR)

The cover management factor of the USLE reflects the varying degree of erosion protection that results from different cover types. It integrates a number of factors including vegetative cover, plant litter, soil surface, and land management. For the purpose of this study, the C-factor is the only USLE parameter that can be altered by the influence of human activity. Based on this conditioning, C-factors were estimated for each of the two management scenarios and vary based on the amount of ground cover present (Table-1 & 2).

C-factors were defined spatially through use of a modified version of the Anderson land cover classification (1976) and the 1992 30m Landsat Thematic Mapper (TM) multi-spectral imaging (NLDC, 1992) (Figure-8). A number of land cover types are present in the watershed and include alpine tundra in the higher elevations, mixed conifer forest on upper slopes, and mixed grassland at lower elevations (NLDC, 1992 & Bahls, 2001). C-factor values were assigned globally to each land type and range from 0.001 to 1.0 (Figure-9). No field efforts were initiated as part of this study to refine C-factor estimation for the watershed although final results were compared to reainfall simulator studies in the Gravely Range conducted by Meeuwig (1970) and Mullem (2000), Lisle(1972) and Page (1978).

C-factors were increased by 10% in pasture, grassland and mixed grass / shrublands for a simulation of improved upland grazing management scenario. The justification for the 10% increase in vegetation cover in grass and shrub dominated areas of the watershed is based on limited review of literature and estimated average conditions observed during field reconnaissance of the overall project. The 10% increase in vegetation cover in these areas is based on best professional judgment. Rainfall simulator studies conducted in the Ruby Watershed by Beeuwig (1970) were also used to determine if the upland sediment modeling estimates were reasonable. Because of the uncertainties involved, a conservative approach was used in assessing an estimated increase in vegetative cover due to upland grazing BMPs. The assessors thought a higher level of cover could likely be achieved, on average, across the watershed.

P-FACTOR ASSIGNMENT

All conservation practice factors (P) in the Ruby River USLE 3-D model were set to unity because contour farming and terracing were not applied.

FIGURE-5. RUBY RIVER R-FACTOR

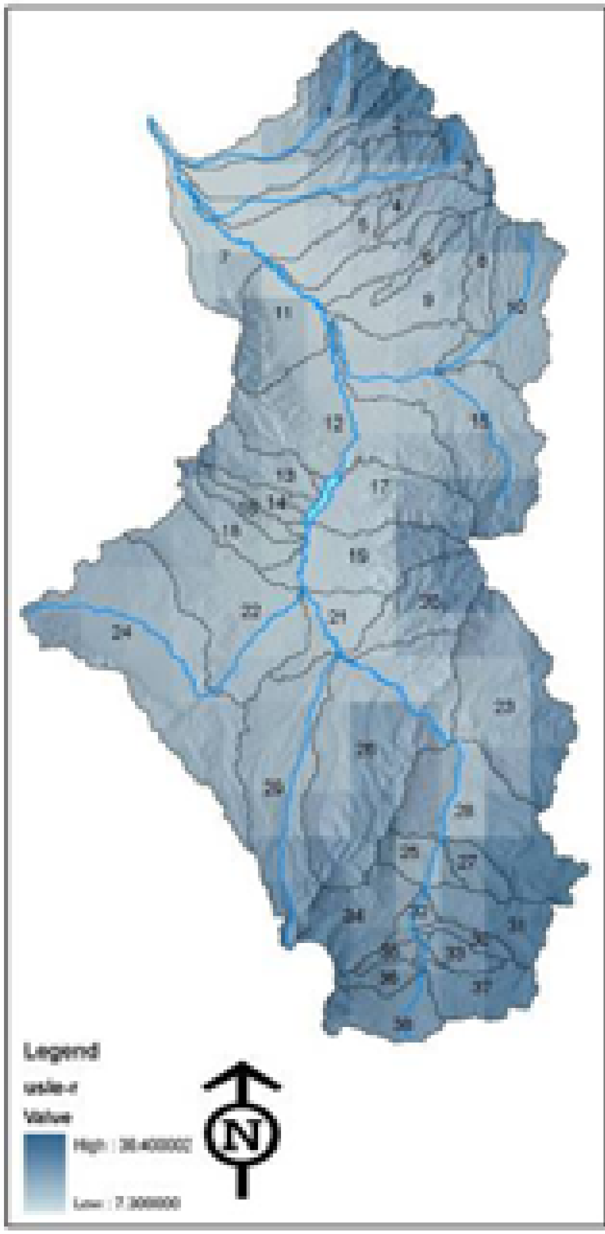


FIGURE-6. RUBY RIVER K-FACTOR

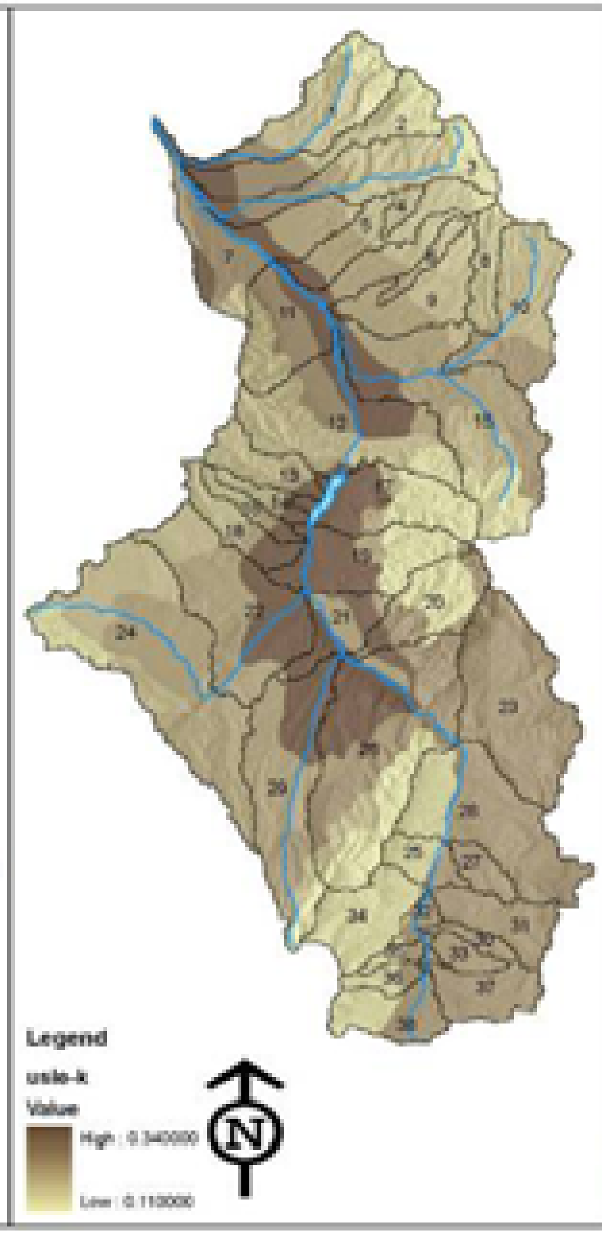


FIGURE-7. RUBY RIVER LS-FACTOR

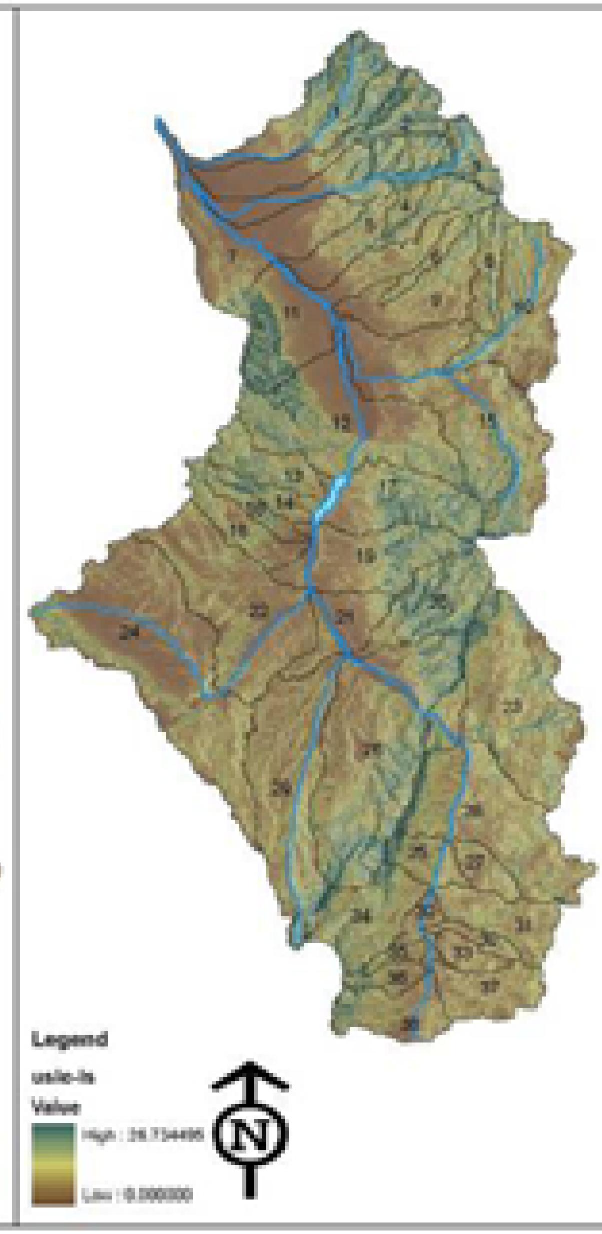


TABLE-1. RUBY RIVER C-FACTOR; EXISTING CONDITIONS

USLE C-FACTOR PARAMETER			VEGETATION MANAGEMENT FACTOR		
CODE	**DESCRIPTION**	**C-FACTOR**	**GROUND OR CANOPY COVER**	**CANOPY TYPE**	**COVER TYPE**
11	Open Water	0.000	---	---	---
12	Perrenial Ice/Snow	0.000	---	---	---
21	Low Intensity Residential	0.000	---	---	---
22	High Intensity Residential	0.000	---	---	---
23	Commercial/Industrial/Transport.	0.000	---	---	---
31	Bare Rock/Sand/Clay	0.000	---	---	---
32	Quarry/Strip Mines/Gravel Pits	0.000	---	---	---
33	Transitional	0.220	20%	NONE	G/W
41	Decidous Forest	0.002	75%	FOREST	60% DUFF
42	Evergreen Forest	0.003	65%	FOREST	40% DUFF
43	Mixed Forest	0.003	70%	FOREST	50% DUFF
51	Shrubland	0.042	55%	20" BRUSH	G
71	Grassland/Herbaceous	0.050	55%	NONE	G
81	Pasture/Hay	0.012	---	---	---
82	Row Crops	0.240	---	---	---
83	Small Grains	0.230	---	---	---
84	Fallow	1.000	---	---	---
85	Urban/Recreational Grasses	0.008	90%	NONE	G
91	Woody Wetlands	0.001	99%	6.5' BRUSH	G
92	Emergent Herbaceous Wetl.	0.002	99%	NONE	G

G – Cover at surface is grass or grasslike plants, or decaying compacted duff
W – Cover at surface is broadleaf herbaceous plants with little lateral root network
Values designated "---" taken from McCuen (1998)

TABLE-2. RUBY RIVER C-FACTOR; IMPROVED MANAGEMENT CONDITIONS

USLE C-FACTOR PARAMETER			VEGETATION MANAGEMENT FACTOR		
CODE	**DESCRIPTION**	**C-FACTOR**	**GROUND OR CANOPY COVER**	**CANOPY TYPE**	**COVER TYPE**
11	Open Water	0.000	---	---	---
12	Perrenial Ice/Snow	0.000	---	---	---
21	Low Intensity Residential	0.000	---	---	---
22	High Intensity Residential	0.000	---	---	---
23	Commercial/Industrial/ Transport.	0.000	---	---	---
31	Bare Rock/Sand/Clay	0.000	---	---	---
32	Quarry/Strip Mines/Gravel Pits	0.000	---	---	---
33	Transitional	0.220	20%	NONE	G/W
41	Decidous Forest	0.002	75%	FOREST	60% DUFF
42	Evergreen Forest	0.003	65%	FOREST	40% DUFF
43	Mixed Forest	0.003	70%	FOREST	50% DUFF
51	Shrubland	0.029	65%	20" BRUSH	G
71	Grassland/Herbaceous	0.035	65%	NONE	G
81	Pasture/Hay	0.009	---	---	---
82	Row Crops	0.240	---	---	---
83	Small Grains	0.230	---	---	---
84	Fallow	1.000	---	---	---
85	Urban/Recreational Grasses	0.008	90%	NONE	G
91	Woody Wetlands	0.001	99%	6.5' BRUSH	G
92	Emergent Herbaceous Wetlands	0.002	99%	NONE	G

G – Cover at surface is grass or grasslike plants, or decaying compacted duff
W – Cover at surface is broadleaf herbaceous plants with little lateral root network
Values designated "---" taken from McCuen (1998)

FIGURE-8. LANDSAT TM LAND COVER CLASSIFICATION

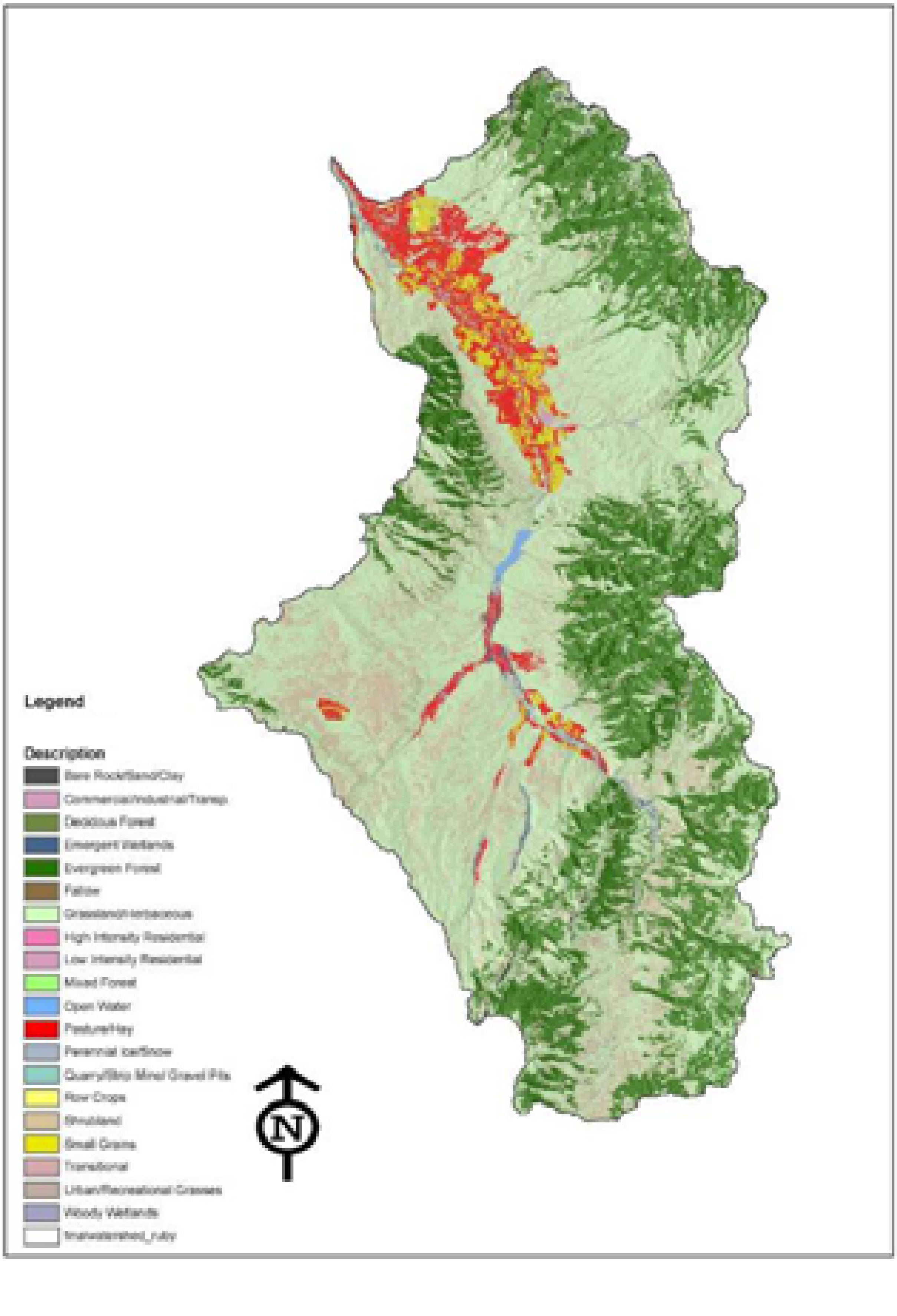


FIGURE-9. RUBY RIVER C-FACTOR

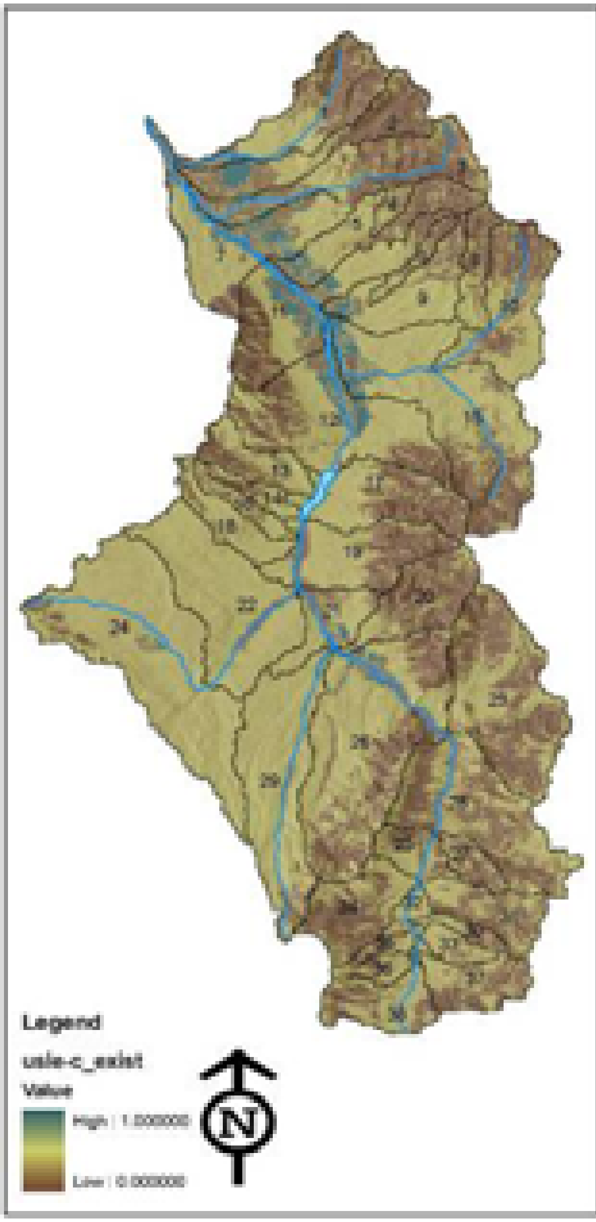


FIGURE-10. RUBY RIVER SDR-FACTOR

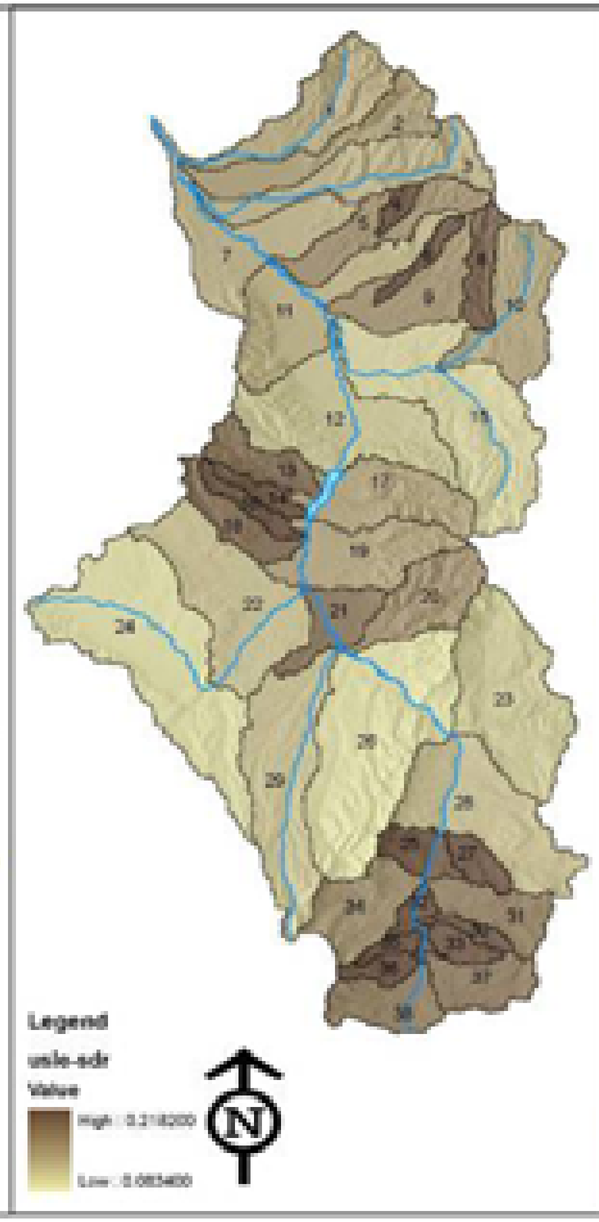
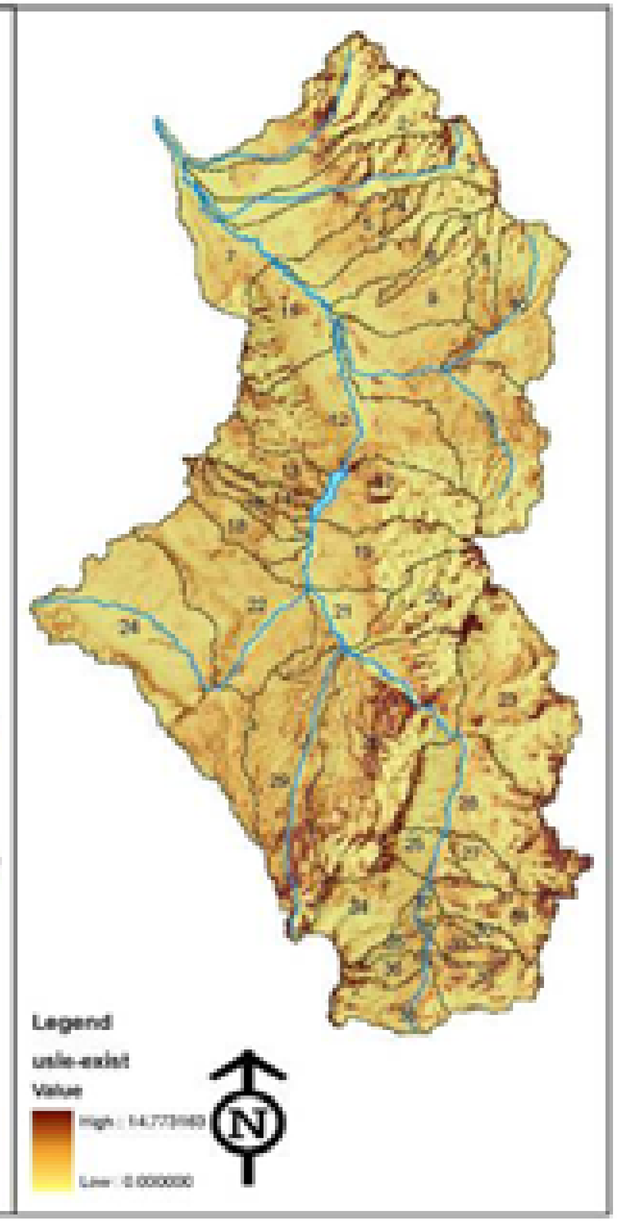


FIGURE-11. RUBY RIVER EROSION GRID (TONS ACRE^{-1} YEAR^{-1})



SEDIMENT DELIVERY RATIO (SDR)

Although USLE calculates soil erosion for a given slope, much of the eroded soil in a watershed is not delivered to a point downstream. Rather, it is re-deposited at locations where the momentum of transporting water is insufficient to keep the material in suspension or to move the soil particles along the watershed surface. A sediment delivery ratio (SDR) was applied to the USLE-3D estimate for each subwatershed to determine the net sediment load estimate for the watershed. The SDR is a function of watershed area and reflects the actual percentage of sediment that it delivered to the sub-watershed outlet. SDR's for the USLE-3D Ruby River Watershed model are based on Equation (3) presented in USDA0ARS-S-40 by Boyce (1975) where:

(3) $SDR = 0.31\ A^{-0.3}$ (A is area in mi^2)

The equation assumes that the probability of particle entrapment and deposition increases with the size of the drainage area. Sediment delivery ratios in the Ruby River Watershed range from 0.0834 to 0.2182 (Figure-10).

USLE-3D MODELING

USLE 3-D modeling results can viewed in one of two formats depending on whether the SDR is applied. These include: (1) the gross erosion rate for each raster cell in tons $acre^{-1}$ $year^{-1}$ or (2) the net erosion for each cell. The gross erosion rate is the direct output of Equation-4 where the inputs are the USLE raster layers developed in the previous sections.

(4) A = [usle-r] [usle-k] [usle-ls] [usle-c_exist]

Gross erosion is the erosion rate calculated in each 30 x 30 m grid cell (every 0.222 acre) using the ArcGIS raster calculator. Net erosion is then determined by multiplying the gross erosion rate with the SDR, and then by normalizing it with the grid cell area. Net erosion is reported in tons $year^{-1}$ and represents the actual amount of sediment delivered to the outlet point of the sub-watershed annually.

EXISTING CONDITION USLE 3-D RESULTS

Existing condition erosion rates (gross-erosion) in the Ruby River Watershed range from 0.0- 14.77 tons $acre^{-1}$ $year^{1}$ (Figure-12). Transitional lands exhibit the highest mean annual erosion rate at 2.17 tons $acre^{-1}$ $year^{1}$ followed by fallow, grassland, shrubland, row crops, and small grains at 1.53, 0.63, 0.54, 0.45, and 0.45 tons $acre^{-1}$ $year^{1}$ respectively (Figure-12, Attachment-A). Error bars (35%) have been added to the USLE 3-D estimate based on the cumulative uncertainty of USLE model parameters. These are estimated at: R-factor ~10%, K-factor ~ 5%, LS-factor ~ 5%, and C-factor ~ 15%.

The sediment load source distribution in the Ruby River is a function of net erosion and is based on the sum of the individual grid cell values for each land cover type. Major sources in the watershed include grassland / herbaceous land cover, shrubland, evergreen forest, and small grains. The overall contribution from each is 7,156, 2,384, 558, and 479 tons $year^{1}$ respectively (Figure-13, Attachment-A). Reported values are based on an estimated five percent passage of sediment through the Ruby Reservoir (Mullen, 2000).

The overall sediment load is determined by summing the net amount of erosion from all grid cells in the watershed. The total amount contributed by uplands to the Beaverhead River is 10,684 tons annually. Of this, 18,263 tons originate from the upper watershed, 17,350 are lost to deposition in the Ruby Reservoir, and 9,771 are generated in the lower watershed (Table-3).

TABLE-3. EXISTING CONDITIONS SEDIMENT LOAD

WATERSHED	Sediment Load (ton/yr)	Sediment Yield (ton/mi^2)
Upper Ruby to Reservoir	18,263	31.8
Reservoir Deposition	17,350	---
Reservoir to Beaverhead River	9,771	24.9
Ruby River Load (w/ reservoir)	10,684	11.1
Ruby River Load (w/out reservoir)	28,034	29.0

Sediment yield in individual watersheds varies considerably in the Ruby, and ranges from 16 to 74 tons per square mile. The five highest sediment producers in the Ruby River Watershed (per unit area - e.g. excluding the SDR) are: Basin Creek, East Ruby River, Robb Creek, Ruby River-06, and Peterson Creek (Figure-15). These are all steeply sloped rangeland watersheds located upstream of the reservoir. An analysis mask and zonal statistics function was used to calculate sediment production and source yields from the individual subwatersheds.

FIGURE-12. EXISTING CONDITION EROSION RATES

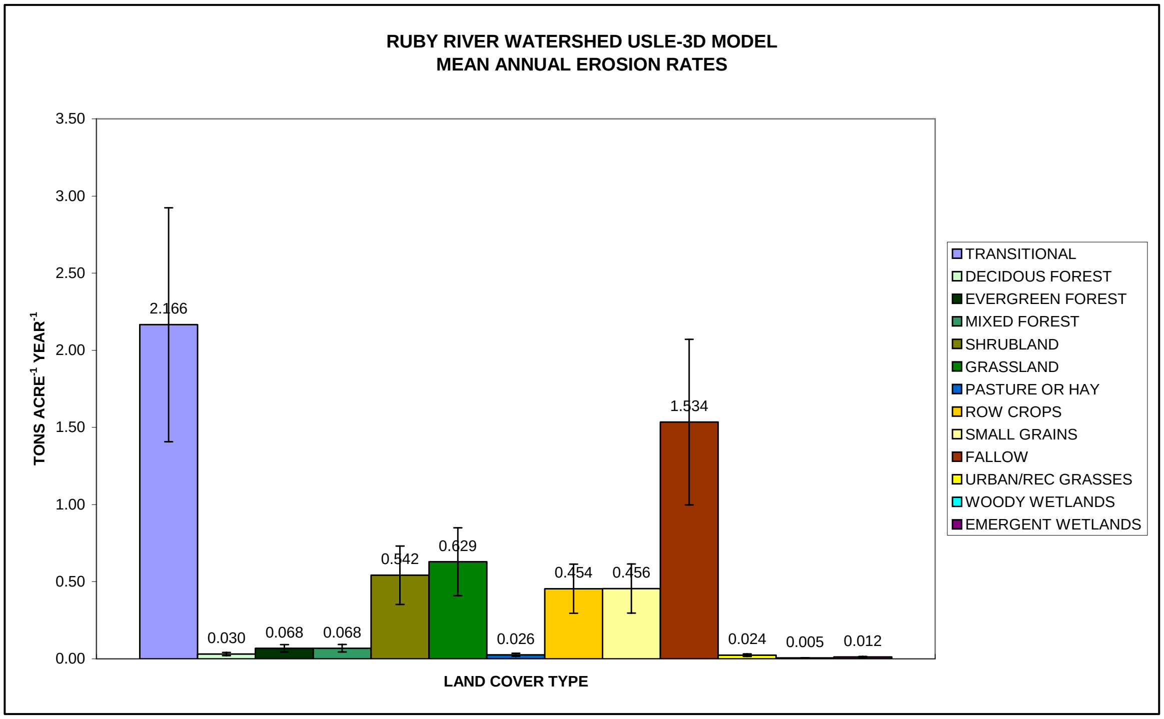


FIGURE-13. EXISTING CONDITION SOURCE LOADS

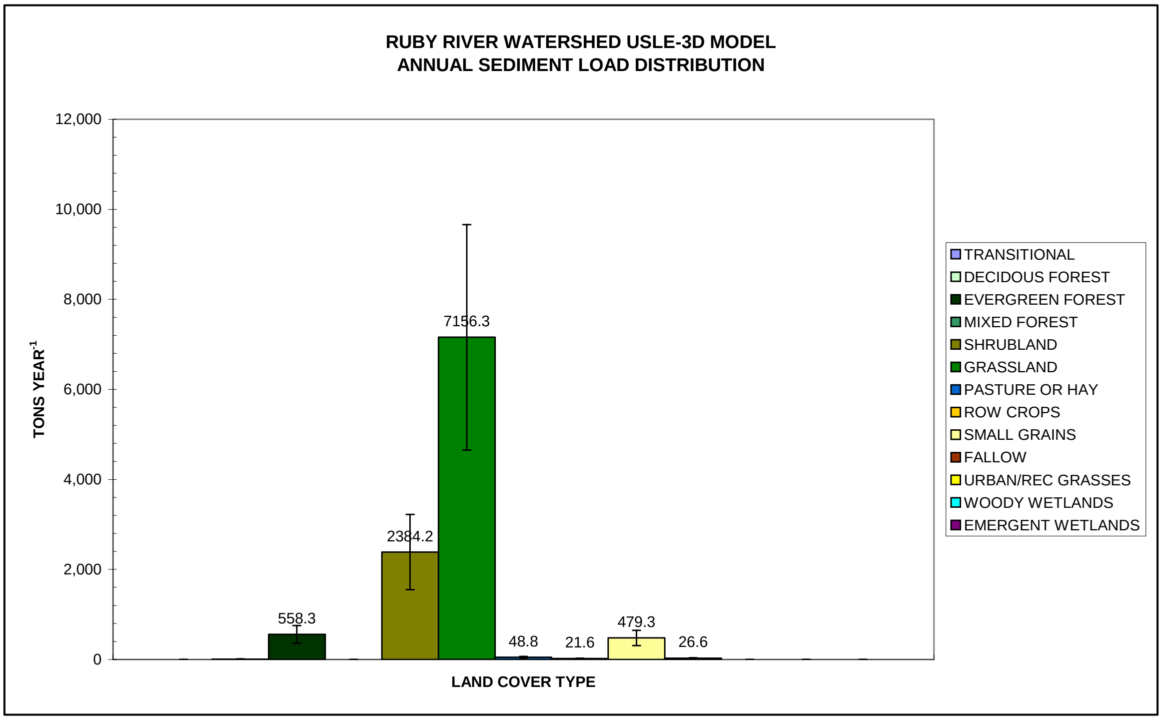
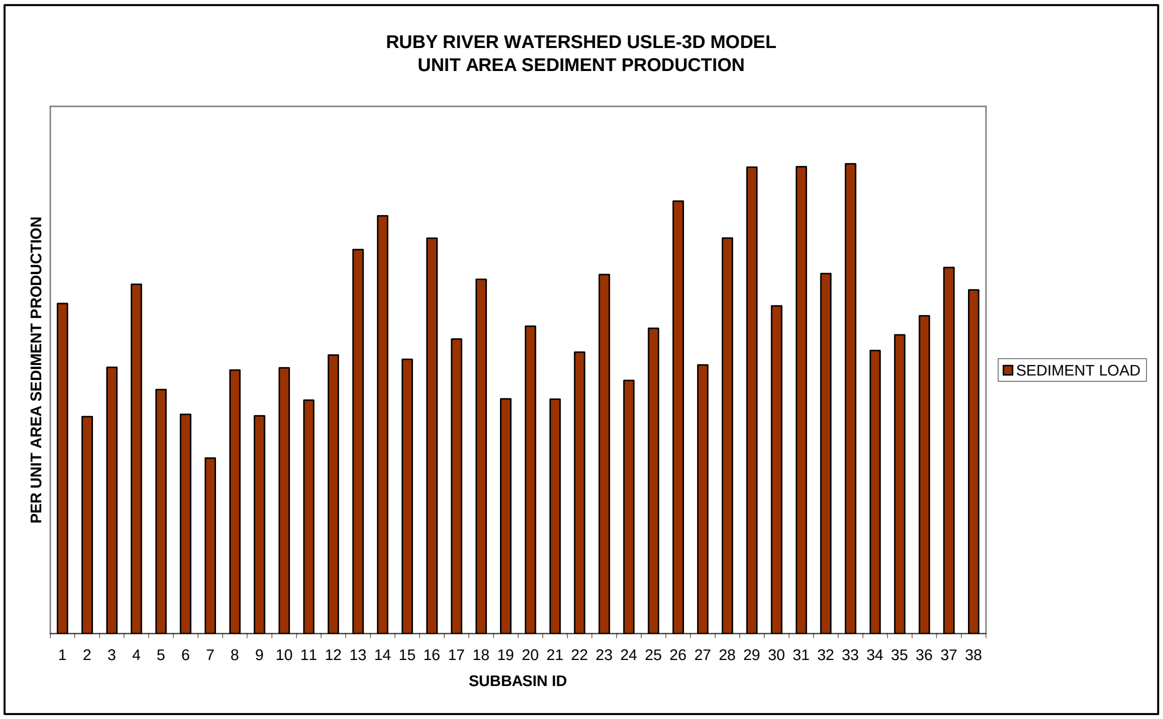


FIGURE-15. SUBWATERSHED SEDIMENT PRODUCTION



ID	WATERSHED NAME		ID	WATERSHED NAME
1	Wisconsin Creek		20	Greenhorn Creek
2	Indian Creek		21	Ruby River-05
3	Mill Creek		22	Sweetwater Creek-01
4	Currant Creek		23	Warm Springs Creek
5	Ramshorn Creek		24	Sweetwater Creek-02
6	Harris Creek		25	Ruby River-08
7	Ruby River-01		26	Ruby River-06
8	Mill Gulch		27	Burnt Creek
9	California Creek		28	Ruby River-07
10	Granite Creek		29	Robb Creek
11	Ruby River-02		30	Poison Creek
12	Ruby River-03		31	E. Ruby River
13	Garden Creek		32	Ruby River-09
14	Peterson Creek		33	Basin Creek
15	Alder Gulch Creek		34	W. Ruby River
16	Mormon Creek		35	Hawkye Creek
17	Ruby Reservoir		36	Shovel Creek
18	Cottonwood Creek		37	Coal Creek
19	Ruby River-04		38	M. Ruby River

FIGURE-16. IMPROVED MANAGEMENT SCENARIO EROSION RATES

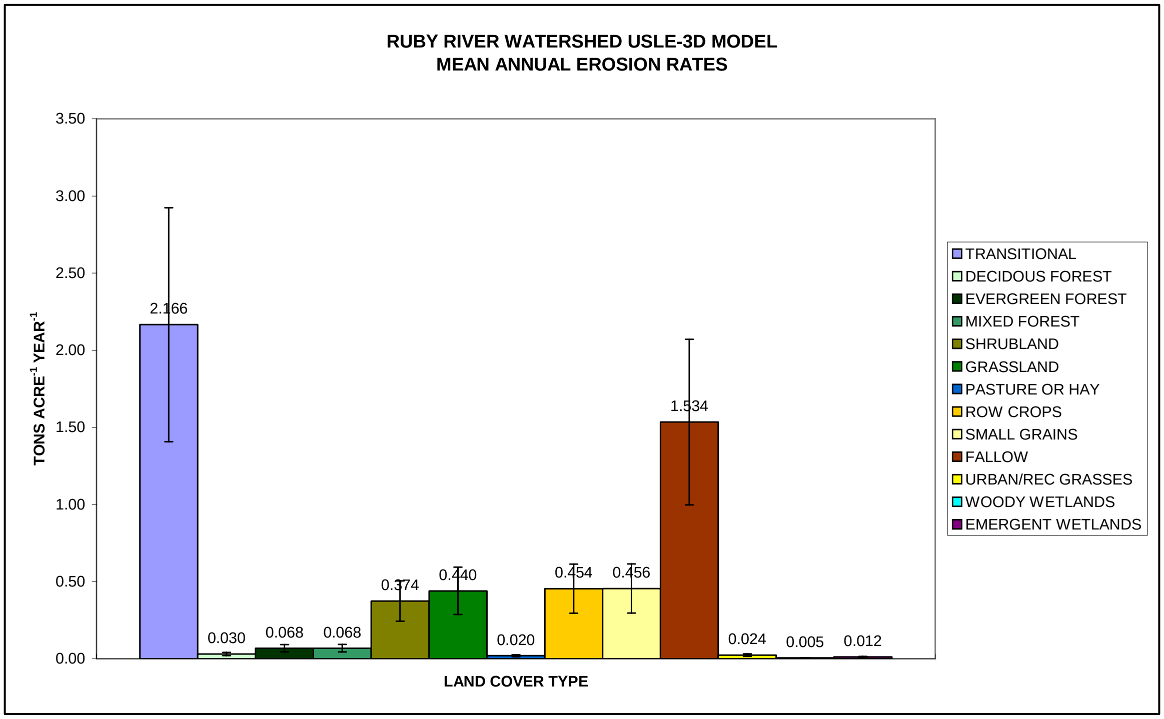
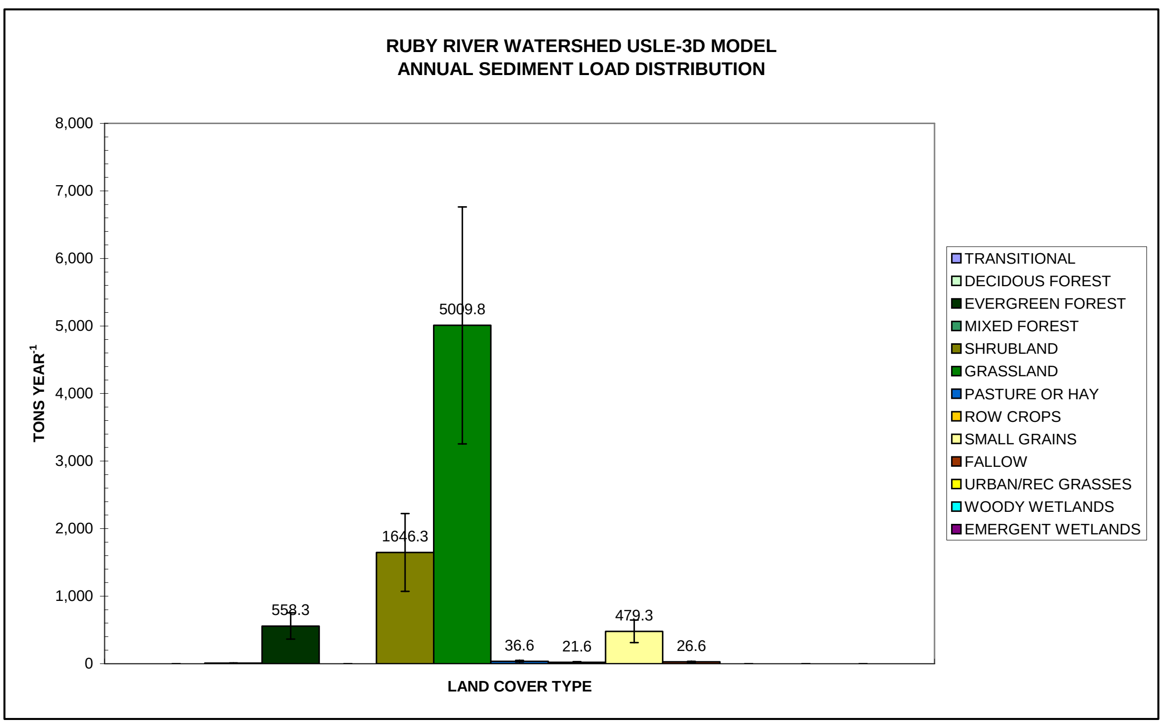


FIGURE-17. IMPROVED MANAGEMENT SCENARIO SOURCE LOADS



IMPROVED MANAGE MENT RESULTS

The implementation of a grazing management strategy is shown to slightly reduce erosion rates and sediment yield for grassland / herbaceous land cover, shrubland, and pastureland / hay in the watershed. Erosion rates decline by 0.17, 0.19, and 0.006 tons acre^{-1} year^{1} respectively from each land use category (Table-4, Figure-16, Attachment-A).

TABLE-4. EROSION RATE COMPARISON

Description	Existing Conditions Erosion Rate (ton/acre-yr)	Improved Management Erosion Rate (ton/acre-yr)
Grassland/Herbaceous	0.63	0.44
Shrubland	0.54	0.37
Pasture/Hay	0.03	0.02

The overall sediment yield of the watershed decreases by approximately 30 percent, from 10,684 to 7,787 tons per year. Sediment yield is reduced from 29.0 to 20.8 tons per square mile (Table-5, Figure-17, Attachment-A).

TABLE-5. SEDIMENT YIELD & LOAD COMPARISON

Description	Existing Conditions	Improved Management
Sediment Yield (ton/mi^2)	29.0	20.8
Sediment Load (ton/yr)	10,684	7,787

Individual subwatershed erosion rates, annual sediment loads, and the load source distribution for each of the modeling scenarios are shown in the tables in Attachment-A.

DISCUSSION

Annual sediment yield from rill and inter-rill (sheet) erosion in the Ruby River Watershed was estimated at 29.0 tons per square mile using the Montana DEQ USLE 3-D model. Yield upstream of the reservoir was slightly higher - 31.8 tons per mi^2. A comparison of these values to other studies has been presented as part of the discussion to evaluate the relative usefulness of the modeling approach for TMDL decision-making.

Mullem (2000) recently reports a suspended sediment load of 64 tons per square mile for the Upper Ruby River based on two-years of suspended sediment monitoring upstream of the reservoir (1997-1998). Although conditions during the monitoring period were somewhat wetter than normal, the results of this study would seem to suggest that approximately 50 percent of the suspended load in the Upper Ruby River Watershed originates from hillslope erosion (e.g. 31.8 divided by 64 tons per square mile). Lisle (1972) reports similar results for the Madison River. Suspended sediment yield was measured at 69 tons per mi^2. Of this, approximately 52 percent was thought to originate from upland / road erosion sources.

Comparison of the USLE-3D results with an older study completed by Page in 1978, further supports this conclusion. Approximately 30 percent of the measured suspended load in the headwaters is attributed to rill and inter-rill erosion (Table-6). This statement would assume that there has been no change in land cover or management practices over the last 25 years.

TABLE-6. COMPARISON OF MODELING RESULTS

WATERSHED	USLE-3D (2005)	PAGE (1978)	Percent of TSS
Basin Creek	414.6	509	0.81
Burnt Creek	276.6	1,104	0.25
Coal Creek	651.8	2,115	0.31
Cottonwood Creek	556.0	8,024	0.07
East Fork of Ruby	873.7	4,018	0.22
Middle Fork of Ruby	645.5	6,887	0.09
West Fork of Ruby	648.2	4,322	0.15
Poison Creek	234.1	1,004	0.23
Warm Springs Creek	1493.2	4,055	0.37
Average	**---**	**---**	**0.28**

From review of the USLE 3-D modeling effort with that of Mullem (2002) and Page (1978), between one-third and one-half of the overall suspended load in the Ruby River Watershed is comprised of overland sediment. This appears to be reasonable given the variability of watershed-scale sediment studies. Additionally, qualitative observations seem to support this assertion. Best et al. (1979) indicates that at least half of all the sediment in the watershed originates from channel migration and bank cutting. More recent source assessment activities confirm this concept (DEQ, 2005).

A comparison of observed and predicted erosion rates is also appropriate for this study. According to Meeuwig (1970), surface recession rates for rangelands in the Gravelly Mountain Range (on the western side of the Ruby River Watershed) are between 0.65-0.75 tons acre^{-1} (assuming 5% organic matter and 60% cover). This is close to the predicted value of 0.63 and 0.54 for grassland and shrubland. Forested areas show a wide variance in the literature, ranging from 0.01- 0.05 tons $year^{-1}$ (Elliot 2001, Patric 1986). USLE 3-D model predictions are within this specified range, however, interpretation of the USLE 3-D results has been precluded due to the limited application of USLE technology in forested environments.

CONCLUSION

The complex nature of the detachment and movement of soil particles presents a significant challenge for estimation of sediment yield in the Ruby River Watershed. A modification of the Universal Soil Loss Equation (USLE 3-D) was used to estimate net sediment production in the Ruby River Watershed. Through this approach, it was estimated that 10,684 tons are contributed annually to the Beaverhead River from overland sediment sources. Additionally, the average sediment yield was 29.0 tons per square mile.

Based on a comparison of modeled and monitored results, the USLE 3-D model estimate appears to be a reasonable indicator of the sheet erosion sediment contribution to the overall load distribution in the watershed. Estimated values for this contribution range from 30-50 percent and carry an approximate uncertainty of 35 percent. This suggests that 50-70 percent of the annual sediment load in the Ruby River Watershed originates from other sources such as landslides, bank erosion, or road sediment. No attempt was made to quantify these effects as part of the study. Other studies are being funded as part of the TMDL Program to estimate the sediment contribution from these sources.

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ATTACHMENT-A

USLE 3-D Calculated Erosion Rates – Existing Conditions (tons acre^{-1} year^{-1})

ID	SUBBASIN	TRANSITIONAL	DECIDUOUS FOREST	EVERGREEN FOREST	MIXED FOREST	SHRUB LAND	GRASS LAND	PASTURE OR HAY	ROW CROPS	SMALL GRAINS	FALLOW	URBAN/REC GRASSES	WOODY WETLANDS	EMERGENT WETLANDS
1	WISCONSIN CREEK	---	0.041	0.090	0.074	0.830	0.793	0.013	0.274	0.316	2.083	---	0.000	---
2	INDIAN CREEK	---	0.023	0.094	---	0.748	0.644	0.015	0.340	0.314	1.516	---	0.001	---
3	MILL CREEK	---	0.032	0.072	---	0.773	0.880	0.017	0.268	0.217	---	0.016	0.001	0.001
4	CURRANT CREEK	---	0.029	0.048	---	0.583	0.720	---	---	---	---	---	---	---
5	RAMSHORN CREEK	---	0.029	0.053	0.066	0.519	0.572	0.018	0.453	0.373	---	---	0.010	---
6	HARRIS CREEK	---	0.025	0.045	---	0.492	0.513	---	---	---	---	---	0.015	0.010
7	RUBY RIVER-01	---	0.005	0.065	---	0.318	0.339	0.019	0.424	0.344	---	---	0.001	0.002
8	MILL GULCH	---	0.037	0.056	---	0.706	0.625	---	---	---	---	---	0.012	0.020
9	CALIFORNIA CREEK	---	0.028	0.049	0.075	0.333	0.367	0.023	0.518	0.347	---	---	0.012	0.016
10	GRANITE CREEK	---	0.030	0.049	0.037	0.547	0.554	0.033	---	---	---	---	0.008	0.025
11	RUBY RIVER-02	---	0.017	0.073	---	0.575	0.488	0.028	0.428	0.560	---	---	0.003	0.009
12	RUBY RIVER-03	---	0.018	0.051	---	0.502	0.565	0.025	0.312	0.377	---	0.005	0.004	0.013
13	GARDEN CREEK	---	0.041	0.060	---	0.650	0.743	---	---	---	---	---	0.010	0.024
14	PETERSON CREEK	---	0.033	0.056	---	0.631	0.734	---	---	---	---	---	0.010	0.019
15	ALDER GULCH CREEK	2.166	0.026	0.061	0.071	0.463	0.499	0.026	0.806	0.496	---	0.057	0.005	0.012
16	MORMON CREEK	---	0.033	0.055	---	0.670	0.595	0.027	---	---	---	---	0.005	0.020
17	RUBY RESERVOIR	---	0.035	0.058	0.049	0.661	0.709	---	---	---	---	---	0.006	0.011
18	COTTONWOOD CREEK	---	0.032	0.058	---	0.522	0.515	0.033	---	---	---	---	0.014	0.011
19	RUBY RIVER-04	---	0.022	0.057	0.050	0.479	0.487	0.037	---	---	---	---	0.003	0.006
20	GREENHORN CREEK	---	0.049	0.078	0.064	1.015	1.169	0.041	0.643	0.404	---	---	0.017	0.006
21	RUBY RIVER-05	---	0.002	0.047	---	0.433	0.407	0.032	0.341	0.504	---	---	0.002	0.005
22	SWEETWATER CREEK-01	---	0.021	0.021	---	0.373	0.400	0.049	---	---	---	---	0.003	0.007
23	WARMSPRINGS CREEK	---	0.032	0.082	0.095	0.797	0.997	---	---	---	---	---	0.013	0.017
24	SWEETWATER CREEK-02	---	0.014	0.039	0.024	0.286	0.387	0.034	---	0.958	---	---	0.005	0.011
25	RUBY RIVER-08	---	0.026	0.045	0.066	0.524	0.693	---	---	---	---	---	0.005	0.018
26	RUBY RIVER-06	---	0.035	0.078	0.056	0.778	0.893	0.059	1.550	0.916	---	---	0.007	0.015
27	BURNT CREEK	---	0.034	0.069	0.055	0.644	0.892	---	---	---	---	---	0.016	0.053
28	RUBY RIVER-07	---	0.026	0.068	0.037	0.732	1.024	---	---	---	---	---	0.006	0.007
29	ROBB CREEK	---	0.053	0.079	---	0.604	0.691	0.095	1.675	0.828	---	---	0.012	0.027
30	POISON CREEK	---	---	0.073	0.027	0.569	0.769	---	---	---	---	---	0.007	0.017
31	E. RUBY RIVER	---	0.044	0.080	0.071	0.872	1.123	---	---	---	---	---	0.007	0.043
32	RUBY RIVER-09	---	0.027	0.058	0.073	0.448	0.556	---	---	---	---	---	0.010	0.016
33	BASIN CREEK	---	0.044	0.064	0.060	0.653	0.763	---	---	---	---	---	---	0.018
34	W. RUBY RIVER	---	0.027	0.052	0.033	0.585	0.809	---	---	---	---	---	0.010	0.019
35	HAWKEYE CREEK	---	0.026	0.044	0.051	0.521	0.614	---	---	---	---	---	0.013	0.037
36	SHOVEL CREEK	---	0.036	0.043	0.019	0.459	0.651	---	---	---	---	---	0.009	0.020
37	COAL CREEK	---	0.036	0.069	0.062	0.684	0.960	---	---	---	---	---	0.007	0.010
38	M. RUBY RIVER	---	0.041	0.056	0.058	0.539	0.712	---	---	---	---	---	0.010	0.023
	WATERSHED AVERAGE	**2.166**	**0.030**	**0.068**	**0.068**	**0.542**	**0.629**	**0.026**	**0.454**	**0.456**	**1.534**	**0.024**	**0.005**	**0.012**

USLE 3-D Sediment Yield – Existing Conditions (tons year^{-1})

ID	SUBBASIN	TRANSITIONAL	DECIDUOUS FOREST	EVERGREEN FOREST	MIXED FOREST	SHRUB LAND	GRASS LAND	PASTURE OR HAY	ROW CROPS	SMALL GRAINS	FALLOW	URBAN/REC GRASSES	WOODY WETLANDS	EMERGENT WETLANDS	TOTAL LOAD
1	WISCONSIN CREEK	---	2.0	75.5	0.0	209.5	646.7	1.3	0.2	10.2	1.1	---	0.0	---	946.5
2	INDIAN CREEK	---	0.8	66.7	---	112.5	297.1	5.3	9.0	37.3	25.5	---	0.0	---	554.2
3	MILL CREEK	---	1.8	72.2	---	170.5	588.2	5.9	0.5	8.9	---	0.1	0.0	0.0	848.0
4	CURRANT CREEK	---	0.3	6.7	---	54.4	148.4	---	---	---	---	---	---	---	209.8
5	RAMSHORN CREEK	---	0.3	28.5	0.0	119.4	357.8	3.0	1.6	35.4	---	---	0.1	---	546.1
6	HARRIS CREEK	---	0.1	11.8	---	33.4	125.2	---	---	---	---	---	0.1	0.0	170.6
7	RUBY RIVER-01	---	0.1	9.5	---	126.9	338.7	10.0	3.7	81.5	---	---	0.1	0.0	570.4
8	MILL GULCH	---	0.5	27.6	---	68.2	270.1	---	---	---	---	---	0.0	0.0	366.4
9	CALIFORNIA CREEK	---	0.1	13.2	0.0	68.0	399.9	2.2	1.7	18.5	---	---	0.1	0.0	503.8
10	GRANITE CREEK	---	0.7	40.3	0.0	142.9	595.0	0.0	---	---	---	---	0.1	0.0	778.9
11	RUBY RIVER-02	---	0.2	50.3	---	180.6	402.2	11.1	1.3	142.3	---	---	0.1	0.0	788.0
12	RUBY RIVER-03	---	0.2	37.4	---	293.0	747.4	5.9	1.4	76.9	---	0.0	0.1	0.0	1162.2
13	GARDEN CREEK	---	0.2	21.0	---	219.4	375.8	---	---	---	---	---	0.0	0.0	616.5
14	PETERSON CREEK	---	0.1	8.0	---	95.1	267.7	---	---	---	---	---	0.0	0.0	370.9
15	ALDER GULCH CREEK	0.0	0.2	52.2	0.0	240.6	977.8	2.9	1.9	63.2	---	0.0	0.1	0.0	1339.1
	SUM DOWNSTREAM	**0.0**	**7.4**	**520.7**	**0.1**	**2134.5**	**6537.9**	**47.5**	**21.4**	**474.1**	**26.6**	**0.1**	**0.8**	**0.1**	**9771.1**
	US OF RUBY RESEVOIR														
16	MORMON CREEK	---	0.1	5.5	---	113.5	249.9	0.1	---	---	---	---	0.0	0.0	369.1
17	RUBY RESERVOIR	---	0.2	49.3	0.0	202.9	555.6	---	---	---	---	---	0.0	0.0	808.0
18	COTTONWOOD CREEK	---	0.0	5.8	---	166.9	383.0	0.2	---	---	---	---	0.0	0.0	556.0
19	RUBY RIVER-04	---	0.1	38.1	0.0	171.1	441.1	3.1	---	---	---	---	0.1	0.2	653.8
20	GREENHORN CREEK	---	0.4	89.7	0.0	164.5	454.6	0.3	0.1	1.6	---	---	0.2	0.0	711.3
21	RUBY RIVER-05	---	0.0	2.7	---	100.1	273.0	5.9	0.3	19.6	---	---	0.1	0.2	401.9
22	SWEETWATER CREEK-01	---	0.0	0.0	---	354.3	777.7	5.1	---	---	---	---	0.0	0.1	1137.2
23	WARMSPRINGS CREEK	---	2.3	127.5	0.6	375.9	986.8	---	---	---	---	---	0.1	0.1	1493.2
24	SWEETWATER CREEK-02	---	0.0	4.1	0.0	454.4	955.7	1.7	---	15.2	---	---	0.0	0.0	1431.1
25	RUBY RIVER-08	---	0.1	14.6	0.1	124.0	254.9	---	---	---	---	---	0.0	0.1	393.8
26	RUBY RIVER-06	---	0.6	92.6	0.0	636.8	1597.9	6.8	3.0	50.5	---	---	0.6	0.8	2389.7
27	BURNT CREEK	---	0.3	30.3	0.0	98.9	147.0	---	---	---	---	---	0.0	0.0	276.6
28	RUBY RIVER-07	---	0.7	84.8	0.1	375.0	1062.2	---	---	---	---	---	0.2	0.1	1523.0
29	ROBB CREEK	---	0.1	9.7	---	481.0	1375.2	4.7	0.5	17.8	---	---	0.3	0.4	1889.6
30	POISON CREEK	---	---	16.0	0.0	64.8	153.4	---	---	---	---	---	0.0	0.0	234.1
31	E. RUBY RIVER	---	0.2	49.2	0.1	176.2	647.9	---	---	---	---	---	0.0	0.0	873.7
32	RUBY RIVER-09	---	0.2	1.2	0.0	112.1	193.0	---	---	---	---	---	0.1	0.0	306.6
33	BASIN CREEK	---	0.1	5.7	0.1	143.4	265.4	---	---	---	---	---	---	0.0	414.6
34	W. RUBY RIVER	---	0.5	44.5	0.0	146.4	456.8	---	---	---	---	---	0.0	0.0	648.2
35	HAWKEYE CREEK	---	0.1	6.4	0.0	66.7	108.3	---	---	---	---	---	0.0	0.0	181.6
36	SHOVEL CREEK	---	0.0	7.4	0.0	79.3	185.7	---	---	---	---	---	0.1	0.1	272.5
37	COAL CREEK	---	0.2	42.6	0.1	169.3	439.6	---	---	---	---	---	0.0	0.0	651.8
38	M. RUBY RIVER	---	0.0	23.0	0.1	217.6	404.4	---	---	---	---	---	0.1	0.2	645.5
	SUM UPSTREAM	**0.0**	**6.2**	**750.4**	**1.3**	**4995.1**	**12369.0**	**27.9**	**4.0**	**104.7**	**0.0**	**0.0**	**2.1**	**2.2**	**18263.0**
	WATERSHED TOTAL*	**0.0**	**7.7**	**558.3**	**0.1**	**2384.2**	**7156.3**	**48.8**	**21.6**	**479.3**	**26.6**	**0.1**	**0.9**	**0.2**	**10684.3**

* Assuming 5% of sediment flows through Ruby Reservoir

USLE 3-D Calculated Erosion Rates – Managed Conditions (tons $acre^{-1}$ $year^{-1}$)

ID	SUBBASIN	TRANSITIONAL	DECIDUOUS FOREST	EVERGREEN FOREST	MIXED FOREST	SHRUB LAND	GRASS LAND	PASTURE OR HAY	ROW CROPS	SMALL GRAINS	FALLOW	URBAN/REC GRASSES	WOODY WETLANDS	EMERGENT WETLANDS
1	WISCONSIN CREEK	---	0.041	0.090	0.074	0.573	0.555	0.010	0.274	0.316	2.083	---	0.000	---
2	INDIAN CREEK	---	0.023	0.094	---	0.516	0.451	0.011	0.340	0.314	1.516	---	---	---
3	MILL CREEK	---	0.032	0.072	---	0.534	0.616	0.013	0.268	0.217	---	0.016	---	---
4	CURRANT CREEK	---	0.029	0.048	---	0.402	0.504	---	---	---	---	---	---	---
5	RAMSHORN CREEK	---	0.029	0.053	0.066	0.358	0.400	0.014	0.453	0.373	---	---	0.010	---
6	HARRIS CREEK	---	0.025	0.045	---	0.340	0.359	---	---	---	---	---	0.015	0.010
7	RUBY RIVER-01	---	0.005	0.065	---	0.220	0.237	0.014	0.424	0.344	---	---	0.000	0.002
8	MILL GULCH	---	0.037	0.056	---	0.488	0.437	---	---	---	---	---	0.012	0.020
9	CALIFORNIA CREEK	---	0.028	0.049	0.075	0.230	0.257	0.017	0.518	0.347	---	---	0.012	0.016
10	GRANITE CREEK	---	0.030	0.049	0.037	0.377	0.388	0.025	---	---	---	---	0.008	0.025
11	RUBY RIVER-02	---	0.017	0.073	---	0.397	0.341	0.021	0.428	0.560	---	---	0.000	0.009
12	RUBY RIVER-03	---	0.018	0.051	---	0.346	0.396	0.019	0.312	0.377	---	0.005	0.000	0.013
13	GARDEN CREEK	---	0.041	0.060	---	0.449	0.520	---	---	---	---	---	0.010	0.024
14	PETERSON CREEK	---	0.033	0.056	---	0.435	0.514	---	---	---	---	---	0.010	0.019
15	ALDER GULCH CREEK	2.166	0.026	0.061	0.071	0.320	0.349	0.019	0.806	0.496	---	0.057	0.000	0.012
16	MORMON CREEK	---	0.033	0.055	---	0.463	0.416	0.020	---	---	---	---	0.005	0.020
17	RUBY RESERVOIR	---	0.035	0.058	0.049	0.456	0.496	---	---	---	---	---	0.006	0.011
18	COTTONWOOD CREEK	---	0.032	0.058	---	0.360	0.361	0.025	---	---	---	---	0.014	0.011
19	RUBY RIVER-04	---	0.022	0.057	0.050	0.331	0.341	0.028	---	---	---	---	0.000	0.006
20	GREENHORN CREEK	---	0.049	0.078	0.064	0.701	0.818	0.031	0.643	0.404	---	---	0.017	0.006
21	RUBY RIVER-05	---	0.002	0.047	---	0.299	0.285	0.024	0.341	0.504	---	---	0.000	0.005
22	SWEETWATER CREEK-01	---	0.021	0.021	---	0.258	0.280	0.037	---	---	---	---	0.000	0.007
23	WARMSPRINGS CREEK	---	0.032	0.082	0.095	0.550	0.698	---	---	---	---	---	0.013	0.017
24	SWEETWATER CREEK-02	---	0.014	0.039	0.024	0.198	0.271	0.025	---	0.958	---	---	0.000	0.011
25	RUBY RIVER-08	---	0.026	0.045	0.066	0.362	0.485	---	---	---	---	---	0.005	0.018
26	RUBY RIVER-06	---	0.035	0.078	0.056	0.537	0.625	0.044	1.550	0.916	---	---	0.007	0.015
27	BURNT CREEK	---	0.034	0.069	0.055	0.445	0.624	---	---	---	---	---	0.016	0.053
28	RUBY RIVER-07	---	0.026	0.068	0.037	0.505	0.717	---	---	---	---	---	0.006	0.007
29	ROBB CREEK	---	0.053	0.079	---	0.417	0.484	0.071	1.675	0.828	---	---	0.012	0.027
30	POISON CREEK	---	---	0.073	0.027	0.393	0.538	---	---	---	---	---	0.007	0.017
31	E. RUBY RIVER	---	0.044	0.080	0.071	0.602	0.786	---	---	---	---	---	0.007	0.043
32	RUBY RIVER-09	---	0.027	0.058	0.073	0.309	0.389	---	---	---	---	---	0.010	0.016
33	BASIN CREEK	---	0.044	0.064	0.060	0.451	0.534	---	---	---	---	---	---	0.018
34	W. RUBY RIVER	---	0.027	0.052	0.033	0.404	0.567	---	---	---	---	---	0.010	0.019
35	HAWKEYE CREEK	---	0.026	0.044	0.051	0.360	0.430	---	---	---	---	---	0.013	0.037
36	SHOVEL CREEK	---	0.036	0.043	0.019	0.317	0.456	---	---	---	---	---	0.009	0.020
37	COAL CREEK	---	0.036	0.069	0.062	0.472	0.672	---	---	---	---	---	0.007	0.010
38	M. RUBY RIVER	---	0.041	0.056	0.058	0.372	0.498	---	---	---	---	---	0.010	0.023
	WATERSHED AVERAGE	**2.166**	**0.030**	**0.068**	**0.068**	**0.374**	**0.440**	**0.020**	**0.454**	**0.456**	**1.534**	**0.024**	**0.005**	**0.012**

USLE 3-D Sediment Yield – Managed Conditions (tons year^{-1})

ID	SUBBASIN	TRANSITIONAL	DECIDUOUS FOREST	EVERGREEN FOREST	MIXED FOREST	SHRUB LAND	GRASS LAND	PASTURE OR HAY	ROW CROPS	SMALL GRAINS	FALLOW	URBAN/REC GRASSES	WOODY WETLANDS	EMERGENT WETLANDS	TOTAL LOAD
	DS OF RUBY RESEVOIR														
1	WISCONSIN CREEK	---	2.0	75.5	0.0	144.7	452.7	0.9	0.2	10.2	1.1	---	0.0	---	687.3
2	INDIAN CREEK	---	0.8	66.7	---	77.7	208.0	3.9	9.0	37.3	25.5	---	0.0	---	428.9
3	MILL CREEK	---	1.8	72.2	---	117.8	411.7	4.4	0.5	8.9	---	0.1	0.0	0.0	617.3
4	CURRANT CREEK	---	0.3	6.7	---	37.5	103.8	---	---	---	---	---	---	---	148.4
5	RAMSHORN CREEK	---	0.3	28.5	0.0	82.5	250.5	2.2	1.6	35.4	---	---	0.1	---	401.0
6	HARRIS CREEK	---	0.1	11.8	---	23.1	87.7	---	---	---	---	---	0.1	0.0	122.7
7	RUBY RIVER-01	---	0.1	9.5	---	87.6	237.1	7.5	3.7	81.5	---	---	0.1	0.0	427.0
8	MILL GULCH	---	0.5	27.6	---	47.1	189.1	---	---	---	---	---	0.0	0.0	264.3
9	CALIFORNIA CREEK	---	0.1	13.2	0.0	46.9	279.9	1.6	1.7	18.5	---	---	0.1	0.0	362.2
10	GRANITE CREEK	---	0.7	40.3	0.0	98.6	416.5	0.0	---	---	---	---	0.1	0.0	556.2
11	RUBY RIVER-02	---	0.2	50.3	---	124.7	281.5	8.3	1.3	142.3	---	---	0.1	0.0	608.7
12	RUBY RIVER-03	---	0.2	37.4	---	202.3	523.2	4.4	1.4	76.9	---	0.0	0.1	0.0	845.8
13	GARDEN CREEK	---	0.2	21.0	---	151.5	263.1	---	---	---	---	---	0.0	0.0	435.8
14	PETERSON CREEK	---	0.1	8.0	---	65.7	187.4	---	---	---	---	---	0.0	0.0	261.1
15	ALDER GULCH CREEK	0.0	0.2	52.2	0.0	166.1	684.4	2.2	1.9	63.2	---	0.0	0.1	0.0	970.5
	SUM DOWNSTREAM	**0.0**	**7.4**	**520.7**	**0.1**	**1473.8**	**4576.5**	**35.6**	**21.4**	**474.1**	**26.6**	**0.1**	**0.8**	**0.1**	**7137.2**
	US OF RUBY RESEVOIR														
16	MORMON CREEK	---	0.1	5.5	---	78.4	174.9	0.1	---	---	---	---	0.0	0.0	259.0
17	RUBY RESERVOIR	---	0.2	49.3	0.0	140.1	388.9	---	---	---	---	---	0.0	0.0	578.5
18	COTTONWOOD CREEK	---	0.0	5.8	---	115.3	268.1	0.1	---	---	---	---	0.0	0.0	389.4
19	RUBY RIVER-04	---	0.1	38.1	0.0	118.2	308.8	2.3	---	---	---	---	0.1	0.2	467.7
20	GREENHORN CREEK	---	0.4	89.7	0.0	113.6	318.2	0.2	0.1	1.6	---	---	0.2	0.0	523.9
21	RUBY RIVER-05	---	0.0	2.7	---	69.1	191.1	4.5	0.3	19.6	---	---	0.1	0.2	287.5
22	SWEETWATER CREEK-01	---	0.0	0.0	---	244.6	544.4	3.9	---	---	---	---	0.0	0.1	793.0
23	WARMSPRINGS CREEK	---	2.3	127.5	0.6	259.6	690.8	---	---	---	---	---	0.1	0.1	1080.9
24	SWEETWATER CREEK-02	---	0.0	4.1	0.0	313.7	669.0	1.2	---	15.2	---	---	0.0	0.0	1003.4
25	RUBY RIVER-08	---	0.1	14.6	0.1	85.6	178.4	0.0	---	---	---	---	0.0	0.1	278.9
26	RUBY RIVER-06	---	0.6	92.6	0.0	439.7	1118.5	5.1	3.0	50.5	---	---	0.6	0.8	1711.5
27	BURNT CREEK	---	0.3	30.3	0.0	68.3	102.9	---	---	---	---	---	0.0	0.0	201.9
28	RUBY RIVER-07	---	0.7	84.8	0.1	258.9	743.5	---	---	---	---	---	0.2	0.1	1088.3
29	ROBB CREEK	---	0.1	9.7	---	332.1	962.6	3.5	0.5	17.8	---	---	0.3	0.4	1327.0
30	POISON CREEK	---	---	16.0	0.0	44.7	107.4	---	---	---	---	---	0.0	0.0	168.1
31	E. RUBY RIVER	---	0.2	49.2	0.1	121.7	453.5	---	---	---	---	---	0.0	0.0	624.7
32	RUBY RIVER-09	---	0.2	1.2	0.0	77.4	135.1	---	---	---	---	---	0.1	0.0	214.0
33	BASIN CREEK	---	0.1	5.7	0.1	99.0	185.8	---	---	---	---	---	---	0.0	290.6
34	W. RUBY RIVER	---	0.5	44.5	0.0	101.1	319.8	---	---	---	---	---	0.0	0.0	465.8
35	HAWKEYE CREEK	---	0.1	6.4	0.0	46.1	75.8	---	---	---	---	---	0.0	0.0	128.5
36	SHOVEL CREEK	---	0.0	7.4	0.0	54.8	130.0	---	---	---	---	---	0.1	0.1	192.3
37	COAL CREEK	---	0.2	42.6	0.1	116.9	307.7	---	---	---	---	---	0.0	0.0	467.6
38	M. RUBY RIVER	---	0.0	23.0	0.1	150.3	283.1	---	---	---	---	---	0.1	0.2	456.8
	SUM UPSTREAM	**0.0**	**6.2**	**750.4**	**1.3**	**3449.0**	**8658.3**	**20.9**	**4.0**	**104.7**	**0.0**	**0.0**	**2.1**	**2.2**	**12999.2**
	WATERSHED TOTAL*	**0.0**	**7.7**	**558.3**	**0.1**	**1646.3**	**5009.4**	**36.6**	**21.6**	**479.3**	**26.6**	**0.1**	**0.9**	**0.2**	**7787.2**

* Assuming 5% of sediment flows through Ruby Reservoir