Road Cut and Fill Slope Sediment Loading Assessment Tool:

Project Report

Prepared by

Kevin Drake and Rachel Arst McCullough

Integrated Environmental Restoration Services

Dr. Mark Grismer

UC Davis

Submitted to

Jonathan Long

U.S. Forest Service – Pacific Southwest Research Station

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INTEGRATED ENVIRONMENTAL
RESTORATION SERVICES, INC

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Table of Contents

Project Overview

Background and Purpose

Achieving the fine sediment load reduction targets set forth in the Lake Tahoe TMDL depends on an accurate understanding and characterization of sediment source areas. An estimated 72% of the fine sediment particle (FSP, <16 microns) load entering Lake Tahoe is believed to originate from urban areas. Road cut and fill slopes represent a persistent and readily treatable source of FSP loading and are widespread along most roadways in the Lake Tahoe Basin, particularly within urban areas. Roads cut and fill slopes tend to be characterized by steep slopes, compacted soils, and low levels of soil cover. Such areas represent a "perfect storm" for detachment and transport of FSPs. Several studies using rainfall simulation have produced valuable quantitative data characterizing a wide range of disturbed and treated conditions on steep disturbed soil areas, including road cut and fill slopes and ski runs in the Lake Tahoe region (Grismer et al. 2004-2008). This research has shown that steep disturbed slopes, such as road cuts, may produce sediment yields an order of magnitude (or more) greater than that from relatively undisturbed or "native" soil conditions (Grismer and Hogan 2004, Grismer et al. 2008). Currently, road cut and fill slope areas are generalized with other land uses in modeling tools such as the Pollutant Load Reduction Model (PLRM), which is likely to be misleading and inaccurate, as the types and volumes of fine sediment and their transport mechanisms from disturbed cut and fill slopes are known to be quite different from other land use types.

The overall purpose of this project was to develop the data and tools necessary to improve estimates of pollutant loading and load reductions from road cut and fill slopes. The end product of this effort is the Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT), a simple and repeatable field assessment methodology and spreadsheet tool designed to assist the Lake Tahoe erosion control and stormwater community in characterizing the functional condition of road cut and fill slopes and estimating the associated sediment and FSP loading from these areas.

Goals, Objectives, and Hypotheses Tested

The goals of this study were to: 1) improve understanding of sediment loading (amounts and particle size classes) from road cut and fill slope sources; 2) inform the selection, design, and implementation of water quality improvement projects to maximize load reduction effectiveness; and 3) improve the predictive accuracy of the PLRM for road cut and fill areas to support achievement of TMDL goals.

The project objectives were to: 1) develop a new land use category for road cut and fill slopes for the PLRM that leverages existing quantitative data and builds on the treatment tiers and functional condition classes already developed in earlier stages of the TMDL; and 2) develop well-defined classifications and field identification protocols for a range of disturbed and treated cut and fill slope conditions with associated loading potentials.

The primary hypothesis that was tested was that cut and fill slopes exhibit a wide range of characteristic runoff concentrations, depending on level of disturbance and/or subsequent level of treatment (i.e. functional condition class). Therefore, clear definition of functional condition classes for road cut and fill slopes will improve our ability to identify load reduction opportunities and accurately track fine sediment load reductions in urban upland areas.

Deliverables

The intent of this project was to develop the data and tools necessary to enable the eventual creation of a discrete road cut and fill land use category for PLRM. Using the most complete set of directly measured erosion data in this region, supplemented by additional targeted rainfall simulation under this project, the project team developed the runoff pollutant concentration values needed to support a road cut and fill slope land use category. In collaboration with agency personnel, we also developed an assessment methodology for directly measuring several key erosion parameters in the field. After several discussions with the developers of PLRM, it became clear that formal integration of the road cut and fill land use into PLRM would require a new module that was beyond the scope of this project. Therefore, we developed a simple, stand-alone spreadsheet tool – the Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT) – which regulators and project implementers can use to estimate the sediment loading potential of cut and fill slopes before and after project implementation. The data outputs from this tool (sediment loads and runoff volumes) can be used in conjunction with PLRM or separately. Proposed and actual deliverables for this project are compared in Table 1.

Table 1. Comparison of proposed project deliverables to actual project deliverables.

Proposed Deliverables	Actual Deliverables
Final project report summarizing project, research methods and results	Final project report summarizing project, research methods and results
Table of input parameters for PLRM road cut and fill land use category including: characteristic runoff concentrations for each pollutant of concern for each functional condition class and accompanying table of soil hydrologic properties (Ksat and infiltration rate) for each functional condition class	Table of sediment yields (total and FSP fractions) organized by soil type, slope angle, surface cover and cone penetrometer depth (which correspond to the field assessment methods). Hydrologic properties (runoff fractions) are provided based on slope category.
Field identification protocols for functional condition classes (including summary of agency input)	Road Cut and Fill Slope Sediment Loading Assessment Tool User's Guide; summary of agency input in this report
PLRM application guide for modeling road cut and fill land use category	The User's Guide walks users through the use of the spreadsheet tool (Road Cut and Fill Slope Sediment Loading Assessment Tool – see row below). A PLRM-specific application guide is not necessary until this data is fully integrated into PLRM as a new module.
n/a	The stand-alone spreadsheet tool (Road Cut and Fill Slope Sediment Loading Assessment Tool) is beyond the scope outlined in the proposal. However, this tool was developed to provide a consistent methodology for assessing loading from road cut and fill slopes and is intended to be fully integrated into PLRM in the near future.

Field Methods

Existing data from over 900 rainfall simulations in the Lake Tahoe area collected between 2002 and 2009 provided the basis for the this Road Cut and Fill Slope Sediment Loading Assessment Tool. In 2009, additional simulation sites were selected to fill data gaps based on cut/fill condition, functional condition class, cover, and slope. The additional rainfall simulation monitoring was conducted at two Lake Tahoe area sites, one with granitic soils and one with volcanic soils. At each site, rainfall simulation tests were conducted at both cut and fill slopes on two to three slope angles per cut or fill.

Rainfall Simulation

The rainfall simulator is a custom-designed monitoring tool used to simulate natural rainfall events and directly measure infiltration, runoff, and erosion rates from disturbed, treated, and reference areas. The methods described below follow those established by Grismer and Hogan (2004) and have been used for hundreds of simulations since establishment (Grismer and Hogan 2005a, 2005b; Grismer et al. 2008b).

The 1 m^2 rainfall simulator "rains" on a 0.64 m^2 square plot from an average height of 3.3 feet (Figure 1 and Figure 2). The rate of rainfall is controlled at 4.7 inches per hour and runoff is collected from a trough at the bottom of a 6.5 ft^2 frame that has been pounded into the ground (Figure 3 and Figure 4). While this rainfall intensity is large for the Tahoe area, the combined fall height and intensity produce a rain "power" of ~1220 J/m^2-hr, a value mid-range of that for "natural" between 200 – 3500 J/m^2-hr (Madden et al., 1998; and van Dijk, 2002). The volume of water collected is measured, and then the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 45 minutes, the simulation is stopped. The average steady state infiltration rate is calculated from three simulation frames and the collected runoff samples are then analyzed for steady state sediment yield and particle size distribution.

A cone penetrometer is used to record the depth to refusal (DTR) surrounding the rainfall frames before and after rainfall simulations. Volumetric soil moisture is also measured in each frame before and after rainfall simulations. After rainfall simulation, the wetting depth is measured at nine locations within the frame to determine how deeply water has infiltrated into the soil column.

Figure 1. Rain drops are generated from more than 800 hypodermic needles on the rainfall simulator.

Figure 2. Rainfall simulation at one of the road cut plots.

Figure 3. Bottles collected during rainfall simulation.

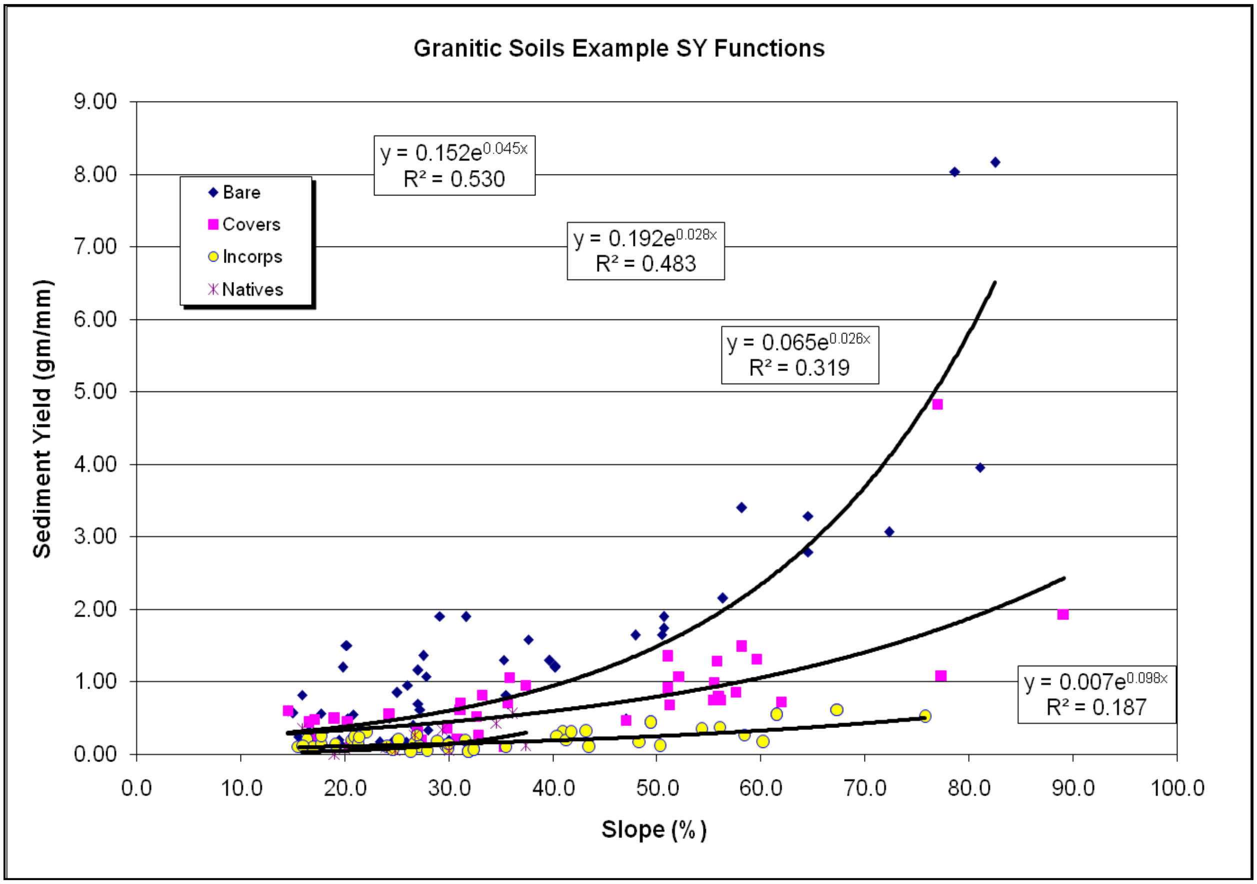
Figure 4. Bottles collected during rainfall simulation.

Analysis Methods

Data Analysis

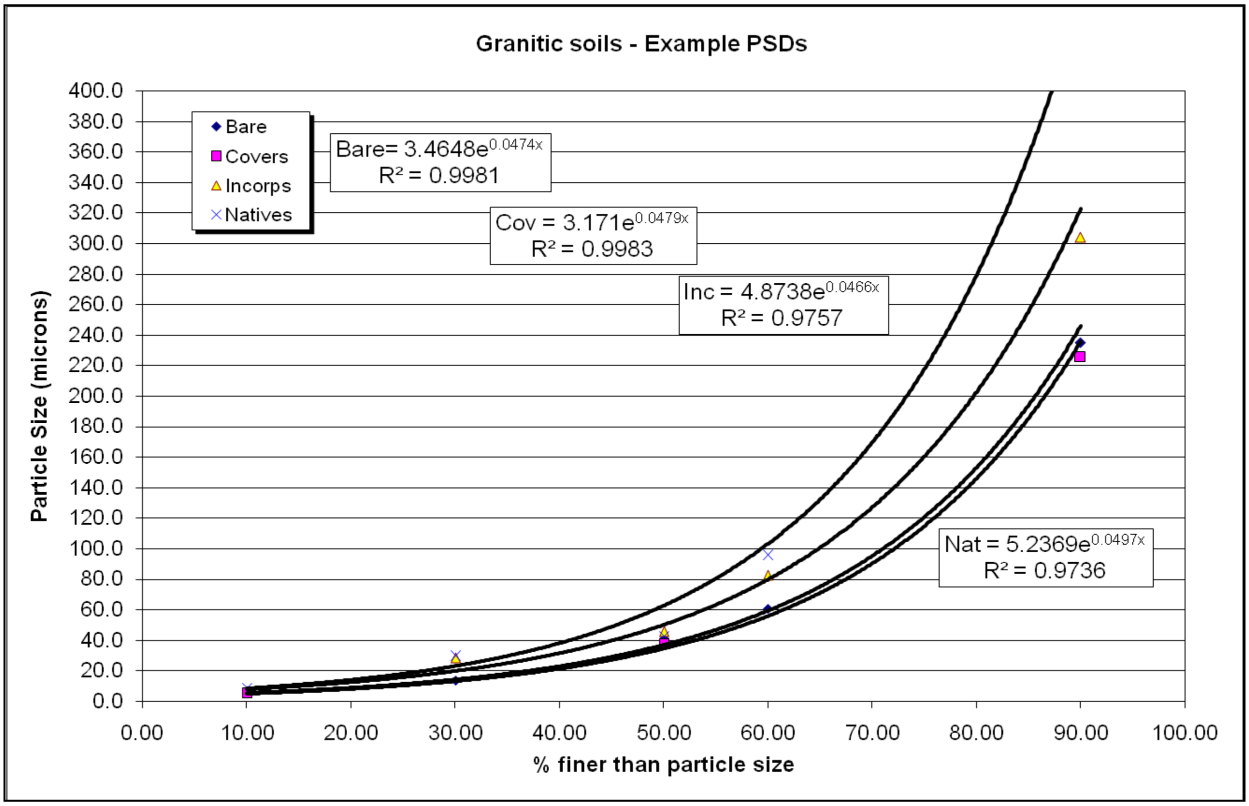
Runoff and erosion rate data developed from numerous rainfall simulations test plots across the Tahoe Basin during the past several years (e.g. Grismer & Hogan, 2004, 2005a & 2005b, Grismer et al., 2008a) were combined with more recently collected road cut specific data and used to develop the anticipated sediment loading rates for road cut areas. Erosion rate data was grouped first by soil type (volcanic and granitic), then by treatment type (i.e. bare or nearly bare soil; grass and/or mulch covers only; incorporation of amendments; and reference "native", relatively undisturbed plots that have intact mulch, litter and well-established vegetation). Sediment yield (mass of sediment per unit of runoff) values within each soil type/treatment grouping were plotted as functions of slope (see Figure 5) and obvious outlier values were removed. Non-linear regression exponential functions for each group were obtained and these functions formed the basis of the sediment loading values and functional classes in the spreadsheet tool. Final sediment yield values were adjusted in part to achieve consistency across all slope and treatment ranges, when the data behind the regression curves were limited.

Figure 5. Example runoff sediment yield (SY) dependence on granitic soil treatment and slope.



More recently collected rainfall simulation data also included runoff particle-size distributions (PSDs) for individual runoff samples that were averaged for each test plot area. Although PSD data for each of the soil/treatment groupings was initially considered to be slope-dependent (Grismer & Ellis, 2006; Grismer et al., 2008a), there was insufficient data to support such a general conclusion here. Rather, the PSDs were primarily only soil/treatment-dependent such that averages of all PSD values across the test plot data for a given soil/treatment were averaged and used to develop the <16µm and <20µm fine sediment particle (FSP) fractions of the sediment loads (see Figure 6).

Figure 6. Example FSP fraction dependence on PSD for runoff from different granitic soil treatment conditions.



Nutrient Concentrations

Nutrient concentrations of rainfall simulation plot runoff were not measured in this study as the initial studies from 2002 found that TKN, TP and TDP concentrations in the plot runoff could not be realistically distinguished from that of the rainfall water used in the simulations. Generally, TKN levels in the rain water used averaged 0.1-1 mg/L and those in the runoff samples about 1-2 mg/L. Similarly, though with no detectable increase, levels of TP in the rainwater and runoff samples averaged ~0.1 mg/L, while TDP concentrations were an order of magnitude less. Runoff nutrient concentrations could not be correlated to soil type or treatment at the time (Grismer & Hogan, 2004), and these measurements were abandoned in favor of later measurements of PSDs. Alternatively, we considered the nutrient loading concentration factors employed in the LSPC modeling for TMDL loading in the Basin, but found these too variable and inconsistent with other runoff-related nutrient loading measurements, such as those reported by Heyvaert et al. (2008). Runoff water datasets containing both PSDs and nutrient concentrations are needed to more accurately predict nutrient concentrations in runoff and relate this to treatment effects, but no such datasets yet exist in the Basin.

Development of Field Assessment Methodology

A field assessment methodology (RCAT User's Guide) was developed to directly measure the primary parameters thought to affect surface erosion rates in the field. Key parameters of interest are plot slope angle, surface cover, infiltration and runoff rates and of course, soil type. After fixed site variables such as soil type and slope angle, soil cover is the most sensitive parameter affecting erosion rates from disturbed soil areas (Grismer & Hogan, 2005b). Therefore, soil cover is a key measurement in the field assessment methodology. Another key variable affecting runoff, and therefore sediment yield rates, is soil infiltration capacity. Direct measurements of soil saturated hydraulic conductivity would provide a good measure of soil infiltration capacity, but previous studies using a constant-head Johnson, or "Amooza-meter" type permeameter devices (Grismer & Hogan, 2004) found that independent measurements of field soil hydraulic conductivity were inconsistent with the infiltration rates determined from the rainfall simulations and are not able to be correlated with soil type or treatment. There are a number of factors that affect surface soil hydraulic conductivity in the field including surface water repellency (Rice & Grismer, 2010) and depth to restricting layers, and these are difficult to assess quantitatively. Levels of soil compaction are an indirect measure of hydraulic conductivity and in practice easy to measure, which is why the field assessment methodology includes cone penetrometer (CP) depth-to-refusal (DTR) measurements. CP DTR measures of soil strength combined with measurements of soil moisture are used as a surrogate for the more difficult to measure hydraulic conductivity at the soil surface (Hatchett et al., 2006). This measurement method also provides some insight into depths of restricting layers. Unfortunately, due to variable soil moisture and compaction levels, the DTRs are not readily correlated with infiltration or erosion rates, but the project team has observed relative "threshold levels" of DTRs that are associated with higher runoff potential based on field experience.

Determining Runoff Fractions

Runoff fractions from individual storm events or on an annual basis are widely variable depending on a number of factors including type of precipitation, antecedent soil moisture and soil hydraulic properties and are not readily modeled or rapidly evaluated. Here, we rely in part on field-based professional judgment as well as the observations of Heyvaert et al. (2008) in their assessment of runoff from a range of urban/suburban slopes in the Brockway area on the north shore of Lake Tahoe for 2007-2008, which suggested that on an annual basis, and in some cases for individual storms, the maximum runoff rate was <15% of total precipitation. Setting this 15% runoff fraction as the maximum associated with very steep slopes of 90%, we used the square-root relationship between runoff velocity and slope or headloss to set the runoff fraction from progressively flatter road cut slopes. Thus, the runoff fractions of total precipitation range from 5 to 15% non-linearly for slopes from 10 to 90%.

Development of Functional Condition Classes

Five *functional condition classes* were determined after ranking all of the sediment yield values for all soils and treatments at 10% slope intervals to provide a relative index of the *functional condition* (or erosion resistance) of each assessment area based on field measurements. Functional condition classes range from 1-5, with 1 being the least desirable (highest sediment yield) and 5 being the most desirable (lowest sediment yield). Break points were chosen such that sediment yield means in each class are significantly different (>99% CL). That is, class means and ranges do not overlap. Table 2 summarizes the characteristics of each functional class. Functional condition classes use a scoring system similar to that used in the BMP and Road Rapid Assessment Methodologies (RAMs), providing a common framework for eventually integrating the Road Cut and Fill Slope Sediment Loading Assessment Tool into the Lake Clarity Crediting Program. Break points in the ranked values, known ranges in variability, as well as professional judgment were used to define the classes.

Table 2. Functional condition class characteristics, sediment yields and FSP fractions.

Functional Condition Classes and Abbreviated Example Descriptions	Statistic	SY (lb/ac/in)	FSP <20 μm (%)	FSP <16 μm (%)
Class 1 - includes Granitic soils with >80% slopes and litter depth<1" for all CPs and Volcanic soils with >50% slopes and litter depth<1" and CP<4", or granitics with >80% slopes and little/no litter or CP depth	**Mean**	3687.38	53.4	49.2
	Std Dev	2214	7.54	7.48
Class 2 - includes Granitic soils with >60% slopes and litter depth<1" for all CPs and Volcanic soils with 30-80% slopes with litter depth~1" and CP<3"	**Mean**	1101	47.8	43.6
	Std Dev	292	5.93	5.92
Class 3 - includes Granitic soils with >50% slopes and litter depth<1" for all CPs and Volcanic soils with 20-80% slopes and litter depth<3" and 3"<CP<6"	**Mean**	606	43.9	39.7
	Std Dev	75	8.67	8.56
Class 4 - includes Granitic soils with 30-80% slopes and all other ranges and Volcanic soils with 30-60% slopes, all litter depths and CP>4", or 10-30% slopes	**Mean**	318	39.5	35.2
	Std Dev	84	9.09	8.88
Class 5 - includes Granitic soils with 30-80% slopes and >2" litter depth, or 10-20% slopes and 0.5-2" litter depth, and Volcanic soils with 30-80% slopes and >2" litter depths and CP>6" or 10-30% slopes with <2" litter depths	**Mean**	102	34.3	29.9
	Std Dev	52	7.86	7.68

Table 3 summarizes example calculations of sediment and FSP loading that may occur following a 20-yr 1-hr storm (1" depth) from a one-acre road cut with a 40% slope (assuming 10% runoff fraction) for each functional condition class to illustrate the range and variability that might be expected in the Tahoe Basin.

Table 3. Example calculations of sediment and FSP loads for each functional class from a one inch storm event on a one acre road cut with an average 40% slope.

Class	Sed Load (lb)	FSP<20 μm (lb)	FSP<16 μm (lb)	TN* (mg/L)	TP* (mg/L)
1	922	492.0	453.3	144.7	42.5
2	275	131.6	120.0	61.9	11.4
3	152	66.6	60.1	40.7	5.7
4	79	31.3	27.9	25.9	2.7
5	25	8.7	7.6	11.6	0.8

*Nutrient loads based on factors developed by Heyvaert et al. (2008).

Stakeholder Input and Peer Review

Stakeholder input was critical to the development and refinement of RCAT. Below is a brief overview of stakeholder outreach and peer review efforts associated with this project and development of the deliverables.

- The primary rainfall simulation-derived data set and functional condition classes were originally developed during Phase 2 of Lake Tahoe TMDL for the Forested Uplands element of the Pollutant Reduction Opportunities Report, which was subject to extensive peer review by the Lake Tahoe research community.
- The sediment yield and FSP data and methods used in this project have been rigorously scrutinized and published in numerous peer-reviewed journals from 2002 to present. See example references in Literature Cited section. The project team intends to submit a journal article for publication based on this project once the project is finalized and an appropriate applied science journal is identified.
- Hydraulic parameters and assumptions (i.e. infiltration and runoff fractions) were discussed and determined in close cooperation with Brent Wolfe (nhc).
- Functional condition classes and opportunities for integration of RCAT with other RAMs and the Lake Clarity Crediting Program were discussed with Chad Praul (Environmental Incentives) and Nicole Beck (2ND Nature).
- The field assessment methodology (RCAT user's guide) and RCAT spreadsheet tool was field-tested with Brendan Ferry (El Dorado County) and Nova Lance-Seghi (Placer County). Their input was invaluable to developing a clear and understandable field methodology. Additionally, Kris Klein from Washoe County provided specific feedback on the draft User's Guide. Specific input is summarized in Appendix B.
- Kevin Drake (with assistance from Brent Wolfe, nhc) presented a draft version of RCAT at LTIMP in July to a small but diverse group of interested stakeholders.

Tool Uses and Limitations

Stand-Alone Tool – RCAT is designed to estimate sediment and FSP yield from small-scale (<1 acre), relatively uniform road cut and fill slope areas. It does not account for downstream pollutant removal via stormwater treatment BMPs or particle settling/sediment storage due to landscape configuration. Project implementers can perform downstream pollutant removal calculations independently of RCAT if desired.

Integration with PLRM – RCAT is intended to eventually be integrated as a unique module within the Pollutant Load Reduction Model (PLRM). At this time, there are two options for using RCAT in conjunction with PLRM:

1. **Account for road cut and fill slope loading externally from PLRM.** The total area of road cut and fill slopes can be subtracted from the urban area of interest modeled in the PLRM and the output (sediment and fine sediment load) from RCAT can simply be added to pollutant loads generated from PLRM. However, this method

assumes that road cut and fill slope areas are not directly hydrologically connected to a treatment BMP and there will be no downstream treatment of sediment loads generated from road cut and fill slope areas. This is similar to the approach currently recommended for gully erosion in the PLRM Applications Guide.

2. **Match loading outputs from RCAT with PLRM output for the same area.** (Note: this work-around is only appropriate for experienced users of PLRM).
    a. Estimate pollutant loading from the cut and fill slopes using RCAT.
    b. Define the cut and fill slopes as a separate catchment in PLRM and connect the catchment in PLRM to another catchment using a junction. Make a first guess at the land use class for the cut and fill slope (i.e. a land use class of Erosion Potential 1 through 5).
    c. Adjust the saturated hydraulic conductivity for the "Other Land Uses" category in the PLRM Drainage Conditions Editor until the average annual runoff volume predicted for the catchment by PLRM is close to the volume predicted from RCAT.
    d. Adjust the Erosion Potential land use class (EP 1-5) in the PLRM for the cut and fill slope until the average annual fine sediment load for the catchment is close to the load predicted by RCAT.

Scale Considerations – Rainfall simulation (RS) tests are conducted at the 1m^2 scale and the measured erodibilities (sediment yields) from these tests most likely reflect "inter-rill" erodibilities from surface sheet flow. Typically, plot-measured erosion rates are expected to over-estimate actual erosion rates due to several factors associated with soil and topographic variability across the larger landscape. Scaling RS test results up to the local watershed scale for three west-shore watershed suggests that the RS-derived erosion rates over-estimated in-stream loading by a factor of roughly 5 (Grismer 2010a, 2010b). On the other hand, inter-rill erosion rates are far smaller than rill-derived erosion rates. Rilling (and gullying in extreme cases) is more common across disturbed soils such as road cuts, suggesting that RS-derived erosion rates on road cuts will under-estimate actual erosion rates, especially when substantial rilling occurs. Overall, then, the RS-derived rates are expected to provide a reasonable estimate of the sediment loads that might be expected in the field.

Beyond Road Cut and Fill Slopes – Although RCAT has been specifically developed for use on cut and fill slope areas, this tool and assessment methodology may be highly useful for estimating sediment and FSP loads from other disturbed soil areas such as residential homes, forest road segments and ski runs.

Recommendations

- Integration with PLRM – add road cut module to PLRM's Land Use Editor to allow for seamless and efficient integration of loading from cut and fill slopes into catchment-scale loading estimates in urban areas.
- Development of runoff water data sets containing both particle size distributions and nutrient concentrations in order to assess statistical relationships between variables and determine if reasonably accurate estimates of nutrient concentrations can be generated.
- Specific guidance on soil and vegetation treatment and maintenance actions linked directly to functional condition class scores and reducing pollutant loads from road cut and fill slope areas.
- Additional research to improve estimates of runoff volumes (fractions) from cut and fill slopes under a range of soil moisture conditions.
- Additional field testing and refinement of sediment and FSP loading predictions from RCAT.
- Create spatially-explicit road cut and fill slope inventory and land use layer (GIS shapefile) using LiDAR analysis or ground-based surveys in order to prioritize and target field assessment efforts in areas likely to generate the largest sediment loads.
- Determine appropriate monitoring frequency/duration and associated credit award schedule for road cut and fill slopes to support integration of RCAT with Lake Clarity Crediting Program.
- Investigate potential to expand RCAT into a Source Control RAM for estimating sediment and FSP loads from other disturbed soil areas such as residential home sites, unpaved road segments and ski runs.

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Appendix A: Erosion Model Comparison: El Dorado County Case Study

Comparison of Sediment Loading Predictions from the Revised Universal Soil Loss Equation (RUSLE) and the Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT): El Dorado County Case Study

Prepared by

Dr. Mark Grismer – UC Davis
Kevin Drake – Integrated Environmental Restoration Services

The Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT), which is designed for estimating sediment loads from disturbed cut and fill slopes, requires locally-derived information about the depth of rain (runoff), soil type, average slope, surface cover, and cone penetrometer (CP) depth-to-refusal (DTR), and the size of the area of interest. Note that CP DTR is a surrogate measurement for hydraulic conductivity or infiltration rate as well as infiltration capacity and depth to restricting layer. For comparison purposes, we consider the Revised Universal Soil Loss Equation (RUSLE) estimation of annual sediment loads from small cut slopes off Rubicon Drive on the west shore of Lake Tahoe as developed by El Dorado County Transportation Department[1]. Soils were of granitic origin, the cut slopes were all 2:1 or 50%, there was presumably little to no surface cover (no cover factor was used), and variable slope lengths, resulting in a range of estimated annual loads as summarized in Table 1 below. While the average sediment loss estimated by RUSLE was 0.13 tons/ac/yr, the range was approximately an order of magnitude or 0.03 to 0.34 tons/ac/yr. RUSLE or USLE determinations of sediment loads, or soil losses, rely on soil survey information about erodibility and rainfall factors as well as slope angle and slope length – factors that are combined relative to the original tests conducted on a 22m long test plot on a 9% slope at Purdue University, which USLE is based on. The erodibility factor in USLE is largely a function of soil texture and includes to some degree effects of organic matter content and soil permeability. The rainfall factor is regionally derived from values representing the product of rainfall energy (erosive power) and 30-min maximum intensity estimated for the area of interest. USLE-calculated sediment loads represent an estimated average annual value where the rainfall factor is largely interpreted in terms of relative risk.

RCAT sediment yield estimates for the same slope conditions (granitic parent material, 50% slopes, little to no surface cover) range from 196 – 610 lbs/ac/in runoff across a range of CP DTRs of 8 – 1 inches, respectively. RCAT requires knowledge of storm depths, that is,

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[1] El Dorado County. 2008. Rubicon Phase 5 Water Quality and Erosion Control Project: Feasibility Report, Project No. 95178. June 2008.

an event-driven evaluation, and assumes that some soil moisture is already present such that runoff will occur. In this case, El Dorado County estimated annual precipitation of ~32 in/yr for the Rubicon Drive area. Using a 10% runoff fraction (which corresponds to 50% slopes in RCAT) for individual storm events, but applied here on an annual basis, results in estimated sediment yields (losses) of 0.31 – 0.98 tons/ac/yr, or an average of 0.65 tons/ac/yr, or approximately 5 times greater than that estimated from RUSLE. This latter comparison is largely affected by CP DTRs and estimated runoff fractions from precipitation as compared to the annualized USLE-type predictions. In USLE, the rainfall index is determined from regional information and is not otherwise verifiable with local data in the Tahoe Basin. In the RCAT case, if the CP DTR is large, estimated sediment loads decrease towards the lower end of the range, or sediment load values near the high end of the RUSLE-derived range of loads.

Table 4. Developed from Table 22 (p. 59 of Report*) – RUSLE Sediment Load Calculations

Location	Slope (%)	Slope-LF	LS	Length-LF	Factor ($x10^3$)	USLE Soil loss (ton/ac/yr)
CS-17 Rubicon Dr.	50	15	4.08	20	0.275	0.34
CS-18 Rubicon Dr.	50	5	2.36	10	0.275	0.03
CS-19 Rubicon Dr.	50	8	2.98	30	0.275	0.20
CS-20 Rubicon Dr.	50	6	2.58	20	0.275	0.09
CS-22 8984 Rubicon Dr	50	15	4.08	15	0.275	0.25
CS-25 Rubicon Dr.	50	6	2.58	20	0.275	0.09
CS-31 Rubicon Dr.	50	5	2.36	15	0.275	0.05
CS-46 8808 Rubicon Drway	50	25	2.33	8	0.275	0.13
CS-47 Rubicon Dr	50	5	2.36	20	0.275	0.06
CS-49 Rubicon Dr.	50	6	2.58	6	0.275	0.13
CS-50 Rubicon Dr.	50	5	2.58	30	0.275	0.10
CS-52 Rubicon Dr.	50	5	0.78	25	0.275	0.03
Averages	**50**	**8.83**	**2.64**	**18.25**	**0.275**	**0.13**

*El Dorado County. 2008. Rubicon Phase 5 Water Quality and Erosion Control Project. Feasibility Report, Project No. 95178. June.

Key Differences between RCAT and RUSLE

- **Reproducibility** – RCAT estimates are reproducible on any time scale because they are process-driven and event-based, enabling users to directly compare pre- and post-treatment conditions at a site, which cannot be done readily with RUSLE.
- **Locally calibrated** – RCAT sediment yield estimates are already "calibrated" to Lake Tahoe soils with locally-measured rainfall simulation data, then further refined based on site-specific measurements of cover and soil compaction. In contrast, RUSLE

relies on generalized regional parameters from the soil survey and empirical erosion relationships developed in other areas of the country.

- **Directly measured cover and soil hydrologic parameters** – RCAT uses site-specific measurements of cover and soil compaction to refine rainfall simulation-derived erosion estimates. In contrast, these parameters are largely collapsed in the erodibility factor in RUSLE, and to a lesser extent, the rainfall factor.
- **Time scale –** RUSLE annual estimates of annual sediment loss rely on regional annual rainfall averages whereas RCAT annual estimates of annual sediment loss are driven by locally-measured, event-based sediment concentrations and slope-dependent runoff-infiltration fractions.
- **Slope length** – slope length is not directly accounted for in RCAT whereas RUSLE includes a slope length factor. The RS-derived erodibilities used in RCAT are based on a 1m length of run. However, since many cut and fill slopes in Tahoe have relatively small run lengths (as exemplified in Table 4), RCAT is expected to be accurate for smaller slopes. Certainty in sediment yield estimates is likely to decrease for longer slope lengths, where RCAT is expected to over-predict sediment yield since little local data exists on the effect of longer run lengths.

Appendix B: Summary of Agency Input

Eldorado County Input

- Be more specific about linkages with PLRM
- Explain that this tool does not address downstream pollutant removal or routing
- Describe different ways of using assessment method on larger projects – all areas vs. targeted assessment
- Can areas that are not adjacent, but in the same general area and share the same characteristics, be grouped together for an assessment?
- Add sampling methods for areas less than 10m x 10m
- Add toe slope condition to the list of physical characteristics that define an area
- Add more guidance on taking photo points
- Add a method to measure soil moisture without a moisture meter
- Add that distances can be approximated by pacing rather than measured with a tape
- Remove the step for marking corners of the area
- More clearly specify the number of quadrats necessary per area
- Add that penetrometer DTRs should be sampled from the top to the bottom of the quadrat to avoid disturbance
- Mention that stepping in the quadrat will cause disturbance
- For sampling in the quadrat, instruct the user to use 9 locations marked on the quadrat rather than random locations
- Add that spikes or other stakes can be used to hold the quadrat in place on steep slopes
- Suggest a numbering system for areas and sub-areas

Placer County Input

- Add example photos showing the 0-25%, 26-50%, 51-75%, and 76-100% cover ranges
- Add guidance on timing of monitoring, which would include soil moisture and plant maturity criteria
- For penetrometer sampling, add a rule for hitting rocks
- Define slope aspect
- Define forbs
- Add the option of sampling with a ladder for safety and avoiding disturbance

Washoe County Input

- Clarify that slope “length” is from the hinge (top) to the toe (bottom) of the slope.
- How to apply RCAT on slopes with toe walls/retaining walls?
- How can RCAT be used to account for load reductions within the Lake Clarity Crediting Program.
- There is a definite need to address cut and fill slope erosion potential and FSP loads in PLRM.
- In the second method suggested for using RCAT in conjunction with PLRM (“Match loading outputs from RCAT with PLRM output for the same area”), would this be done for both baseline and post-project PLRM runs?
- “In addition to the comments in the document, Washoe County thinks it is extremely important that there be a consistent way to track FSP loading from untreated and treated cut and fill slopes. Much of our past effort has been treating eroding slopes in our right-of-way, and this still seems to be an important component to keep sediment out of the lake. If there is no straightforward and consistent method to earn credits for treating cut and fill slopes, it is likely that eroding slopes will no longer be treated.”