SPECIFIC DEGRADATION OF WATERSHEDS

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ABSTRACT

An extensive database of reservoir sedimentation surveys throughout continental United States is compiled and analyzed to determine specific degradation SD relationships as function of mean annual rainfall R, drainage area A, and watershed slope S. The database contains 1463 field measurements and specific degradation relationships are defined as function of A, R and S. Weak trends and significant variability in the data are noticeable. Specific degradation measurements are log normally distributed with respect to R, A, and S and 95% confidence intervals are determined accordingly. The accuracy of the predictions does not significantly increase as more independent variables are added to the regression analyses.

Key Words: Specific degradation, Sediment yield, Reservoir sedimentation

1 INTRODUCTION

Soil erosion and sediment transport by overland flow involve very complex processes influenced by factors such as climate, watershed drainage area, soil type, topography, vegetation and human activities. The annual gross erosion is the total erosion of detached and entrained material in a given watershed.

Sediment yield Y is the total sediment outflow from a drainage basin, or watershed, over a specified period of time. It is generally measured in tons per year. For a given watershed, the specific degradation SD is obtained by dividing the sediment yield Y by the drainage area A of the watershed. Thus:

$$SD = \frac{Y}{A} \tag{1}$$

where: SD = specific degradation in metric tons/km^2 • year, A = drainage area in km^2.

Several researchers have tried to correlate specific degradation with climatic parameters such as: mean annual rainfall precipitation R, drainage area A, etc. Rainfall and drainage area are the most widely independent variables used in specific degradation relationships. For rainfall as independent variable, the models of Fournier (1960), Langbein and Schumm (1958), and Wilson (1973) are well known. Simple models using drainage area as independent variable were summarized by Roehl (1962), Boyce (1975), Strand (1975), Jansson (1982), Lahlou (1982, 1996), Julien and Frenette (1985, 1987), Julien (1995, 2002) and others. All these simple models were tested with limited field data and displayed some regional trends due to similarity in climatic, topographic or geologic conditions. In the past decades, efforts were found on the development of more advanced models like USLE (Wischmeier and Smith, 1978), RUSLE (Renard et al., 1991 and 1992), WEPP (USDA, 1995) and CASC2D-SED (Johnson et al., 2000).

The primary purpose of this study is to examine a rather extensive data set of sediment yield measurements on many reservoirs in the US. The data set is examined with respect to the variability in specific degradation with drainage area, rainfall precipitation and watershed slope. These parameters have been believed for a long time to predict most of the variability in sediment production on watersheds. An extensive database allows for a clearer definition of the variability around mean values, and also allows for results that are not specific to regional topography or specific climatic or geological conditions.

In this study, an extensive database covering different climates throughout continental United States is analyzed to define regression equations relating specific degradation SD as function of three parameters: mean annual rainfall R; drainage area A; and mean watershed slope S.

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2 DATABASE

Kane (2003) compiled a large database from publications made available by the Agricultural Research Service (ARS) from 1964 through 1978 and from a 1992 publication of the Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation). The database contains 1463 data points relating *SD* with *A* in various U.S. reservoirs. The specific degradation values were obtained from field measurements of mean annual sediment yield of watersheds of given drainage area using Eq. (1). Kane (2003) completed the database by adding *R*-values from different sources such as the National Climatic Data Center and some websites containing rainfall information for different sites.

Additionally, a database with 551 data points including slope values was obtained using USGS HYDRO1k and NOAA (1992). HYDRO1k is a geographic database developed at the U.S. Geological Survey's (USGS) EROS Data Center. Topographically derived data sets are based on USGS 30 arc-second digital elevation model (DEM) of the world (GTOPO30), which provides a standard suite of geo-referenced data sets (at a resolution of 1 km). Slope values are watershed average values obtained from the DEM at the given site. The land cover data set is an Arc/INFO grid map of land cover characteristics for North America. The nominal spatial resolution is 1 km and the data set is based on 1-km AVHRR data.

The period of record for individual basins ranges from 0.3 to 107 years with a median of 7.8 years. Drainage areas range from 0.017 km^2 to 89,852 km^2 with a median of 6.1 km^2. All different climatic regions in continental United States are represented in the database. Mean annual rainfall values vary from a minimum of 167 mm to a maximum of 2243 mm with a median of 808 mm. The slopes of the basins range from 0.05% to 11.52% with a median of 2.62%. The entire database is available in Kane (2003).

3 SPECIFIC DEGRADATION ANALYSIS

3.1 Function of Mean Annual Rainfall *R*

Due to the great variability in the data, an analysis of the mean SD values was performed. The data were divided into 29 classes of rainfall each containing 50 data points. The mean value for each class was computed and then plotted against mean annual rainfall *R*. Since more consistent results are obtained with observations made over a long period of time, more weight was given to long-term observations. The mean value was thus computed by taking a weighted average in which each specific degradation value is multiplied by its number of years of observations, i.e.:

$$\overline{SD} = \frac{\sum_{i=1}^{N} Yr_i SD_i}{\sum_{i=1}^{N} Yr_i} \tag{2}$$

where $\overline{SD}$ is the weighted average specific degradation, Yr_i is the number of years during which the measurements have been for i^{th} *SD*, and *N* is the total number of observations in any class.

Figure 1 shows the graph of specific degradation *SD* vs. mean annual rainfall precipitation *R* in mm. The obtained regression equation that fits the mean value is as follows:

$$SD = 0.02R^{1.7}e^{-0.0017R} \tag{3}$$

The coefficient of determination based on the mean values for each class is $R^2 = 0.53$; comparatively $R^2 = 0.06$ when applied to all data. The trends suggested by Fournier (1960), Langbein and Schumm (1958) and Wilson (1973) are not supported by this large database.

The 95% confidence interval is shown on Fig. 1 and the corresponding equations are listed in Table 1. The distribution of the *SD* data in each class was analyzed with respect to *R*. The analysis shows a log normal distribution of the data (Kane, 2003). An example is shown in Fig. 2.

3.2 Function of Drainage Area *A*

Plotting the raw specific degradation *SD* data with respect to drainage area *A* in km^2 yields the chart shown in Fig. 3. The entire database was subdivided into 29 classes and the weighted average procedure of Eq. (2) was used to fit a regression equation through the mean value. A slightly decreasing trend with drainage area *A* in km^2 is noticeable and the mean value is:

$$\overline{SD} = 410A^{-0.09} \tag{4}$$

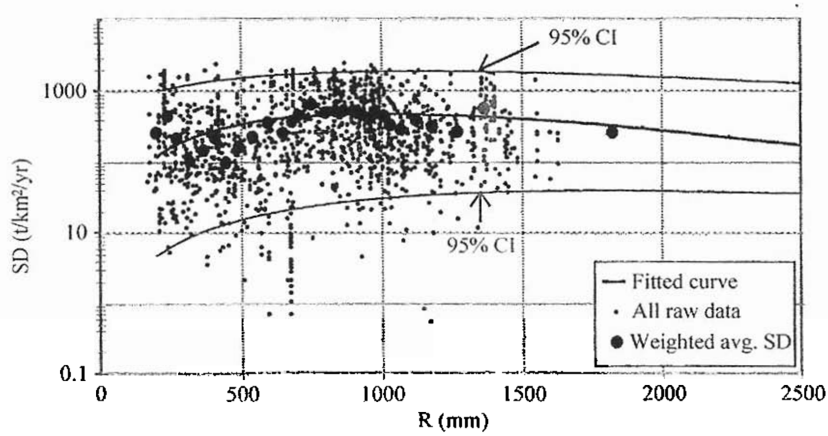

Fig. 1 SD as function of R and 95% confidence interval

Table 1 List of equations for 95% confidence intervals

Parameter used	Lower limit	Upper limit
R	$\log SD_5 = 0.22R^{0.4}e^{-0.00037R} - 2.67R^{-0.1584}$	$\log SD_{95} = 0.22R^{0.4}e^{-0.00037R} + 2.67R^{-0.1584}$
A	$SD_5 = 19A^{-0.05}$	$SD_{95} = 2573A^{-0.12}$
S	$SD_5 = 43e^{-0.35S}$	$SD_{95} = 2219e^{-0.16S}$

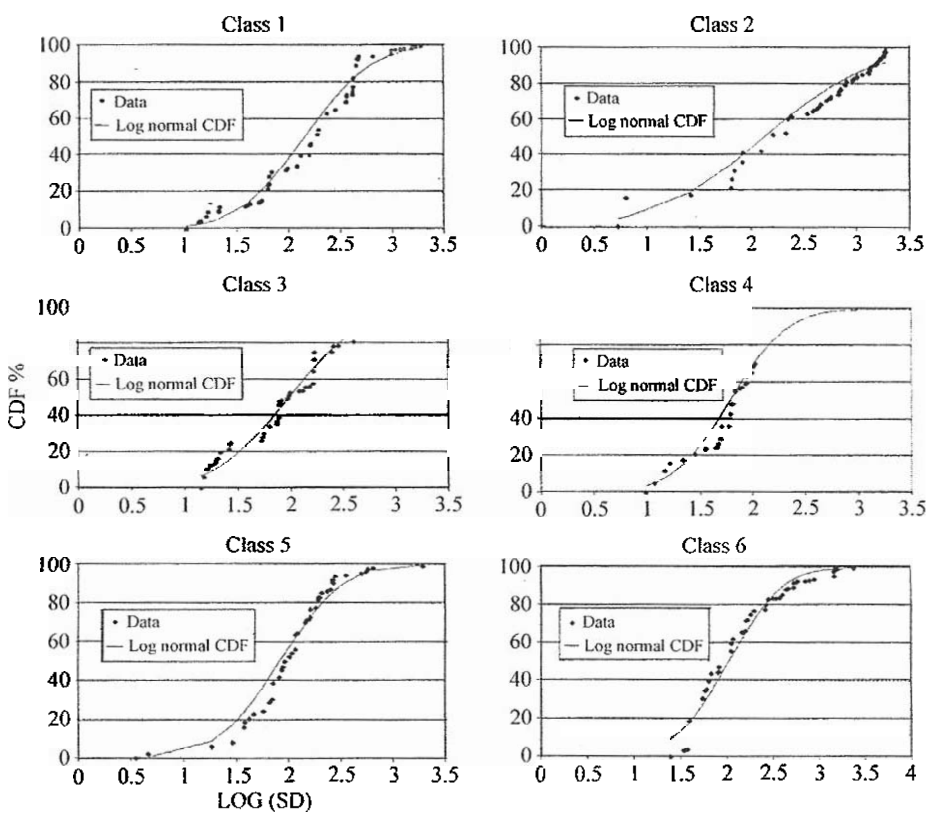

Fig. 2 Log normal distribution of SD with respect to R (class 1 through 6)

When applied to all the raw data, this equation yields a coefficient of determination of $R^2 = 0.06$, compared with $R^2 = 0.66$ for the mean values. The slightly decreasing trend in specific degradation SD values with drainage area A corroborates earlier investigations. As with R, observed SD values follow a log-normal distribution with respect to A (Kane, 2003). The confidence intervals are calculated with the equations listed in Table 1 and shown on Fig. 3.

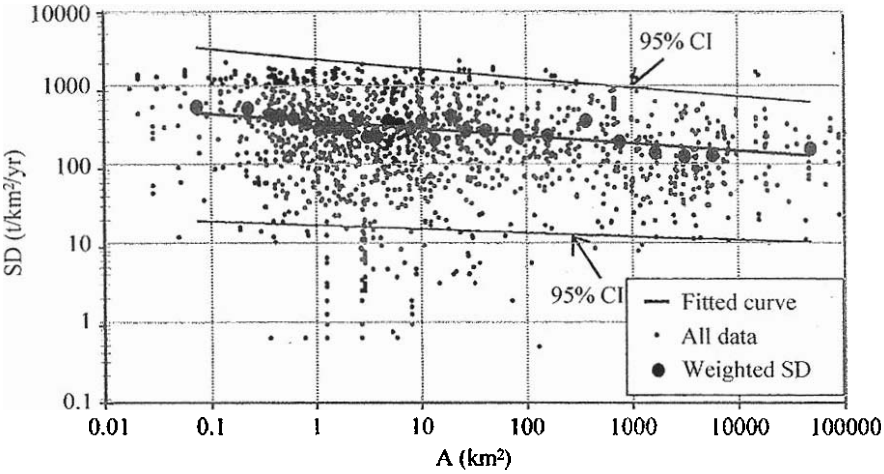

Fig. 3 SD as function of A at 95% confidence interval

3.3 Function of Slope S

A similar analysis of the specific degradation SD versus slope S in percentage is shown in Fig. 4. The obtained regression equation that fits the mean value is given by the following:

$$\overline{SD} = 402e^{-0.13S} \quad (5)$$

with $R^2 = 0.53$, when applied to mean values and $R^2 = 0.12$ for the entire dataset. Again, the SD data is log-normally distributed (Kane, 2003). The confidence intervals are calculated with the equations listed in Table 1 and shown on Fig. 4.

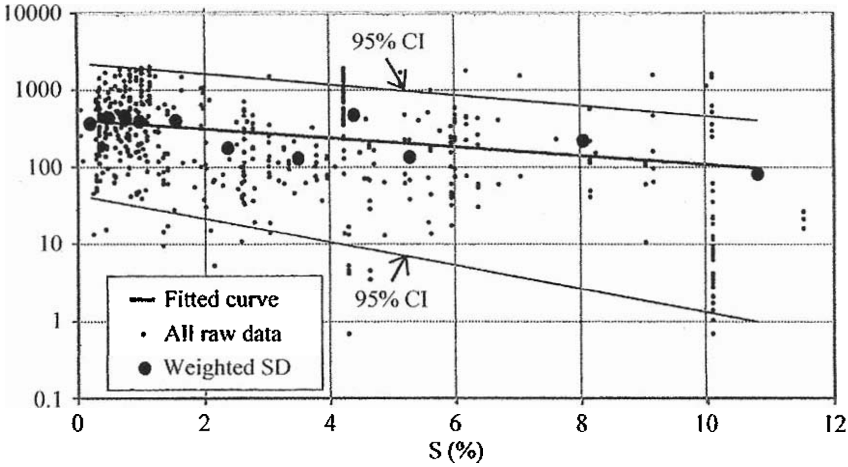

Fig. 4 SD as function of S and 95% confidence interval

The decrease in specific degradation with increasing slope is rather counter-intuitive. Perhaps the best explanation for this is that the steep watersheds are forested and mostly located in the Rocky Mountains while the flat watersheds are developed for agriculture.

Finally, multiple regression analysis with *R*, *A* and *S* were attempted but without much success. The coefficients of determination did not significantly increase by adding several variables to the regression analysis. Details are not reported here, but can be found in Kane (2003).

4 SUMMARY AND CONCLUSIONS

A large dataset of 1463 specific degradation *SD* measurements in the continental United States, has been analyzed. The database covers a wide range of mean annual rainfall precipitation *R* and drainage area *A*. Most of the specific degradation values typically range between 100-1,000 ton/km^2 year. Weak relationships with *R* and *A* are obtained using regression analysis. The findings support previous investigations showing a gradual decrease in specific degradation with drainage area. However, the results do not support the earlier findings on large variability in *SD* with rainfall precipitation. The decreasing trend in *SD* with watershed slope reflects on agriculture effects on flat watersheds and vegetation on steeper rocky watersheds. The variability in the data prohibits accurate prediction of specific degradation from *R*, *A* or *S*. Multiple regression analysis did not significantly improve the results.

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NOTATION

A drainage area (in km^2);
R mean annual rainfall (in mm);
R^2 coefficient of determination;
S average slope of a watershed (in percentage);
SD specific degradation (in t/km^2-year);
$\overline{SD}$ average specific degradation;
SD_{calc} predicted/calculated specific degradation;
$SD_{obs.}$ observed measured specific degradation;
Y sediment yield;
Yr number of year of experimental observation