Fifth International
Symposium on Ecohydraulics
September 12-17, 2004, Madrid, Spain

Aquatic Habitats: Analysis & Restoration

IAHR AIRH
International Association of
draulic Engineering and Research

Universidad Politécnica de Madrid

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AN ASSESSMENT OF THE INTERACTION BETWEEN STORM EVENTS AND SEDIMENT TRANSPORT

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ABSTRACT
The main objective of this paper is to identify the relation between intense storm events and corresponding sediment transport. Intense storm events are related to the watershed erosion mainly through the rainfall erosivity factor (R) of the Universal Soil Loss Equation (USLE). The Venetikos River catchment, which is situated in the Western Macedonia, Greece, has been selected for this analysis. It was found that there is a very weak correlation between the annual values of the R-factor and the mean sediment transport derived from the sediment rating curves. Sediment delivery ratio of the catchment was found equal to 0.11, i.e. 11% of the eroded sediment has been transported to the catchment outlet. This value is substantially less than the most common values found in the international literature.

1 INTRODUCTION
1.1 Soil erosion and sediment yield modeling
Research on soil erosion and sediment yield modeling is today focused on developing robust tools for calculating sediment yield from intense storm events. This necessity is strongly dictated in the Mediterranean catchments, where the severity of intense storm events significantly enhances the wash-load effects.

However, in most engineering applications the issue of soil erosion and sediment transport is restricted to estimate long-term average values for design and management purposes, e.g. simulating future siltation in reservoirs or total amount of material transport to river mouths for pollution control (Walling 1983; Zarris et al. 2002). The long-term average values are most often needed for river systems with a catchment area of the order of hundreds to thousand square kilometers. On this scale, detailed data on hydrology, meteorology, geology and land use are generally scarce even in technologically developed countries. In this case, the use of comprehensive computer models, based on a distributed approach on sediment yield modeling, is ineffective and the use of traditional and lumped approaches, such as the Universal Soil Loss Equation and/or the sediment rating curve is preferred.

1.2 The Universal Soil Loss Equation (USLE)

The USLE (Wischmeier and Smith 1965, 1978) is a simple empirical model, based on regression analyses of soil loss rates on erosion plots in the US. The model is designed to estimate long-term annual erosion rates on agricultural fields. Although the equation has many shortcomings and limitations, it is still widely used because not only of its relative simplicity and robustness but also because it represents a standardized approach.

Soil erosion is estimated using the following empirical equation:

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

where A is the mean annual soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope factor, S is the slope length factor, C is the cover management factor and P is the conservation practice factor.

The numerical values of the different factors of the equation have been computed after processing data collected in small catchments in the United States. This obviously suggests a weakness of the method in case of applying it elsewhere from the US with different climatic and topographic conditions. Additionally, USLE does not account for sediment transport in hillslopes and streams and does not perform well in large scale catchments. However, in terms of computing only the catchment soil erosion, USLE is a quite satisfactory preliminary approximation.

1.3 The Rainfall Erosivity Factor

This paper is mainly dealing with intense storm events; therefore special attention is draw to the R factor. Summing the products of total storm energy E and the maximum 30-minute intensity I_{30} for each rainstorm we obtain the R factor for any given period. In mathematical terms, the rainfall erosivity factor for a single storm event R_r [J mm / m^2 / h] is computed as (Morgan 1995)

$$R_r = \frac{\sum_{i=1}^{n} (E_i D_i)}{1000} I_{30} \qquad (2)$$

where E_i [J / m^2] = the kinetic energy of rainfall during the ith portion of a storm; D_i [mm] = the rainfall depth during time interval i; and i = the rainfall hyetograph time interval. To get the annual R-value, individual R_r values are summed (USLE only uses storms with more than 12.7mm of rainfall in a 6-hour period, unless more than 6.35mm of rain fell in 15min). Generally, the values of the units are incredibly complicated because of the extensive variety of different units found in the international literature.

Unfortunately rain-recording gauges are rarely available in most countries or it is rather difficult to access and manipulate the required data. Moreover, the workload involved would be immensely high for any national rainfall erosivity assessment. Therefore, many researchers have developed equations that relate the *R* factor with more easily acquired and manageable parameters, such as the mean annual rainfall depth *P*.

For instance, van der Kniff et al. (2000) stated that in Tuscany, Italy, the *R*-factor is related to mean annual rainfall *P* (m), so that *R* can be approximated by the equation:

$$R = aP \tag{3}$$

where *R* is expressed in units of MJ mm / ha / h and coefficient *a* ranges from 1.1 to 1.5. They also stated that this equation is based on rainfall data from 25 locations, with *P* ranging from 600 to 1200 mm. Furthermore, extrapolating the formula to cover the whole of Italy is not wholly appropriate, because the characteristics of rainfall in Tuscany are not representative for other parts of Italy.

Much earlier, Schwertmann et al. (1990) utilizing rainfall data from Germany concluded that the *R*-factor could be also expressed in the form of the following equation:

$$R = 0.83P - 17.7 \tag{4}$$

where *R* is also expressed in units of MJ mm / ha / h.

1.4 Sediment discharge rating curves

A sediment discharge rating curve describes the relation between river and suspended sediment discharge for a certain cross-section of a river. The most commonly used sediment discharge rating curve is a power function (e.g. Mimikou 1982; Asselman 2000):

$$Q_s = aQ^b e \tag{5}$$

where Q_s = the sediment discharge (usually in kg / s); Q = the river discharge (m^3 / s); *a* and *b* = the rating coefficients; and *e* = the lognormally distributed error term.

2 RESEARCH FRAMEWORK

2.1 Scope of the research work

The main aims of this research work are (a) to compare the value of the *R*-factor resulted from the comprehensive computations (see Equation 2) to the values resulted from other areas (see Equations 3 & 4) with, more or less different hydro-meteorological regimes, and (b) to comment on the compatibility of the soil erosion values resulted from a application of the USLE to a specific catchment with the sediment discharge measurements at the outlet of this catchment.

The second aim is to investigate the influence of the intense storm events, which are included in the R-factor computation, to the sediment discharge that is measured in the river outlet. It is important to note, that the simultaneous measurements of river and sediment discharge are being performed near low or medium flows and certainly not during floods. However, it certainly is of great importance when actually rivers are transporting the majority of their catchment's sediment load. In most cases, particularly in Mediterranean type catchments, most of the annual sediment load is transported in a few days around peak flow conditions. Particularly, the Var River in France, a small river with a typical Mediterranean behavior can deliver in one-day long flood an amount of sediment equivalent to its annual load (Mulder et al., 1998). Similarly, North American rivers transport 50% of their load in 1% of the time and between 80% and 90% of their load in 10% of the time (Meade et al., 1990).

2.2 Area of research

The Venetikos River catchment, which is situated on the Western Macedonia, in Greece, has been selected for analysis of the USLE equation. The catchment of Venetikos River is mountainous with mean elevation of 998 m, an area of 847 km^2, intense topographical variations, and an almost circular shape (Maggina 2002).

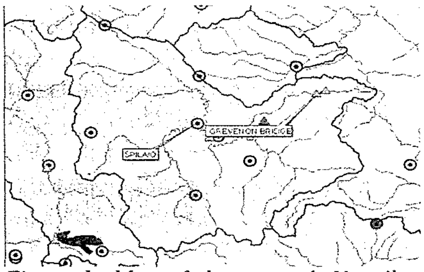

Figure 1: Map of the research Venetikos catchment in the Western Macedonia

The catchment has a dense hydrographic network including four main streams that start from the southern part of the Pindus mountain range. The main and longest stream of the Venetikos River is 54 km with an average slope of 1.5%. The mean annual discharge of the River is 18.3 m^3/s, and the mean annual rainfall calculated from 10-year period (1973/74-1983/84) is 876 mm. The meteorological data have been collected from the Spilaio recording station lying at 900m elevation with latitude 40°00´ N and longitude 21°17´ E. The discharge and sediment discharge measurements have been performed at outlet of the Venetikos River catchment, namely Grevenon Bridge, at altitude of 468 m. Figure 1 presents a brief geographical setting of the research area as well as the Spilaio rain recording gauge station and the Grevenon Bridge discharge measurement station.

2.3 Rainfall erosivity factor

To assess the interaction of storm events to rainfall erosivity, runoff, and sediment transport a series of fractional rainfall (threshold) above which the intensity is highest is usually considered, ranging from 1% to 50% of total rainfall or a physically-based threshold can be distinguished (Yu 1995). In this work the threshold of 12 mm in total rainfall (Wischmeier and Smith 1978) is considered.

The rainfall charts selected from the Spilaio recording rain gauge were analyzed for the period between the hydrological years 1973-74 and 1983-84. For this period, 170 storm events were found to have the appropriate rainfall depth so as to be included in the analyses and for each one the R_r term was computed. The sum of the R_r values for each hydrological year gave the annual value of R-factor for that year. Because the examined catchment was mountainous an increase of 60% in the values of R-factor were considered for the melt of the snow during the December-March period. Thus, the average value of R-factor for the 10-year period was obtained, that is R=58 J mm / m^2 / h. Ignoring the snow melt effect, the value of the R factor is 36 J mm / m^2 / h. This value is remarkably less than the corresponding values for the peninsular Malaysia reported by Wu et al. (2001) (R = 136 to 216 J mm / m^2 / h), which is apparent for wet climates with monsoon periods. Equations 3 and 4 give much less values (13.4 and 7.1 J mm / m^2 / h respectively). The relation derived from central Italy gives results somewhat closer to our data that could be interpreted as a proof of the similarity of the two regions in terms of intense storms structure. It is clear that it is a misleading procedure to use relations that have been developed in other parts of the world with the particular hydrologic regime. Finally the USLE has been applied to the Venetikos River catchment and was found that the mean annual soil loss is equal to 6.43 t/ha.

2.4 Sediment discharge rating curve

The Public Power Corporation (PPC) has been conducted sediment discharge measurements at the Grevenon Bridge measurement site for many years. However, the PPC supplied us only with the measurements for the same period as the rainfall data and the mean monthly discharges for this station. Figure 2 shows the sediment discharge measurements for the time period from 1973-74 to 1983-84 and the sediment discharge rating curve for the whole period of the station operation. The application of the rating curve equation to the mean monthly discharges (although is not a completely correct methodology) gives the mean annual sediment discharge and the mean annual sediment yield. The mean annual sediment discharge is 1.65 kg / s and the mean annual sediment yield is 0.68 t / ha.

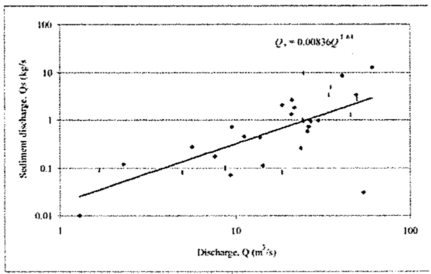

Figure 2: Sediment discharge rating curve for Grevenon Bridge measuring station.

3 CONCLUSIONS

Sediment delivery ratio of the catchment was found equal to 0.11, i.e. 11% of the eroded sediment was transported until the catchment outlet, and this value is substantially less than the most common of the corresponding values found in the international literature.

This deviation is mainly associated with the inability of the sediment discharge rating curves to account for the most intense flood episodes within a given hydrologic year. The investigation of the posed theme is continued taking into account the spatial variation of the rainfall, i.e., more than one rainfall recording gauges in the catchment are included for storms' analysis.

It was found that there is a very weak correlation between the annual values of the R-factor and the mean sediment transport derived from the sediment rating curves. Therefore, if we accept the hypothesis that during low flows the sediment discharge of the river is almost zero, the weak correlation is explained from the range of discharges in the sample of the simultaneous measurements of river and sediment discharges. In fact, there are only a few measurements during flood episodes, in which the majority of the annual sediment discharge is transported.

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AKNOWLEDGMENTS

The authors are indebted in the Public Power Corporation (PPC) of Greece for supplying the rain recording gauge station data of Spilaio, the mean monthly discharges and the sediment discharge measurements at Grevenon Bridge measurement station.