Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996.

Erosional processes in small Carpathian watersheds

TADEUSZ BEDNARCZYK & MAREK MADEYSKI
Department of Water Engineering, Agricultural University, Mickiewicza 24, 30-059 Krakow, Poland

Abstract Carpathian river basins are particularly susceptible to surface erosion. Investigations of the erosion intensity in small Carpathian basins with different amounts of forest cover have been carried out for several years. Both the proportion of forest and the distribution of the forest within the river basins were taken into consideration. The effect of variable factors such as precipitation and vegetation season was also considered by distinguishing hydrometeorological seasons. It can be concluded that proper land exploitation and forest cover are important in controlling erosional processes in small Carpathian basins.

INTRODUCTION

Human activity, deforestation of large areas and changes in land use in drainage basins will cause changes in runoff as well as intensification of erosional processes. Decreases in forest area and the distribution of the forest in the river basin are here of special importance. Investigations have demonstrated that the basins of small Carpathian streams are particularly prone to erosion. After deforestation, surface runoff from crop land can increase by 25% (Slupik, 1981) and this results in more intense surface runoff. Crop land utilization also has an important influence on the intensification of erosional processes. According to measurements undertaken in the vicinity of the village of Szymbark (Gil, 1976) and in the Beskid Mountains (Gerlach, 1976), the annual soil loss from pasture areas is about 3-70 kg ha^{-1}, whereas on fields under grain cultivation values increase to 100 kg ha^{-1} and under root crops values as high as 10-100 t ha^{-1} can occur. Runoff from field roads, incised up to several metres into the soil or rock, may also play a significant role in the formation of flood waves and in transporting river load (Froehlich & Slupik, 1980). Deforestation of a basin can also cause more intensive erosion. According to existing investigations, about 70-80% of the annual river load is transported during summer floods in Poland (Madeyski, 1983), whereas in Denmark about 80% of the suspended load is transported during the winter season (Hasholt, 1994).

INVESTIGATION AIMS AND METHODS

The investigation was aimed at determining the influence of forest cover on the intensity of erosional processes in small Carpathian river basins. In addition to the influence of forest area, the effect of the distribution of the forest cover on the amount of surface runoff was also investigated. The results of these investigations were used to determine the significance of the factors influencing the intensity of erosional processes in Carpathian basins.

The following methodological assumptions were employed:

- the river basins chosen for investigation should be characterized by different amounts of forest cover and different distributions of the forest areas;
- the basins selected should have similar physiographic conditions;
- the species composition of the forest cover within the basins should be the same; and
- sediment sampling and water discharge measurements at the outlets of the basins provided a basis for evaluating the intensity of erosion processes.

When considering the factors influencing the intensity of erosion processes, some factors may be viewed as constant (e.g. geological structure, soil type, slope inclination, density of river network etc.), whilst some are variable (e.g. nature and extent of vegetated areas, degree of plant development, intensity of precipitation etc.). Distinguishing hydrometeorological seasons (Nilsson, 1971; Walling, 1977), proved very helpful in considering the variable factors. Each of the seasons distinguished is characterized by a typical set of hydrometeorological conditions which is repeated

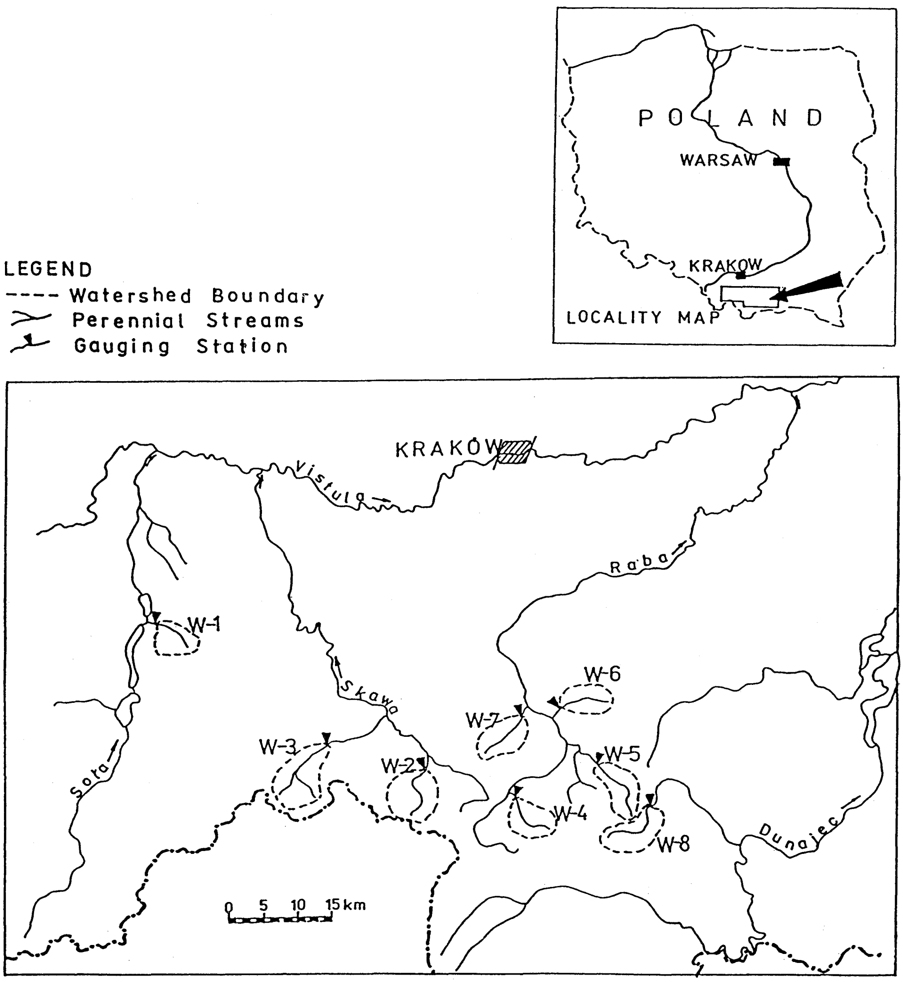

Fig. 1 Map of the study basins.

during the period of the investigation. Two seasons were distinguished: the summer season of flood water and the autumn season of low water. In both seasons measurements of suspended sediment concentration were undertaken every two days at low discharge and every two hours during periods of high water. In winter the basins in this region are covered with deep snow and the streams are covered with thick ice, making turbidity measurements impossible. The spring season which is characterized by meltwater was not marked by appreciably higher suspended sediment concentrations in the study basins (Osuch, 1978; Nippes, 1974).

Investigations were carried out in eight Carpathian stream basins ranging in size from 19 to 77 km^2, over a period of 4 years (1976-1979). These streams constitute headwaters of the rivers Sola, Skawa, Raba and Dunajec which are right bank tributaries of the River Vistula. Figure 1 shows the the location of the study basins. The most important features of the basins are given in Table 1. This Table also lists the mean annual sediment yields (in t km^{-2} $year^{-1}$) calculated from the sediment sampling programme. The above data were used to assess the significance of particular factors in influencing the intensity of surface runoff. Significance was evaluated according to the SAS statistical system (1992 version).

Table 1 Characteristics of the basins.

Name of stream	River basin	Symbol	Catch-ment area	Crop land ratio	Forest ratio	Index of forest development	Average annual precipitation	Density of the river network	Annual rain wash index
				O	L	E	P	G	Z
			(km^2)				(mm)	(km km^{-2})	(t km^{-2} $year^{-1}$)
Wielka Puszcza	Sola	W-1	19.3	0.16	0.82	0.87	960	1.60	30
Bystra	Skawa	W-2	77.0	0.25	0.54	0.69	853	1.76	28
Skawica	Skawa	W-3	48.6	0.10	0.79	0.93	1190	1.86	32
Poniczanka	Raba	W-4	33.1	0.40	0.43	0.64	901	2.40	66
Mszanka	Raba	W-5	51.0	0.44	0.39	0.55	879	2.60	64
Kasinka	Raba	W-6	32.0	0.41	0.44	0.49	914	1.77	46
Lubienka	Raba	W-7	48.7	0.43	0.37	0.43	979	1.31	71
Kamienica	Dunajec	W-8	38.0	0.08	0.88	0.89	588	1.15	22

THE GEOLOGICAL CHARACTERISTICS OF THE STUDY REGION

In Poland the Carpathian Mountains cover the southern part of the upper Vistula basin. The study area is underlain by sedimentary rocks of the Carpathian flysh. Spatial variability and rhythmic sequences of sand and clay rocks are characteristic of this area. The major part of the Carpathian Mountains is mantled by Quaternary deposits. The most common deposits are alluvial and colluvial clays derived from the physical erosion of the base rocks. The Carpathian Mountains are an area of mountainous and sub-mountainous relief. The area of mountainous relief is an area of high precipitation and accounts for the higher spring floods in the upper course of the Carpathian tributaries of the Vistula River. The transport of suspended sediment is, however, often greater in the sub-mountainous basins than in the mountainous zone (Branski, 1975). This is connected with the susceptibility of the soil to erosion, intensive farming, and the high density of roads. The Carpathian valleys periodically store large amounts of suspended and bed load which is eventually transported downstream to the Carpathian foreland.

The soils of the Carpathian area are in general highly susceptible to erosion.

ANALYSIS OF RESULTS

The index of forest development (*E*) proposed by Lambor is a measure of forest distribution. The forest development curve represents the relationship between the increase in the basin surface area and the forest area expressed as a percentage. The index of forest development (*E*) reflects the area below the curve in relation to the total area of the diagram. The index can assume values from 0 to 1. An index value close to 1 indicates that the forest lies in the upper part of the basin. Such a forest distribution is considered advantageous in terms of hydrological conditions. The calculated values of the coefficient *E* for the study basins are given in Table 1. Figure 2 shows the index of forest development for the basins with the lowest and highest index values (W-7, $E = 0.43$ and W-3, $E = 0.93$ respectively).

The investigation enabled the general relationship:

$$N = f(Q) \tag{1}$$

(where N = suspended sediment concentration in g m^{-3}; and Q = water discharge in m^3 s^{-1}) to be established. Using these data a number of loops were traced by hand for particular catchment areas and for different hydrometeorological seasons. Figure 3 illustrates suspended sediment transport for two basins for the summer and autumn seasons.

Investigations carried out to date have shown that the index of forest development is a significant factor in influencing the amount of surface runoff (Bartnik & Madeyski, 1991). As an example, suspended sediment transport loops for two basins characterized by the lowest (Lubienka basin) and highest (Skawica basin) values of the index of forest development were compared. These loop traces show that a greater water turbidity is associated with the same water discharge during the rising stage of a flood than during the falling stage. At the same time, a substantial difference in erosion process intensity

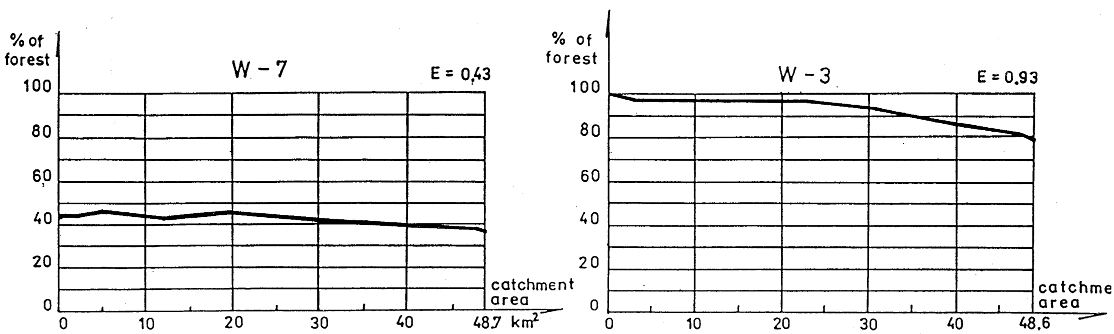

Fig. 2 The index of forest development for two of the study basins.

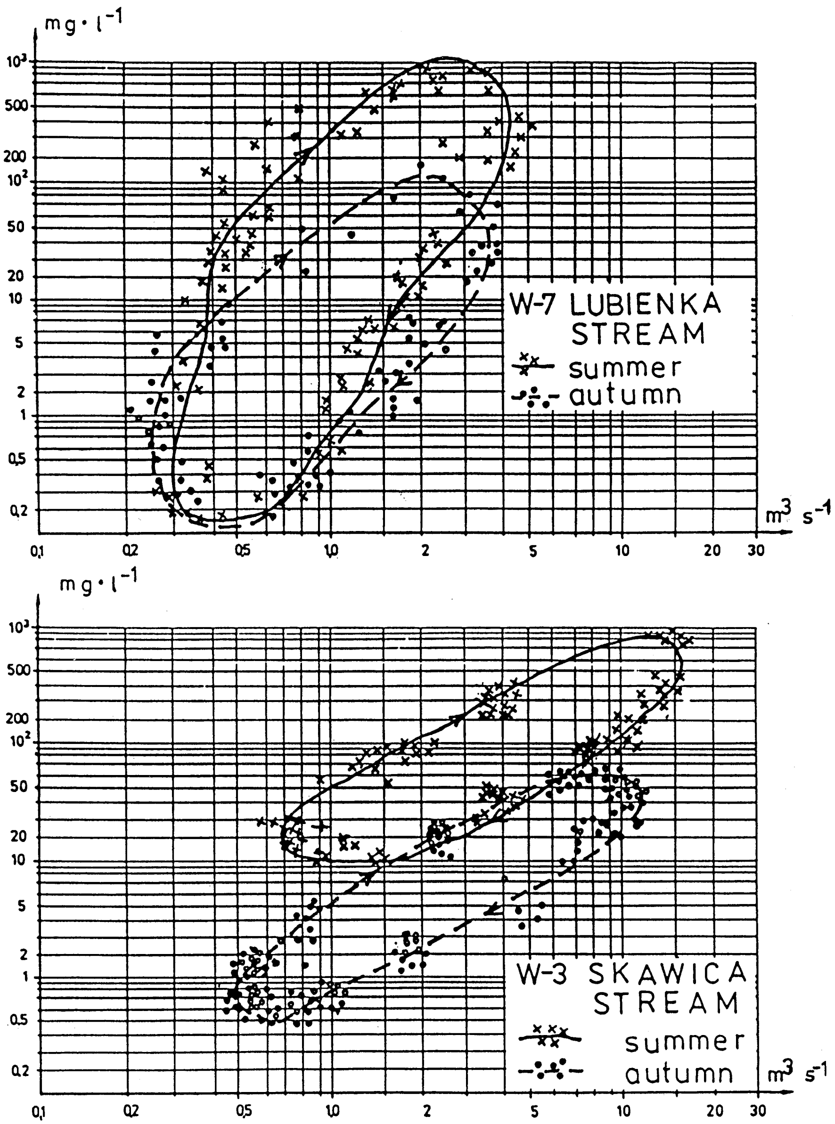

Fig. 3 Suspended sediment transport loops for two basins during the summer and autumn seasons.

is evident in basins with different forest cover. In the case of basins characterized by a lower index of forest development, the loops overlap when in the summer season turbidity maxima are ten times higher. In basins with considerable forest cover and high indices of forest development, the influence of forests on water turbidity is clearly visible; this being expressed by the loop shift between the two seasons. The loop inclination is also reduced, providing evidence of a reduced reaction of the basin to changes in of meteorological conditions. In the basins with low forest cover, surface runoff occurs at relatively lower water discharges.

The index of forest development for which the Fischer test at the 0.95 level of significance is 22.6, is the most significant factor among those investigated. The other factors (precipitation, crop land ratio, forest ratio, average annual precipitation, river network density) are less significant. The relationship between the annual rain wash index (Z) and the forest development index (E) is described by a regional linear regression equation of the form:

$$Z = -81.25 * E + 100.64 \qquad (\text{t km}^{-2}\ \text{year}^{-1})$$

(correlation coefficient $r = 0.81$; standard error of estimate = 12.75).

CONCLUSIONS

(a) The erosional system in small Carpathian basins is very complex. A number of factors (both constant and changeable by season) with different roles influence this process.

(b) The investigations confirmed the significant role of forest cover in influencing erosion phenomena. This involves not only the forest area but also its distribution within a basin. (The index E proved highly significant in these investigations.)

(c) Attempts to determine erosion process intensity should distinguish the main hydrometeorological seasons. This enables conditions which change with season, e.g. degree of vegetation development to be taken into account.

REFERENCES

Bartnik, W. & Madeyski, W. (1991) The ratio of suspended and bed load in mountain streams. In: *Proc. Int. Symp. The Transport of Suspended Sediments and its Mathematical Modelling* (Florence, Italy), 495-500.

Branski, J. (1975) Ocena denudacji dorzecza Wisly na podstawie wynikow pomiarow rumowiska unoszonego (Evaluation of denudation of the river Vistula basin on the basis of the results of suspended load measurements) (in Polish with an English summary). *Proc. IMGW.* **6**, 5-58.

Froehlich, W. & Slupik, J. (1980) Drogi polne jako zrodla dostawy wody i zwietrzelin do koryta cieku (Field roads as sources of water and sediment contribution to stream channel) (in Polish with English summary). *Zesz. Problem. Pods. Nauk Roln.* **235**, 269-279.

Gerlach, T. (1976) Wspolczesny rozwoj stokow w Polskich Karpatach Fliszowych (Present development of slopes in the Polish Flysh Carpathian mountains) (in Polish with English summary). *Prace Geograf. IG PAN* **122**.

Gil, E. (1976) Splukiwanie gleby na stokach fliszowych w rejonie Szymbarku (Soil wash off on flysh slopes in the region of Szymbark village) (in Polish with English summary). *Dokument. Geogr. IG PAN* **2**.

Hasholt, B. (1994) Erosional and sediment sources, rill and stream channel erosion – factors affecting the intensity of soil erosion. In: *Proc. TEMPUS Ewa-Ring short intensive course on Erosion, Sediment Transport and Deposition Processes* (Warsaw, 13-18 June).

Madeyski, M. (1983) An expression of suspended load transportation due to high discharge in small flysh river basins. *Studia Geomorph. Carpatho-Balcanica* **XII**, 131-141.

Nilsson, B. (1971) Sediment transport in Swedish rivers. An IHD-Project. Part 2: Catchment areas stations.

Nippes, K.-R. (1974) A new method of computation of the suspended sediment load. In: *Mathematical Models in Hydrology* (Proc. Warsaw Symp., July 1971), vol. 2, 659-666. IAHS Publ. no. 101.

Osuch, B. (1978) O ocenie ladunku materialu unoszonego w rzekach (On the evaluating of the transport of suspended load in rivers) (in Polish). In: *Proc. Conference Erosion Intensity of Mountain Soils on the Basis of River Load Transport.* (Piwniczna, Poland, September 1978), 29-41.

Slupik, J. (1981) Rola stoku w ksztaltowaniu odplywu w Karpatach fliszowych (Role of slope in generation of runoff in the flysh Carpathians) (in Polish with an English summary). *Prace Geograf. PAN* **142**, 1-89.

Walling, D. E. (1977) Assessing the accuracy of suspended sediment rating curves for small basins. *Wat. Resour. Res.* **13**, 531-538.