Sediment delivery model for the Homerka drainage basin

WOJCIECH FROEHLICH
Department of Geomorphology and Hydrology
Polish Academy of Sciences
św. Jana 22, 31-018 Kraków
Poland

ABSTRACT The Homerka stream drains an area of 19.6 km^2 situated in the Carpathian Mountains 375-1060 m a.s.l. and built of flysch series. Measurements of suspended sediment transport were performed at experimental slope and in the stream channel. The experimental slope represents three basic, in the Carpathians at least, potential source areas of runoff production and sediment supply into the stream channel. These are: 1 - the Holocene gully; 2 - the unmetalled roads, and 3 - the interchannel area. The supply of sediments into the channels with the slope is predominately from the unmetalled roads and the Holocene gullies. These roads contribute 70-80 percent of annual sediment yield of the Homerka drainage basin. Direct supply by overland washing from interchannel areas does not exceed one percent.

STUDY AREA AND METHODS OF INVESTIGATIONS

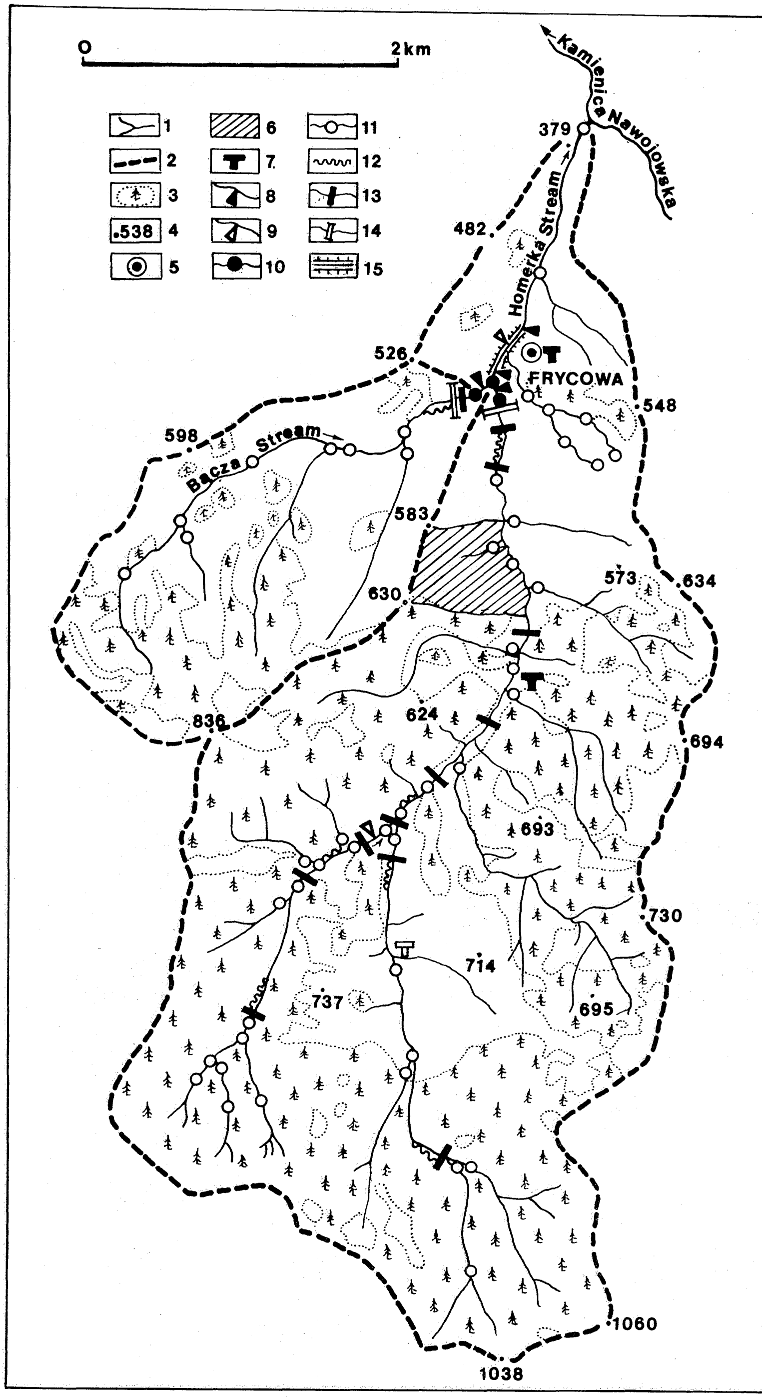
This work is based on the results of a 15-year cycle of station research and field experiments. The investigations were carried out on the experimental slope of the instrumented drainage basin of the Homerka stream (Fig. 1, 2).

The 19.6 km^2 Homerka drainage basin (375-1060 m a.s.l.) is a small Carpathian basin which is underlain by flysch rocks of varying resistance to weathering. The dominant relief type are mountains of intermediate height with a plenty of high and medium hills. It is composed of two parts: the montane higher one, and the lower foothill one. The former rises up to 1060 m a.s.l. It is built of a series of sandstones with shales admixed. The denivelations between the ridges and valley bottoms are of the order of 400 m. That part of the basin having steep slopes (15-30°) and more skeletal shallow soils as well as the steep hillsides are forested (52 percent of basin area). The woodlands show a dense network of unmetalled roads and lumber tracks.

The part of foothills rises up to 650 m a.s.l. The denivelations between the ridges and valley bottoms amount to about 150-200 m. That part of the drainage basin is built of shale-sandstone flysch series. The silty-clayey soils, the permeability of which decreases with the depth of the profile are used for farming. The mosaic of arable fields is crossed by a network of unmetalled roads, which most often are of the character of sunken roads (Fig. 2). Their density on the experimental slope exceeds 11 km km^{-2}. The lower valley floor and moister places are occupied by meadows and pastures.

In the lower part of the basin area, the mean annual total of precipitation amounts to about 900 mm, and in the headwater part it exceeds 1000 mm. The mean annual air temperature is 7.5°C and 5.0°C, respectively.

The experimental slope occupies an interchannel area of the Homerka drainage basin. It is 500-700 m long and 480-600 wide, and covers an area of 26.5 ha bordered by a natural water divide. It rises to heights



0
2km
1
2
3
.538 4
5
6
7
8
9
10
11
12
13
14
15
Kamienica Nawojowska
Homerka Stream
Bacza Stream
FRYCOWA
379
482
526
548
598
583
630
573
634
624
836
694
693
730
714
737
695
1060
1038

ranging from 458 to 608 m a.s.l. Its shape is convex-concave in the longitudinal profile, and concave in the transversal profile. The slope bears clay-silty sheets which increase in depths at the foot. The slope is cultivated transversally to the inclination. Between the fields there are unmetalled roads, which - in the course of centuries of cultivation have been transformed into sunken roads cutting the waste covers.

The experimental slope is composed of several sub-basins representing the main Carpathian areas contributing to stream water and sediment. These are: 1 - drainage basin of the Holocene gully; 2 - drainage basins of the unmetalled roads; 3 - drainage basins of the interchannel areas (Fig. 2). The two former areas supply water and sediment from the slope to the stream channel in a form of concentrated flow while the third area delivers water and sediment as sheet flow and subsurface flow.

Each of these drainage basins was instrumented. At the outlets of the unmetalled roads and the Holocene gully in the stream channel the sediment load was measured. Sheet flow was collected in plastic bags placed at the footslope and at the contact of the valley bottom with the stream channel (Fig. 2).

Rainsplash erosion has been observed on experimental plots simulating both an unmetalled road and a ploughed field.

These drainage basins represent the fundamental Carpathian contributing areas defined as parts of slope, and at the same time parts of the basin delivering water and sediment from slope to the stream channel. The water and sediment derived from these source areas reach the stream channel quickly - in the case of concentrated flow along unmetalled roads, Holocene gully, or drain-pipes, and slowly - in the case of overland or subsurface flow. That is why unmetalled roads and Holocene gullys which are only the areas drained by concentrated flow, as well as other areas which lie in the immediate vicinity of the stream channel and which have been wet before precipitation, contribute to high water flows (Słupik, 1981; Froehlich, 1982).

RESEARCH RESULTS

The sediment being transported in suspension consists largely of fine clay-silt fractions with vari-grained sand. Amount of clay-silt fraction in the suspended sediment increases downstream. The greatest variations in the particle size occur on the rising stage of discharges, whereas the falling stage is marked by the progressive refinement of the suspended sediment which becomes homogeneous in a granulometrical composition.

In the case of the experimental slope the largest concentration of the suspended sediment is observed on unmetalled roads. Changes of the suspended sediment concentrations on the unmetalled roads are analogical to those in stream channels (Fig. 3). During the rising phase of flow the suspended sediment concentration in unmetalled roads was always much

---

FIG. 1 The Homerka drainage basin.
1 - stream network, 2 - water divides, 3 - forest, 4 - altitude, 5 - Research Station of the Department of Geomorphology and Hydrology of the Polish Academy of Sciences, 6 - the experimental slope, 7 - rain gauges, 8 - analogue water level recorders, 9 - water level posts, 10 - permanent stream sampling stations, 11 - periodic stream sampling stations, 12 - measuring points for bed load transport, 13 - drop structure dams, 14 - sites for measuring channel erosion rates, 15 - experimental stream channel segment.

FIG. 2 The experimental slope in the Homerka drainage basin.
1 - water divides; A - drainage basin of the Holocene gully; B - drainage basins of the unmetalled roads; C - drainage basins of the interchannel areas, 2 - unmetalled roads, 3 - field boundaries, 4 - points for measuring concentrated flow and taking water samples, 5 - containers for measuring sheet flow and taking water samples, 6 - wells for measuring water level changes and taking water samples, 7 - points for measuring water discharge of springs and taking water samples, 8 - points for measuring soil moisture.

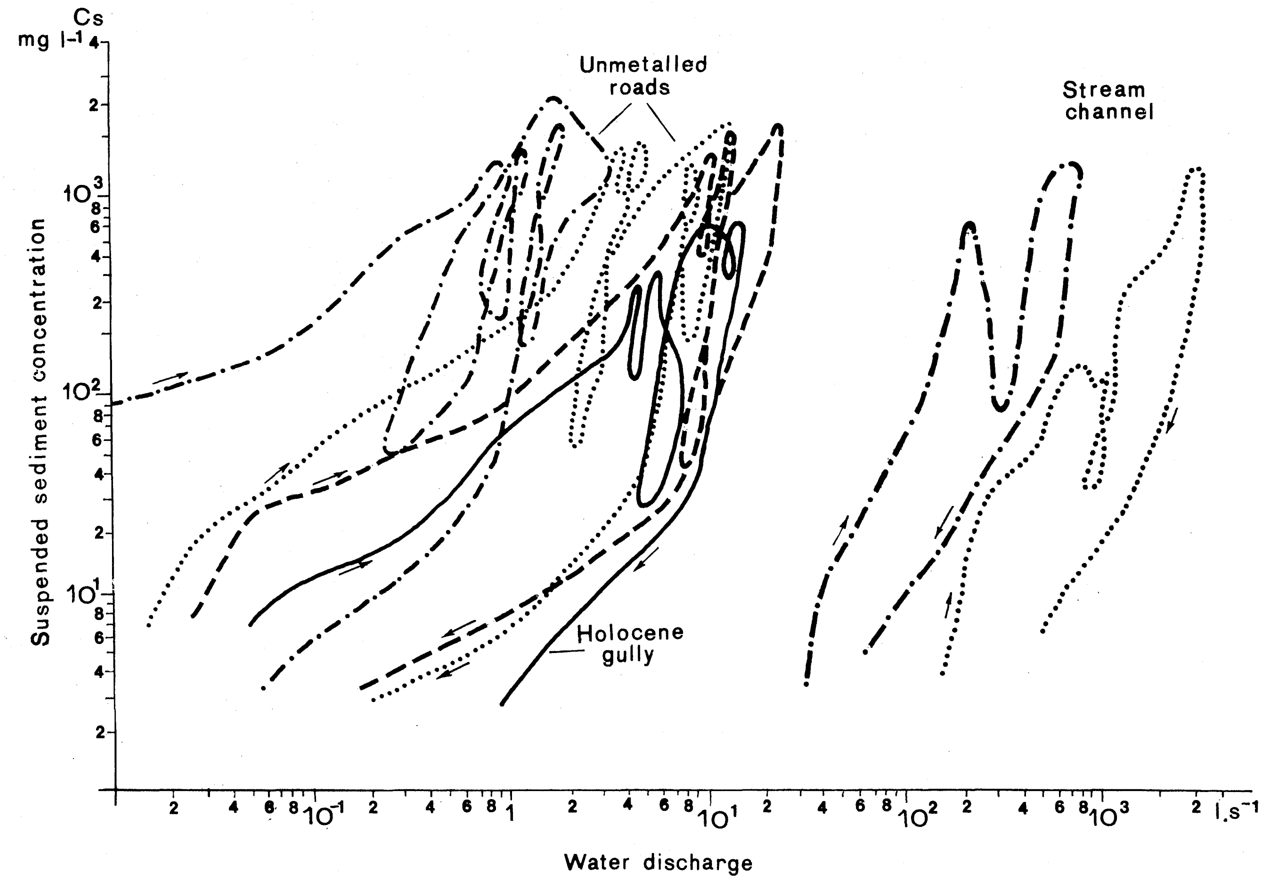


FIG. 3 The relationship between water discharge (Q) and suspended sediment concentration (Cs) during high water flow, May 1978.

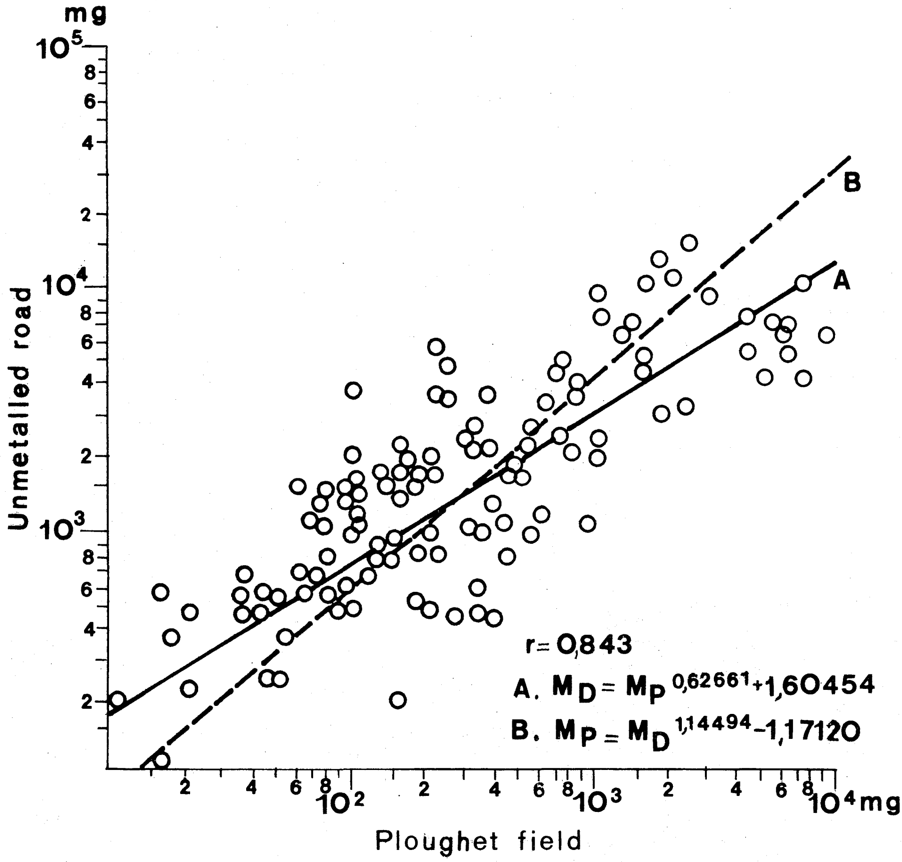


FIG. 4 The relationship between mass of soil detached under raindrop impact on ploughed field (Mp) and on unmetalled road (M_D).

larger than in the Homerka channel, except in the case of local flash flood and melting in the headwater part of the drainage basin.

Maximum recorded concentration of suspended sediment in the unmetalled road was 147 889 mg l^{-1}. Magnitude of suspended sediment concentration is strongly related to an intensity of soil splash caused by rain drop impact. Results of experimental studies on the soil splash on plots simulating a ploughed field and unmetalled road indicate that the intensity of the process in question can be 30 times larger in the case of an unmetalled road than ploughed field (Fig. 4) (Froehlich and Słupik, 1980). A rapid formation of a surface detention layer on a road results in an increased intensity of soil splash. That indicates a larger supply of sediments from unmetalled roads when compared to ploughed fields.

Suspended sediment concentration was always much lesser in the Holocene gully than in unmetalled roads. Moreover, it was variable in particular roads (Fig. 3). That results from individual properties of each unmetalled road, and especially from the ravine bottom, from ravine moisture, and the way and frequence of its use. These factors affect varying in an annual cycle as well as from rainfall to rainfall the amount of loose particles of weathered materials on the ravine bottom

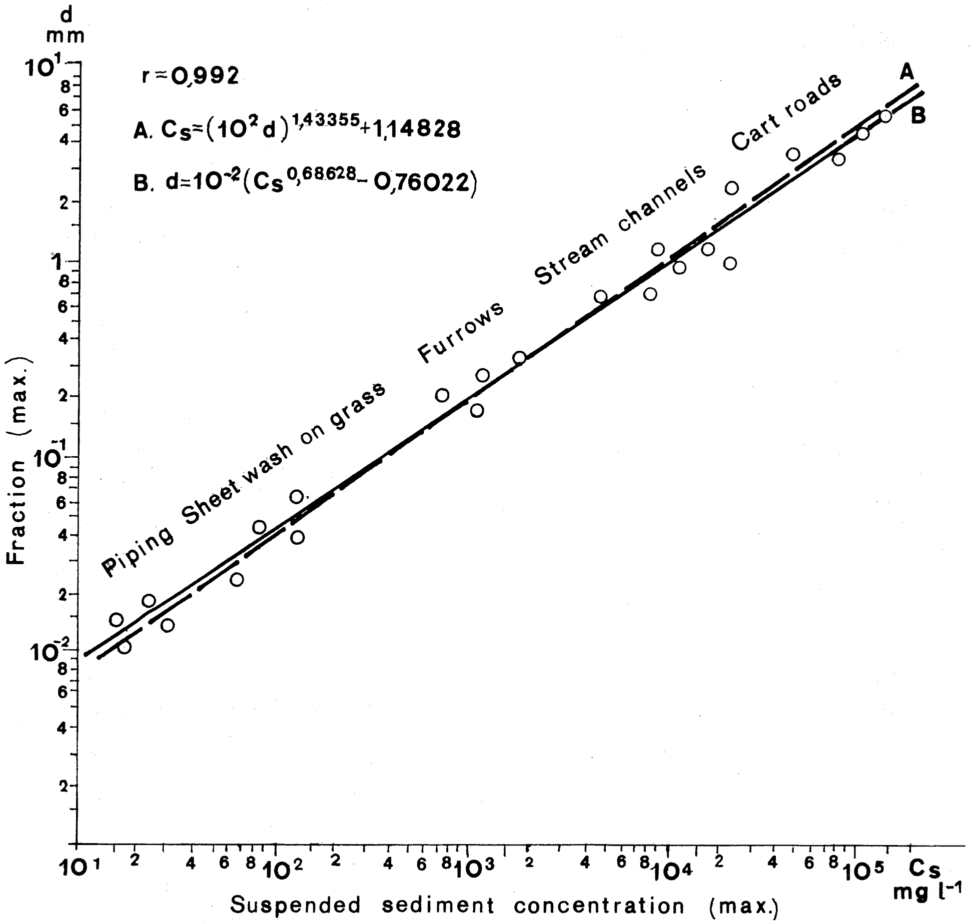


FIG. 5 The relationship between maximum values of suspended sediment concentration (Cs) and maximum diameter of mineral particles transported in suspension (d) in the Homerka stream and on the experimental slope.

which can be transported. Thus, each flood wave is characterized by a specific relationship between discharge and suspended sediment concentration (Froehlich, 1982).

Sediments supplied from the experimental slope to the Homerka channel by a system of unmetalled roads originate mainly just from the unmetalled road ravine. Some sediments washed from fields during periods of overland flow are supplied to the unmetalled roads directly or via a system of furrows. That is indicated by the magnitude of the suspended sediment concentration in furrows which was always definitely smaller than that in unmetalled roads (Fig. 5). Flow on unmetalled roads is formed during almost each rainfall (Słupik, 1981). It is always accompanied by an increase of a suspended sediment concentration (Froehlich, 1982).

Similar parameters of suspended sediment transport on unmetalled roads were obtained in a forest part of the Homerka drainage basin. It should

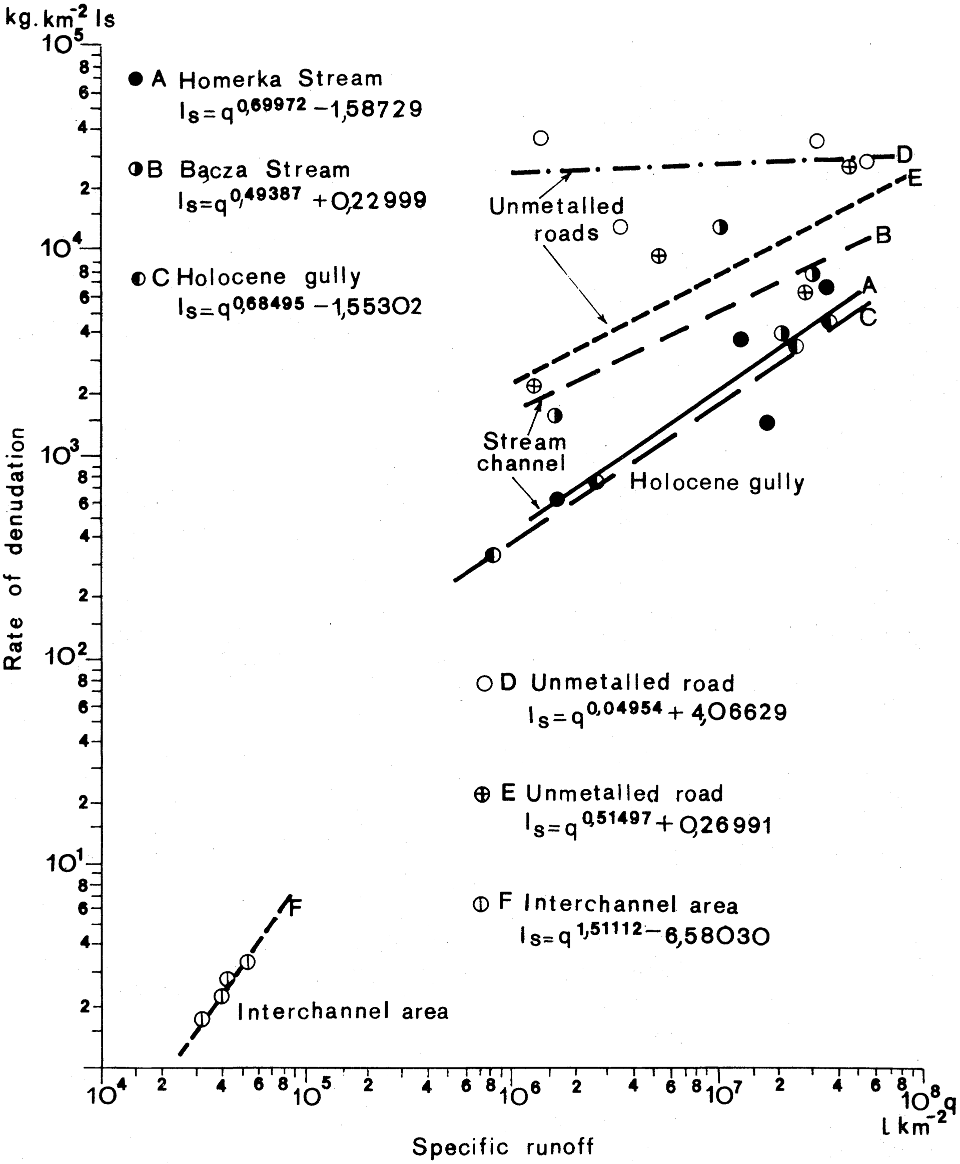


FIG. 6 The relationship between specific runoff (q) and rate of denudation (ls) in the Homerka drainage basin.

be emphasized that washing in the forested areas of the Carpathians is very small (Gerlach, 1976). Therefore, a direct sediment supply from forested surfaces to unmetalled roads can be neglected. It is always lesser than that from pasture areas. The concentration of suspended sediment of the sheet flow on the pasture areas was 25-65 mg l^{-1}, and was always many times lesser than that observed in channels. Thus, it is straightforward that the large concentration of suspended sediment in the Homerka channel, which sometimes exceeds 10 000 mg l^{-1}, could not have been caused by a sediment supply from the interchannel under farming as well as induced by overland flow (Fig. 5). Washed sediment is being trapped within pasture areas extending along the channels.

Direct supply of sediment to the channel varies depending on a rainfall duration and its intensity. Circa 98 percent of suspended sediment is supplied from unmetalled roads within the interchannel area during precipitation not triggering the overland flow. Sediment originating from the channel constitutes ca. two percent. It is deposited during longer inter-flood periods.

Sediment supplied from unmetalled roads and ploughed fields during annual floods constitutes ca. 60-70 percent. The Holocene gullies supply 10-15 percent while bank and bed erosion of channels 15-30 percent. Direct supply by overland washing from interchannel areas does not exceed one percent.

During extreme floods an increase of the supply from fields under cultivation to the unmetalled roads is difficult to be determined. However, unmetalled roads deliver over 50 percent of sediments in such periods. Supply from the channels still increases and is ca. 25-35 percent. Considering an average contribution of sediment source of the sediment yield from the unmetalled roads, ca. 70-80 percent of sediments are supplied in the Homerka drainage basin.

The definite dominance of linear supply over the supply due to the overland flow from interchannel area (< one percent) is present-day feature of the sediment supply from slopes to channels in the small Carpathian drainage basins.

The magnitude of the supply from fields in various parts of the Carpathians depends on the slope shapes and inter relations between fields, furrows and unmetalled roads. Direct sediment supply from fields to unmetalled roads is performed both with and without direct involvement of running water, and is associated with eolian processes. However, the magnitude of this supply is difficult to be determined quantitatively.

Sediment source areas do vary from rainfall to rainfall in dependence on intensity and duration of precipitation, soil moisture and its permeabilitiy. These areas form narrow bands along the main channel, tributary channels, linear incisions and depressions of concentrated flow during periods of melting and precipitation (Walling, 1971, 1983; Moore et al., 1976; Słupik, 1981; Froehlich, 1982). The width of that zone varies along the channel. The farther a distance of a slope from a channel the longer a discharge response to precipitation and longer the time of sediment supply from slopes. Contribution of slopes to a sediment supply decreases in a favour of tributaries. Wider and wider valley floor loosing its hydraulic relation with slope water takes over a role of a contribution area. Under such circumstances the main sediment sources are bank and bed erosion as well as rubbing of the transported bedload. That is expressed as a decrease of the sediment delivery ratio when the basin area increases.

Weather conditions cause an expansion and contraction contributing areas during precipitation as well as during runoff regression after precipitation due to a change of the length of the channel carrying water and changes of the area occupied by a saturation zone (Dunne and Black, 1970; Walling, 1971; Słupik, 1981). Widths of sediment source are subject to substantial changes in particular years, since extremal events, both rapid floods and long lasting low water stages (Froehlich, 1982; Walling, 1983), play an important role.

REFERENCES

Dunne, T. and Black, R.D. (1970) Partial area contributions to storm runoff in a small New England watersheds. Wat. Resour. Res. 6, 1296-1311.

Froehlich, W. (1982) Mechanizm transportu fluwialnego i dostawy zwietrzelin do koryta w górskiej zlewni fliszowej (The mechanism of fluvial transport and waste supply into the stream channel in a mountainous flysch catchment). Pr. Geogr. IG i PZ PAN. 143, 1-144.

Froehlich, W. and Słupik, J. (1980) Importance of splash in erosion process within a small flysch catchment basin. Stud. Geomorph. Carpatho-Balcanica. 14, 77-112.

Gerlach, T. (1976) Współczesny rozwój stoków w polskich Karpatach fliszowych (Present-day slope development in the Polish Flysch Carpathians). Pr. Geogr. IG i PZ PAN. 122, 1-116.

Moore, T.R., Dunne, T. and Taylor, C.H. (1976) Mapping runoff-producing zones in humid regions. J. Soil Water Conserv. 31, 160-164.

Słupik, J. (1981) Rola stoku w kształtowaniu odpływu w Karpatach fliszowych (Role of slope generation of runoff in the flysch Carpathians). Pr. Geogr. IG i PZ PAN. 142, 1-98.

Walling, D.E. (1971) Streamflow from instrumented catchments in Southeast Devon. In: K.J. Gregory and W.L.D. Ravenhil (ed.), Exeter Essays in Geography. University of Exeter, Exeter, 55-81.

Walling, D.E. (1983) The sediment delivery problem. J. Hydrol. 65, 209-237.