Water Erosion and Characteristics of Sediment Load in the Kopaninský Stream Basin – Short Communication

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Abstract: In May 2005, a major part of the Czech Republic was hit by an extreme rainstorm resulting in both soil erosion and flood events. We surveyed the erosion rills and soil material deposits produced by this rainstorm in the most damaged field of the experimental catchment Kopaninsky stream in the Bohemo-Moravian Highland. We measured the volume of the deposited sediment, its texture, bulk density, and other properties. The sediment consisted of two layers with a fuzzy boundary between them. The lower layer contained more fine particles, while the upper layer was mainly formed by a coarser material. The sediment generally contained lower amounts of C_{ox} and available nutrients than the original soil from which it was eroded. The results of the measurements were put into a broader context by using an event-based erosion prediction model ERCN, based on the curve-number method and on the Universal Soil Loss Equation. It was demonstrated that a 75 m wide riparian grassland strip in the study area was able to detain about 70% of the soil material eroded from the uphill ploughed land during the extreme rainfall-runoff event of 23rd May 2005. It was confirmed that grassland and other vegetation strips along water courses are highly efficient in reducing the surface water pollution during extreme erosion events.

Keywords: water erosion; sediment; texture; available nutrients

Soil and water are two important and closely interrelated components of the environment. The presence and movement of water influences the soil characteristics, while the existing soil profile properties and attributes affect the rate of water retention, runoff, infiltration, and evaporation. The exchange of matter between soil and water affects the quality of the environment. In particular, water erosion removes the surface soil layers and causes siltation and pollution of water streams and reservoirs with both suspended solids and dissolved and colloid substances. It is therefore necessary to solve the soil and water conservation problems simultaneously.

The harmful effects of the water erosion are investigated on various space scales – from small erosion plots to the sediment yields in large rivers. The research on small catchments (1–50 km^2) is an important source of the data and findings about the erosion and sediment transport processes, because these act as a connecting link between the soil particles sources and sediment yields in the rivers and reservoirs in the landscape (Bečvář 2006). All factors, events, and relationships can be clearly supervised in small basins: the erosion processes as well as the ways of land use, soil and water courses impairing human activities. Hydrologic, meteorologic, and water pollution data should stem from a direct monitoring.

The determination of total suspended sediment load on the watershed scale is critical for charac-

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terising water quality and establishing tolerable amounts. Local extreme storms evoke disastrous effects on the soil profile and surface water quality in agricultural catchments. Many studies focus on quantifying the rate of soil loss on fields in response to various farming practices (e.g. Russel *et al*. 2001; Gao *et al*. 2007). Despite the research effort (e.g. Fryirs & Brierley 2001; Vestraeten & Poessen 2002, Walling *et al*. 2002; Owens & Collins 2006 and others), the processes of soil particles detachment, slope transport, sedimentation, and channel distribution have not yet been explored sufficiently.

MATERIAL AND METHODS

The experimental basin Kopaninský stream was founded in the year 1985 in the Bohemo-Moravian highland. The area of the catchment is 7 km^2 (to the outlet Velký Rybník) and belongs to the drainage area of the Vltava River. The discharges, precipitations, and water quality have been observed in the long term (Kvítek &Doležal 2003).

The natural and anthropic characteristics of the experimental basin are well known and are systematically up-dated. The relief is a hilly country with average elevation of 550 m a.s.l. The basin of the Kopaninský stream is classified in view of the climate as gently warm, damp, characterised by average annual temperature of 6.5°C and average annual total rainfall of 700 mm.

Geologic substrate is formed by gneiss and locally quartzite. Cambisols on gneiss, medium-heavy or middle textured, are characteristic for this experimental basin. Stagnogleyic Cambisols and Stagnosols on gneiss are further significantly extended. Gleysols occur locally near the streams. Agricultural land predominates in the experimental catchment covering 57% of the territory. Forests occupy 41% of the area, and others 2% (Uhlířová 2005).

In May 2005, most of the Czech Republic territory was hit by an extreme rainstorm, causing soil erosion and flood events. One of the most affected areas was the experimental basin Kopaninsky stream. There we surveyed the erosion rills and soil material deposits on the field most damaged by water erosion due to this event. The investigated field (Figures 1 and 4) is a 600 m long slope with the gradient of 5°. It is interrupted in the middle by a road ditch. Above and below the road grow potatoes, the rows roughly patterned the contour lines at the event time.

On 23rd May 2005, there rained 90 mm of precipitations during 6 h, with maximum intensity of 42.6 mm/h and 1.7 mm/min. For comparison, the rainfall intensities recorded by the nearest stations observed by the Czech Hydro-Meteorological Institute – Pelhřimov (cca 10 km in the southwest from the catchment´s outlet profile) and Humpolec (cca 5 km in the northeast) – were 75.3 and 41.0 mm/day. Kulasová *et al.* (2004) estimated maximum 24-hour rainfall intensities with the probability of the return period of 100 years (on the monitoring basis in the years 1890, 1895–2002). The area incorporating the Kopaninský stream is

Figure 1. Investigated field with erosion rills and sediment deposit

Figure 2. Detail of middle part of the gully

characterised by a value of 80.0–90.0 mm. Janeček *et al*. (2005) stated 100.0 mm and 99.8 mm as maximum 24-hour rainfall intensity with the probability of the return period of 100 years for the nearest meteorological stations Humpolec and Pelhřimov. The rainfall gauge Velký Rybník thus recorded 24-hour rainfall intensities reaching or exceeding 100-year rainfall.

At the initial phase of the rainfall-runoff event, the uninfiltrated rainwater started to accumulate among the potato rows. Some rows ruptured and concentrated the runoff formed. The water courses bound into the rills and a gully across the potato rows. The ditch along the road was overfilled with washed-off soil and run over by water. The gully, formed below the road due to the concentrated runoff, was roughly 1 m wide and 0.5 m deep and it uncovered the deep subsoil (Figure 2). The transported material was deposited mainly on the wide meadow below the slope and smaller amounts entered into the stream (Figure 3). The platform of the solid sediment had almost a rhomboid shape with diagonals 75 m (in the runoff direction from the field to the channel) and 54 m (in the direction parallel with the stream channel). The source microbasin above the deposit covered a total area

Figure 3. Deposited mass

of 5.37 ha, it had an elongated shape, the average width being cca 91 m (Figure 4).

The volume of the sediment deposit was ascertained by measuring its geometric parameters – points position and layer depth. We took some reference soil samples from the apparently undamaged parts of the field from the depth of 0–10 and 10–20 cm. Another sediment samples were taken from the topsoil (approx. 0–6 cm) and subsoil (6–12 cm). Disturbed and core samples were taken from the same depths. Bulk density was measured using the core samples. The disturbed material was analysed for the percentages of textural fractions and the contents of C_{ox}, N_{tot}, available P, K, Mg and Ca (Table 3).

The model values of the actual discharge and sediment transport were processed by the ERCN software (Chlada & Dumbrovský 2000). Long term soil loss on the detached slope was calculated using the USLE method (Janeček *et al.* 2005).

RESULTS AND DISCUSSION

Bulk density of the sediment amounted to 1.49 t/m^3, based on the evaluation of the samples collected. The road ditch detained circa 13 m^3 of the transported soil material, that is approximately 19 t. The volume of the sediment below the slope was 25 m^3 on the low part of the field and 88 m^3 on the meadow. Total sediment volume (113 m^3) was expressed in the weight (168 t) to which was added the soil amount caught within the ditch. On the whole, 187 t of the soil material was eroded off and than deposited on the locality under study. If we spread the total amount of the deposited sediment on the area of the microbasin concerned, that is 5.37 ha, we would obtain the actual washing-off at 35 t/ha. The overall washing-off was higher because some material was transported into the stream running through the meadow.

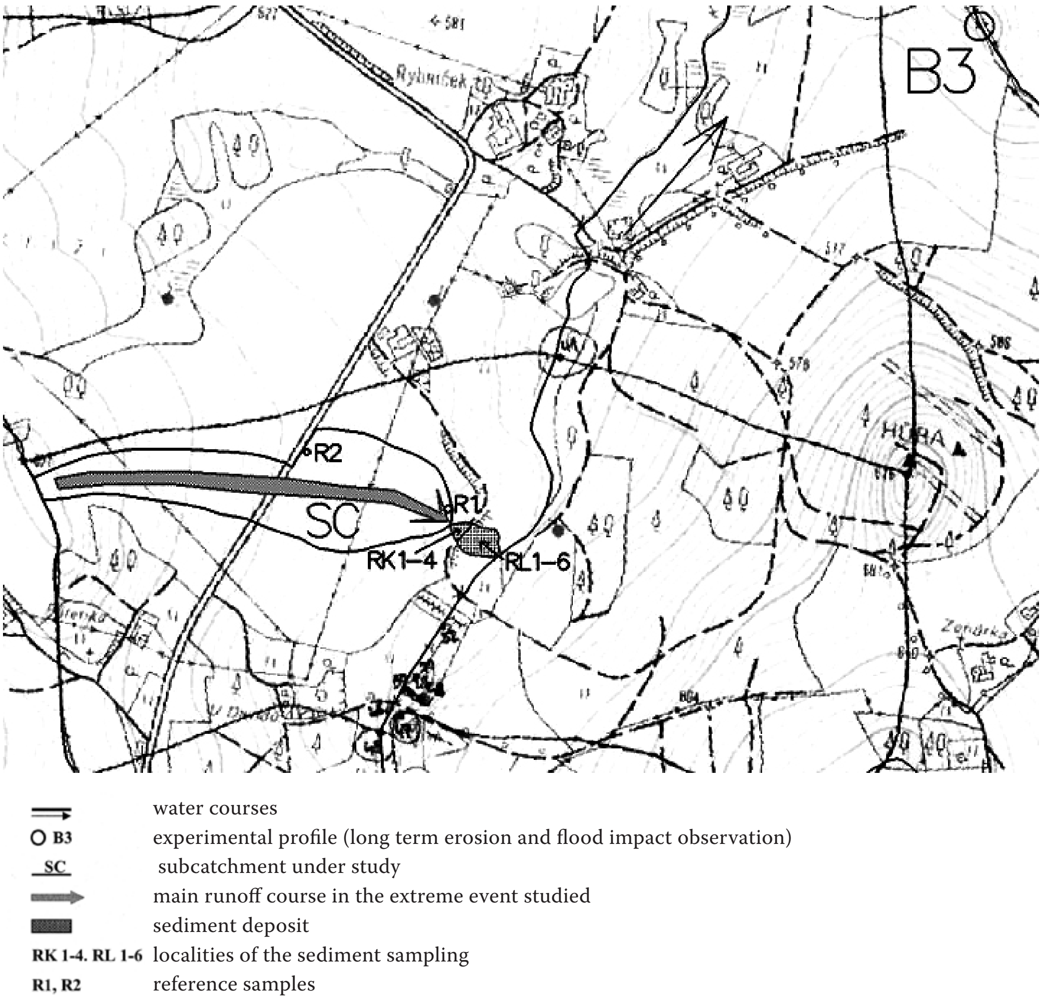

Figure 4. Studied locality in the Kopaninský stream basin

Table 1. Average annual soil loss caused by the sheet water erosion (according to the USLE)

Line	1A	1B
l 1 (m)	37.29	37.29
h 1 (m)	4.00	4.00
K1	0.34	0.34
c1	0.190	0.650
s 1 (%)	10.73	10.73
S 1	0.02	0.02
l 2 (m)	107.42	107.42
h 2 (m)	12.00	12.00
K2	0.34	0.34
c2	0.190	0.650
s 2 (%)	11.17	11.17
S 2	0.18	0.18
l 3 (m)	140.77	140.77
h 3 (m)	12.00	12.00
K3	0.34	0.34
c3	0.190	0.650
s 3 (%)	8.52	8.52
S 3	0.24	0.24
l 4 (m)	90.90	90.90
h 4 (m)	8.00	8.00
K4	0.34	0.34
c4	0.190	0.650
s 4 (%)	8.80	8.80
S 4	0.20	0.20
l 5 (m)	140.20	140.20
h 5 (m)	13.00	13.00
K5	0.34	0.34
c5	0.190	0.650
s 5 (%)	9.27	9.27
S 5	0.40	0.40
Sa li (m)	516.58	516.58
Sa hi (m)	49.00	49.00
s (%)	9.49	9.49
R	21.90	21.90
L	4.83	4.83
S	1.04	1.04
K	0.34	0.34
shape	1.00	1.00
C	0.190	0.650
P	1.00	1.00
G (t/ha/year)	7.13	24.38
Limit (t/ha/year)	10	10

Runoff line 1 is identical with the main runoff course (Figure 4)
1A – computation variant with factor C for local average rotation of crops
1B – computation variant with factor C for potatoes
R – rainfall factor, L – slope length factor, S – slope gradient factor, K – soil erodibility factor, C – crop (vegetation) factor, G – annual average soil loss

Table 2. Maximum discharge and sediment transport (using the ERCN software)

Parameters	Values
Catchment area (ha)	5.37
Max. 24-hour rainfall total (mm)	89.8
Average slope length (m)	134
Average slope steepness (%)	8.9
K (soil erodibility factor)	0.32
C (crop factor)	0.65
Average CN (curve number)	73
Sheet runoff	
Length (m)	104
Roughness	0.06
Hydraulic gradient (tg α)	0.07
2-year 24-hour rainfall (mm)	39.7
Time of concentration T_{ta} (h)	0.18
Concentrated runoff	
Length (m)	495
Hydraulic gradient (tg α)	0.09
Surface	unconsolidated
Mean profile speed (m/s)	1.475
Time of concentration T_{tb} (h)	0.09
Trunk runoff	
Time of concentration T_{tc}	0
Time of total concentration T_c (h)	0.275
Direct runoff (mm)	30.57
O_{max} (m^3)	1 642
Q_{max} (m^3/s)	0.43
G (t)	234

O_{max} – volume of maximum discharge, Q_{max} – maximum discharge, G – sediment runoff evoked by the extreme rainfall event

The calculation of the average annual soil loss (G) affected by the sheet water erosion on the detached slope is presented in Table 1. For the average crop rotation system (crop factor C = 0.2), the value G amounts to 7.13 t/ha/year, being below the limit given for deep soils (10 t/ha/year). In the hypothetic case of the long term production of potatoes on the field observed (C = 0.65), G would be 24.38 t/ha/year thus exceeding the limit. The confrontation with the actual washing-off (35 t/ha)

Table 3. Analyses of soil and sediment material

Sample No.	Locality	Textural fraction (%)			C_{ox} (%)	N_{tot} (%)	Availab. nutrients (mg/kg)			
		< 0.01 mm	0.01–0.05 mm	0.05–2.0 mm			P	K	Mg	Ca
R1/T	apparently undamaged field (refer. samples)	28.4	19.2	52.4	1.18	0.086	148	81	56	862
R1/S		27.8	22.7	49.5	1.41	0.166	167	190	68	880
R2/T		21.7	18.1	60.2	1.3	0.117	124	200	105	1658
R2/S		20.8	18.3	60.9	1.37	0.159	123	278	101	1636
RK1/T	sediment on the field heel	4.2	2.8	93						
RK1/S		11	8.2	80.7						
RK2/T		5.2	3.3	91.6	0.23	< 0.050	29.8	53	50	340
RK2/S		6.2	5.1	88.7	0.34	< 0.050	59.3	76	57	437
RK3/T		6.7	5.2	88						
RK3/S		8.5	6.3	85.2						
RK4/T		17.5	14.1	68.4	0.88	0.088	105	99	68	835
RK4/S		30.9	27.2	41.9	1.79	0.206	144	115	72	1191
RL1/T	sediment on the meadow	5.9	4.9	89.3						
RL1/S		10.4	7.8	81.8						
RL2/T		4.8	2.9	92.3	0.19	< 0.050	40.8	78	53	439
RL2/S		5.7	2.7	91.6	0.19	< 0.050	47.1	77	52	451
RL3/T		5.4	5.9	88.7						
RL3/S		4.1	3.5	92.3						
RL4/T		6.2	9	84.8	0.46	< 0.050	47	120	82	962
RL4/S		6.9	7	86.1	0.46	< 0.050	58	118	64	626
RL5/T		4.9	5.5	89.6						
RL5/S		4.7	3.5	91.7						
RL6/T		<4.0	3.5	93.6						
RL6/S		<4.0	2.8	94.4						

Behind slash: T – topsoil (top layer), S – subsoil (down layer)

is only illustrative because of the difficulty in comparing long term and actual soil losses.

The parameters of the microbasin investigated and the event meteorological data were processed by the software ERCN (Table 2). The model is based on the method of the curve numbers and it enables to obtain model values for the actual rainfall-runoff event. The calculated maximum discharge (430 l/s – in the lowest point of the watershed) and sediment runoff (234 t) were compared with the field data amount. As can be seen, the value of the sediment runoff given by the model is 20% higher than the deposit amount. This difference was expected, because part of the transported material flowed into the water course. If we presume that 80% of the soil eroded from the investigated slope was deposited, than the road ditch (50 cm deep, located crosswise in the middle of the slope) trapped 8% of the sediment yield. Consequently, the shore meadow (including the minor part on the field heel) retained 72% of the assumed eroded and transported mass. The estimated amount of the suspended matter floated into the stream coincides with the sediment concentration measuring at a near and similar subcatchment of the Kopaninský stream basin (Podhrázská & Uhlířová 2005). The measured sediment delivery into the stream was 8.8 t from 1 ha in the locality "Na hřebelci" (profile B3 at the Figure 4). This value applied by analogy to our field under study (5.37 ha) indicates that 47 t of the sediment load can have been transferred to the water stream. The sediment load calculated as the difference between the model sediment runoff total (234 t) and the measured deposit (187 t) is likewise 47 t. It is not possible to place great importance on this concurrent result, because it is derived only from one rainfall-runoff event. Generally, our conclusions are in agreement with some literature sources (e.g. Swiechowicz 2002 and Walling *et al*. 2002) reporting that the bulk of the eroded material is deposited on the field heels and adjoining grasslands in catchments with wide and vegetation covered valleys. Bečvář (2006) declares that the sediment yield in the water courses and basins equals approximately 20% of the soil erosion.

Table 3 presents the results of the sediment and soil analyses. Statistical evaluation (t-test) of physical and chemical analyses showed differences between the reference soil samples and deposited material. The fraction distribution in the reference soil top (0–10 cm) and bottom (10–20 cm) layers was practically equal. The sediment subsoil (Figure 5) revealed a higher proportion of fine particles (fractions to 0.05 mm) while the topsoil contained a higher amount of sandy particles (fraction 0.05–2 mm). Unfortunately, the differences are not statistically significant, probably on account of the low number of samples. Nevertheless, we can estimate that initially fine particles were washed-off from the field forming the first layer of the deposit. This was then overlaid by coarser material, derived from the rill and gully erosion phase. These results are consistent with the published findings (e.g. Fulajtár & Janský 2001; Janeček *et al*. 2005).

The reference samples (R1, R2) had a higher content of all chemical elements analysed. Statistically significant is the fact that the original soil is richer in the contents of C_{ox}, P, K and Ca. We found out that deeper base subsoil layers with low contents of humus and nutrients were eroded and deposited also by the gully erosion. We can take into account that the nutrients originating from fertilisers are partly dissolved in the soil and, during extreme runoff events, are diluted and flow out to a stream, similarly as the very fine particles of the organomineral complex (according e.g. to Evans 2006). That is why the sediment is a relatively depleted mass (Figure 6).

CONCLUSION

If we presume the value of the erosion sediment transport as calculated by the ERCN model, then the surface water pollution control efficiency of the 75 m wide riparian grassland in the investigated area was 72% during the extreme rainfall-runoff

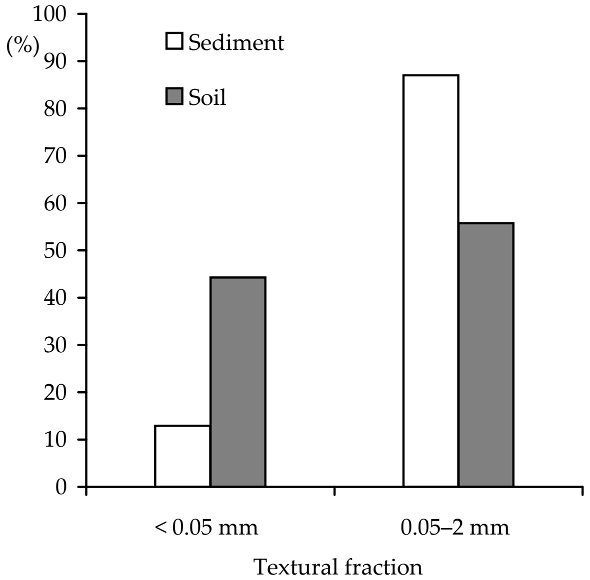

Figure 5. Textural fractions – average values from all samples

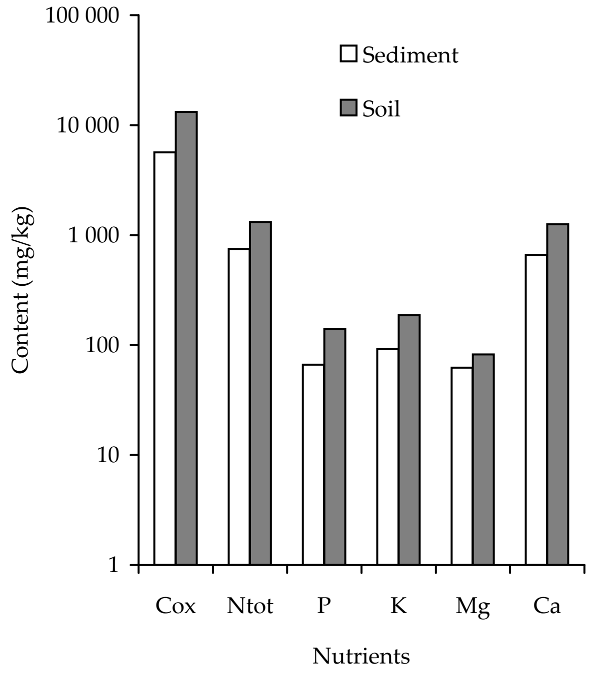

Figure 6. Contents of nutrients – average values from all samples

event on 23rd May 2005. It was confirmed that grassland and other vegetative cover along the water courses have potentially high efficiency to restrict surface water pollution during extreme erosion events. Local conditions significantly influence the sediment concentration, thus limiting the mathematical models application, however, the curve-number model used proved to be convenient.

The analysis of the sediment texture shows that the profile is not homogenous but consists of two layers with fuzzy borders between them. The lower layer contains more fine particles while the upper layer is formed by coarser material. The sediment samples contained generally lower amounts of C_{ox} and available nutrients than the original soil. The investigation on this small erosion plot contributes to the study of the water erosion processes and distribution of the sediment load.

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