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# THE ROLE OF COARSE WOODY DEBRIS IN FLUVIAL PROCESSES DURING THE FLOOD OF THE JULY 1997, KAMIENICA ŁĄCKA VALLEY, BESKIDY MOUNTAINS, POLAND

## INTRODUCTION

This paper discusses the role of coarse woody debris in fluvial processes during the flood which took place in July 1997 in Kamienica Łącka valley, the Gorce Mountains. These mountains belong to the Beskid Nowosądecki Mountains (Klimaszewski 1972) and they compose part of the flysch Western Carpathian Mountains (Fig. 1a). They are built of the rocks of Magurska nappe. The ranges of the hills of a medium mountain type dominate here. They are cut by deep V-shaped valleys (Klimaszewski 1972). The Kamienica Łącka is the largest valley. It starts on the slopes of Turbacz (1,311 m a.s.l.). This mountain makes a central point where the most important watershed ranges of the Kamienica Łącka drainage basin ramify radially. The area studied belongs to two climatic zones: pluvial zone (temperate cold zone at the altitude of 600–1,100 m a.s.l.) and nival-pluvial zone (cold zone at the altitude above 1,100 m a.s.l.) (Hess 1965). Despite the fact that the Kamienica Łącka drainage basin occupies a relatively small area (125 km$^2$), it shows large changeability of precipitation. According to altitude, the annual sum of precipitation ranges from 723 mm at Kamienica to 1,230 mm at Turbacz (Obrębska-Starklowa 1970). Precipitation concentrates in summers. The Kamienica Łącka is a typical river of rain-snow-ground regime (Ziemońska 1973). This results in the occurrence of two periods of high river stages during summer precipitation (June–July) and a bit lower river stages during spring thaws. Large amount of precipitation and geological conditions are the main factors that stimulate geodynamic processes in the Gorce Mountains (Klimek 1987; Krzemień 1984). Intensive summer precipitation increases the delivery of mineral and organic debris to the river channel. This precipitation is the most important in the morphogenesis of the slopes and river channel (bank and bottom erosion, transport and sedimentation of debris). Forests occupy a considerable part of the Gorce Mountains area (Dziewolski 1989). In the Kamienica Łącka drainage basin, they comprise about 95% of the area. Mountainous forest (spruce

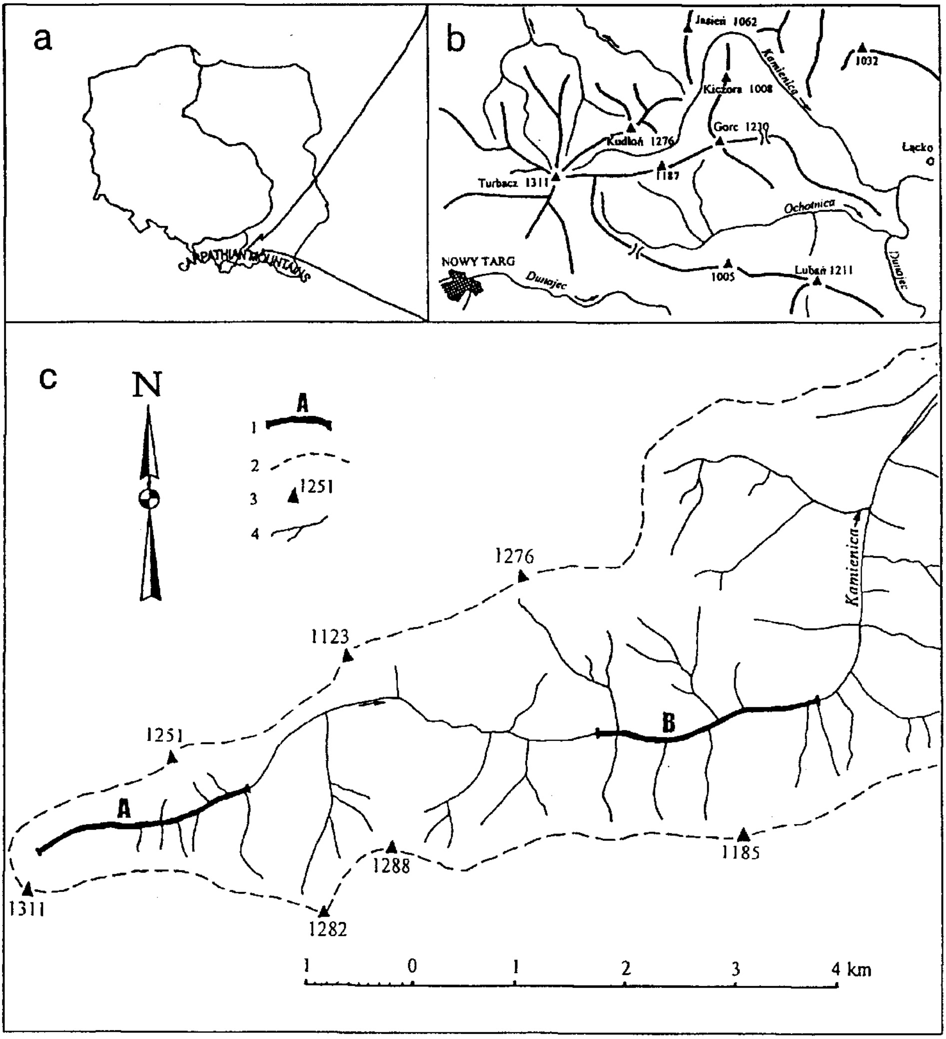


Fig. 1. Location of area investigated. 1 — study area in section A and B, 2 — limits of Kamienica Łącka drainage basin, 3 — summits (height in m a.s.l.), 4 — rivers

and fir wood of lower subalpine forest zone and spruce wood of upper subalpine forest zone) is the dominated habitat in this area.

## METHODS

The investigations started in August 1997. This enabled the author to observe the results of the flood directly after it occurred. The studies were carried out in two experimental sections, each 2 km long (Fig. 1c). They are located in the area

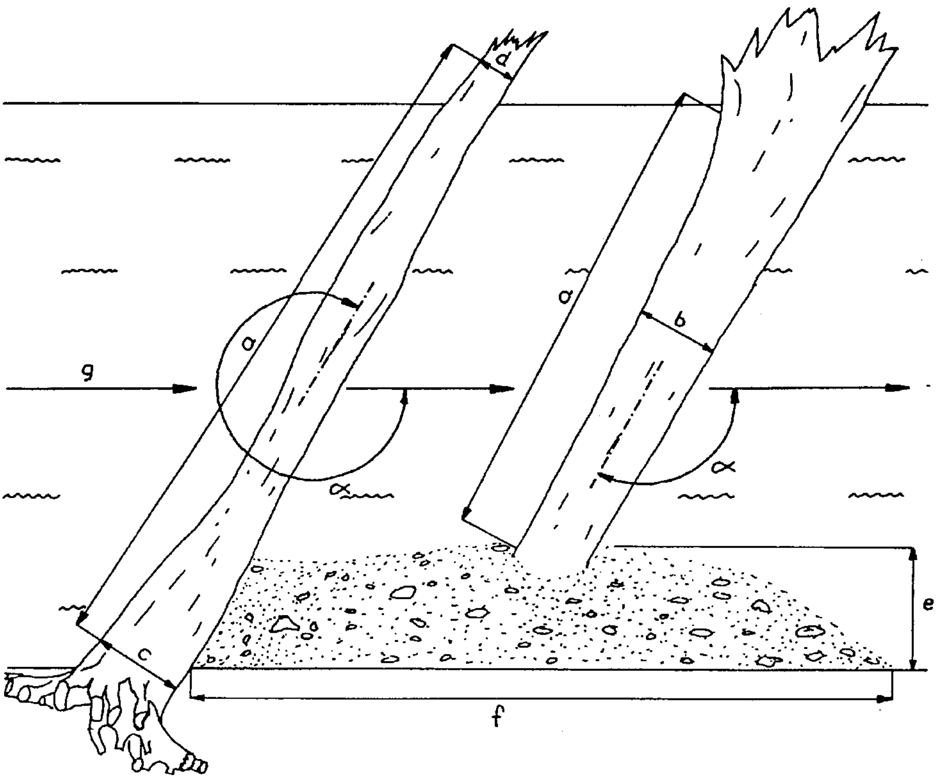


Fig. 2. Dimension and situation parameters of coarse woody debris (CWD) piece and bar. a — lenght of CWD piece, b — diameter of CWD piece, c — diameter of the bottom of the CWD piece, d — diameter of the top of the CWD piece, e — width of the bar, f — lenght of the bar, g — river main axis, α - angle between CWD piece and main channel axis

of the strict reserve in the Gorce National Park. The section A comprised the upper, source part of the river course. The section B was located in lower course of the river (from the eastern part of the reserve upstream). The fluvial forms in the valley floor were mapped. Main attention was paid however to map the distribution and dimensions of coarse woody debris as well as channel forms associated with it. The orientation of debris pieces in the channel and the degree of their decomposition were investigated (Fig. 2). Coarse woody debris (CWD) was defined as a fragment of a tree above 1 m long with a diameter in the half-length above 10 cm. The length, diameter and bearing of debris pieces were measured. The limit measurements of CWD and types of classification were taken from I. Van Sickle and S. V. Gregory (1990) and F. Nakamura and F. I. Swanson (1994). The total number of coarse woody debris pieces investigated was 1,049. During the fieldwork, such instruments as compass, clinometer, measuring tape and diameter measurement device were used.

## RESULTS

### THE PROCESS OF THE FLOOD

As there are no meteorological and hydrological measurements in the upper part of the Kamienica drainage basin, the author made an attempt to estimate the precipitation in this area basing on the quotient method (Dreger 1981). Intensive precipitation that results in raised water stages in summers is a periodical phenomenon in the Gorce Mountains. But flood in July 1997 resulted from exceptionally heavy rainfalls. First, showers and storms, which occurred in the beginning of July, saturated rock mantle cover with water. Then, heavy rainfalls which occurred at the end of the first decade of July caused catastrophic raised water stage (Dreziński *et al.* 1997). A reconstructed mean monthly sum of precipitation in July 1997 for Turbacz reached 410 mm. More then a half of this precipitation concentrated in the period of six days (4–9.07. 1997).

### THE SUPPLY OF COARSE WOODY DEBRIS AND THE ROLE OF FLUVIAL PROCESSES

The comparison of spatial distribution of the amount (Fig. 3 and 4), dimensions and orientation of CWD pieces in the river channel (Tab. 1) is the basis to estimate their role during the flood. Smaller volume and dimensions of CWD pieces observed in B section resulted from the intensive removal of the debris beyond this section during the largest discharges.

The distribution of coarse woody debris in the longitudinal profile of the river is associated with the valley width. In wide sections of the valley, the river lost its transport ability and part of CWD pieces was deposited on the riverbanks and valley floor. F. Nakamura and F. I. Swanson (1994) described similar observations. One of the most crucial features of coarse

Table 1

Mean parameters of coarse woody debris (CWD) in sections A and B

| Section | Number of CWD pieces | Number of CWD pieces per metre of river course | Total volume of CWD pieces [$m^3$] | Mean length of CWD pieces [m] | Mean diameter of CWD pieces [cm] | Mean volume of CWD pieces [$m^3$] |
|---|---|---|---|---|---|---|
| A | 520 | 0.26 | 257.3 | 8.4 | 20.9 | 0.494 |
| B | 529 | 0.265 | 181.2 | 6.93 | 18.8 | 0.343 |

woody debris is its length. In relation to the channel width, this feature influences either the transport of the CWD pieces or their ability to catch and deposit mineral debris.

The dimensions of CWD pieces present in a given river section depend on the structure of the forest stand which is the source of the supply. Part of CWD pieces contains dead trees with preserved roots and branches. But the majority represents fragments of tree trunks broken after the trees fell down or after some other processes. The pieces of coarse woody debris of small and medium diameter (below 10 cm) predominate in the area studied (Fig. 5). In B section of the river, the domination of short CWD pieces is very clear. B section is considerably wider than A section (mean valley width of A section — 8 m, B section — 28 m). This conditioned the transport of large pieces of coarse woody debris during the flood and their removal beyond the area studied. The CWD pieces of smaller dimensions were deposited in the final stage of the raised water stage.

The orientation of CWD pieces was studied measuring the angle between a debris piece and the direction of the river course (Fig. 2). Also their position in the channel was investigated.

CWD pieces show differentiated position in A section (Fig. 6). Most of them have their bases on the riverbank in different distance from the channel and their tops are located in the channel. It is a typical position for the trees

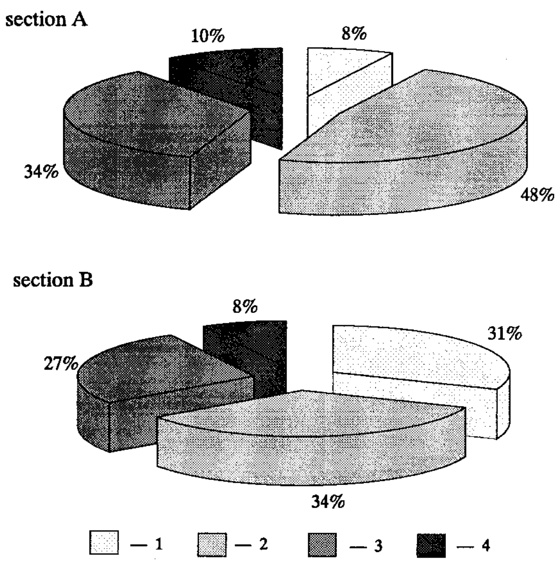


Fig. 3. Degree of decay of coarse woody debris. Presence of fresh pieces of wood reflects the CWD deliver intensity. 1 — fresh wood, 2 — CWD with loose bark. 3 — hard wood, no bark, 4 — soft wood, no bark

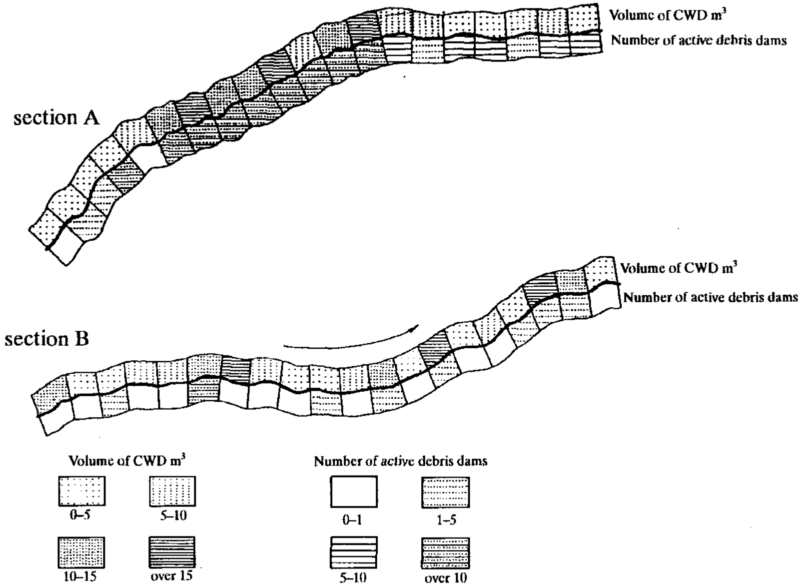


Fig. 4. Generalised distribution of coarse woody debris (CWD) volume per 100 m of river channel (over main chanel axis) and generalised distribution of active debris dams (under main chanel axis) within section A and B

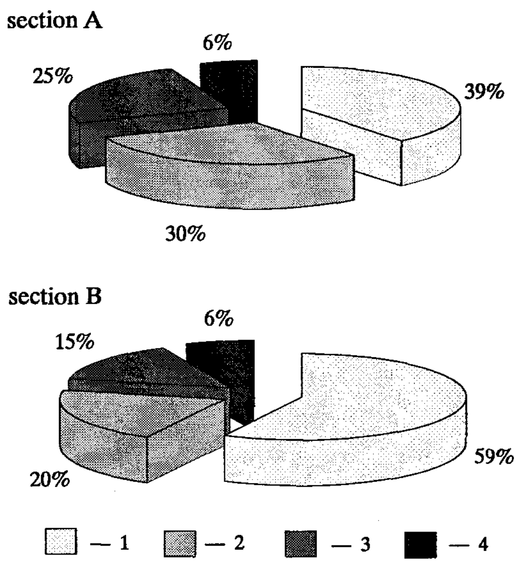


Fig. 5. Percentage composition of coarse woody debris length in the spring section (A) and in the lower sector of river course (B). 1 — not more that 5 m, 2 — 5–10 m, 3 — 10–20 m, 4 — over 20 m

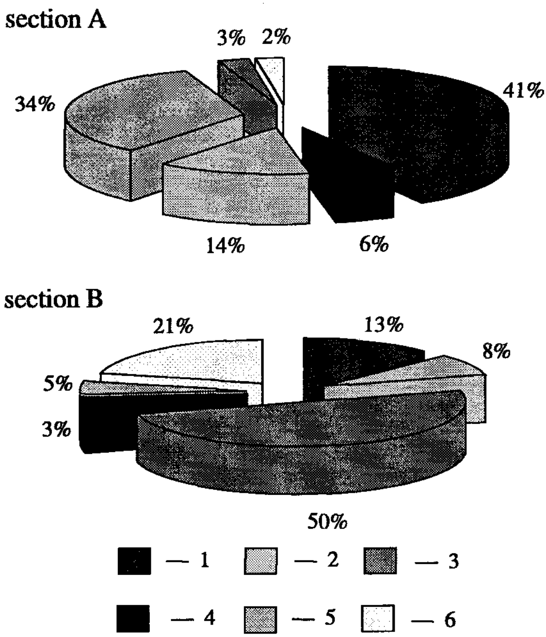


Fig. 6. Predominant types of coarse woody debris (CWD) location in the bed within section A and B. 1 — top of CWD in the river bed, 2 — all CWD in the river bed, 3 — all CWD on the left bank bar, 4 — bottom of CWD in the river bed, 5 — ends of CWD on the opposite river banks, 6 — all CWD on the right bank bar

that fell down from the slope. A similar number of CWD pieces have their bases and tops on the opposite banks of the river. Such position is considerably important for the development of accumulation forms. Also large number of CWD pieces is entirely located in the river channel. These are mainly small, old fragments of trees (Fig. 3), they may also generate accumulation forms. Small number of CWD pieces is located on the channel bars and their bases rest in the channel. These are small, deposited by river, parts of the trees.

In B section, the structure of CWD position is less differentiated. The pieces located on bank bars predominate. Other types of CWD position make an insignificant part of their total number. Such a structure indicates the domination of debris pieces, which are transported by the river in different forms and on different distances. There is also a small number of CWD pieces, which condition the development of accumulation forms.

Pieces of coarse woody debris present in A section show large changeability of their orientation in relation to river course. Most of them are orientated parallel to the river course (angle 0–10°). This shows that the debris was transported by the river's water. The thicker end of a separate CWD piece, as a heavier one, was anchored on the riverbank and the thinner end was moved with water flow. CWD pieces of an orientation perpendicular or almost perpendicular to the river course (60–120° or 240–300°) showed also large participation (Fig. 7). Such an angle of CWD orientation makes it possible to hold mineral debris and develop bars. These observations are consistent with the observations by K. I. Gregory et al. (1993).

In B section, CWD orientation of a small angle in relation to the river course predominated. This evidences much more intensive transport of coarse woody debris in this section. There is also a large percentage of CWD pieces of an angle of 180–220°. Such pieces of course woody debris were not anchored at all and were often carried out by water with their roots downstream. There was a small number of CWD pieces, which could influence the development of accumulation forms.

## INFLUENCE OF COARSE WOODY DEBRIS ON FLUVIAL PROCESSES

Coarse woody debris, which falls to river channel and dams up the water flow, generates gravel stream shadows (Fig. 8). In similar conditions, by damming up the water and directing its current towards the riverbank, CWD pieces may also influence development of erosional undercuts and landslides (Fig. 9).

Two hundred cases of the arrestment of mineral debris of different sizes by coarse woody debris were observed in A section (38% of the total number of CWD pieces in this section). The amount of the deposited material was different. The accumulation forms include small sand-gravel shadows, bars and dams. Stony bars represent the largest accumulation forms in the river channel. The most characteristic feature of CWD is its position. The pieces with their tops placed in the channel or these extended between two riverbanks predominate. The orientation of CWD pieces which hold mineral debris is different, with a predominance of the directions from the range of 50–90°. (Fig. 7). This indicates that CWD which is placed at the angle that secures contact with water on the entire length of the debris, shows larger morphogenetic activity then others. There is a small number of CWD pieces that occur at the angle close to 90°.

In the section studied, the development and preservation of majority of bars should be associated with the activity of coarse woody debris. It generates and preserves about 63% of the bars which occur in the experimental section. The participation of bank bars is the largest (61%). This results mainly from the domination of CWD pieces with tops located in the channel. Such debris influences the bank zone. Individual pieces usually initiate the development of small bars. Large bars are preserved by groups of CWD pieces, which, due to their specific orientation, act as natural groyne. Such bars are usually elongated. This results from a unification of the adjoining

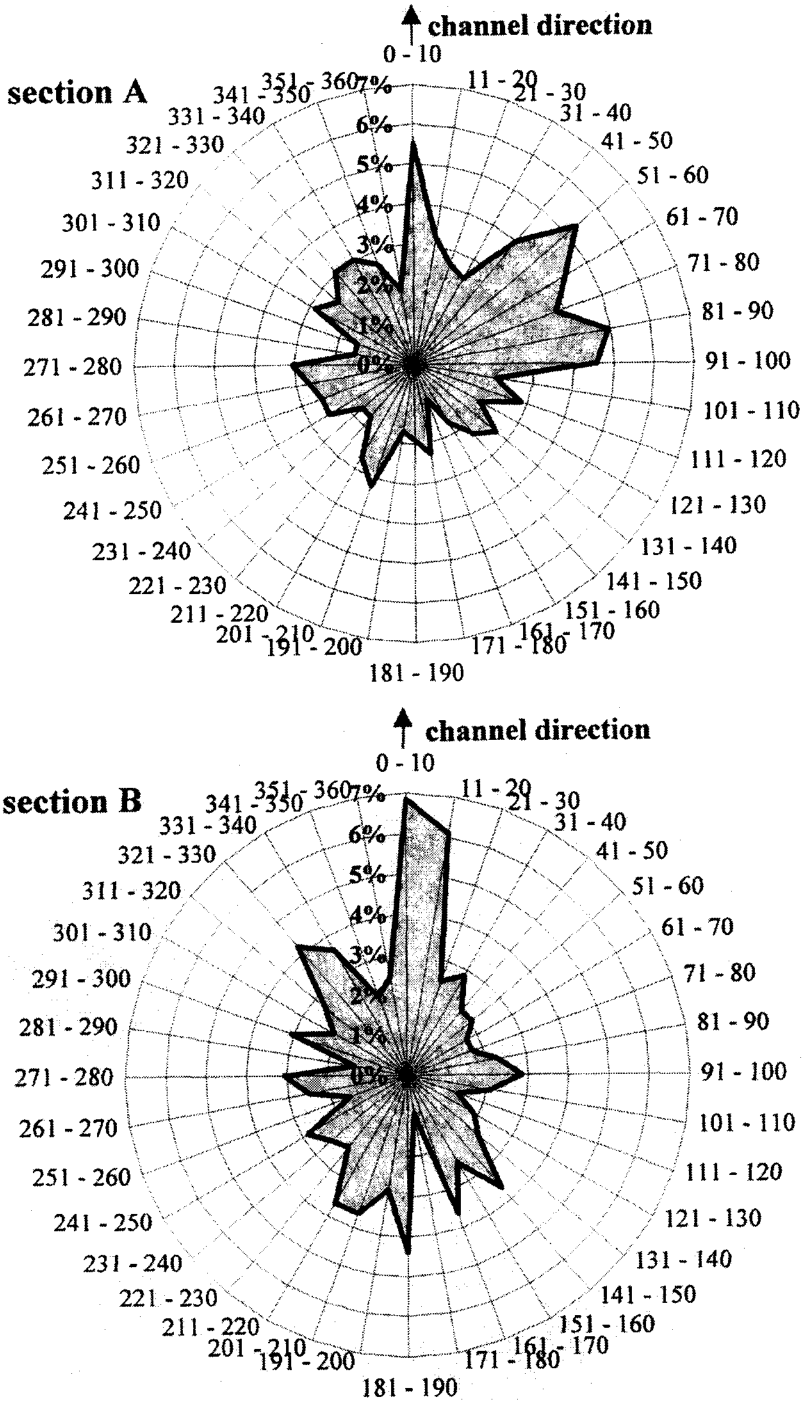


Fig. 7. Orientation of coarse woody debris (CWD) pieces, based on angles between CWD pieces and main channel within section A and B

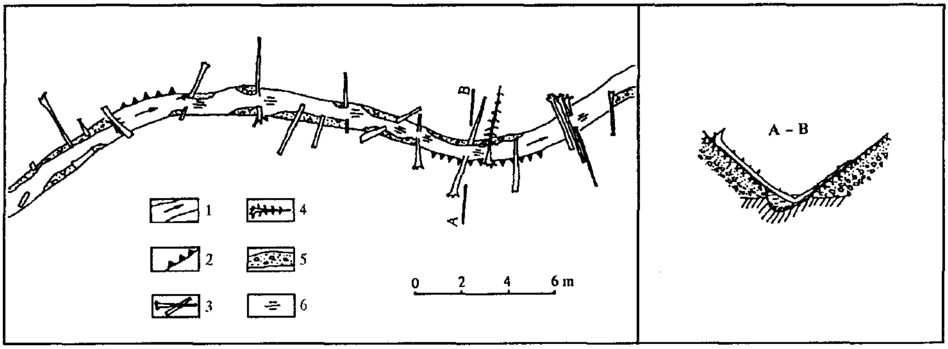


Fig. 8. Geomorphological sketch of study area in section A (see Photo 1 for comparison). 1 — main water current, 2 — erosional undercut 1 meters high, 3 — CWD pieces, 4 — fallen trees, 5 — gravel bar, 6 — erosional kettles

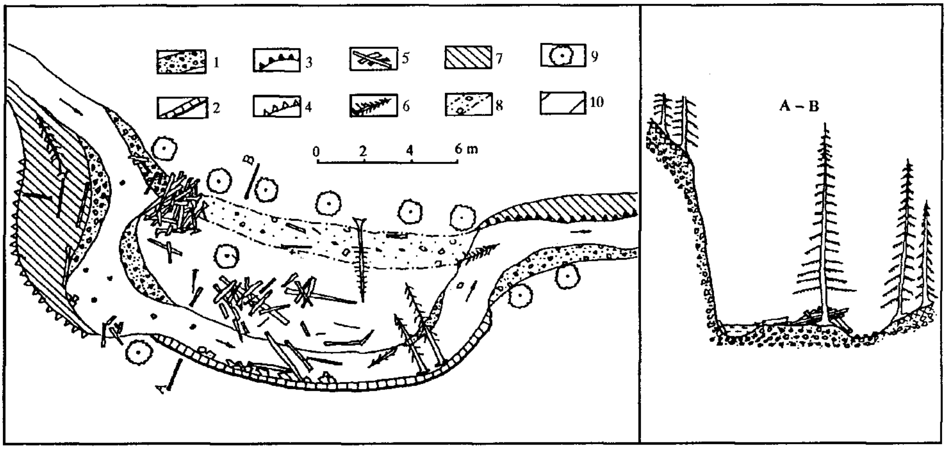


Fig. 9. Geomorphological sketch of study area in section B (see Photo 2 for comparison) 1 — gravel bar, 2 — erosional undercut 12 meters high, 3 — erosional undercut 1 meter high, 4 — inactive erosional undercut, 5 — CWD pieces, 6 — fallen trees, 7 — Terrace, 8 — inactive river channel, 9 — growing tree, 10 — main water current

bars along one of the banks (Fig. 8 and 9). The supply of CWD pieces which constrain the deposition differs in time. This results in age differentiation of individual segments of the bars. Trees falling down on the bars cause the increase of their thickness by the arrestment of the material during the raised water stages.

Dams develop on the pieces of coarse woody debris which are placed on the opposite banks of the river (Photo 1). Such forms, up to 1 m high, origin as a result of the accumulation of large amount of mineral debris and detritus at the distal side of CWD. At the proximal side, falling water forms erosional kettles. The dams often consist of the group of CWD pieces that

Photo 1. Debris dams causes mineral debris acumulation at the distal side. Water falling down from waterstep creates an erosional kettle (section A)

Photo 2. Various sizes of coarse woody debris (CWD) were introduced to the river bed. In some cases water couldnt get through the dam. Main steam axis was replaced (section B)

show similar orientation. Transported fragments of tree trunks, branches and leaves are held by CWD pieces which are anchored permanently. It improves the efficiency of the dam (Wallance and Meyer 1995). The increasing mass of woody and mineral material influences the stabilisation of these forms. This decreases discharge velocity and water energy. As a result, large amount of mineral debris is deposited. Arrested by the dam mineral debris causes channel aggradation by local raising of erosion base-level. The water falling down from the dam creates erosional kettles. The number and dimensions of water steps and erosional kettles generated by CWD are larger then similar forms associated with rocky steps. Water steps developed due to the presence of the dams of the height above 1 m. The dimensions of the erosional kettles depend on the height of the steps, the age of the dam, but most of all, on the parent rock resistance.

In B section, 33 pieces of coarse woody debris held mineral debris (6% of their total number). These pieces do not form any important accumulation forms, just small gravel shadows. During the July 1997 raised water stage, they did not play any important role in stimulating deposition of the transported material (Photo 2). In this section, coarse woody debris usually stimulates bank erosion. This contributes also to channel transfer during catastrophic raised water stages.

## CONCLUSIONS

Trees which fall down to the river may be, depending on river energy, transported by water or they may themselves crucially influence the transport of debris. The importance of course woody debris decreases with the increase of water energy. The width of the channel and valley floor in relation to the dimensions of debris pieces is very important. The distribution of CWD pieces is different in different sections of the river. In source section, the energy and transport ability of river is small. The presence of CWD in this section is more associated with the processes which influence the supply (bank erosion, initiation of mass-movements). In lower section of the river, where morphometric features of the valley are favourable and discharges are much larger, the distribution of CWD is associated with fluvial transport. In source section, debris pieces can significantly influence fluvial processes (generate steps and bars). In lower sections of the river, their importance is much smaller. They are transported and deposited due to the action of floodwater (Photo 2). This confirms the observations of C. A. Braudrick et al. (1997) and A. Kotarba (1998).

Raised water stages, which create and rejuvenate erosional forms and stimulate mass-movements on the slopes, considerably influence the supply of coarse woody debris to the river channel. Landslides and erosional undercuts may stay active even after the level of floodwater decreases. The unsettled balance of the slope causes increased delivery of the CWD, also after the flood.

Coarse woody debris influences erosional-accumulation balance and transport capacity of the river, and also conditions the development of both erosional and accumulation forms (sand-gravel shadows, bars, dams). CWD that builds the dams decreases water energy, and contributes to the differentiation of the floor morphology. Among the studied pieces of CWD, only their small number fulfils the requirements to stimulate channel processes (38% of the total number of CWD in A section and 6% in B section). These requirements include: length of the CWD, their orientation and position. Similar observations were described by E. B. Bilby (1984) and I. Van Sickle and S. V. Gregory (1990).

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## STRESZCZENIE

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### ROLA KŁÓD W PRZEBIEGU PROCESÓW FLUWIALNYCH PODCZAS POWODZI W LIPCU 1997 ROKU, DOLINA KAMIENICY ŁĄCKIEJ — GORCE, POLSKA

Powódź z lipca 1997 roku doprowadziła to do intensywnego przemodelowania dna doliny Kamienicy Łąckiej. Obszar ten jest silnie zalesiony, głównie drzewostanem świerkowym. W czasie powodzi w wyniku erozji brzegów i ruchów masowych miała miejsce duża dostawa drzew do koryta rzeki. Wielkość dostawy i znaczenie materiału organicznego były różne w źródliskowym A i niższym B biegu rzeki. Związane było to z różną energią rzeki oraz szerokością dna doliny. Duże znaczenie miały również cechy geometryczne kłód. Zróżnicowanie wielkości i usytuowania kłód w korycie pozwoliło na odtworzenie ich roli podczas wezbrania. W górnym odcinku, gdzie energia rzeki była mniejsza kłody wymuszały depozycję materiału w postaci cieni żwirowych, łach i lokalnej agradacji koryta wymuszonej przez tamy. W niższym odcinku kłody nie generują większych form akumulacyjnych, jedynie niewielkie cienie żwirowe, same podlegają transportowi dalszemu i ponownej depozycji wskutek dziaûania wód powodziowych.