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THE ROLE OF DEBRIS-MUD FLOWS IN DEVASTATION OF SETTLEMENT INFRASTRUCTURE IN THE FLYSCH CARPATHIANS

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The paper presents potential threats caused by debris and mud flows in the Flysch Carpathians. There were 6 disastrous floods in the Carpathians during the last 50 years. They caused great changes in relief and destruction of economic infrastructure. Debris and mud flows are created during long term and heavy precipitation and they are of great destructive strength. Morphodynamic zones in the Carpathians with different frequencies of debris and mud flows were distinguished. A typology of flows was also presented according to the size of heavy precipitation, geological structure and relief.

Key words: Flysch Carpathians, mud and debris flows, landslides, disastrous floods

INTRODUCTION

Disastrous floods are the greatest threats in the zone of wet, temperate climate. People have settled in valleys from the past and they have been threatened by floods. Protection against them was based on technical activities. It has been assumed that river regulation, construction of strong banks or big retentional reservoirs limit or prevent losses caused by disastrous floods. This also con-

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od terraces have been sold for construction purposes, not only for ware-uses, but also for housing estates. The results is that floods cause greater fi-ncial losses and of course the moral losses cannot be estimated in terms of ney. In 1997-1998 there were also disastrous floods on the Morava and the er in Czech Republic and in the Slovak Carpathians (Stankoviansky and driak 1998, Hanušin 1998 and 1999, Hrádek 1998).

The present flood threats and intensity of losses caused by floods are the re-t of disturbances to the ecological balance caused by man or minimizing the essity of undertaking the prevention activities (Lach 1997). According to tistical data, extreme meteorological and hydrological phenomena are the re-ts of about 70 % of all natural disasters. Historical records say that the worst asters in Poland were caused by floods which appeared several times during last century (Cebulak 1998, Malarz 1997, Niedbała 1998). The main reason them is rainfalls and in spite of the fact that the average annual precipitation Poland is 633 mm, in the mountains depending on the height, day and night nfall can reach 300 mm.

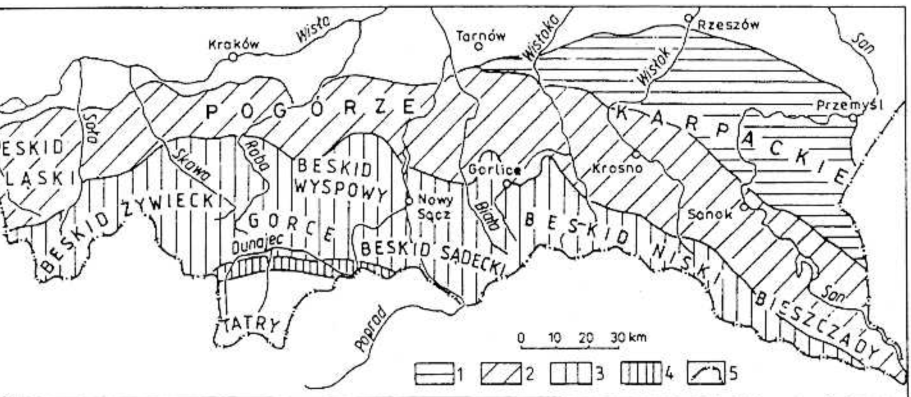

Fig. 1. Geomorphological units of the Flysch Carpathians against the background of ectonics. 1 – Skolska nappe, 2 – Śląska nappe, 3 – Magurska nappe, 4 – the Pieniny, 5 – boundary of Poland

There is a rich literature concerning the origin and classification of floods in land and great floods in Poland were described. There were six (Cebulak 98, Niedbała 1997 and 1998) disastrous floods (in 1958, 1960, 1970, 1973, 96, 1997) in the Polish Carpathians. They caused great changes in relief and stroyed economic infrastructure within reach of the high water. The analysis high water across an extended period of time indicates that heavy and disas-ous rainfalls and floods never affect the entire Carpathian catchment area of e Vistula (Fig. 1) but only particular parts, for example, the western (the Mała isla, the Soła, the Skawa, the Raba), the middle (the Raba, the Dunajec, the isłoka) or the eastern parts (the Wisloka, the Wisłok, the San). Rapid, heavy rainfalls and high waters greatly increase the erosion and denudation on slopes and erosion and accumulation in valley bottoms. This occurs when the stability threshold on slopes is exceeded (Daukszta and Kotarba 1973, Gil and Starkel 1979, Gil 1997, Starkel 1996, 1998 and 1999, Kotarba 1994 and 1998, Bajgier-Kowalska 1996, Ziętara 1968, 1996 and 1998 and others). Gradually increasing precipitation does not initially affect the balance on the slopes because the weathered covers and rocks are able to contain a certain amount of water. During more intensive precipitation erosional and denudative processes become more active, but changes on the slopes remain very small (floods in the Beskidy in 1959 and 1972) until the slope stability threshold is exceeded. When this happens even the smallest increase of precipitation causes very intensive slope processes (floods in 1958, 1960, 1970, 1996 and 1997). The slope stability threshold depends not only on the amount of rainfall, but mainly on the rhythm of precipitation proceeding heavy rainfall, which in turn influences the height and run of the high water level in valley bottoms. The same amount of disastrous precipitation (28-50% of annual average), but a different rhythm of proceeding precipitation causes different forms of slope modelling (Kotarba 1986 and 1994, Ziętara 1997 and 1998).

In high mountains (e.g. Alps, Caucasus, Andes, Himalayas and others) debris and mud flows are frequent and cause great damages in relief (Starkel 1972, Froehlich and Starkel 1987, Ziętara 1976, Graham and Lest 1995, Ibetsberger 1996). They are episodic in the Carpathians (Kotarba 1994 and 1998, Ziętara 1997 and 1998) but significantly influence relief modelling in the region and damage to hydrotechnical, communication and settlement infrastructure. So the paper aims present the potential threats in the Beskidy valleys caused by debris and mud flows and to present prognoses and phases of relief destruction during floods.

POTENTIAL THREATS FROM DEBRIS AND MUD FLOWS IN DIFFERENT MORPHODYNAMIC ZONES IN THE CARPATHIANS

Thick ground or weathered covers provide good conditions for the creation of debris-mud flows. The covers become fluid as a result of soaking with water and flow with great speed down the slopes and into the valleys which separate the Beskidy. The flows are formed when there is a high degree of slope incline and very intensive precipitation or sudden melting of snow fills slope deposits with water. According to the type of slope cover, mud, debris or mixed (mud and debris) flows are created. The types and distribution of slope covers vary according to the morphodynamic zones in the Flysch Carpathians (Starkel 1960 and 1972, Kotarba 1976b, 1986, Ziętara 1989 and others). Four morphodynamic zones can be distinguished in the Carpathians: high montane, middle montane, foreland and submontane zones (Kotarba and Starkel 1972, Ziętara 1976).

The high montane zone (above 1800 m a.s.l.) is more or less situated in the moderate cold and cold climatic zones (Hess 1965). Slope inclination is often higher than 800 and slopes are usually free of any cover or they are covered with a thin weathered mantle. Here, the slopes are cracked and mechanical weathering predominates (Kotarba 1976, Kotarba et al. 1983). Steep slopes are modelled by rockfalls and they are weathered and degradational. Gravitational movement results in the fallen-out material collecting in gullies and at slope outlets to create debris covers. During heavy rainfall the material collected in gullies or on debris slopes is quickly displaced in the form of debris flow. There are different heights in the zone within the north- and south-facing slopes (Hess 1965). The lower part of the zone is above the tree line and covers the belt of dwarf pine alternating with high montane pastures. Slope inclination is usually 50-70° and sometimes even greater. The most common slopes are weathering-gravitational (agradational) ones and gravitational-talus slopes. There are also slopes built of solifluctional covers. Huge landslides (Babia Góra, Pilsko, Tarnica, Halicz and others) and block fields, resulting from deep-seated mass movements exist in that zone (Starkel 1960, Alexandrowicz 1978, Pękala 1969, Ziętara 1989, Henkiel and Terpiłowski 1992 and others). It can be said that the zones which are the most susceptible to displacement from debris flows are those with the greatest amount of loose material. A high degree of incline on slopes dissected by valleys with a high gradient also provides favourable conditions for creation of debris flows in that zone.

The middle montane zone (from 800 to 1800 m a.s.l.) is overgrown with coniferous and mixed forests and slope incline varies from 40 to 60°. In the Polish part of the Carpathians this zone contains the Beskidian slopes. In the Beskidian zone debris and mud flows are created when the outlets of valleys intersect with V-shaped valleys, covered with colluvial deposits (colluvial-agradational slopes), or stone fields created as a result of mechanical weathering (weathering slopes) or development of landslides (colluvial slopes on Babia Góra, Pilsko, the Beskid Wyspowy or Śląski and Mały). Partially preserved landslide niches indicate that colluvial material forms a thick layer (Starkel 1960, Alexandrowicz 1978, Kotarba 1986, Ziętara 1989, Łajczak 1992). Their surfaces consist of angular debris of various sizes including larger rocky blocks. The surfaces of colluvial slopes consist of numerous transversal ramparts, they are step-like and full of depressions without outlets and shallow basins. These depressions are often dissected by V-shaped valleys which cut landslide slopes. In some places, such as valley bottoms, there are great collections of debris and poorly pebbled blocks which are also displaced by debris flows.

The low montane zone (400 to 800 m) is characterized by a slope inclination of 20-45°. The slopes are covered by weathered, solifluctional, colluvial or proluvial covers. They contain more clay than debris material as chemical weathering predominates (Starkel 1960). In this zone flows occur occasionally, mainly in the form of mudflows. Currently slopes are modelled by creeping and sliding (Kotarba 1986, Starkel 1960, Ziętara 1968 and 1988, Bajgier-Kowalska 1994 and 1996).

The slopes in the foreland and submontane zones (to 500 m) are inclined from 5 to 55° and they are covered with thick, clay-dusty covers. Almost the entire zone is used for agricultural purposes. When clay, dusty or sandy deposits are soaked with water they provide good conditions for the mudflows creation. They arise even on slopes with smaller inclinations when the thickness of the deposits is large, when there is strong saturation and the plant cover is poor or destroyed. These forms are very small. Classical mudflows are not created in that zone because slope inclination is small.

PROGNOSES OF RELIEF DESTRUCTION BY DEBRIS-MUD FLOWS

Long term researches on flood results point out that during disastrous floods the stability threshold of relief modelling is exceeded and precipitation and water levels come close to absolute maximum values (Ziętara 1996). Relief modelling is different in the same montane regions when the stability threshold is exceeded, so that six prognoses of relief modelling can be distinguished. The prognoses presented below were prepared on the basis of geomorphological researches on flood results in the years 1958-1960 which were repeated and confirmed during the floods in 1970, 1972, 1996 and 1997. The disastrous floods in the years 1958-1960 were characterized by precipitation and water levels close to the absolute maximum and relief modelling varied (Ziętara 1968).

The first prognosis. A one-cycle, disastrous flood (1958) generally leading to slope dissection and valley deepening and accumulation in basins (Fig. 2). Generally small precipitation but continuous with disastrous heavy rainfall at the end (36 hours of heavy rainfall amounting to 1/3rd of annual average precipitation) caused creation of very high flood waves. Runoff is very quick. This is also caused by great slope inclination and gradient. Runoff on the Beskidian slopes is easier because of spruce trees, the root system of which is shallow and causes small retention (Osuch 1999). The most intensive precipitation and flood waves occur on the same day or with a small delay. The characteristic feature is simultaneous runoff on the whole area, with the result that flood waves overlap and during convergence of tributaries, become higher and more dangerous.

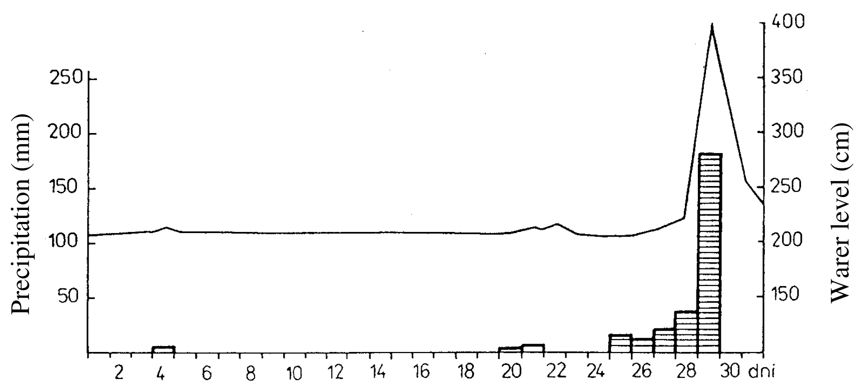

Fig. 2. Precipitation on Pilsko and water level on the Soła in June 1958

Rhythm of precipitation before the heavy rainfall points out for the first prognosis of relief modelling.

Quick runoff of a great amount of water is the result of intensive slope dissection which can be noticed in spring areas and on debris landslide slopes. The majority of landslides are erosionally dissected and modelled by debris and/or mud flows. The surfaces of old landslides are only slightly changed by secondary movements. New landslides are created only on slopes in their lower parts and their origin is caused by intensive slope undercutting by high water carrying a great amount of thick, sharp-edged material. The majority of V-shaped and flat-bottomed Beskidian valleys are modelled by debris-mud flows (Ziętara 1976). During the first stage of a flood erosional waves prevail and debris-mud flows remove the material. At the final stage new debris, neither separated nor bedded, material is deposited and the, deposited surface is similar to great debris-mud avalanche. These valleys are widened and debris or talus cones are formed at their outlets. The phases of erosion and accumulation in the Beskidian valleys change normal V-shaped valleys into chest-like ones.

Stone fields in the main valleys (the Górna Wisła, the Soła, the Skawa, the Raba, the Poprad, the Dunajec) is transported down the rivers by flood waves. In some places river channels were widened by washout, dissecting stone fields or terraces whereas in other places sedimentation processes enlarged terraces and talus cones. It resulted in deepening of the valleys which dissect the Beskidian slopes and accumulation in intermontane and foreland basins (Froehlich et al. 1972, Klimek and Trafas 1972) took place.

The second prognosis. Disastrous floods in two- or more cycles (1970, 1977*)* leads to slope dissection and widespread valley deepening. Relief destruction during the disastrous flood in 1970 was like that in 1958. It was caused by a similar rhythm of precipitation preceding the disastrous flood. Erosional processes prevailed the landslide on slopes during the flood in 1970 (Starkel 1972) and a relatively small number of landslides were formed (Ziętara 1972). The flood in 1970 in the Soła catchment area was two-cyclic and in some catchment areas even three-cyc1ic – after the disastrous flood on 19 July 1970, a smaller high water occured 6 days later in many catchment areas and 10 August 1970 high water levels were again recorded (Fig. 3). These two last mentioned high waters were medium or small during which only terraces were flooded and the stability threshold on slopes was not exceeded. It should be stated that the results of the relief destruction examined in autumn was the sum of two or three floods – the first disastrous and the others medium or small. Similar relief modelling by debris or mud flows took place in 1997 in the Dunajec catchment basin. That flood was also polycyclic as there were four culminations of high water:

- disastrous one July 7-10, the highest flow: in Nowy Sącz - the Dunajec water gauge recorded 2610 m^3/s,
- high water on July 17-24, the highest flow on the Dunajec in Nowy Sącz was 591 m^3/s,
- high water on July 26-28, the highest flow 297 m^3/s Nowy Sącz, the Dunajec profile,
- high water on August 1-4, the highest flow 710 m^3/s (Nowy Sącz profile).

During 28 days, 1 mld m^3 of water flowed through the Nowy Sącz profile on the Dunajec and the amount made 50 % of the average annual flow which is 2 mld m^3/year. The size of flood damages caused by the Dunajec was limited thanks to properly regulated reservoirs in Czorsztyn and Sromowce Wyżne. The greatest damages were recorded in valleys dissecting the Beskidian slopes: the Ochotnica, the Kamienica, the Czarna Woda, the Mordarka, the Słomka, the Smolnik, the Starowiejski Potok, the Łososina and others. The upper parts of these valleys were modelled by structural debris or mud flows (Ziętara 2000).

The third prognosis. Disastrous flood, one-cycle, preceded by long term precipitation (1960) leading generally to surface relief modelling by landslide processes. Though the disastrous precipitation and the highest water level were similar to the situation in 1958, the relief modelling was different. Relief destruction depends on the rhythm of precipitation preceding the flood. Rapid, heavy rainfall preceded by long term precipitation (flood in 1960) and during 24 hours precipitation reached 58.5 mm (Pilsko) but 2 or 5 rainy days were separated by 1 or 2 dry days. These dry days allowed water to soak and it was stored in the ground. The rest flowed away giving higher water levels on some days (Fig. 4).

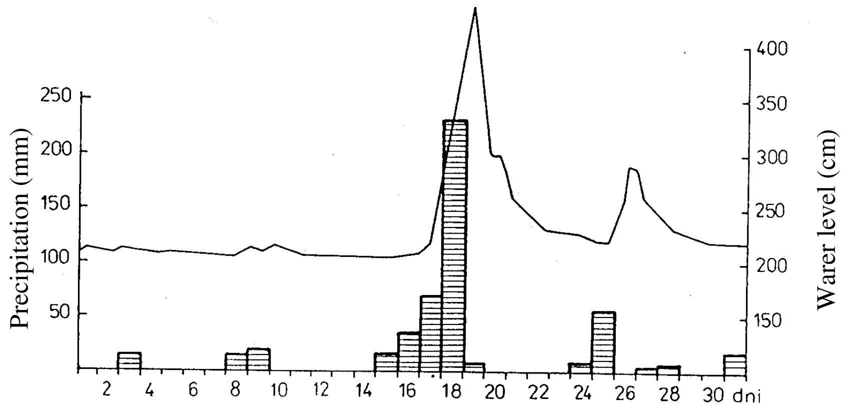

Fig. 3. Precipitation on Pilsko and water level in July 1970 as the example of a two cycle flood, the first disastrous, the second normal

Rhythm of precipitation point out for the first prognosis of relief modelling.

The pattern of precipitation with breaks cause a gentle and slower flow of flood waves (flood in 1960). The flood waves do not overlap and their culmination is more delayed according to the rapid rainfall. A great amount of water stored in the ground caused more intensive slope modelling by landslides. The majority of landslides were rejuvenated by new slidings of rocky and weathered material. New slides also appeared and they enlarged landslide slope surfaces (Ziętara 1964 and 1988). Erosional slope incision is less in comparison to the first stage of modelling. V-shaped valleys are modelled by debris flows which in major part consist of colluvial material. Debris from the bottoms of chest-like valleys was completely removed only in their middle and lower parts in their upper parts it was only partly removed.

The fourth prognosis. Disastrous, polycyclic, during which slopes are modelled by repeated landslide processes. The rhythm of precipitation preceding the flood is similar to the one presented in the third prognosis (Fig. 5), but after the flood there are long, wet periods. In consequence it leads to surface relief destruction by landslide processes and there are secondary movements within them.

The fifth prognosis. Medium and small floods during which only terraces were flooded and slope stability was not disturbed. Prognoses of relief modelling during big, but not disastrous, medium and small floods – flood in 1958, the 2nd and 3rd cycle in 1970 and great areas of the Carpathians in 1972. Slope stability was not disturbed and slope destruction concerns only occasional displacement of rocky-weathered masses. In bottoms of V-shaped valleys material accumulated during previous floods was dissected. In big valleys, on terraces, fine-grained gravel or sandy material was deposited.

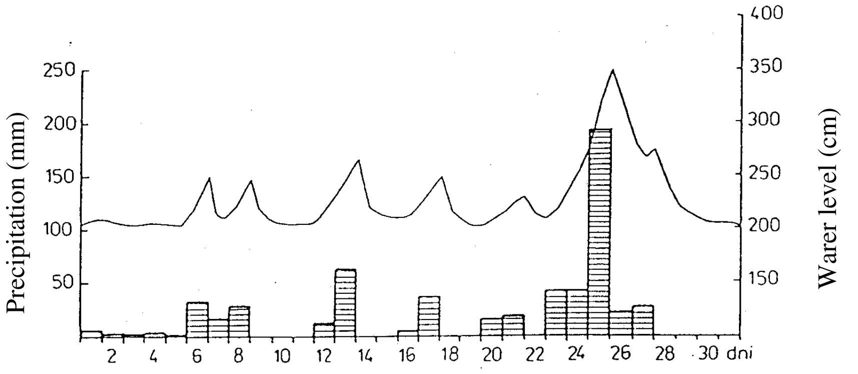

Fig. 4. Precipitation on Pilsko and water level on the Soła in July 1960

Rhythm of precipitation before the heavy rainfall points out for the third prognosis of relief modelling.

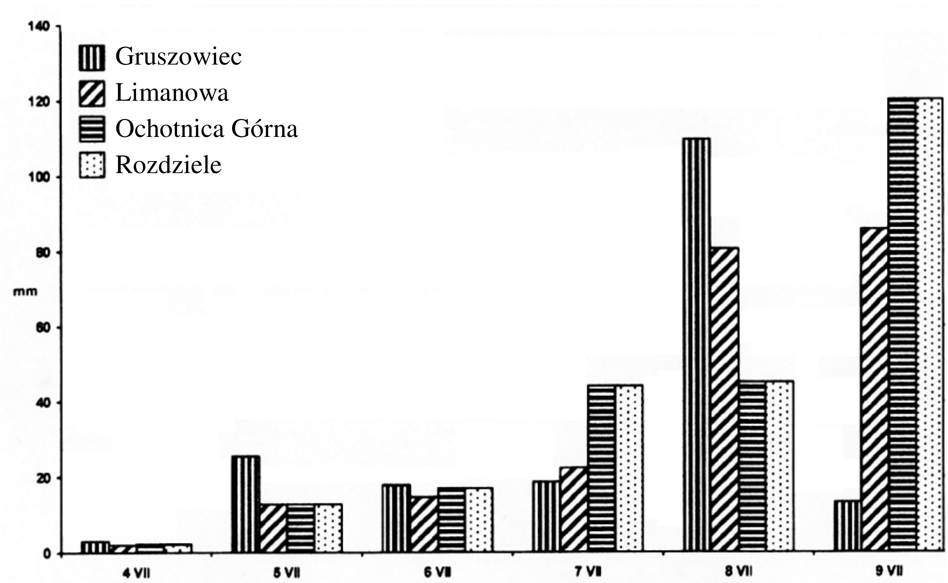

Fig. 5. Disastrous precipitation in the Beskid Wyspowy in July 1997 (Pyrc 2000)

FINAL REMARKS

During long term and heavy precipitation debris and mud flows are indirect links between gravitational movements of rocky masses and fluvial processes and significantly influence the course of erosion, transportation and accumulation in big valleys, to which great masses of material are supplied by structural and turbulentive debris and mud flows. Wet, saturated ground or weathering covers are easily displaced in the form of landslides or rill wash/sheet wash. If debris and mud mass gets into the stream bed, the material is mixed with water making a fluid substance. At first this mass stops making ramparts across the stream. Water gathers up the lobe and then, followed by a loud noise, it begins to move down the valley at a speed of 10-15 km/h. The height of a lobe can reach 5 m above the water level. Displaced material erodes the bottom and the slopes causing undercutting of wet slopes and creation of fall-outs or landslides. The slopes in valley narrowings and river bends are especially affected. As a result, after the first lobe, new ones are created.

This phenomenon can sometimes last for some hours. Thickening of displaced debris and clay occurs and the mass is half plastic or plastic. Everything is destroyed, trees are uprooted and broken. Similar damages affects all constructions made by man. In the upper part of valleys there are structural flows, in the middle and lower parts of flat-bottomed valleys turbulentive flows prevail according to the dynamics of water movement in a river.

Long term and heavy precipitation cause debris and mud flows. They begin during long lasting rainfall ended by rapid, heavy rainfall, with 200-250 mm of rain over 3 days or more than 100-150 mm of rainfall in 2 hours. They also depend on the rhythm of precipitation preceding heavy rainfall.

Each heavy rainfall brings huge economic damage and I present those which occurred after the flood in 1996 as an example. In the area of the former Bielsko-Biała voivodeship the losses were estimated for 27,000,000 USD. The greatest losses were recorded in the Żywiec and Bielsko-Biała regions. The floods covered 420 ha of arable land, 3164 ha of grassland, 2985 buildings, 117 km of local roads together with forest roads, 30 km of country roads and 42 bridges. There were also losses in hydro-technical constructions, river and stream banks and flood-banks. The indirect losses were estimated for 725,000 USD and expenses for flood protection were 610,000 USD.

In the Beskidian valleys with an even gradient (below 10 ‰) and flat, terraced bottoms, each flood caused damage (by turbulentive debris and mud flows) in concrete flood-bends, artificial edges and dams. River channels were widened, slopes were undercut. During floods stone fields are displaced down the valleys and new ones are created whereas flood terraces are made higher by sedimentation of gravel material. On middle terraces sedimention of clay-gravel material, tree trunks and remains from destroyed houses and other constructions takes place. Flood losses (1997) caused mainly by turbulentive and structural debris and mud flows (Fig. 6) in gminas (Chełmiec, Dobra, Kamienica, Laskowa, Limanowa, Łącko, Łososina Dolna, Łukowica, Podegrodzie, Słopnice and Tymbark) in the western part of the Beskid Wyspowy were estimated at 50,000,000 USD.

Flood is a natural phenomenon existing within the long term water circulation, regulating valleys geosystems and ecosystems and that is why they should not be eliminated either in their causes or their results. The course and size of a flood depends on precipitation, the pattern of valleys and the natural conditions of the catchment basin, so all activities should take into account the spatial variety of the phenomena. The areas which can be flooded should be excluded from construction and that would be the best flood protection. It is also very important to regulate flood waves with the help of water reservoirs and bank systems. All technical activities aiming at limiting the course and results of floods should be joined, because this makes it possible to minimize disturbances to the natural systems of water and matter circulation in that way.

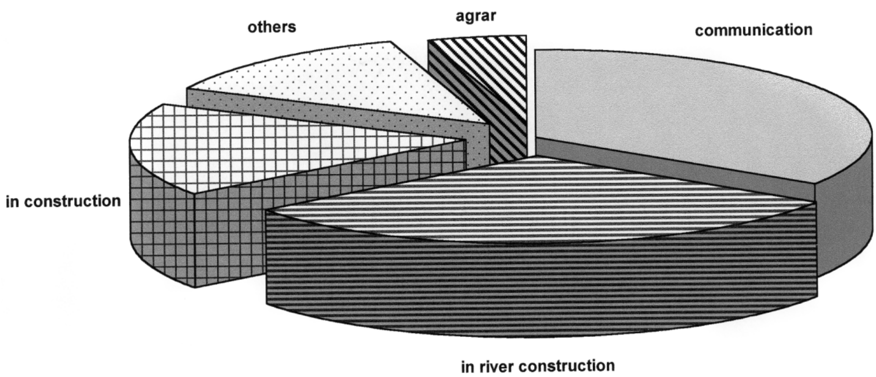

Fig. 6. Flood losses in the Beskid Wyspowy in 1997 (Pyrc 2000)

The magnitude of the flood in 1997 caused huge economic damage greatly exceeding the amount on flood protection activities. Projecting standards should be changed, runoff should be estimated in such a way that high water can flow freely below bridges (Ziętara 1999).

A comprehensive national strategy is needed for such a wide branch as flood protection. It should be a collection of partial strategies used proportionally and in proper sequence. The partial strategies should include the following:

- an investment strategy (structural) aiming at construction of flood control structures: banks, reservoirs, polders, channels,
- an ecological strategy aiming at ”giving back the space to the river” which means that flooded areas should not be built on, to avoid economic, social and ecological damage in the event of floods. The areas of catchment basins should be forested,
- a strategy orientated towards evacuation aiming at preparing a good system of warning and
- an organizational system for evacuation of people, livestock and belongings from the areas threatened by floods,
- an educational strategy aiming at informing people about threats and basic rules of behavour in the event of floods,

- a social strategy aiming at giving the protection activities to local authorities and preparing mechanisms of social protection management in areas they are responsible for.

There is no one optimal protection strategy for the whole country. One strategy will be used in particular towns, another in agricultural areas. The strategy for montane areas depends on the character of catchment basins and valleys character. A narrow river valley is usually built up with houses. A road runs paralel and sometimes even a railway line. In such a situation, besides the investment strategy, other, non investment strategies should be included. At present the prepared General Plans of Communaes should exclude the usually flooded areas from construction purposes. In the event of disastrous floods such a decision reduces the flood and moral losses.

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ÚLOHA SUTINOVO-BAHENNÝCH PRÚDOV V DEVASTÁCII INFRAŠTRUKTÚRY SÍDIEL VO FLYŠOVÝCH KARPATOCH

Hrubá vrstva pôdy alebo zvetralinovej pokrývky vytvára vhodné podmienky pre tvorbu sutinovo-bahenných prúdov. Následkom presiaknutia vodou sa zemina stane plastickou a tečie veľkou rýchlosťou dolu svahmi a ďalej do dolín, rozčleňujúcich Beskydy. Prúdy vznikajú na strmých svahoch, keď veľmi intenzívne zrážky alebo topenie snehu majú za následok nasýtenie svahových sedimentov vodou. Podľa charakteru svahovín vznikajú bahnotoky, sutinové prúdy, alebo kombinované sutinovo-bahenné prúdy. Typ a priestorová distribúcia svahových sedimentov sú odlišné v každej zo štyroch základných morfodynamických zón v Karpatoch, a to vysokohorskej, stredohorskej, predhorskej a podhorskej.

Sutinovo-bahenné prúdy vo flyšových Karpatoch sú súhlasné s morfodynamickými zónami. Ich frekvencia je najvyššia v Beskydách, kde sa na svahoch a v pramenných oblastiach vyskytujú mocné polohy zvetralín a delúvií. Počas extrémnych zrážok sú svahy dolín modelované zosunmi a štruktúrnymi sutinovo-bahennými prúdmi, „V“-doliny a doliny s plochým dnom turbulentnými sutinovo-bahennými prúdmi, vytvárajúcimi veľké kužele.

Možno rozlíšiť tri typy dolín modelovaných sutinovo-bahennými prúdmi: 1) „V“-doliny alebo strže, rozčleňujúce beskydské svahy, vyznačujúce sa veľkým sklonom, často väčším než 100 ‰; 2) veľké doliny s plochým dnom, rozčleňujúce horské chrbty, ako napr. Rycerka, Zlatna, Zabnica, Sopotnia Wielka, Jaworzyna Babiogorska, Rybne, Jalowieckie, Góra Mszanka, Poręba, Starowiejski Potok, Mordarka, Kamienica Górna a iné; 3) hlavné doliny, rozčleňujúce rôzne tektonické a morfologické jednotky (Sola, Koszarawa, Skawa, Dunajec a iné) a doliny so širokým terasovaným dnom a malým sklonom, nepresahujúcim 10 ‰.

Štruktúrne sutinovo-bahenné prúdy sa vyskytujú prevažne vo „V“-dolinách. Beskydské doliny, zberajúce vodu z bočných „V“-dolín, sú modelované turbulentnými sutinovo-bahennými prúdmi. Bočné doliny majú rozhodujúcu úlohu pri povodniach v dnách väčších dolín. Akumulačný materiál je transportovaný skokmi, čo má za následok prehlbovanie dolín, rozčleňovanie beskydských svahov a vypĺňanie predhorských a medzihorských kotlín.

Extrémne zrážky, či už dlhotrvajúce dažde, alebo náhle katastrofické lejaky, iniciujú vznik sutinovo-bahenných prúdov. Spúšťacím mechanizmom týchto prúdov sú teda jednak dlhotrvajúce zrážky s úhrnom 200-300 mm, alebo 2-3 hodiny trvajúce lejaky s úhrnom 100-150 mm. Prúdy tiež závisia od rytmu zrážok predchádzajúcich lejakom.

V Západných Beskydách sa sutinovo-bahenné prúdy následkom dlhotrvajúcich zrážok vyskytli v rokoch 1958, 1970 a 1997, bahnotoky v roku 1960 po mesiac trvajúcich zrážkach s lejakom na ich konci. Za týchto podmienok došlo k modelácii svahov zosunmi, ktoré dodali materiál pre bahnotoky a sutinovo-bahenné prúdy. Najväčšie štruktúrne sutinovo-bahenné prúdy vyvolané lejakmi boli zaznamenané v horských masívoch Beskid Wyspowy a Beskid Żywiecki.

Štruktúrne a turbulentné sutinovo-bahenné prúdy, iniciované dlhotrvajúcimi zrážkami alebo náhlymi lejakmi, predstavujú počas týchto extrémnych udalostí spojovací článok medzi gravitačným pohybom skalných hmôt a fluviálnymi procesmi, ktorý významne ovplyvňuje eróziu, transport a akumuláciu vo veľkých dolinách, nakoľko do nich dodáva veľké množstvo materiálu. Povodňové škody v obciach v oblasti horského masívu Beskid Wyspowy v roku 1997, zapríčinené zväčša oboma spomínanými typmi sutinovo-bahenných prúdov, boli odhadnuté na 50 miliónov USD.