S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
VOL. XXXIII KRAKÓW 1999 PL ISSN 0081-6434

JANUSZ CZERWIŃSKI, ROMAN ŻURAWEK (WROCŁAW)

THE GEOMORPHOLOGICAL EFFECTS OF HEAVY RAINFALLS AND FLOODING IN THE POLISH SUDETES IN JULY 1997

INTRODUCTION

Geomorphic processes, which are directly or indirectly related to surface runoff, belong to the most decisive ones for contemporary landform development in the temperate climatic zone. Here, landform changes of considerable magnitude may result even from a single rainfall event. In particular, geomorphic changes induced by any process, controlled at least partially by gravitation, play a significant role in shaping mountain slopes, since the extent of remodelling is related to slope inclination. Geomorphological effects of surface runoff on both hillslopes and valley floors in the block-faulted mid-mountains, of which

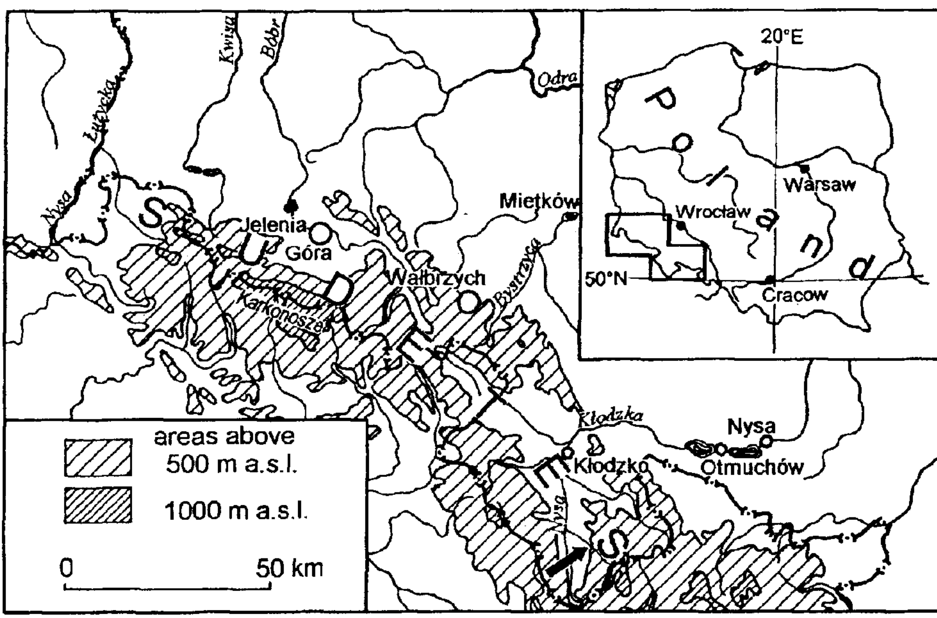

Fig. 1. Location map. The arrow shows Wilczka river

the Sudetes, SW Poland (Fig. 1), are an example, show a certain specificity, which will be examined in more detail in this paper.

Field observations made right after the catastrophic flooding in July 1997 that affected the entire southern Poland, and the catchment of the upper and middle Odra in particular, allow us to reach conclusions about the most important natural and anthropogenic factors influencing the spatial pattern of those geodynamic processes that are causally related to an abnormally high input of water into mountain drainage basins. The locally recorded high magnitude of geomorphic change enables us to identify links between regional relief, land use, hydroengineering, and technical infrastructure and geomorphic processes caused by runoff and flooding, even in the absence of quantitative measurements. Because it would be impossible, and perhaps not practical, to register the effects of flood in each drainage basin affected, we will show the geomorphic impact of heavy rainfall and flood through selected, most representative examples.

Numerous historical documents and systematic hydrological observations conducted in the Odra catchment since the beginning of the 19 Century show that catastrophic floodings, usually caused by rainfall episodes, are not uncommon in the Sudetes (Dubicki 1997). A review of past big floods within the Polish territory as recorded in various historical sources has been provided by Z. Tyszka (1954) and Z. Mikulski (1954), for the Lower Silesia by M. Trzebińska and J. Trzebiński (1954), and for an even smaller area of the Karkonosze Mountains by J. Czerwiński (1991). Among the biggest floods in Lower Silesia are those in: 1320, 1464, 1595, 1729, 1785, 1804, 1813, 1829, 1854, 1893, 1897, 1903, 1938, 1977 and 1985. Although it would be premature to compare the frequency and magnitude of floods based on chronicles alone, it must be emphasised that there were five floods recorded in the 15 Century, 17 in the 16 Century, and 18, 26 and 32 in the following centuries respectively (Trzebińska and Trzebiński 1954). This undoubtedly shows that the phenomenon of flooding has been rather typical for the Sudetes.

THE METEOROLOGICAL AND HYDROLOGICAL BACKGROUND

In the second half of June and the beginning of July 1997 the weather in Central Europe was influenced by atmospheric depressions, accompanied by frontal rainfall zones. June precipitation, although not causing a distinct rise in water level within river channels, resulted in a considerable reduction of natural storage and a rise of groundwater level as compared to multi-annual average (*Powódź opadowa*...1997; Stachý and Bogdanowicz 1997). At the beginning of July, southwestern Poland was located in the border area of a polar maritime air mass from the north and a warm and very humid tropical air mass from the south. The collision of these two air masses generated extraordinarily intense rainfall.

The primary cause of flooding was the first among the three July episodes of very intense rainfall. It lasted from 3 to 10 July, with maximum precipitation between 4 and 8 July. The highest values were recorded in the East Sudetes; in Międzygórze the total rainfall on 5–9 July was 454.8 mm, that is 347.2% of the monthly average (for 1961–1990), in Kamienica 484.3 mm (341.1% of the monthly average), in Stronie Śląskie 367.9 mm (296.7%), in Głuchołazy 307.5 mm (267.4%). On the Czech side of the Sudetes the respective values were even higher, with 512 mm in Jesenik (368.3%) and 586.4 mm (275.3%) at Lysá hora in the Moravo-slezské Beskydy Mts (all the above data after Dubicki 1997). The absolute maximum was recorded in Šance, with 602 mm of rainfall between 5 and 8 July (Munzar et al. 1997). Daily precipitation was in excess of 200 mm, often higher than the monthly averages for July. The area affected by heavy rainfall covered about 12 000 km^2 (Dubicki 1997).

The second rainfall episode took place between 15 and 23 July, with the peak period from 18 to 22 July. This time, the highest level of precipitation was recorded in the Middle and West Sudetes, yet the values were significantly lower than those from the beginning of the month in the East Sudetes. The last rainfall series occurred from 24–28 July, but the intensity of precipitation in south-western Poland was much lower than during any of the preceding events.

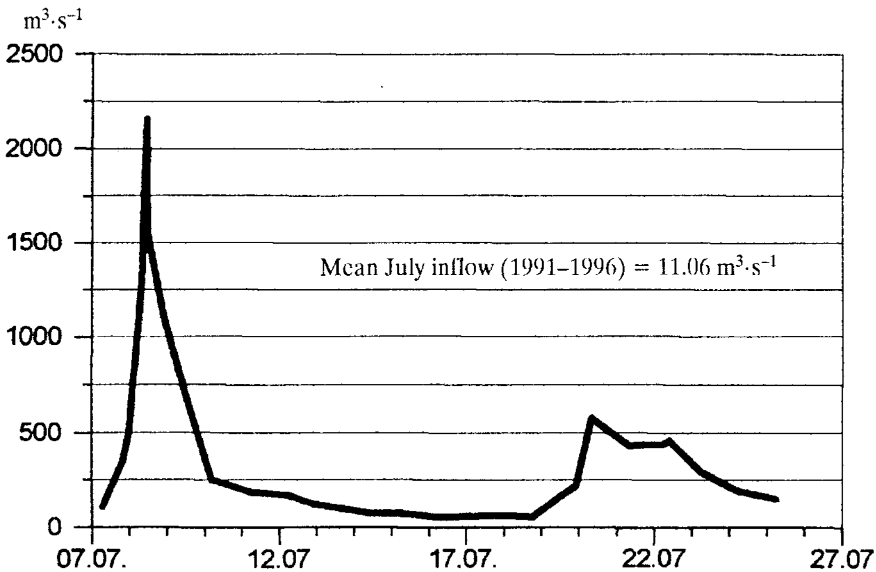

Fig. 2. Generalised diagram to show discharge of Nysa Kłodzka river — inflow to the reservoir of Otmuchów (for location see Fig. 1) during flood in July 1997. Data after Okręgowa Dyrekcja Gospodarki Wodnej (Regional Survey of Water Management) in Wrocław

Abnormally high precipitation in the first decade of July resulted in a sudden rise in water levels in the Sudetic rivers (Fig. 2), which eventually became higher than the absolute maximum values recorded before; similarly, the highest discharges ever have been recorded during the July 1997 flooding. This event affected Czech tributaries of the Odra river, the Odra itself in the upper and middle reach, the Nysa Kłodzka, Biała Lądecka, Ścinawka and Biała Głuchołaska rivers (Dubicki 1997).

A new flood wave was generated by the second precipitation episode in the second decade of July, yet this was of a smaller magnitude than the former one in the East Sudetes, but higher than in the Middle and West Sudetes (Fig. 3). Absolute high water marks were exceeded along, among others, the Bystrzyca, Kaczawa, and Bóbr (gauging stations Jelenia Góra and Dąbrowa Bolesławiecka) rivers, but not on the Kamienna, Kwisa and Nysa Łużycka rivers, although even there the high water levels recorded surpassed emergency levels (Dubicki 1997).

Maximum values of runoff in individual drainage basins within the Odra catchment in July 1997, calculated according to the data published by the Instytut Meteorologii i Gospodarki Wodnej (Weather and Water Management Institute) (Dubicki 1997), approached 2.5 m³/s/km² (2.47 in Żelazno at the Biała Lądecka river; 2.4 in Jugowice at the Bystrzyca river). The values must have been even higher in the small, high-altitude catchments.

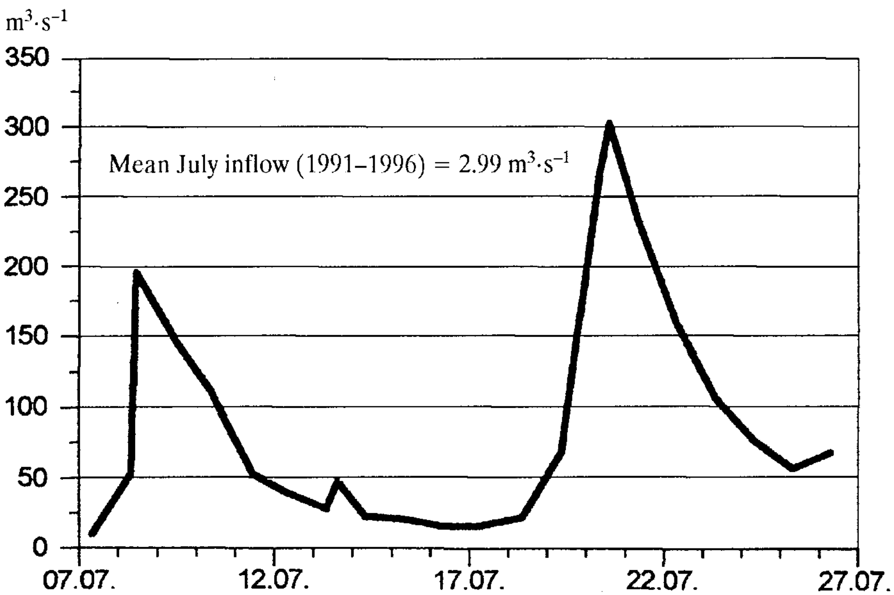

Fig. 3. Generalised diagram to show discharge of Bystrzyca river — inflow to the reservoir of Mietków (for location see Fig. 1) during flood in July 1997. Data after Okręgowa Dyrekcja Gospodarki Wodnej (Regional Survey of Water Management) in Wrocław

GEOMORPHOLOGICAL EFFECTS ON SLOPES

Geological structure is one of the most important factors controlling characteristics of surface runoff on the slopes of the Sudetes. The highest and most extensive mountain ranges of the Sudetes, which receive the most precipitation in the area, are built of crystalline basement rocks. The mantle derived from *in situ* weathering has a variable, yet usually rather good permeability; the granular weathering mantle developed on granite is a good example of this (Tomaszewski 1979). Owe to its regolith characteristics, rainwater infiltrates relatively quickly and, under normal circumstances, surface runoff becomes a very rare phenomenon, except in areas with extensive human interference.

Storage potential in the Sudetes is additionally enhanced because of the occurrence of broad watershed flattenings. Low gradients within upland-top surfaces slow down groundwater circulation in areas which would otherwise have highest precipitation. A specific example of groundwater storage is that caused by water retention in upland peatbogs, which are relatively common in the Izera Mountains, Karkonosze, Bystrzyckie Mountains and Hrubý Jeseník.

Therefore, in spite of an unparalleled amount of rainfall in July 1997, overland flow happened incidentally and at specific localities only. In the subalpine forest belt, on forested and deforested slopes alike, virtually no signs of overland flow have been observed. To some extent, this is caused by the watershed setting of this belt within the most affected area of Śnieżnik Massif. Nonetheless, we must point out that it is the presence of thick undergrowth that has played a decisive role in protecting slope surfaces against erosion. The erosional effects of heavy rainfall in July 1997 have only become visible in places stripped of natural vegetation, such as footpaths, forest tracks and logging tracks. It is there where the process of gully erosion has been most efficient and has achieved impressive results. Concentration of overland flow was taking place entirely along forest tracks (Fig. 4). The most protracted and deepest erosional gullies originated along tracks of the greatest length, and not necessarily within slope sections of the highest gradient. This confirms observations from the flysh-built areas (Słupik 1973), according to which sheet wash on forested surfaces is negligible and slope inclination does not exert any important influence on differences in its magnitude. In the Śnieżnik Massif individual gullies have reached great sizes, up to 4.3 m deep and a few kilometres long. They were initiated on forest tracks and even in watershed areas, and were increasing in size down the slope, culminating in total road destruction. Locally, we may even be justified talking about ravines replacing former forest tracks rather than just about gullies developing along these tracks (Photo 1).

The connection between gully erosion and overland flow on the one hand, and the presence of vegetation cover and slope-crossing roads and tracks on

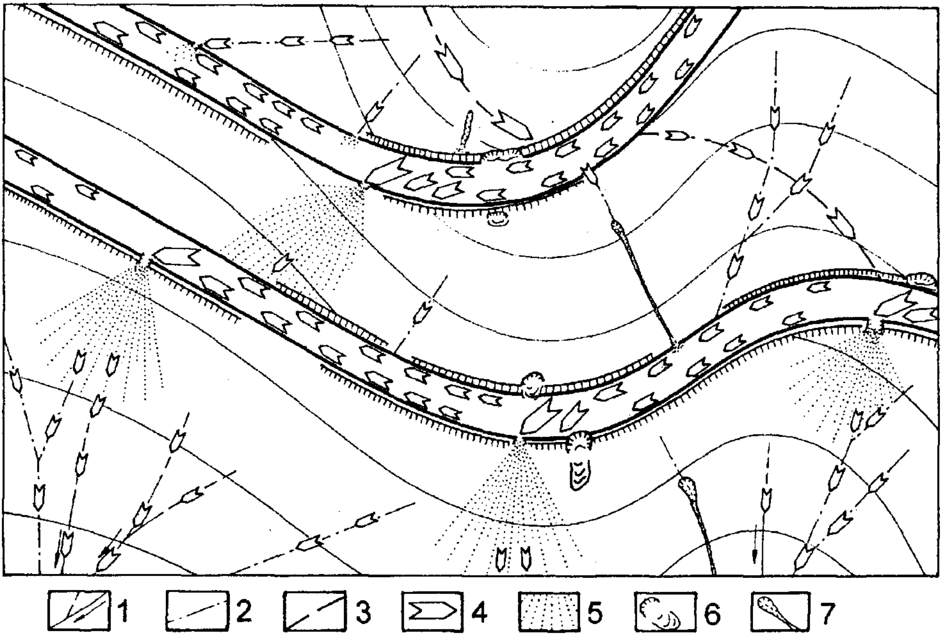

Fig. 4. A cartoon showing organisation of surface runoff on slopes. 1 — perennial and periodic streams, 2 — logging tracks, 3 — footpaths, 4 — gully erosion and resultant forms, 5 — quasi-torrential cones, 6 — landslides, 7 — debris flows. Further explanations in the text

the other, are general rules, applicable also to other areas and less extreme meteorological events. This has been confirmed by observations from the Karkonosze Mountains (Parzóch 1995) and the Beskidy Mountains (Gil and Słupik 1972; Froehlich and Słupik 1986). Besides the Śnieżnik Massif, gully erosion proceeded extremely effectively in the adjacent Bialskie Mountains and the Karkonosze.

The most pronounced geomorphological effects of overland flow and gully erosion have taken place at the outlets of erosional gullies and below the lower limit of the subalpine forest (ca 1,000 m a.s.l.). In many places the layer of undergrowth has been totally stripped, often on the near-surface part of the slope cover (Photo 2). Debris accumulation cones have originated at the terminus of large erosion gullies, although they have lacked the features of typical torrential cones, being discontinuous and rather thin. Coarse debris has been deposited in the form of stripes extending downslope and according to the plane of greatest inclination. Low ridges built of debris and deposited on the proximal side of obstacles — mostly tree trunks — have been another characteristic form. Degradation effects of overland flow have included irregular depressions up to a few tens of centimetres deep, usually located in between tree roots across the entire area affected by surface runoff.

It is symptomatic that no erosion effects of water flow have been observed within valley heads, usually considered to be spring sapping niches. In spite of traces of surface runoff across the undergrowth mat, neither sheet wash nor gully erosion have left their imprint, except in places where valley head morphology has been modified through human interference. In light of the extremely high amount of rainfall recorded it may be assumed that these forms are not being currently shaped, at least not by fluvial processes. It is more likely that their origin should be sought in the specificity of periglacial processes, for instance nivation, and the age ascribed to the Pleistocene.

Mass movements are of rather minor importance in the Sudetes, as compared to the Carpathians for example. Because most of the Sudetic mountain ranges, including the highest one such as Karkonosze and Śnieżnik Massif, are built of crystalline rocks of high shear strength. Hence deep-seated landslides, mud and debris flows and related gravitational phenomena are quite rare. Nevertheless, the July 1997 rains did induce gravitational mass movements under specific circumstances. Small and shallow landslides were fairly common on road embankments and road cuttings. They were restricted to regolith cover and man-made ground; solid bedrock has usually remained unaffected.

Another factor stimulating the downslope movement of water-saturated ground was the lateral erosion of rivers. The undercutting of riverbanks has caused a few landslides of considerable dimensions. The largest one has been

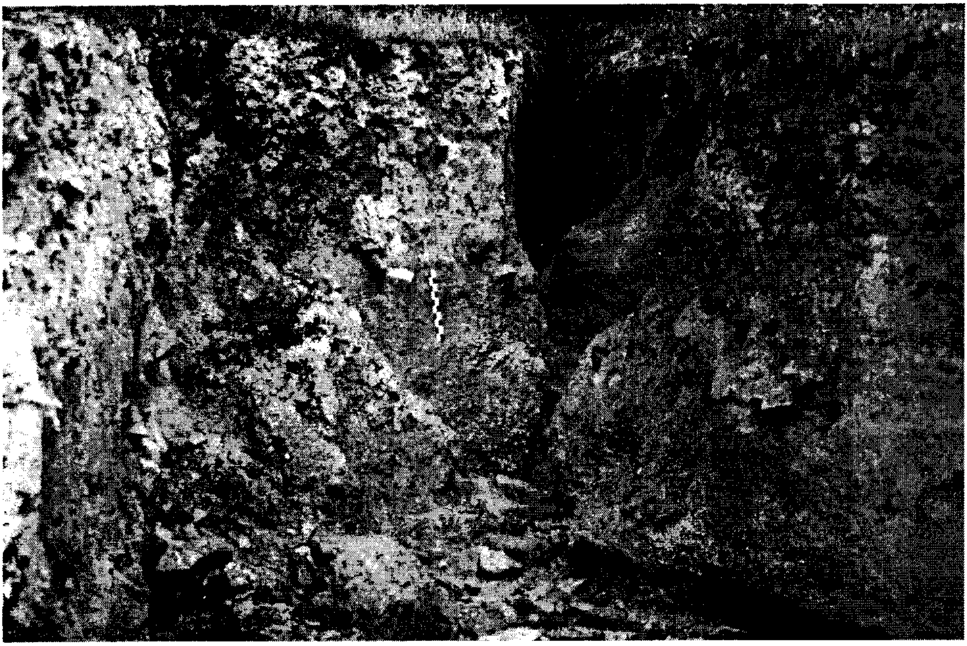

Photo 1. A gully originated in July 1997 replaced a former tourist trail on the slope of Igliczna (845 m a.s.l.), Śnieżnik Massif, East Sudetes. Bar length is 0.5 m (by R. Żurawek)

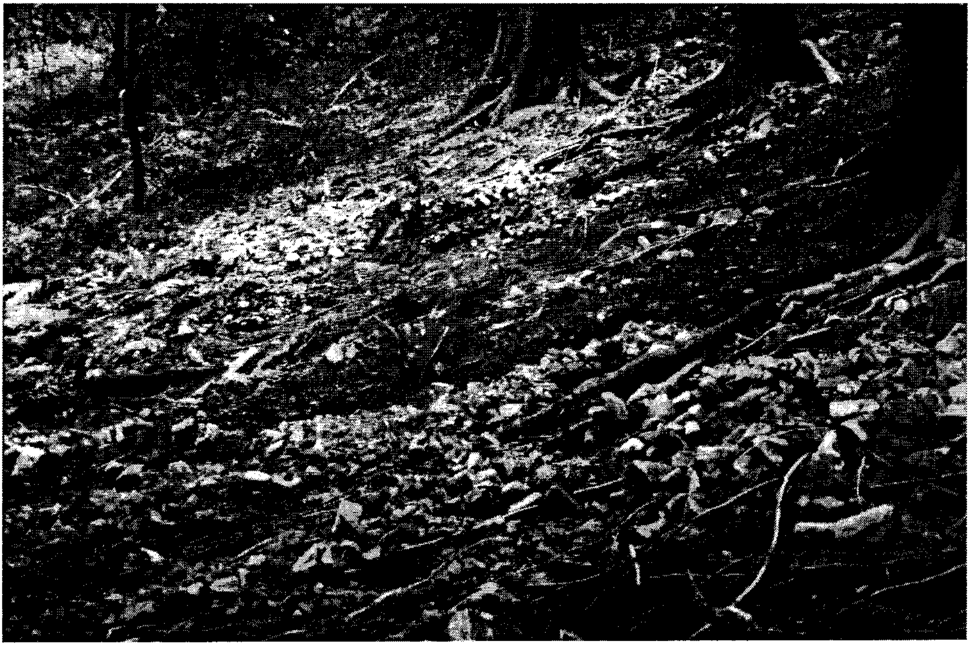

Photo 2. Results of sheet wash below the outlet of gully shown on Photo 1 (by R. Żurawek)

found in the village of Janowiec, at the outlet of the Nysa Kłodzka river, from an antecedent gorge between Kłodzko and Bardo in the Sudetic Foreland. The undermining of the right-hand valleyside resulted in a landslide that affected the metamorphic bedrock, and the terrace gravel, and the overlying slope cover. The width of the landslide head was ca 130 m, its perimeter was 155 m, and the original upper surface was located about 30 m above the valley floor. The landslide mass did not slip into the channel; the vertical displacement was on average of 3 m, up to 4.5 m at most (Photo 3). Other examples include landslides in the Wilczka valley (Śnieżnik Massif), Bielawica valley (Sowie Mts) and Biała Głuchołaska valley, in the gorge-like section upstream of Głuchołazy.

Debris flows are rare in the Sudetes, as are landslides, the glacial cirques in the Karkonosze Mountains being an exception. Considerable slope gradients and large amounts of water coming from upland peat bogs undercut by cirque scars explain the high frequency of debris flows on cirque walls. However, a few large flows were mobilised in July 1997 (e.g. in the Łomniczka cirque and the Czarny Kocioł Jagniątkowski). Smaller debris flows have also been recorded outside the cirques. On the slopes of the Śnieżnik Massif debris flows of saturated regolith have been quite numerous, but once again most occurrences are related to anthropogenic transformation. In almost all cases, the debris flows were following belts of stripped vegetation, most commonly logging tracks (Fig. 4). They were hardly ever longer than 10–20 m, yet longer ones were occasionally recorded. The latter were exemplified by the debris flow which followed a depression between two rocky spurs in the Wilczka gorge, causing the undercutting of the major road to Międzygórze. It was 94 m long and the niche was 15 m wide. Landforms typical for a debris flow have developed such as levees built of coarse material and a furrow reaching down to the bedrock in between. The scar is partially located within a road bank supported by a stone wall, and the presence of this artificial bank was perhaps the necessary factor in producing the debris flow.

In general, however, the dimensions of mass movement-related landforms originating in July 1997, although quite considerable for the Sudetes, were much smaller than those typical in landslides in the Beskidy Mountains (Ziętara 1968), or in debris flows in the Tatra Mountains (cf. Krzemień et al. 1995; Kotarba 1996).

An important part of the lithology in generating mass movements is confirmed by the common occurrence and large dimensions of landslides in the Czech Carpathians in July 1997 (Kirchner and Krejčí 1998) and the patterns of landslides related to flooding in the Bystrzyca Dusznicka river, Middle Sudetes, in 1998 (Żurawek, in print). The latter area is built predominantly of Upper Cretaceous sandstones, mudstones and marls, often dipping in accordance with the level of incline in the valley. In spite of the significantly lower amounts of precipitation than those recorded in the East Sudetes in 1997, gravitational phenomena — chiefly shallow landslides — affected many of the slopes and were not restricted to stream undercutting.

Photo 3. Initial landslide scar in Janowiec near Bardo (by R. Żurawek)

Photo 4. Pillar of a destroyed bridge on Wilczka river, where major avulsion took place (by R. Żurawek)

GEOMORPHOLOGICAL EFFECTS IN RIVER VALLEY FLOORS

The flood in July 1997 was associated with an increase in erosional activity and accumulation within valley floors. Field observations on the geomorphological effects of flooding in the most affected valleys indicate that patterns of erosion and deposition have been controlled primarily by variations in regional topography of the Sudetes. Within elevated areas — usually tectonic horsts — incision predominated, accompanied by mass movement on steep valleysides subjected to fluvial undercutting. By contrast, at the valley outlets towards the intramontane basins lateral erosion and intense overbank deposition played the most important part. A good example of the above regularity can be found in the Wilczka river valley, which was among the most affected by July 1997 flood. Results of the detailed geomorphological mapping of flood-related landform change all along the valley have already been partially published (Żurawek 1998). The Wilczka valley has been studied in detail also because the Wilczka catchment may be regarded as representative of the Sudetes in its overall geomorphology, geological structure, and land use.

The drainage basin consists of two contrasting landscape units, separated by a 200–300 m high escarpment of tectonic origin, that follows the course of the Wilkanów Fault (Wroński 1982). Upstream of the escarpment the drainage basin is mountainous, with the watershed located close to the summit dome of Mt Śnieżnik (1,425 m a.s.l.), at an altitude of 1,410 m a.s.l. Deep V-shaped valleys, arranged in a dendrite pattern, are incised into two levels of planation surfaces (Migoń 1996). Most of the catchment area is forested. At the marginal escarpment the valley floor rapidly widens out, yet the floodplain is bordered by distinct erosion scarps which indicate an incision into older fluvial and slope deposits. Watershed surfaces in the fore-mountain part of the catchment are gently rolling and almost the entire area is used for agriculture, chiefly as arable land.

The diversity of geomorphological processes within the Wilczka catchment during the July 1997 flood, and their varied intensities, were controlled by the shape of the valley cross-section and the valley slope (Fig. 5). Erosional activity in the upper part of the catchment has resulted in the evacuation of older alluvial fill and rock floor incision; the depth of the latter may be easily estimated as up to 1.5 m within slightly weathered bedrock. The ability of water to displace and move bed material has also been considerable, as indicated by the 4.8 m long boulder, originally located on a small channel bar in the village of Międzygórze, that has been moved 3.5 m downstream. The length of displacement can be inferred from the position of a commemorating plaque on the boulder.

Lateral erosion in the mountainous part of the catchment has been recorded less frequently, and its effects have been rather insignificant. The river was neither able to spread its channel nor create new channels, because of the very narrow valley bottom. Slopes, covered only by a relatively thin mantle of debris served to limit lateral erosion. In places where lateral erosion did occur, however, shallow slumps were activated. Similarly, overbank deposition has been of minor importance, despite the presence of local levees built of coarse debris that could have reached as much as 1 m high.

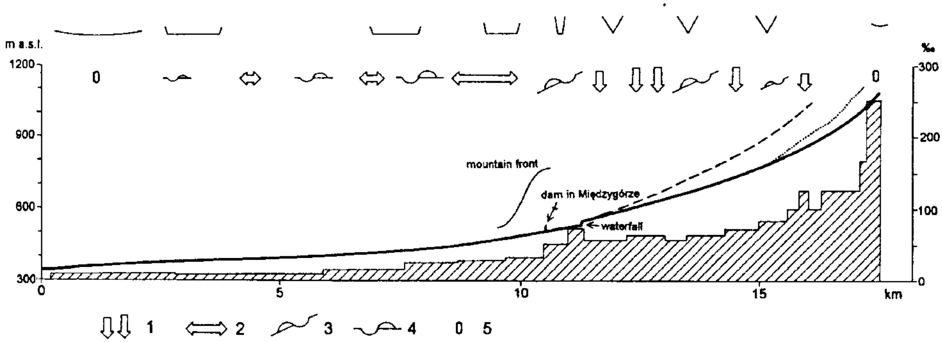

Fig. 5. Longitudinal profile of Wilczka river and its two tributaries: Bogoryja (dashed line) and Czarna (dotted line), valley slope of Wilczka (bar chart, individual bars for 25 m high intervals), general shape of valley cross-section (upper symbols) and dominant geomorphological processes during July 1997 flood (lower symbols). 1 — downcutting, 2 — lateral erosion, 3 — mass movements, 4 — overbank deposition, 5 — no significant change

At the outlet of the valley from the mountainous part lateral erosion accompanied by, and causally linked with, overbank deposition (see for instance Kaszowski and Kotarba 1970) has clearly been dominant. The river channel has changed its position within the valley floor within the 1 km long section, shifting 150–300 m sidewards (Fig. 6). Moreover, a number of ephemeral braided channels have been incised, most of them abandoned immediately after the passage of a flood wave. Boulder deposition typified the inter-channel areas and the former floodplain, where preserved, has been covered by gravel and boulders up to 0.5–0.7 m in diameter. Pebbles building channel bars could not have been transported over long distances and perhaps were moved downstream by as little as a few tens of meters. The presence of a dam in the village of Międzygórze (see Fig. 5) acting as a trap for sediments coming from the mountainous part of the catchment is an indicator of the very local provenience of pebbles and gravel in the downstream section of Wilczka. It was a local alluvial cover, deposited at the mountain front, that provided the source of sediment for overbank deposition. According to A. K. Teisseyre (1979), who observed flood-induced river transformation on an alluvial fan from a single channel into a braided one, such a phenomenon is most efficient from the geomorphological point of view. It may be considered an initial, rather short-lasting phase of a specific fluvial cycle, whose essence is the transformation of one of the flood braided channels into an incised sinuous channel, and later into an "incised meander belt". Undoubtedly, a road bridge (Photo 4) located at the apex of the alluvial fan acted as a trigger for avulsion, because of the logs and debris jamming it and causing an increase in water level. Further downstream, similar channel displacements and zones of intense lateral erosion have been observed in a few more places, although the lengths of the newly created channels were smaller. Erosional effects have become most pronounced at bridges. Besides lateral erosion on the outer banks of meander bends, meander cut-offs and overflow channels within meander bars have been recorded. Because of the specificity of fluvial processes in a high-energy mountain environment, the floodplain of Wilczka does not bear all the erosional and depositional landforms that are characteristic of lowland alluvial rivers (cf. Gonera et al. 1985). For instance, lateral levees, crevasses and crevasse cones could not been demonstrated; instead, fan-like gravel spreads elongating according to the direction of centrifugal force have been common.

Very efficient lateral erosion and overbank deposition within the transitional section of the Wilczka valley at the mountain/basin junction (Fig. 6) have resulted in heavy economic loss in the village of Wilkanów, located downstream from the mountain front. Ten houses have been completely destroyed or considerably damaged (*Wykaz rodzin*... 1997), as have been many farm buildings and a more than 1 km long section of the main road.

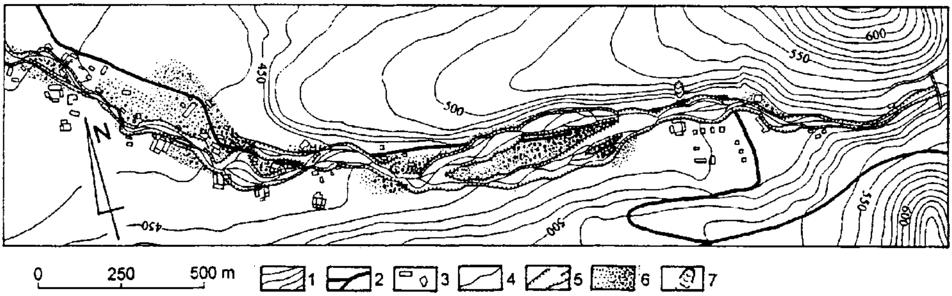

Fig. 6. Erosion and accumulation effects in the valley floor of Wilczka, immediately downstream of mountain front. 1 — contour lines, 2 — roads, 3 — buildings, 4 — permanent and braided flood channels, 5 — erosion scarps, 6 — sand, gravel, pebble accumulation, 7 — landslides

We do not know precisely the water levels and discharges of the Wilczka river in July 1997, because of the demolition of the gauging stations within the catchment. Nevertheless, according to personal communication with the staff of a dry reservoir in Międzygórze regarding the water levels observed, the maximum discharge of the Wilczka on 6/7 July 1997 surely exceeded 75 $m^3 \cdot s^{-1}$ (*Instrukcja*... 1988). Assuming that the discharge a few kilometres downstream, at the mountain front could not have been much higher than that estimated for Międzygórze, the conditions necessary for a significant geomorphic impact of flood may be assessed. The most marked changes have been recorded along the valley section, whose slope varies from 30‰ to 60‰. The channel itself is rather straight, and the floodplain is built of coarse gravel and boulders. It is worth mentioning in this context, that erosional effects, including those of lateral erosion, on a small Flysh Carpathian stream characterised by a flood discharge of 75 $m^3 \cdot s^{-1}$, (similar to that estimated for Wilczka), have also been recorded at a channel gradient of 30‰ (Gil 1998). Although the efficiency of erosional processes is controlled by a number of factors, the relationship between both valley slopes, as well as shape of the valley bottom (Fig. 5) and the magnitude of lateral erosion seems to be clear enough.

Where the longitudinal gradient of the Wilczka river was smaller than 30‰, geomorphic effects were of a considerably smaller magnitude, although localised lateral erosion and deposition of gravel and sand bars on the floodplain were present. Close to the river mouth, the geomorphic consequences of flooding were rather insignificant, the only related landforms being widespread, but thin veneers of sand.

Observations made along the Wilczka river valley are paralleled, to various degrees, in other Sudetic valleys, which cut mountain fronts and were affected by flood in July 1997. These include other right-hand side tributaries of the upper the Nysa Kłodzka river (e.g. Goworówka — Photo 5, Pławna), Nysa Kłodzka itself at the marginal escarpment of the Sudetes, or rivers draining the Sowie Mountains. Yet these regularities do not appear clearly in river valleys and drainage basins of

Photo 5. Effects of lateral erosion in the channel of Goworówka within the alluvial fan at the valley outlet from the Śnieżnik Massif (by R. Żurawek)

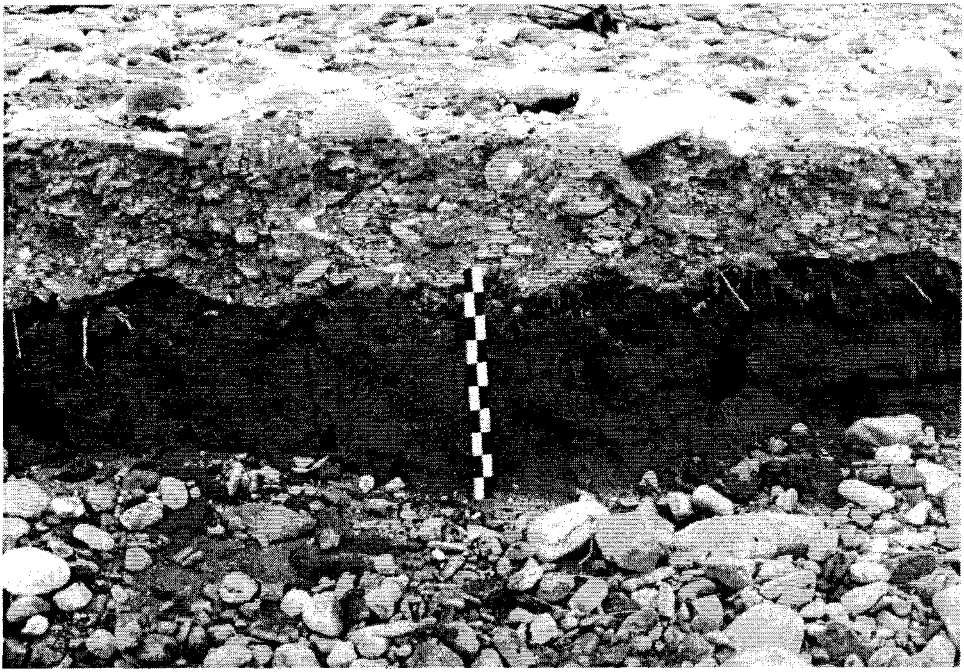

Photo 6. Gravel deposition on a terrace surface of Biała Lądecka river used as an arable land in Żelazno, Kłodzko Basin. Bar length 0.5 m (by R. Żurawek)

complex morphology, geological structure and land use, such as Biała Lądecka, Biała Głuchołaska, or Łomnica and Kamienna in the Karkonosze Mountains. Considerable geomorphic changes have been recorded in those valleys as well (Photo 6), in many cases, however, it would be premature to advance any model explaining spatial differences in geomorphological effects.

FINAL REMARKS

The scale of geomorphological consequences of abnormally high precipitation and related flooding in July 1997 provides a confirmation of general validity of the magnitude-frequency relationship. This event, although rare, has played a very significant part in the transformation of slopes in valley floors in the affected catchments. The spatial diversity of flood effects is related to two principal factors, regional relief in macroscale, and human interference in meso- and microscale.

Most spectacular changes of valley morphology have been identified immediately downstream from topographic escarpments, separating mountain ranges and intramontane basins, on alluvial fans. These are caused by lateral erosion and overbank deposition. The formation of wide erosional surfaces during the flood, subsequently covered by coarse bed-transported material, is typical for alluvial fan river sections below mountain fronts within the entire Holocene (Starkel 1972). Downcutting predominates in deeply incised valley sections within mountainous areas, and is capable of totally scouring the alluvial fill and significant incising the bedrock.

Slope processes, including gully erosion, overland flow, and mass movements, are enhanced by human interference, landforms, and vegetation changes. Due to the concentration of flow, forest tracks, footpaths and logging tracks channel runoff and become lines of erosion, whilst sheet rock plays a significant part downstream from the lower termini of gullies. Technical infrastructure especially bridges which are not prepared for very high discharges, multiply the effects of lateral erosion and overbank accumulation, which are responsible for the largest geomorphic changes in valley bottoms.

ACKNOWLEDGEMENT

The authors wish to thank Dr Piotr Migoń for translation of the text into English.

Department of Geomorphology
Geographical Institute
University of Wrocław
Pl. Uniwersytecki 1
PL 50-137 Wrocław 56

REFERENCES

Czerwiński J., 1991. *Powodzie w rejonie Karkonoszy od XV w. do czasów współczesnych.* Acta Univ. Wratisl. No 1237, Prace Inst. Geogr., ser. A, t. 6, 85–104.

Dubicki A., 1997. *Charakterystyka procesu formowania oraz przebieg powodzi i osłony hydrologicznej w dorzeczu Odry,* [in:] *Forum Naukowo-Techniczne — Powódź 1997. Wstępna ocena przyczyn, rozmiarów i skutków,* Ustroń k. Wisły, 10–12 września 1997, 59–90.

Froehlich W., Słupik J., 1986. *Rola dróg w kształtowaniu spływu i erozji w karpackich zlewniach fliszowych.* Przegląd Geogr. 58, 1–2, 67–87.

Gil E., 1998. *Spływ wody i procesy geomorfologiczne w zlewniach fliszowych podczas gwałtownej ulewy w Szymbarku w dniu 7 czerwca 1985 roku.* Dokumentacja Geogr. 11, 85–107.

Gil E., Słupik J., 1972. *The influence of the plant cover and land use on the surface run-off and wash-down during heavy rain.* Studia Geomorph. Carpatho-Balcanica 6, 181–190.

Gonera P., Kijowski A., Zwoliński Z., 1985. *Powezbraniowe formy akumulacyjne na terasie zalewowej Warty i Parsęty w świetle analizy zdjęć lotniczych.* Fotointerpretacja w geografii 8 (18), 24–42.

Instrukcja gospodarki wodnej, eksploatacji i utrzymania — suchy zbiornik przeciwpowodziowy Międzygórze. Okręgowa Dyrekcja Gospodarki Wodnej we Wrocławiu, Wrocław, 1–47.

Kaszowski L., Kotarba A., 1970. *Wpływ katastrofalnych wezbrań na przebieg procesów fluwialnych (na przykładzie potoku Kobylanka na Wyżynie Krakowsko-Częstochowskiej).* Prace Geogr. 80, 5–87.

Kirchner K., Krejčí O., 1998. *Charakteristika jevů způsobených extrémními srážkami v roce 1997 na vsetínsku: návrhy řešení způsobených škod.* Geological Research in Moravia and Silesia in the year 1997, 5, 103–108.

Kotarba A., 1996. *Współczesne procesy rzeźbotwórcze,* [in:] *Przyroda Tatrzańskiego Parku Narodowego,* Tatrzański Park Narodowy, Kraków — Zakopane, 125–137.

Krzemień K., Libelt P., Mączka T., 1995. *Geomorphological conditions of the timberline in the Western Tatra Mountains.* Zesz. Nauk. UJ, Prace Geogr. 98, 153–170.

Migoń P., 1996. *Zarys rozwoju geomorfologicznego Masywu Śnieżnika,* [in:] *Masyw Śnieżnika. Zmiany w środowisku przyrodniczym,* Wydawnictwa PAE, 35–45.

Mikulski Z., 1954. *Katastrofalne powodzie w Polsce.* Czasopismo Geogr. 25, 1–2, 380–396.

Munzar J., Ondráček S., Táborská J., 1997. *Disastrous floods in Moravia and Silesia in July 1997 (A preliminary report on their causes, course and losses).* Moravian Geographical Report 2/1997, 5, 44–59.

Parzóch K., 1995. *Wstępne uwagi nad rozwojem erozji pokryw stokowych w Karkonoszach,* [in:] *Geoekologiczne problemy Karkonoszy,* Materiały z sesji naukowej w Borowicach, 13–15 X 1994, Wydawnictwo „Acarus", Poznań, 21–23.

Powódź opadowa w lipcu 1997 r. Gospodarka Wodna 8/1997, 227–228.

Słupik J., 1973. *Zróżnicowanie spływu powierzchniowego na fliszowych stokach górskich.* Dokumentacja Geogr. 2, 188 pp.

Stachý J., Bogdanowicz E., 1997. *Przyczyny i przebieg powodzi w lipcu 1997 r.* Gospodarka Wodna 11/1997, 344–350.

Starkel L., 1972. *Trends of development of valley floors of mountain areas and submontane depressions in the Holocene.* Studia Geomorph. Carpatho-Balcanica 6, 121–133.

Teisseyre A. K., 1979. *Przebieg zjawisk erozji i sedymentacji w środowisku rzek górskich,* [in:] *Powódź w 1977 roku i jej skutki na Dolnym Śląsku,* Sesja Naukowa, 3 marca 1978 r., Polska Akademia Nauk, Oddział we Wrocławiu, Wrocław, 59–67.

Tomaszewski J., 1979. *Przepuszczalność wodna karkonoskich gruntów.* Problemy Zagospodarowania Ziem Górskich 20, 103–126.

Trzebińska M., Trzebiński J., 1954. *Zagadnienie powodzi na Dolnym Śląsku.* Gospodarka Wodna 4/1954, 146–150.

Tyszka Ż., 1954. *Powodzie w Polsce i ochrona przed nimi w zarysie historycznym.* Gospodarka Wodna 4/1954, 144–146.

Wroński J., 1982. *Objaśnienia do Szczegółowej Mapy Geologicznej Sudetów 1:25000, Arkusz Domaszków.* Wydawnictwa Geologiczne, Warszawa, 1–58.

Wykaz rodzin z terenu gminy Bystrzyca Kłodzka, których budynki zostały zniszczone wskutek powodzi w dniach 7–8 VII 1997 r. lub nie nadają się do zamieszkania. Biuletyn Bystrzycki, Informator Samorządowy 4/24/1997, 6.

Ziętara T., 1968. *Rola gwałtownych ulew i powodzi w modelowaniu rzeźby Beskidów.* Prace Geogr. 60, 116 pp.

Żurawek R., 1998. *Geomorphological effects of catastrophic flooding in a small drainage basin in European Mid-Mountains.* Geomix — glasilo Študentske sekcije ljubljanskega geografskega društva 4/1, 24–31.

Żurawek R., in print. *Zmiany erozyjne w dolinach rzek Sudetów kłodzkich wywołane powodziami w lipcu 1997 r. oraz w lipcu 1998 r.* Problemy Zagospodarowania Ziem Górskich.

STRESZCZENIE

J. Czerwiński, R. Żurawek

GEOMORFOLOGICZNE EFEKTY ULEWNYCH OPADÓW DESZCZU I POWODZI W LIPCU 1997 W SUDETACH POLSKICH

Powódź, która objęła zlewnię środkowej i górnej Odry, w tym Sudety, w lipcu 1997 r. była największym odnotowanym na tym terenie od początku systematycznych pomiarów hydrologicznych wezbraniem. Obserwacje poczynione bezpośrednio po powodzi, w szczególności kartowanie jej geomorfologicznych skutków w dolinie Wilczki — jednego z dopływów górnej Nysy Kłodzkiej, pozwalają na wskazanie uwarunkowań przestrzennego zróżnicowania procesów związanych z anormalnie wydajnymi opadami deszczu oraz wywołaną nimi powodzią w środowisku średnich gór. Mimo bardzo dużego przychodu wody, zmyw powierzchniowy i erozja rynnowa przekształciły stoki wyłącznie tam, gdzie zniszczona została naturalna pokrywa roślinna, tj. na szlakach zrywkowych oraz drogach i ścieżkach leśnych. Procesy masowe, takie jak osuwiska i spływy gruzowo-błotne, najczęściej zachodziły również na powierzchniach przekształconych antropogenicznie, a ponadto na zboczach dolin podcinanych erozyjnie przez rzeki. Zróżnicowanie przestrzenne procesów fluwialnych wykazuje wyraźny związek z makrorzeźbą Sudetów. Erozja wgłębna zachodziła najintensywniej w górnych odcinkach dolin, w obrębie czytelnych w morfologii horstów. Erozja boczna i towarzysząca jej intensywna akumulacja pozakorytowa dominowały natomiast niepodzielnie u wylotu dolin z górskich części zlewni do kotlin śródgórskich. Największe przeobrażenia den dolinnych, polegające na formowaniu przez rzeki wielokorytowych łożysk erozyjnych i zasypywaniu dna doliny różnofrakcyjnymi aluwiami bliskiego transportu miały miejsce na stożkach napływowych, formowanych u podnóży krawędzi morfologicznych.