STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
VOL. XXXIV KRAKÓW 2000 PL ISSN 0081-6434
LANDFORM EVOLUTION IN EUROPEAN MOUNTAINS ISBN 83-86726-96-2

JOLANTA ŚWIĘCHOWICZ (KRAKÓW)

THE THRESHOLD CONDITIONS FOR SLOPE WASH PROCESSES IN THE FOOTHILL CATCHMENT (CARPATHIAN FOOTHILLS, SOUTH POLAND)

Abstracts. This paper presents rainfall conditions for slope wash occurrence on the experimental slope in a foothill catchment of the Stara Rzeka River and differences in the amounts of the transported material in ralation to parameters of rainfall (frequency, amount, intensity and duration). Threshold values of rainfall initiating runoff and slope wash on the slope are different for particular segments on the slope profile, which confirms that the processes of erosion and transport of the material are not simultaneous during the same slope wash event. Threshold values of rainfall change during the year depending on the condition of the soil (vegetation stage, soil moisture, freezing) at particular segments on the slope profile. Three threshold values of the rainfall important for the morphodynamics of the catchment were distinguished. The probability of exeeding the third threshold value, which triggers overland flow and slope wash on all the slopes in a catchment, decreases together with an increase in the area of the catchment.

Key words: Threshold values, slope wash, soil erosion, landuse effects, Carpathian Foothills

INTRODUCTION

In a temperate climate zone, water is the main geomorphological factor. As a result of morphogenetic processes, the slope and the bed in a catchment are transformed after exceeding threshold values for the dynamics. This dynamics is first of all influenced by variable weather conditions and agricultural use of the catchment, connected with crop rotation and the vegetation season (e.g. stage in vegetation, different density of plant cover). Other conditions connected with landforms, geology and soil cover are relatively stable.

The fundamental factor in water circulation in a catchment is precipitation. However, not only the amount of precipitation is decisive as far as morphogenetic effectiveness of water is concerned, but also its type (rain or snow), distribution, and especially such features like the frequency of rainfalls of different amount, duration and intensity of particular events during the study period (Wit-Jóźwik 1977). The occurrence of morphogenetic processes and their effectiveness in a catchment is different in space and variable in time.

Geomorphological literature on morphological role of rainfall in relief modelling in different regions is abundant including works by L. Starkel (1972, 1976, 1979a, 1979b, 1986, 1996, 1997, 1998); E. Gil and L. Starkel (1979); A. Kotarba (1994, 1998) and W. Froehlich and L. Starkel (1995). The role of morphological processes in relief transformation is intrinsically linked with their duration. L. Starkel (1986) distinguishes in an annual cycle secular processes (characterised by small intensity but long duration) and episodical processes (occurring seldom and lasting for several hours or days). To this group belong first of all extreme events of high intensity and small frequency (once a year at the most).

Processes of particular types may occur only if hydrometeorological threshold values are exceeded (Selby 1974; Kotarba 1994, 1998; Starkel 1996). If those values are established, the frequency of the events as well as the probability of their occurrence can be estimated (Kotarba 1998). L. Starkel (1986, 1996) determines three fundamental types of rainfalls during which threshold values in the Carpathians are exceeded. Local, short-lasting downpours (amount of 30–70 mm, intensity of 1–3 mm · min^{-1}) trigger intensive slope wash, soil flows and in the Tatras debris flows. Continuous rainfalls (150–400 mm in 2–5 days if the rainfall intensity does not exceed 3–12 mm · $hour^{-1}$) lead to earth slides, transformation of river channels and of floodplains. Rainy seasons with precipitation amounting to 100–500 mm a month lead to saturation of soil and deep landslides.

Exceeding threshold values which trigger catastrophic processes may lead to disturbance in metastable dynamic equilibrium in a catchment (transformation is possible in both slope and channel systems) (Starkel 1986; Kotarba 1990; Froehlich and Starkel 1995). Processes which are intensive but short (catastrophic) have a direct influence on relief transformation, while secular processes smooth form shapes (Kotarba 1990).

The research conducted so far by various authors shows that there is not a single threshold value which triggers a process. Every region has its own characteristics of weather conditions or landforms. Actual effectiveness of a particular rainfall depends on relief, plant cover, soil cover and soil moisture in the period just before a process takes place (Kotarba 1998). Also stability of forms is important, which depends on the time which has passed since weathered covers were formed (in case of high-mountain slopes) (Kotarba 1998) or on the long-lasting agricultural cultivation (in case of foothill slopes) (Kaszowski 1995b).

One of the most important morphogenetic processes is slope wash, that is the process of transport of surface soil downslope by running water which happens periodically (Klimaszewski 1978). Thus the neccesary condition for a process to occur is rainfall, although not every rainfall triggers slope wash (Święchowicz 1995, 1998).

Slope wash depends on the one hand on meteorological conditions, that is rainfall (its frequency, amount, intensity and duration) and temperature of the air, and on the other hand, on geological structure, relief, soils and land use (Gerlach 1966, 1976; Gil and Słupik 1972; Słupik 1973, 1981; Gil 1976, 1986; Święchowicz 1995, 1998).

This paper presents rainfall conditions for slope wash occurrence on the experimental slope in a foothill catchment of the Stara Rzeka River and differences in the amounts of the transported material in ralation to parameters of rainfall (frequency, amount, intensity and duration). Also the results of heavy rainfalls which took place in April and June 1998 are discussed. On the basis of the results obtained, three threshold values important for morphodynamics in a foothill catchment have been determined. The research was conducted as part of the research program of the Field Research Station of the Institute of Geography of the Jagiellonian University in Łazy (Kaszowski 1991, 1995a).

STUDY AREA

The Stara Rzeka catchment is situated on the edge of the Carpathian Foothills, in the northern part of the Wiśnicz Foothills. The dominant type of relief are low and medium hills (Święchowicz 1991, 1992; Kaszowski, Święchowicz 1995; Fig. 1).

The research of slope wash was carried out in the Dworski Potok sub-catchment (0.3 km^2), which is part of the Stara Rzeka catchment. The area is characterised by a typical low foothill relief (Święchowicz 1991, 1992; Fig. 1A, B).

The investigation was carried out on the slope profile, which is 133 m long, from the local watershed divide (245 m a.s.l.) to the bottom of the valley (231 m a.s.l.). The slope is convex-concave and N-exposed. The angle of the upper part of the slope is 6.5° while that of the lower part is 4.5°. The slope steeply (14°) changes into the valley bottom which is filled with both alluvia and deluvia an cut by the Dworski Potok channel (Fig. 1C). The slope is covered with pseudogley soils (*Stagnic Luvisols*) (Skiba 1992). The analysed slope was used as pastureland except for the tree-covered edge at the border between the pastureland and the valley bottom. The valley bottom has rich meadow-type hydrophilous vegetation.

The research into the effects of the heavy rainfall which took place in April 1998 was carried out in the Brzeźnicki Potok sub-catchment (1 km^2) (Fig. 1). It is situated 225–295 m a.s.l. This area is covered mainly by the so-called loess-like deposits. The dominant relief type of the Brzeźnicki sub-catchment are low hills. The valley bottom of the Brzeźnicki Stream is flat, wide and wet. The inclination of the slopes is 3–12°. The Brzeźnicki catchment is cultivated. Arable land constitutes 65% of the area, grasslands and pastures 22.4%, forests only 0.4% (Święchowicz 1992). The present plot layout is a result of the medieval system of plots. The fields are long, narrow and separated by boundary strips. They stretch from the watershed

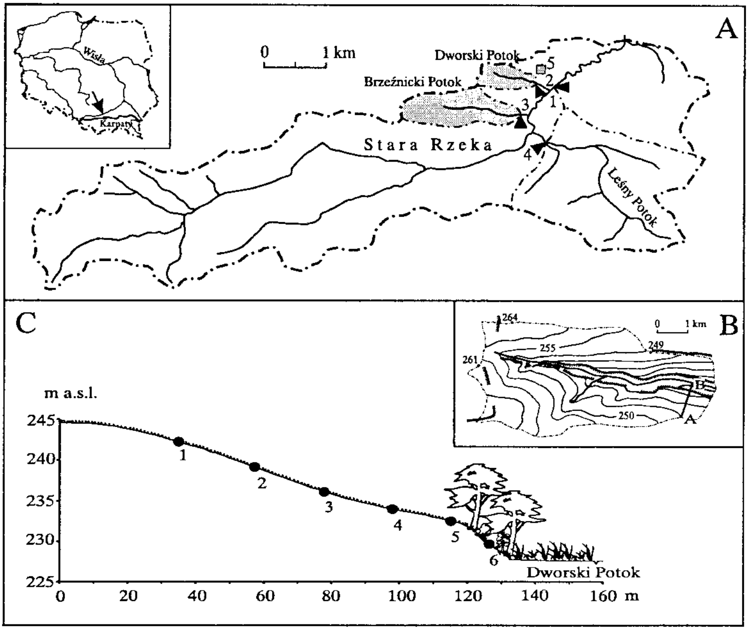

Fig. 1. Location of the study area. A. 1–4 — water gauges, limnigraphs: 1 — the Stara Rzeka Stream (the Research Station Łazy), 2 — the Dworski Stream, 3 — the Brzeźnicki Stream, 4 — the Leśny Stream, 5 — the Pumpkin Field; B. the Dworski Stream sub-catchment: AB — examined profile; C. Longitudinal profile of the examined slope

divide to the valley bottom. The fields are traditionally plaughed along the slopes. Typical for the Brzeźnicki Potok catchment is high density of cart roads and tracks (3.6 km · km^{-2}) (Święchowicz 1992).

The research into the effects of extreme rainfall, which took place in June 1998, was conducted in one of the sub-catchments of the Stara Rzeka River (the Pumpkin Field), periodically drained, which covers the area of 0.06 km^2 (Fig. 1). The sub-catchment, whose ranges of altitude are 227.5–242.5 m a.s.l., has low foothill relief. The inclination of the slopes is 3–6°. The whole area of the sub-catchment is agriculturally used. The most common crops were pasturable pumpkins, cucumbers and strawberries.

STUDY METHOD

The research was carried out on the experimental slope from August 1989 to October 1990 at six measuring sites located 35, 58, 78, 98, 115 and 127 m from the watershed divide respectively. The sites 1–5 were located on the pastureland, the site 6 — on the tree-covered edge. At the end of all the experimental fields, 1 m-long Gerlach troughs were placed (Gerlach 1966).

The measurements of the amounts of the slope wash material were taken after each rainfall.

The characteristics of the rainfall conditions were established by using the method of single rainfall analysis created by K. Wit-Jóźwik (1977). The method consisted in describing features of particular rainfall events like their amount, mean intensity and duration.

This paper presents the results of the research into the impact of heavy rainfalls in sub-catchments of the Stara Rzeka, namely the Brzeźnicki Potok and Pumpkin Field.

FREQUENCY OF SLOPE WASH EVENTS

The days with precipitation constituted 42.4% of the study period, but the number of days on which slope wash occured covered only 6.1% (for the pastureland) and 3.0% (for the tree-covered edge).

The number of slope wash events was different at all the sites. The largest number of slope wash events (26) took place in the pastureland — at the site 1 (closest to the watershed divide) and at the site 5 (furthest from the watershed divide). The smallest number of slope wash events (19) took place at the site 2. At the site 6, situated on the tree-covered edge, there were only 13 such events (Fig. 2).

The largest number of slope wash events at all the sites were brought about by medium rainfalls (5–10 mm). They initiated similar number of the events at all the sites except for the site 4 (within the footslope flattening) and the site 6 (within the tree-covered edge), where the number was the smallest (Fig. 2A).

With different number of soil wash events at particular sites, the percentage of events caused by medium rainfalls in the total number of the events ranged from 42.1% (at the site 2) to 23.1% within the tree-covered edge. The second largest number of events were triggered by rainfalls amounting to 20–25 mm. They all produced the same number of events (4). The rainfalls of the amounts of 10–15 mm and 15–20 mm (medium heavy) relatively often caused the soil wash events. In such intervals of precipitation, the greatest differences in the number of events at particular sites took place. Small and very small rainfalls (0–5 mm) just like heavy and very heavy rainfalls (>30 mm) caused an insignificant number of slope wash events. During rainfalls exceeding 20 mm, the number of slope wash events was the same at all the sites. The differences in the number of the events in the slope catena are significant in case of the events triggered by small and medium rainfalls. However, the differences apply only to the middle segment of the slope ("belt of active erosion") and the beginning of the "belt of deposition" (Święchowicz 1998). However, at the site 1 (in the top part) and the site 5 (the footslope part), the pattern of slope wash events of particular frequency was exactly the same. However, the results

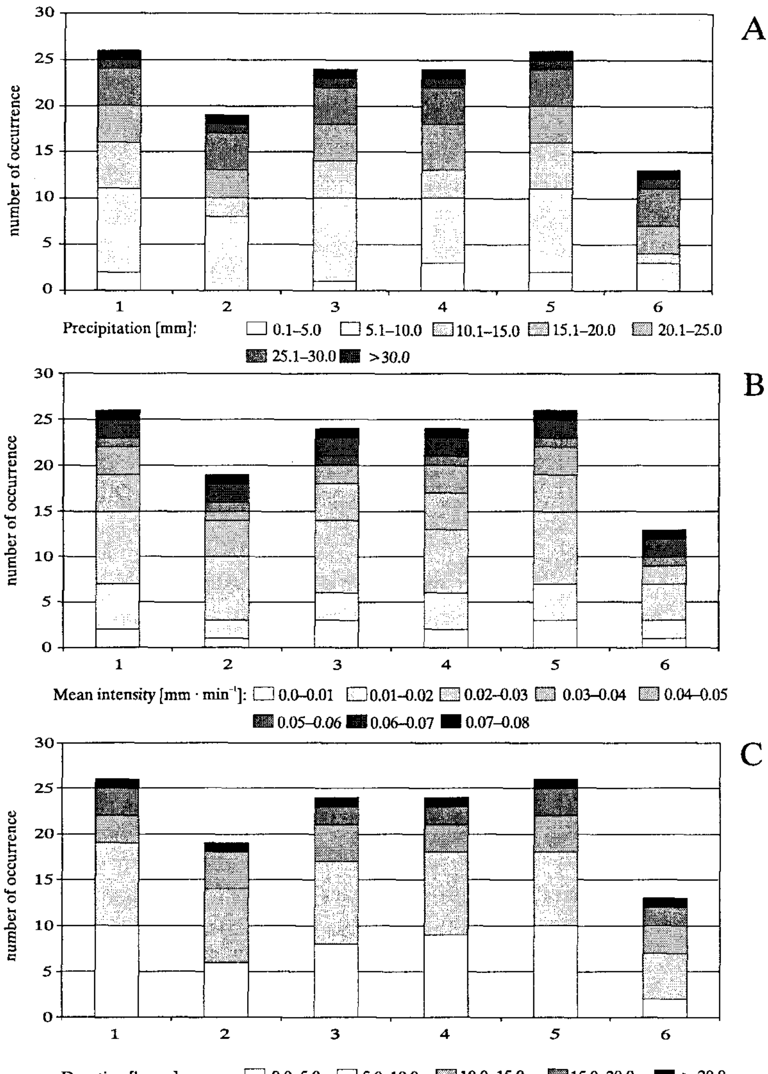

Fig. 2. Number of soil wash events at particular sites on the experimental slope in August 1989–October 1990 produced by rainfalls of variable sum (A), mean intensity (B) and duration (C)

obtained at the site 6 (within the tree-covered edge) were totally different. The number of the slope wash events was the smallest and dominant were the events caused by rainfalls above 20 mm (Fig. 2A). This amount of rainfall seems to be important, because above this value the number of soil wash events was the same at all the sites. During rainfalls below 20 mm, the number of slope wash events was different in relation to the morphological location of the sites; during rainfalls above 20 mm, the number was similar.

The largest number of slope wash events at all the sites (except for the site 3) was caused by rainfalls, whose intensity ranged from 0.02 to 0.03 mm · min^{-1}. The percentage of the events triggered by rainfalls of such intensities was from 37% (at the site 2) to 29% (at the site 4) of the total number of occurrences.

The number of slope wash events caused by rainfalls of low intensities (below 0.03 mm · min^{-1}) was different at particular sites. The largest differences took place in the middle part of the slope ("belt of active erosion"). Similar differences were observed during rainfalls of 0.03–0.05 mm · min^{-1}, especially in the middle part of the slope. Rainfalls with intensities above 0.05 mm · min^{-1} initiated the same number of events at particular sites (Fig. 2B).

During rainfalls lasting up to 5 hours, the differences in the number of slope wash events were the largest. This applies particularly to the middle part of the slope. At the site 6, events caused by rainfalls longer than 5 hours were dominant (Fig. 2C).

THE AMOUNTS OF SLOPE WASH MATERIAL

Transport of the material on the slope was different in the slope catena. The smallest amount of the material (24.7 g) was measured at the site 1, the largest (52.6 g) at the site 4. The amount of the transported material increased down the slope to the site 4, located 98 m from the watershed divide. In the lower part of the slope, at the site 5, the amount of the transported material decreased almost to the value for the site 1. At the site 6, located within the tree-covered edge, the amount of the material was insignificant and 73 times lower than in the middle part of the slope (Fig. 3A). The transported material was accumulated at the footslope (sites 4 and 5) and at the border of the pastureland and the tree-covered edge (Fig. 3A).

Transport of the material on the slope during particular slope wash events was more differenciated (Fig. 3B). The material was transported in a step-like mode and its amount either increased or decreased together with rise in the distance from the watershed divide (Fig. 3B). The shape of the curve for transport for the whole period of study (Fig. 3C) was the resultant of 28 single curves.

Although the experimental slope where the research was conducted is short and has the same geological structure and soil cover, two segments have different morphometric features and are differently used. They are the upper, longer part of the slope (120 m) used as pastureland, and the bottom, short tree-covered edge (13 m). The research carried out so far suggests different functioning of the two segments.

In the upper part the slope wash was small ("belt of no erosion"). The process was more intensive in the middle part of the slope ("belt of active erosion"). The transported material was accumulated at the footslope ("belt of deposition") and at the tree-covered edge. The tree-covered edge was a barrier preventing the material from reaching the valley bottom and the Dworski Potok channel (Fig. 3A).

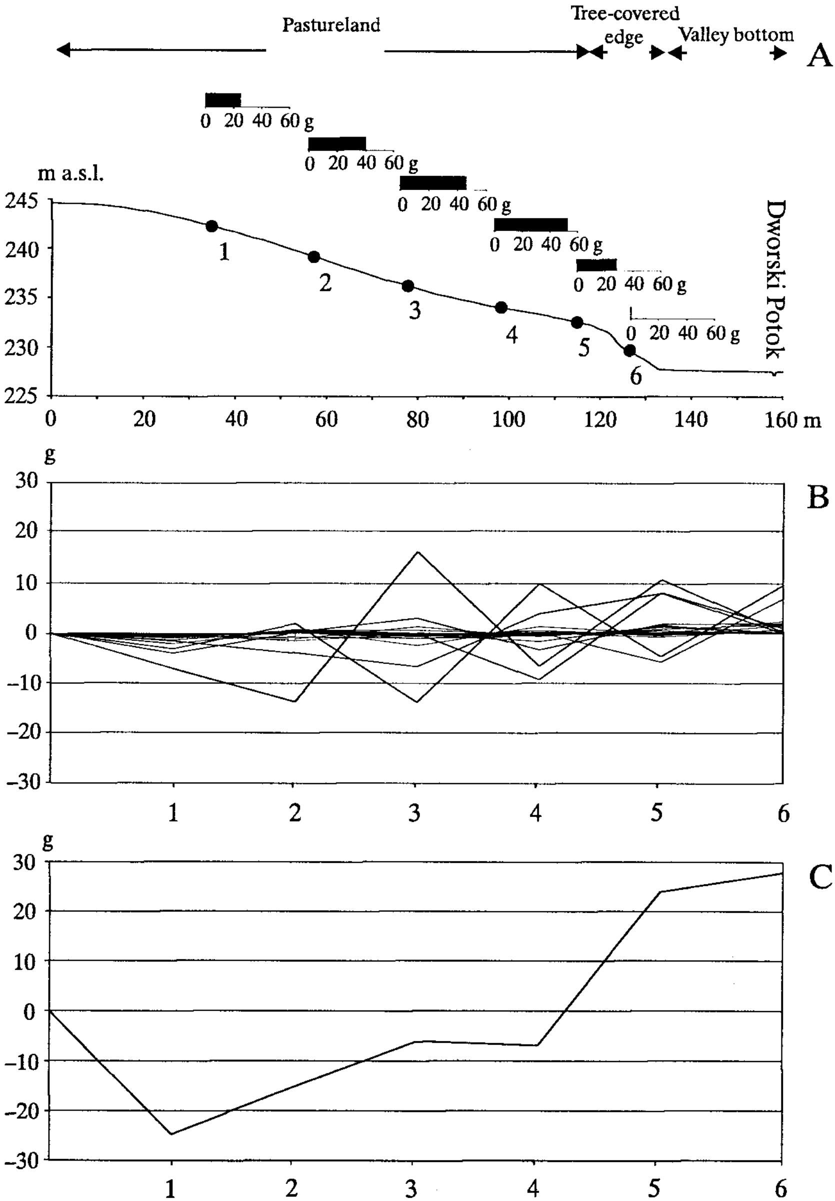

Fig. 3. Soil wash on the experimental slope. A — total amount of soil wash at particular measuring sites in August 1989–October 1990; B — transport and deposition of soil material on particular slope segments in August 1989–October 1990; C — transport and deposition of soil material on particular slope segments during single soil wash events

RAINFALL CONDITIONS FOR SLOPE WASH TRANSPORT

The amount of the transported material, just like the number of the slope wash events, was different in the slope catena during rainfalls of different parameters.

The largest amount of the material was transported down the slopes during rainfalls of 15 mm (Fig. 4.1B), and the amount of the transported material depended on slope shape. During rainfalls of 15–20 mm, the largest amount of the material was transported in the lower part of the slope ("belt of deposition"). During rainfalls of 20–25 mm the largest amount of the material was transported within the pastureland at the sites 3 and 5, and the more so within the tree-covered edge. Rainfall of 25–30 mm caused transport of the largest amount of the material at the site 2 in the "belt of active erosion" (almost 53%) (Fig. 4.1B). Within the tree-covered edge, 86.1% of the material was transported during slope wash events caused by rainfalls of above 20 mm (Fig. 4.1B).

The largest amount of the material was transported during events triggered by rainfalls of 0.03–0.04 mm · min^{-1}, where the amounts of the transported material were different in the slope catena: the largest (21.3%) at the site 2, the smallest (8.3%) at the site 3 (Fig. 4.2B). A relatively large amount of the material was transported during events triggered by rainfalls of 0.05–0.06 mm · min^{-1}. The largest (15.1%) at the site 3, the smallest (1.2%) at the site 2. Similarily significant differences took place during events caused by rainfall of 0.06–0.07 mm · min^{-1} (Fig. 4.2B).

The largest amounts of the material were transported during rainfalls lasting from 5 to 10 hours. They constituted from 21.4% (at the site 2) to 84.3% (at the site 5) of the total amounts of the transported material. Subsequently, during rainfalls lasting from 10 to 15 hours, from 11.5% (at the site 5) to 57.0% (at the site 2) respectively. The rainfalls of such duration brought about 50% of all the slope wash events, during which at all the sites along the slope almost 3/4 of the total amount of the material were transported. Within the tree-covered edge the largest amount of the material was transported during rainfalls lasting from 5 to 10 hours (Fig. 4.3B).

On the pastureland rainfalls of 0–15 mm triggered at all the sites from 50 to 60% of all the slope wash events, but they were responsible for the transport of only about 10% of the total amount of the material. Rainfalls of 15–25 mm triggered at all the sites 20–30% of all the events, transporting 70% of the material on the slope. Events caused by rainfalls of above 25 mm constituted slightly above 10% of all the slope wash events, transporting 10–20% of all the material (Fig. 4.1A, B). Within the tree-covered edge, rainfalls of above 20 mm bring about transport of 85% of all the transported material.

Thus "small events" were the most numerous, but their morphological effectiveness was very small. On the other hand, slope wash events triggered

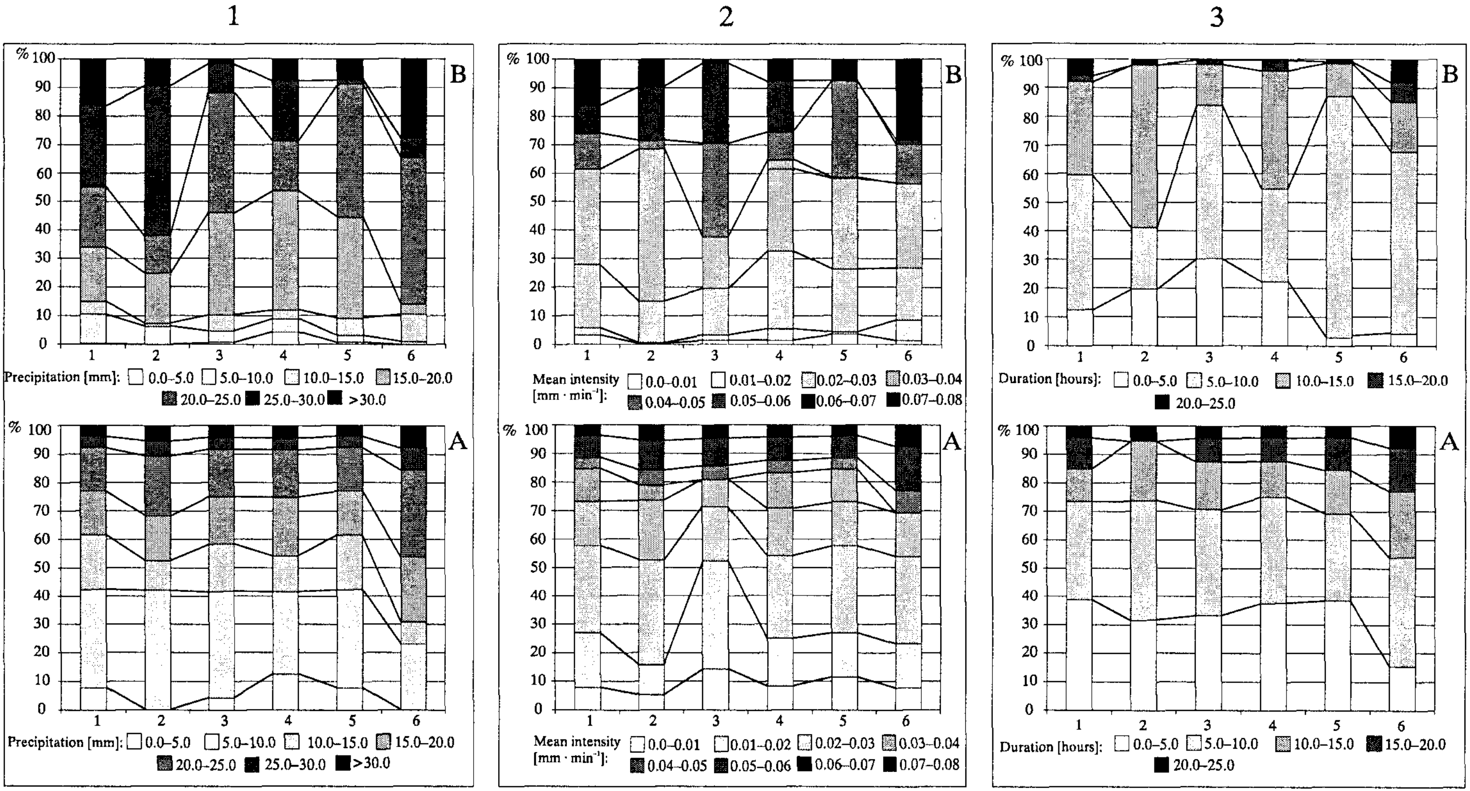

Fig. 4. The number (in %) of soil wash events (A) and the amount (in %) of slope wash material (B) at particular sites on the experimental slope during rainfalls of a different amount (1), mean intensity (2) and duration (3)

by the largest amounts of rainfalls were rare. Morphological effectiveness of particular events was relatively large. However, because they constituted only a small percentage of the total number of the events, their role in transport of the material on the slope was relativelly small. The largest amounts of the material were transported during "medium" events, which took place relatively often, with each event triggering transport of relatively large amounts of the material. The large number of the events did not mean that they had big morphological effectiveness. Rainfall of the same parameters did not bring about the same number of the slope wash events at particular sites and the morphological effectiveness of those events was different in the slope catena. At the site 2, within the "belt of active erosion", the number of the events was the smallest but their morphological effectivenes was significant. In this part of the slope there needed to be higher threshold values of rainfall to initiate the process.

At each measuring site a threshold value of amount, intensity and duration of the rainfall can be established, below which a large number of single slope wash events transport a relatively small amount of the material. Above this threshold value a relatively small number of the events transport the majority of the material at all the sites on the experimental slope (Figs 5, 6, 7).

The amount of the rainfall of 15 mm was significant. The number of the events brought about by rainfalls of the amount lower than 15 mm was from 54.2% to 61.5% at particular sites on the pastureland. During those events from 7.3% to 15% of the material was transported (Fig. 5). Rainfalls of intensities below 0.03 mm $\cdot$ min^{-1} caused more slope wash events, but transported small amounts of the material (Fig. 6). During slope wash events brought about by rainfalls of particular duration, the threshold values were different at particular sites. At the sites 1, 3, 5 and 6, the threshold value for the rainfall duration was up to 5 hours (Fig. 7).

MORPHOLOGICAL EFFECTIVENESS OF SLOPE WASH EVENTS

In the slope catena for particular segments of the slope threshold values of amount, intensity and duration can be established. They are decisive for the intensity of the slope wash process, which is significant from the morphogenetic point of view. Above the threshold value, the percentage of slope wash events is small but the percentage of the transported material is large. Below that threshold value, the relation between the number of the events and their morphological effectivess is reverse: rainfalls trigger a large percentage of the slope wash events, during which a small amount of the material is transported. The threshold values for particular segments of longitudinal slope profile are different.

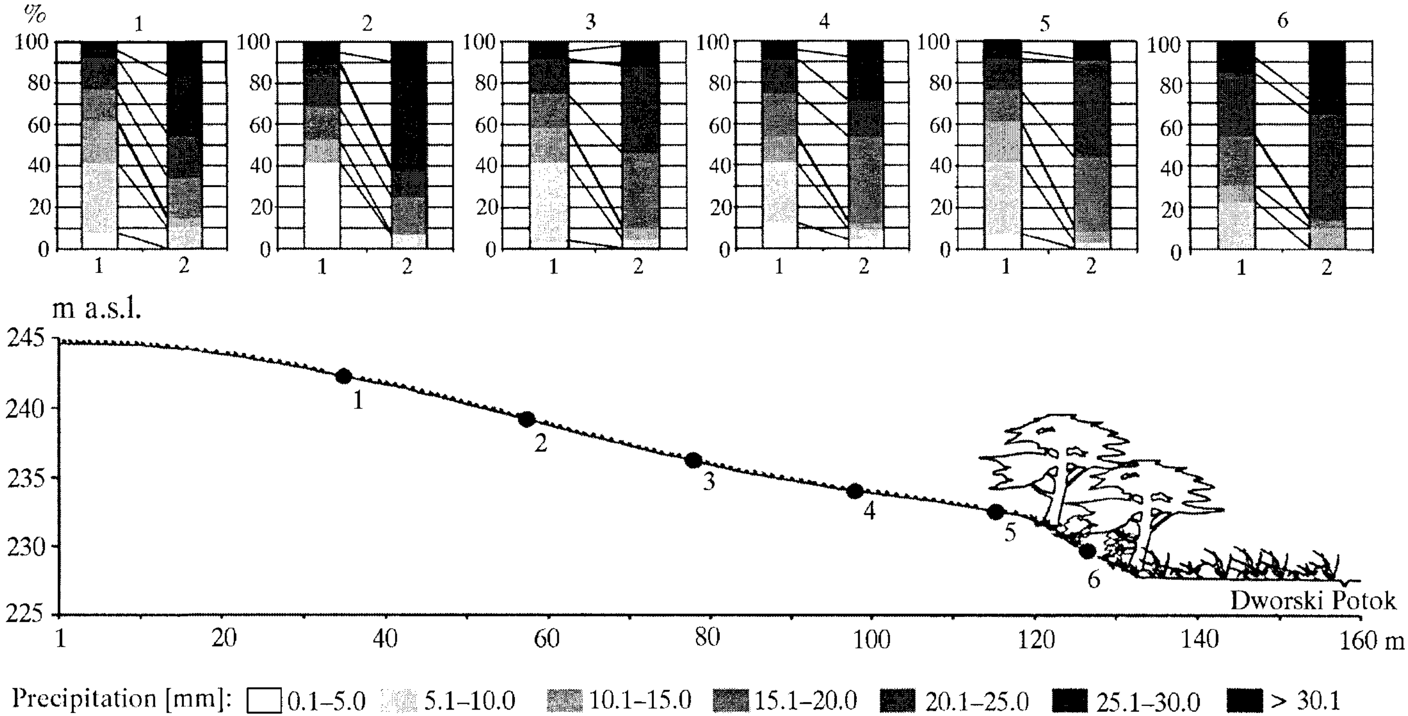

Fig. 5. The number (in %) of soil wash events (1) and the amount (in %) of slope wash material (2) at particular sites on the experimental slope during rainfalls of a different amount

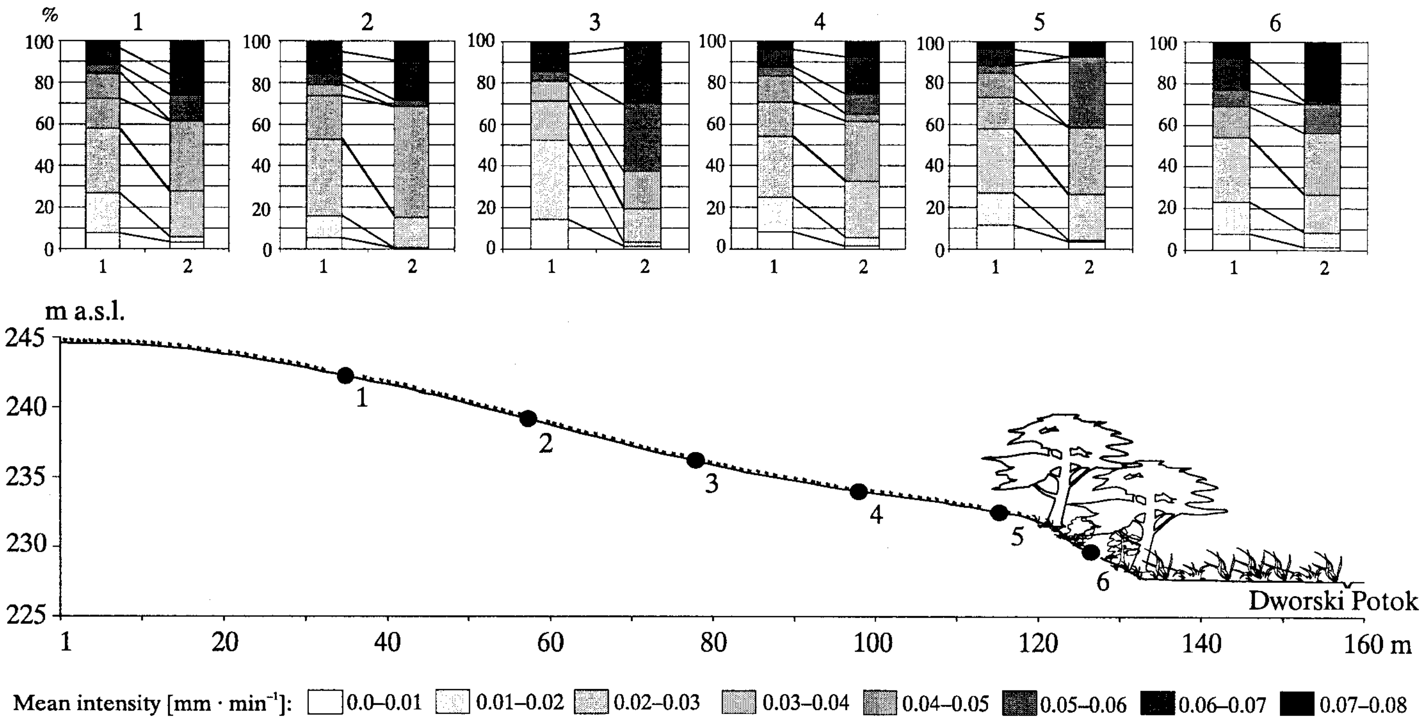

Fig. 6. The number (in %) of soil wash events (1) and the amount (in %) of slope wash material (2) at particular sites on the experimental slope during rainfalls of a different mean intensity

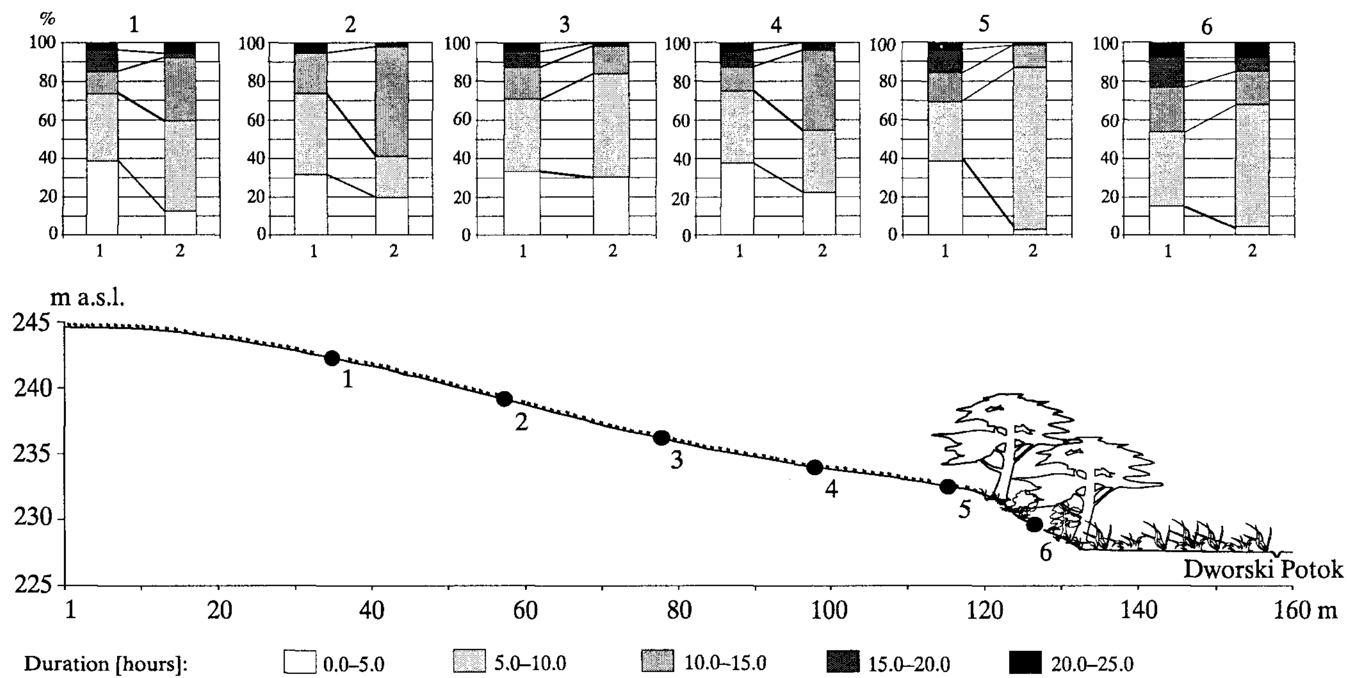

Fig. 7. The number (in %) of soil wash events (1) and the amount (in %) of slope wash material (2) at particular sites on the experimental slope during rainfalls of a different duration

On the basis of the research carried out on the experimental slope, the slope wash events fell into three categories as far as the frequency of their occurrence was concerned:

— slope wash events which took place relatively often but did not require high threshold values of rainfall to occur. Each slope wash event caused transport of insignificant amount of the material so that the overall morphological effectiveness, marked with the amount of the material transported on the slope, was very small;

— slope wash events which occured relatively seldom but required high threshold value of rainfall to occur. Each event transported large amounts of the material. However, due to the small number of the events, their morphological effectiveness, marked with the amount of the material transported on the slope, was also small;

— slope wash events which occured relatively often and required medium threshold values of rainfall to take place. Each event caused transport of medium amount of the material. Due to the highest frequency of occurrence, their morphological effectiveness, marked with the amount of the material transported on the slope, was the largest.

MORPHOLOGICAL EFFECTIVENES OF HEAVY RAINFALLS

In 1998 the annual amount of rainfall was 798.8 mm. It was the largest value measured at the Field Research Station in Łazy in 1987–1999. The mean annual amount for that period was 651.3 mm (Fig. 8A). The largest monthly amounts of rainfall occured in April (151.6 mm) and June (135.7 mm) (Fig. 8B), constituting 19% and 17% of the annual amount respectively. From 18 to 21 April there was 96.4 mm of rainfall, constituting 63.6% of the monthly and 12% of the annual amount of rainfall. The rainfall lasted about 87 hours, its maximum intensity being 0.04 mm $\cdot$ min^{-1} (measurements taken every 3 hours) (Fig. 8C, E).

On 13 April, 1998 there was a downpour, lasting from 4.10 pm to 8.10 pm, its sum amounting to 43.6 mm. After K. Chomicz (1951) rainfall of that order is classified as heavy downpour of the 3rd order (A_3). The rainfall reached its highest intensity (1.2 mm $\cdot$ min^{-1}) from 4.10 to 4.35 pm, producing 31.3 mm of rainfall within 25 minutes. Such rainfall is classified as torrential rain of the 1st order (B_1). The total sum for 24 hours was 43.8 mm. The day before, on 12 April, the 24-hour sum was 30 mm (Fig. 8D, F). The rainfall continued with intervals from 11 pm to 1 am, reaching its maximum intensity of 0.4 mm $\cdot$ min^{-1}. Within 2 days there was 74.9 mm of rainfall altogether, constituting 55.2% of the monthly and 5.4% of the annual sum.

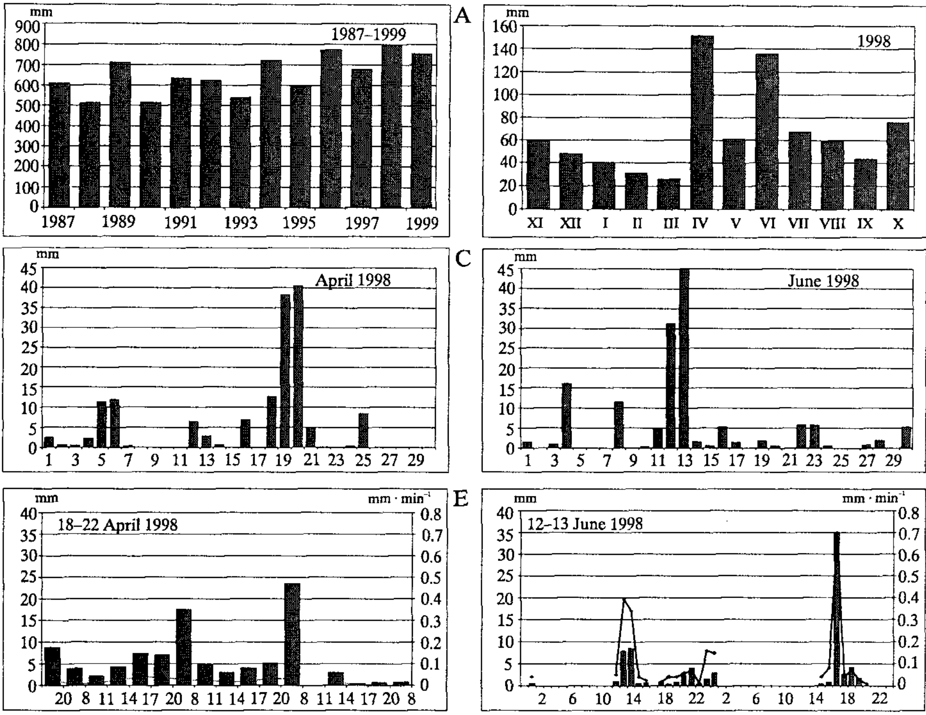

Fig. 8. The characteristics of precipitation (Łazy Research Station). A — annual totals of precipitation in hydrologic years 1987–1999, B — monthly totals of precipitation in hydrologic year 1998, C — daily totals of precipitation in April 1998, D — daily totals of precipitation in June 1998, E — characteristics of the rainfall of 18–21 April 1998, F – characteristics of the rainfall of 12–13 June 1998

BRZEŹNICKI POTOK SUB-CATCHMENT

The rainfall of 18–21 April caused slope wash in the whole area of the catchment. Transport and export of the material on the slopes depended mainly on land use, and on vegetation cover and spacial pattern of crops.

In the catchment the plots are long and narrow and ploughed down the slope. On the slopes which were agriculturally used with particular segments used for different crops and separated with boundary strips, particular segments functioned independently. The material was transported mainly by longitudinal furrows and accumulated at the end of a particular field or at the beginning of the adjacent segment which was differently used. The largest amount of the material came from potato fields. Material exported from fields adjacent to the valley bottom was accumulated in the footslope prolluvial plain or in the valley bottom (Photo 1). The transport of the material was stopped in the valley bottom by exuberant graminaceous plants or by numerous microforms, resulting in uneven and episodic accumulation of the material in the valley bottom. Only

Photo 1. The material exported from fields adjacent to the valley bottom was accumulated in the footslope prolluvial plain or in the valley bottom (photo by J. Święchowicz)

part of the material reached the Brzeźnicki Potok channel. During this particular event the slope and channel systems were locally linked.

PUMPKIN FIELD

During a violent downpour on 13 June the whole area of the sub-catchment was intensively transformed. It was caused not only by the parameters of rainfall but land use as well. In the crop pattern dominant were pasturable pumpkins and cucumbers. The pumpkin was seeded at the end of May in rows 150 cm apart with particular plants 60 cm apart. Thus the field lacked a dense protective leaf cover in the final stage of vegetation. The violent downpour caused both diffused, linear and sheet wash in the whole area of the watershed. During the downpour the catchment was cut in its axis up to the depth of 45 cm (Photo 2). The exported material was accumulated at the outlet of the catchment as a prolluvial fan.

RAINFALL THRESHOLD VALUES FOR DYNAMICS

The threshold value of rainfall is a process feature. In case of episodic processes like slope wash for example, it is important to establish a threshold value of rainfall sum, above which the process is initiated. Establishing further

Photo 2. During the downpour (13 June 1998) the watershed was cut in its axis up to the depth of 45 cm (photo by J. Święchowicz)

threshold values may convey information about change in the intensity of the process and its morphological effectiveness. It may either be expressed with the amount of the material transported on the slope (diffused or sheet wash), or the width or depth of rills (linear slope wash).

Threshold values of rainfall resulting in slope wash were different for particular segments of the slope profile. It shows that the processes of erosion and export during the same rainfall-slope wash event were not simultaneous. Thus three threshold values of the rainfall which are important for the morphodynamics of the catchment can be distinguished:

— the first threshold value — initial surface runoff and local slope wash on a particular slope or in a particular catchment;

— the second threshold value — overland flow and slope wash along the whole profile of a slope or several slopes in a catchment;

— the third threshold value — overland flow and slope wash on all the slopes in a catchment.

Threshold values of rainfall change during the year depending on the condition of the soil (vegetation stage, soil moisture, freezing) at particular segments on the slope profile. To determine the threshold value with one number only is always an estimation of real conditions, which allows a very general outlook on the processes of overland flow and slope wash. Exceeding the first threshold value causes occasional transport of the material on a particular slope and the process is not intensive. Exceeding the second threshold value results in a local erosion on a slope. Exceeding the third value causes general transport on the slope and its deposition in the valley bottom and the most effective erosion and transformation of the whole catchment. The probability of exceeding the third threshold value decreases with the increase in the area of the catchment. When the second threshold value is exceeded, the two subsystems of a catchment, that is the slope and the bed are locally linked. When the third value is exceeded, the connection between the two systems is widespread. Even then, the majority of the material exported from the slope is deposited on the footslope prolluvial plains and in flat valley bottoms.

CONCLUSIONS

Slope wash is an occasional process, which takes place relatively seldom. In the study period, the days with precipitation covered 42.4% of the study period, while the days with overland flow and slope wash only 6.1% (for the pastureland) and 3.0% (for the tree-covered edge).

Every time overland flow occured, the process of slope wash took place as well. However, they did not happen simultaneously at all the measuring sites. The conclusion is that rainfall of the same parameters, even within short and uniform slope profile, does not always bring about slope wash everywhere along the slope.

Transport of the material on the slope is unequal and not simultaneous. The material is transported down the slope in a step-like mode. During a single event material is transported from the upper segment of the slope to its foot. Typical for the pattern of the slope is alternation of degradational and depositional segments; redeposition is a general process.

The total number of slope wash events did not depend on the type of rainfall, but on the morphological and morphometric features of the slope and its use. In the midslope segment ("belt of intensive erosion"), the number of slope wash events was smaller, but in order to initiate transport of the material on the slope the higher threshold values of rainfall were needed. In the midslope segment the morphogenetic effectiveness of rainfalls of higher parameters was greater, which means that they caused transport of a larger amount of the material. A large number of slope wash events do not guarantee transport of a large amount of the material.

For particular segments of the catena, threshold values for amount, intensity and duration of rainfall can be established, above which a small percentage of slope wash events brings about transport of a large amount of the material. Below that threshold value the relation is reverse.

Slope wash events which took place in the study period can be classified into three groups:

1. Slope wash events which required low threshold values of rainfall to occur. Each event caused transport of an insignificant amount of the material. Although the events were numerous, their morphological effectiveness was small;

2. Slope wash events which required high threshold values of rainfall to occur. Each event caused transport of a large amount of the material. Due to the small number of the events, their morphological effectiveness was also small;
3. Slope wash events which required medium threshold values of rainfall to occur. Each event caused transport a of medium amount of the material. Due to the large number of the events, their morphological effectiveness was the largest.

When studying the process of slope wash, which is occassional, the number of the events as well as their intensity have to be considered. In addition, the frequency of the events and their morphological effectiveness have to be taken into account. The most intensive events, if they occur very seldom, do not always have the greatest influence on the total transport of the material on the slope.

Degradational processes initiated by slope wash are greater in the midslope segment which is used as pastureland than in the other segments on the slope. The soil materials are accumulated within the area of flattened footslope and at the border of the tree-covered edge. Within the tree-covered edge the amounts of the material are insignificant and their transport takes place only during events of the highest parameters of rainfall.

Threshold values of rainfall initiating runoff and slope wash on the slope are different for particular segments on the slope profile, which confirms that the processes of erosion and transport of the material are not simultaneous during the same slope wash event. Three threshold values of rainfall important for the morphodynamics of the catchment were distinguished. The probability of exeeding the third threshold value, which triggers overland flow and slope wash on all the slopes in a catchment, decreases together with an increase in the area of the catchment.

Translated by Alicja Waligóra-Zblewska

Department of Geomorphology
Institute of Geography
Jagiellonian University
64 Grodzka Street, 31-044 Kraków, Poland
email: jswiecho@arsenal. geo.uj.edu.pl

REFERENCES

Chomicz K., 1951. *Ulewy i deszcze nawalne w Polsce.* Wiadomości Służby Hydrologicznej i Meteorologicznej 2, 3, 17–88.

Froehlich W., Starkel L., 1995. *The response of slope and channel systems to various types of extreme rainfalls (temperate zone — humid tropics comparison).* Geomorphology 11, 4, 337–346.

Gerlach T., 1966. *Współczesny rozwój stoków w dorzeczu górnego Grajcarka (Beskid Wysoki).* Prace Geograficzne IG PAN 52, 124 pp.

Gerlach T., 1976. *Współczesny rozwój stoków w polskich Karpatach Fliszowych.* Prace Geograficzne IG PAN 122, 116 pp.

Gil E., 1976. *Spłukiwanie gleby na stokach fliszowych w rejonie Szymbarku.* Dokumentacja Geograficzna 2, 60 pp.

Gil E., 1986. *Rola użytkowania ziemi w przebiegu spływu powierzchniowego i spłukiwania na stokach fliszowych.* Przegląd Geograficzny 58, 1-2, 51–65.

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

Gil E., Starkel L., 1979. *Long-term Extreme Rainfalls and their Role in the Modelling of Flysch Slopes.* Studia Geomorphologica Carpatho-Balcanica 13, 207–220.

Kaszowski L., 1991. *Stacja Naukowa Instytutu Geografii UJ w Łazach — cele i zadania.* Zeszyty Naukowe UJ, Prace Geograficzne 83, 159–163.

Kaszowski L., 1995a. *Założenia metodologiczne i metodyczne projektu badawczego,* [in:] *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą,* ed. L. Kaszowski, IG UJ, Kraków, 11–16.

Kaszowski L., 1995b. *Obieg zanieczyszczeń i przeobrażenie geosystemów progu Pogórza Karpackiego między Rabą a Uszwicą,* [in:] *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą,* ed. L. Kaszowski, IG UJ, Kraków, 321–331.

Kaszowski L., Święchowicz J., 1995. *Rzeźba progu Pogórza Karpackiego między Rabą a Uszwicą,* [in:] *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą,* ed. L. Kaszowski, IG UJ, Kraków, 39–42.

Klimaszewski M., 1978. *Geomorfologia ogólna.* PWN, Warszawa, 270–291.

Kotarba A., 1990. *Postęp metodyczny w badaniach współczesnych procesów morfogenetycznych,* [in:] *Współczesne procesy morfogenetyczne w Polsce. Wybrane zagadnienia,* ed. A. Kotarba, Dokumentacja Geograficzna 1, 7–12.

Kotarba A., 1994. *Geomorfologiczne skutki katastrofalnych letnich ulew w Tatrach Wysokich.* Acta Univ. N. Copernici, Geografia 27, Nauki Matematyczno-Przyrodnicze 92, 21–34.

Kotarba A., 1998. *Morfogenetyczna rola opadów deszczowych w modelowaniu rzeźby Tatr podczas letniej powodzi w roku 1997.* Dokumentacja Geograficzna 12, 9–23.

Selby M., J., 1974. *Dominant geomorphic events in the landform evolution.*Bulletin of International Association of Engineering Geology 9, 85–89.

Skiba S., 1992. *Gleby zlewni Starej Rzeki.* Zeszyty Naukowe UJ, Prace Geograficzne 88, 39–47.

Słupik J., 1973. *Zróżnicowanie spływu powierzchniowego na fliszowych stokach górskich.* Dokumentacja Geograficzna 2, 112 pp.

Słupik J., 1981. *Rola stoku w kształtowaniu odpływu w Karpatach fliszowych.* Prace Geograficzne IG PAN 142, 98 pp.

Starkel L., 1972. *The role of catastrofic rainfalls in the shaping of the relief of the lower Himalaya (Darjeeling Hills).* Geographia Polonica 21, 103–147.

Starkel L., 1976. *The role of extreme (catastrofic) meteorological events in the conterporary evolution of slopes,* [in:] *Geomorphology and Climate,* ed. J. Wiley, 203–246.

Starkel L., 1979a. *On some questions of the contemporary modelling of slopes and valley bottoms in the flysch Carpathians.* Studia Geomorphologica Carpatho-Balcanica 13, 191–206.

Starkel L., 1979b. *The role of extreme meteorological events in the shaping of mountain relief.* Geographia Polonica 41, 13–20.

Starkel L., 1986. *Rola zjawisk ekstremalnych i procesów sekularnych w ewolucji rzeźby (na przykładzie fliszowych Karpat).* Czasopismo Geograficzne 57, 2, 203–213.

Starkel L., 1996. *Geomorphic role of extreme rainfalls in the Polish Carpathians.* Studia Geomorphologica Carpatho-Balcanica 30, 21–38.

Starkel L. (ed.), 1997. *Rola gwałtownych ulew w ewolucji rzeźby Wyżyny Miechowskiej (na przykładzie ulewy w dniu 15 września 1995 roku).* Dokumentacja Geograficzna IG PAN 8, 108 pp.

Starkel L., 1998 (ed.). *Geomorfologiczny i sedymentologiczny zapis lokalnych ulew.* Dokumentacja Geograficzna IG PAN 11, 107 pp.

Święchowicz J., 1991. *Budowa geologiczna i rzeźba zlewni Starej Rzeki.* Zeszyty Naukowe UJ, Prace Geograficzne 83, 165–184.

Święchowicz J., 1992. *Naturalne i antropogeniczne uwarunkowania rzeźby w zlewni Starej Rzeki.* Zeszyty Naukowe UJ, Prace Geograficzne 88, 49–69.

Święchowicz J., 1995. *Opadowe uwarunkowania wystąpienia spływu powierzchniowego w zlewni Starej Rzeki na Pogórzu Karpackim,* [in:] *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat miedzy Rabą a Uszwicą*, ed. L. Kaszowski, IG UJ, Kraków, 185–193.

Święchowicz J., 1998. *Spłukiwanie gleby na stoku eksperymentalnym w rejonie Łazów (Pogórze Wielickie),* [in:] *Zintegrowany Monitoring Środowiska Przyrodniczego. Funkcjonowanie i tendencje rozwoju geosystemów Polski,* ed. A. Kostrzewski, Biblioteka Monitoringu Środowiska, Warszawa, 217–227.

Wit-Jóżwik K. 1977. *Analiza deszczów w Szymbarku w latach 1969–1973 (w okresie od maja do września).* Dokumentacja Geograficzna 6, 23–67.

STRESZCZENIE

J. Święchowicz

WARUNKI PROGOWE WYSTĄPIENIA SPŁUKIWANIA W ZLEWNI POGÓRSKIEJ (POGÓRZE KARPACKIE, POLSKA)

W artykule przedstawiono opadowe uwarunkowania wystąpienia spłukiwania w pogórskiej zlewni Starej Rzeki. Analiza uwzględnia zróżnicowanie ilości przemieszczanego materiału na stoku podczas pojedynczych zdarzeń spłukiwania w zależności od właściwości opadu.

Stwierdzono, że spłukiwanie nie zawsze występowało jednocześnie na wszystkich stanowiskach badawczych. Stąd wniosek, że opad o takich samych parametrach, nawet w obrębie krótkiego i mało zróżnicowanego stoku, nie zawsze wywołuje spłukiwanie na całej jego długości. Przemieszczanie materiału na stoku jest procesem nierównomiernym i niejednoczesnym. Materiał spłukiwany podlega skokowemu przemieszczaniu w dół stoku. Podczas jednego zdarzenia rzadko następuje przemieszczenie materiału z górnego odcinka stoku aż do jego podnóża. W obrębie stoku można dostrzec jego alteracyjną strukturę: następstwo odcinków degradacji i depozycji, a procesem powszechnym jest redepozycja. Całkowita liczba przypadków spłukiwania nie zależała od rodzaju opadu, ale od cech morfologiczno-morfometrycznych stoku oraz jego użytkowania.

Wartości progowe opadu wywołujące spłukiwanie są inne dla poszczególnych segmentów stoku, co świadczy o nierównoczesnym występowaniu procesu spłukiwania w jego obrębie oraz zróżnicowanym przemieszczaniu materiału podczas tego samego zdarzenia. Wartości progowe opadu zmieniają się w ciągu roku w zależności od stanu podłoża. Wyróżniono trzy wartości progowe istotne dla morfodynamiki zlewni pogórskiej:

Pierwsza wartość progowa — rozpoczęcie procesu spływu, spłukiwanie lokalne;

Druga wartość progowa — powszechne zachodzenie spływu i spłukiwania na całej długości niektórych stoków w zlewni;

Trzecia wartość progowa — powszechne zachodzenie spływu i spłukiwania na całej długości wszystkich stoków danej zlewni.

Prawdopodobieństwo przekroczenia trzeciej wartości progowej maleje wraz ze wzrostem powierzchni zlewni.