Preliminary Two-fold Classification of Torrents

Vorläufige zweigeteilte Wildbachklassifikation

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Summary

Based on recent theoretical and practical experiences in the field of torrents control a two-fold classification of torrents is now presented. The bipartition is a result of the requirements on the one hand to give a total judgement about the behaviour of the torrent in the area of the torrent cone and on the other hand to explain the conditions which cause the development of this torrent in different parts of the basin and to determine the kinds of counter measures required. In the first part of the total judgement of the behaviour of the torrent along the cone or lower course four types of torrents are distinguished with regard to their varying damage potential: debris flow torrents, debris flood torrents, bedload transporting torrents, flood creeks. The second part of the classification distinguishes the torrents by the action of surface discharge and discharge with embankment failures in the debris sources, and also by special and composite torrents. Further differentiation is given between torrents with depth erosion and torrents with only lateral erosion and also between natural and human influences. At the lowest level of differentiation the natural scour torrents (colluvial scour torrents, volcanic scour torrents, bedrock scour torrents, partial scour torrents, torrents with strong infiltration, gullies, debris accumulating torrents) and induced scour torrents and also natural lateral erosion torrents (torrents with predetermined channel bends, torrents with free meanders, grass-scar torrents) and induced lateral erosion torrents are distinguised. The group of special torrents is divided into ice-debris snow-debris avalanches, Karst torrents, glacial torrents, earthquake torrents. The type of the torrent at the lowest level of differentiation expresses type and cause of the erosion development in different torrents or parts of them. This type is linked with an index of possible maximum development which is divided into five steps. The classification permits correlations for hazard-zoning on the one hand and to counter measures in different parts of the torrent on the other hand. The classification is not limited to the area of the Alps in its application.

Zusammenfassung

Auf Grund der neuen praktischen und theoretischen Erfahrungen und Erkenntnisse in der Wildbachkunde wird eine vorläufige zweigeteilte Wildbachklassifikation vorgelegt und begründet. Die Zweiteilung ergab sich einerseits aus dem praktischen Erfordernis, am Schwemmkegel bzw. am Unterlauf das Gesamtverhalten des Wildbaches im Hinblick auf die Abgrenzung von Gefahrenzonen beurteilen zu müssen, anderseits aus der Tatsache, daß innerhalb des Wildbaches lokal verschiedene Ursachen für die Geschiebebildung vorhanden sein können und dementsprechend eine gesonderte Beurteilung im Hinblick auf die zu treffenden Verbauungsmaßnahmen verlangen. Im Rahmen der ganzheitlichen Beurteilung am Schwemmkegel werden im Hinblick auf ungleiche Gefährdung von Objekten vier Wildbachtypen unterschieden: Murstoßfähige Wildbäche, murfähige Wildbäche, geschiebeführende Wildbäche und lediglich hochwasserführende Wildbäche. Die im zweiten Teil vorgestellte Wildbachbeurteilung im Einzugsgebiet gliedert die Wildbäche zuerst nach Wirkungen der Obertag- und Untertagwässer in den Geschiebeherden, sowie nach besonderen und gemischten Wildbächen. Die weitere Untergliederung unterscheidet Wildbäche bzw. Wildbachabschnitte, verursacht durch Tiefenerosion und Wildbäche, und durch Korrosion entstandene, wobei jedesmal natürliche oder anthropogene Ursachen zur Bildung der Geschiebeherde führen können (künstliche und natürliche Tiefenerosions- und Korrosions-Wildbäche). Diesen Erosionswildbächen, die selbst ihre Geschiebeherde dynamisieren, werden die Hanganbruchsbäche gegenübergestellt, die Geschiebe lediglich aus Hanganbrüchen empfangen

und weitertransportieren. Die letzte Untergliederung drückt direkt Art und Ursache des Erosionsvorganges im Wildbach bzw. Wildbachabschnitt aus und ergibt die letzliche Typenbezeichnung, die mit einem Index der Entwicklungsfähigkeit verbunden wird (Stufen 1 – 5). Demnach sind zu unterscheiden: Lockergesteinsfeilen, Festgesteinsfeilen, Bäche mit nur örtlicher Tiefenerosion, Wasserverlustbäche, Gullies, Schuttstapelbäche, Aschenmuren, Zwangskrümmungs-Wildbäche, freie Mäander in Umlagerungsstrecken. Rasenschälbäche, Hanganbruchsbäche, (bedingt durch verschiedene Ursachen), Eismuren, Schnee-Erdlawinen, Karstbäche, Gletscherbäche und Erdbeben-Wildbäche. Die geschilderte Typisierung erlaubt ebenso Bezüge zur Zonenabgrenzung (Teil 1) wie zu den zu treffenden Verbauungsmaßnahmen (Teil 2). Ihre Anwendung ist nicht auf das Gebiet der Alpen beschränkt.

Introduction

The last Austrian classification of torrents by Stiny (1931) is now 50 years old. It is based on a geological approach. Since that time new parameters for the evaluation of torrents have become significant and thus the emphasis has shifted to meet the new demands. Today a classification of torrents should fulfill three principal functions:

a) It should serve as a practical tool within the framework of the complex real world;
b) It should be accurate as to the effects and hazards to be expected on the debris cones;
c) It should express the genetic role of torrents in the dynamic evolution of valleys.

Having brought new status to torrents in welfare societies the focus has shifted significantly; in days past a better feeling for and experience with natural processes led to the careful selection of human habitats and thus torrent hazards were of less public relevance; today housing developments in our very safety conscious society have advanced far into hazardous terrain, without considering that this very sensitivity demands timely preventive measures. Areas with great population concentrations, such as vacation centres, ski complexes and transportation routes, now extend far into zones which formerly were occupied by fields or had been left in their natural state and were visited only occasionally by farmers, herdsmen, hunters, foresters and tourists. This great change means that new landscapes and population concentrations have to be considered in the study of torrents, and that quantitative data on the magnitude of the potential hazards in space and time have to be collected in order to manage future development. The high hazard levels that have been reached in areas with intensive land use are compounded by the much greater technical possibilities now at hand. By themselves, these can cause relief-related hazards. Thus, during the catastrophe of April 1975 in Carinthia and Styria, [Austria], two thirds of the damage was due to new access and forest roads that had been built without adequate control of runoff and slope stability (Länger 1975). A similar case can be made for regions where agricultural activity has changed. Thus a three fold increase in corn acreage tends to set off serious erosional processes (Tab. 1) and a change in the spacing of vines on loess terrain creates the previously unknown problem of

Table 1. *Surface runoff during the months of May to September 1950 as related to the type of vegetation and methods of cultivation (Harrold 1954)*

Oberflächenabfluß während der Monate Mai bis September 1950 in Abhängigkeit von der Vegetationsart und Landbewirtschaftungstechnik (Harrold 1954)

Vegetation	Technique of cultivation	Runoff mm
Maize	Line ploughing	158
	Contour ploughing	95
	Contour ploughing with litter cover	62
Meadows	Mowing	26
Forest	Old deciduous forest	5

gullying. Thus even flatland terrain has to be seriously evaluated in the fight against erosional processes.

Other recent examples from Austria include a gypsum mine at Tränenbach/St. Johann/ Montafon/Vorarlberg where a potential hazard has been created by an open pit operation in the catchment basin of a notorious torrent; or the Tratzberg settlement near Jenbach/Tirol where large scale excavations for a nearby highway led to substantial repeated debris in 1970; or the Olympic ski area of the Axamer Lizum near Innsbruck/Tirol [Austria] where clearcuts for skiing in the fall-line of a slope set off scour erosion and debris flow damage at the Olympiahotel complex in 1965, one year after the clearing. The problem of human misjudgement is much greater for developing countries where rapid technical development and in particular road construction are soon followed by erosion and debris damage (Jedlitschka 1980). This problem arises from a one-sided technocratic-economic viewpoint that stresses transportation links, labour potential and market situation, but excludes a comprehensive view of the primary natural function of a region. Disregarding natural forces may cause an economically stressed region to respond with forces which cannot be controlled by money alone.

The side effects of growth-oriented progress in many regions of the world have stimulated a new interest in erosion, particularly where this phenomenon was not a big problem before (e.g. USSR, parts of USA, Venezuela, Guatemala, African countries, Iran, Brasil etc.). The changing circumstances have led to the establishment of special organisations and, on account of the human factors involved, have given new impetus to the development of the classification of torrents. Several proposals have come from the USSR, Japan and China (e.g. Chercheulidze 1979, Flejshman 1978, 1979, Nebolozin 1947, Nakamura 1980, Guan Junwei 1960 a. o.).

Thus a new classification of torrents might be useful. Furthermore, the many new findings in the torrent regions of the Alps, the neglect of the human factor in older classifications, their overemphasis in others (Karl Mangelsdorf 1975), and the dichotomy between older classifications (Demontzey 1878, Wang 1901, Salzer 1886, Stiny 1931) and more recent ones cannot be ignored. Today the analysis of torrent types with additional criteria and methods permits a more precise and appropriate differentiation. The classification of Stiny (1931) is mainly useful for the formerly glaciated areas of the Alps and individual torrent segments; it is less adequate for areas located outside of the formerly glaciated areas or for entire torrent basins. Stiny's influential classification deals more with the type of the individual debris sources than with the type of the whole torrent basin. Debris sources along a torrent may play quite different roles with respect to damage on the cone according to their relative position. Also, debris sources which have been called characteristic of residual colluvium (e.g. V-shaped or wedgeshaped erosional scars) by Stiny (1931) are now known to occur in loose alluvium and talus as well. Nevertheless, Stiny's basic idea is still valid. From the morphological evolution and the dynamics of a debris scar within its hydrological context the necessary counter measures can be designed. But this concept requires further refinement if one intends to achieve not only qualitative but also quantitative estimates of potential damage.

We still do not have the necessary scientific background information on mass flows and catastrophic events to lay the groundwork for an exact classification applicable in all practical situations or for a numerical analysis of future torrent activity. This is particularly true with regard to a scheme intended for world-wide use. This paper therefore proposes a preliminary classification which incorporates the present state of theoretical knowledge and takes a step forward in practical application. In spite of the important geological parameters emphasized by Stiny (1931), the present approach deviates from that point of view. The relationship between a certain type of torrent and an appropriate control system within the catchment basin or the application of active and passive measures on the debris cone can only be touched in principle. This relationship is greatly influenced by the variety of possible torrent-ecological parameters on the one hand and the variety of preventive measures on the other hand.

The New Preliminary Two-fold Classification of Torrents

The classification considers

a) the type of the extreme catastrophic events on the debris cone (or lower torrent course) supplemented with a torrent-index (Aulitzky 1973) (see Appendix) for use in torrent hazard zoning of natural debris cones and

b) the type and trend of the erosional processes in the catchment basin.

By definition, torrents flow from small basins (up to 100 km^2), wild rivers from larger basins. Both are perennial or intermittent water courses and by transporting solid materials can become the source of significant damage. For practical purposes it is therefore recommended to subdivide torrents as to their damaging behaviour along the lower course and as to the causal parameters contributing to this behaviour in the debris source area of the catchment basin. Appropriate temporary and permanent measures can then be taken when the character and magnitude of the processes are understood. In all cases extreme or potentially extreme behaviour is the basis for the characterization of a torrent. It is clearly understood that, under favourable circumstances, any torrent may remain far below its catastrophic level.

1. Classification as to Extreme Catastrophic Behaviour on the Debris Cone (Debris Fan, Lower Course, Redepositional Reach or on Another Point of the Basin)

As long as the parameters along a torrent remain the same as the extreme event on the debris cone, debris fan, lower course and redepositional reach, these can be used for a general characterization of a torrent. This concept is also used in the new bedload theory of Hampel (1969, 1970, 1980). In catchment basins, different torrent segments and debris sources along the embankment may become prominent. It is usually difficult to classify all of them under one "torrent type". In such a case the characterization will have to be limited to homogeneous torrent segments, whose quantitative significance will vary as to whether they influence a redepositional torrent reach or the debris cone. Thus several types of debris sources contribute to the deposits of the cone. The catastrophic behaviour of the torrent as indicated by the deposits of the cone is particularly significant in overall evaluation of the torrent and in hazard zoning. A distinct behaviour pattern of torrents on the debris cone corresponds to a distinct set of preventive measures or afforestation techniques. Four torrent types (Tab. 2) have been differentiated, based on the three former types of Aulitzky (1973):

1.1 Debris flow torrents (Murstoßfähige Wildbäche).
1.2 Debris flood torrents (Murfähige Wildbäche).
1.3 Bedload torrents (Geschiebeführende Wildbäche).
1.4 Flood creeks (Nur Hochwasser führende Wildbäche, Gießbäche).

The torrent-index (see Appendix) has been developed for torrents in residual colluvium (Altschuttbäche by Stiny 1931), but it can be modified for other types of debris sources and assures a certain level of awareness of "silent witnesses" (hazard indicators) left behind by large flows in the past.

1.1 Debris Flow Torrents

During extreme catastrophes debris flow torrents are characterized by pulsating, viscous gravitational flows, no longer dominated by the Newtonian laws of hydraulics (Bingham 1922) and with potential velocities of more than 100 km/h. Velocities, impact forces and momentum depend on the distance from a blocking zone that generates such pulsating flows. This type of torrent therefore requires a gorge, blocking trees, embankment failures or lateral debris chutes which temporarily retain the flow of the torrent and, in sudden bursts, release the accumulated debris. The magnitude of the liberated forces and velocities depends on the rate of rupture in the blocking zone

Table 2. *Types of torrents with regard to resulting hazard along the cone, fan, lower course, redepositional reach, bottom of the valley or at any other point of the basin (completed after Aulitzky 1973)*

Typisierung der Wildbäche nach ihrer Gesamtwirkung am Schwemmkegel bzw. Schwemmfächer bzw. am Unterlauf, in der Umlagerungsstrecke oder im Sohlental, bzw. auch an einem anderen Bezugspunkt, bestimmt durch die Auswirkung des Oberliegerbereiches auf diesen (erweitert nach Aulitzky 1973)

	Extreme behaviour including the characteristic mechanisms and debris discharge	Degree of hazard, characteristics and domains of damage	Danger index
1.1 Debris flow torrent	Non-Newtonian viscous, gravitational flows with pulsating and blocking debris discharge reaching velocities of more than 100 km/h; considerable impact forces; "box-shaped" cross sections of deposits by high-velocity flows with abrupt and steep margins; transport of large blocks along radial ridges towards the lower parts of the cone; common in torrents flanked by voluminous and slightly indurated residual colluvium ("Altschuttbäche" of Siny 1931); formation of steep cones.	Very dangerous particularly if a potent debris source is close to the cone, separated from it only by a gorge; debris flows can jump the channel and spread over the whole fan without warning and with destructive impact; solidly built houses may be demolished; it is possible that stacked arrays of check dams along the torrent course are bypassed and that trapezoid discharge sections are breached; discharge sections should preferably imitate the flow profile of debris flows (i.e. the gently curved downward convex "Murprofil"); a series of debris retention basins can be provided on the upper cone.	3.0 – 4.0
1.2 Debris flood torrents	Newtonian viscous mass flows without pulsating and blocking debris waves; velocities, impact forces, and transportation power with regard to large boulders smaller than in debris flows; debris floods spread as flat blankets on torrent cones and fans; they less steep originate in deposits of residual colluvium and fresh alluvial deposits ("Alt- und Jungschuttbäche" of Stiny 1931); water and debris load are thoroughly mixed as described by Thiery (1891).	Dangerous torrents (especially for poorly constructed houses); depending on the water content and velocity debris floods tend to spread over the whole fan or cone area; in view of the smaller velocities as compared to debris flows check dams do not have to be provided with the debris flow discharge section ("Murprofil"), but wings and abutments of dams have to be of sufficient height.	2.4 – 3.0
1.3 Bedload torrents	Debris transport in a bedload "band" or "carpet", with only moderate amounts of fine-grained particles, accompanied by audible noise; aggradation along gentle reaches creates loss of gradient and channel braiding; debris sources of small volume or at a great distance from the generally flat debris fan.	Not as dangerous as debris flows and debris floods; damage due to aggradation, bypassing and erosion of bridge piers; bedload discharge follows established roads and channels down the fan (as in 1.2); a calculation of expected bedload determines channel works and size of retention basins along the torrent and its junction with the receiving river.	1.6 – 3.0
1.4 Flood creeks	Floods carrying finegrained solids, which overflow and cause damage by deposition in low-gradient redepositional reaches; no debris fans develop.	Moderate damage, due to scour along walls of buildings and in finegrained channel beds; lateral erosion; channel revetments and the development of "island" sites as counter measures.	1.0 – 2.2

of a torrent. In the depositional domain debris flows are characterized by a "box-shaped" cross-section (Fig. 1). The flanking ridges give an indication of the velocity and plasticity of the flow. With deceleration and the spreading of a flow the cross-section changes into flat-convex (Fig. 2). Rapid and concentrated debris flows cause damage by direct impact to fixed objects.

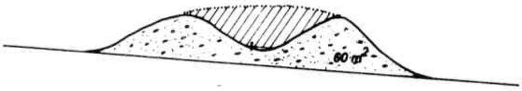

Fig. 1. Box-shaped cross-section of deposits of rapidly moving decelerating debris flow (Aulitzky 1970), observed in the Enterbach/Tirol/Austria

„Kasten"-Form der schnell abfließenden, sich kaum ausbreitenden Mure (Aulitzky 1970)

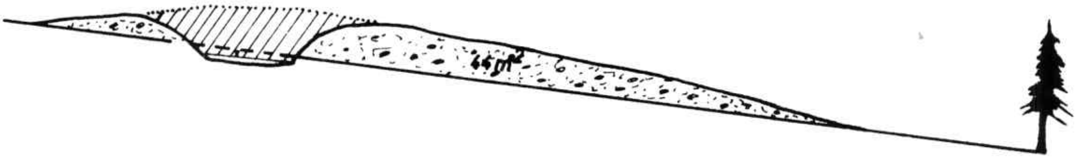

Fig. 2. Flat cross-section of spreading and overflowing debris flow (Aulitzky 1970)

Flache Form der (im Bogen) abfließenden, langsamen Mure, bei der bereits die Ausbreitungstendenz überwiegt (Aulitzky 1970)

They accumulate very steep debris cones and in the Alps they are commonly associated with source areas of residual colluvium ("Altschutt" by Stiny 1931) or plastic clays in Pleistocene valley fill. The natural debris cones are commonly sculptured with ridges and furrows. Check dams designed to guide the flows should take into account the flow velocity profile of debris flows. Asymmetrical wings and well connected abutments are important design criteria. Trapezoid discharge sections should be avoided. The provision of debris retention basins and reinforced concrete dams at the head of debris cones ought to be supplemented by diversion structures to reduce the impact of the high velocity, high density flows. Known pressures during debris flows reach 7 to 13 times the static water pressure (Aulitzky 1970, Eidgenössisches Amt für Straßen- und Flußbau 1973). With regard to potential debris-flow volumes the reader is referred to a new formula by Hampel (1980).

1.2 Debris Flood Torrents

Debris flood torrents are generally characterized by clay-rich colluvial debris and alluvial materials; discharge of thoroughly mixed masses of water, debris and logs occurs without pulsating flows. Absence of blockage also results in lower velocities and impact pressures. Flow proceeds within the laws of Newtonian fluids. The mixing process in debris floods has been described by Thiery (1891). A minimum gradient for the development of debris floods is approximately 15° (Stiny 1919, see Tab. 3). Because of the much reduced velocities and plasticity the deposits on the debris cones lack the distinct radial ridges. The transporting potential for oversize blocks, impact pressures, and debris cone gradients tend to be smaller then those of typical debris flow cones. Debris floods also tend to spread much closer to the head of the cones.

Technical measures are similar to those against debris flows except that smaller velocities and impact forces can be taken into consideration.

Table 3. *Content of water and debris of debris flows and debris floods, depending on bed gradient in the source area of the torrent (Stiny 1922)*

Wasser- und Geschiebeanteile von Muren bei unterschiedlicher Bachbettneigung im Bereich der Murbildung (Stiny 1922)

Bedgradient		Weight percent				Volume percent	
		Limit values		Average			
Degree	Percent	Water	Debris	Water	Debris	Water	Debris
10°	17.6	–	–	53.46	46.54	74.17	25.83
15°	26.8	–	–	50.13	49.87	71.53	28.47
20°	36.4	40.43 – 48.73	51.27 – 59.57	44.21	55.79	66.45	33.55
25°	46.6	–	–	45.42	54.58	67.54	32.46
30°	57.7	32.18 – 39.38	60.62 – 67.82	35.78	64.22	58.21	41.79
35°	70.0	–	–	32.03	67.97	54.09	45.91
40°	83.9	29.95 – 35.20	64.80 – 70.05	32.58	67.42	54.71	45.29

1.3 Bedload Torrents

During flood discharge these torrents are characterized by considerable bedload transport without thorough intermixing of solid load and water across the whole discharge section of the channel. Extreme discharge flows thus remain within the realm of hydraulics ($v_{\max}$ less than 10m/s). The height of the bedload band and transporting potential of the torrent in flood depends greatly on the traction forces and thus on the gradient and depth of water. Damage along the lower course or on the debris cone (or a gentle debris fan) is limited to aggradation along the low-gradient reaches, channel jumping and erosional activity near human works (i.e. walls of buildings etc.). Collapse of buildings is due to erosional scour and not due to direct impact forces. Abrupt loss of viscosity by downward percolation of water in the channel leads to the development of convex depositional lobes in granular debris. In general, these depositional features are flat. Depending on the substratum of the channel the flood wave may be delayed (e.g. in karst) or magnified (e.g. in argillaceous flysch) down the torrent course.

With respect to control structures on the debris fan, the competence of the receiving river, its gradient and transportation potential have to be considered in order to arrange for proper design of channel works and/or debris retention basins. The choice of materials and gradient for the channel are increasingly significant on flat debris fans or low-gradient torrent reaches. Channel sections may be provided for both normal and flood stages if normal runoff aggrades debris and thus significantly lowers the channel gradient.

1.4 Flood Creeks

Flood creeks are characterized by the absence or insignificance of solids during catastrophic discharge. In the strict sense of the definition they are not torrents. With regard to hazard zoning and flood control works, however, they represent the transition towards flood-prone rivers. Damage arises from the direct attack of water or flooding. Deposits are clay, sand or silt. Redeposition occurs along the low-gradient reaches occupied by meanders. Disperse housing developments can be protected on "islands" with elevated or design-protected basements and an uncluttered flood discharge section along the bottom of the valley. This approach circumvents cumbersome meander control.

1.5 The Practical Evaluation of Hazards and Hazard Zoning on Debris Cones

A hazard zone map as a final result has to be based on a comprehensive investigation and ought to be reproducible in the evaluation of the hazard gradient. The considerable number of parameters-both qualitative and quantitative – that have to enter have been shown in a flow chart by Kienholz (1981) (Fig. 3). They are based on a threefold subdivision into debris flow torrents, bedload torrents and flood creeks as proposed by Aulitzky (1973). The difficulties, amount of work, and uncertainties grow with the eventual need for decisions on the scale of individual plots of land for which the quantitative data on potential damage have to enter the imposed building specifications or restrictions. The value of investigation is thus the quantification of the hazard to which a certain point on the debris cone, debris fan, or lower torrent course is exposed. The contributing parameters of the catchment basin are modified by the length of the channel, comminution of debris, blockages, spreading etc. (Hampel 1980). In principle such a point of reference can also be chosen anywhere within the catchment basin and an analogous evaluation can be applied to human structures there. Evaluations which only consider projected runoff without its special context are thus of little use. However the mapping of qualitative hazards in a sector of the catchment basin, as carried out by Kienholz (1977) in Grindelwald, also needs to be supplemented by quantitative grading in order to enter the quantitative hazard zoning on the debris cone. Of course, our present knowledge regarding the quantitative significance of individual hazard parameters only permits crude differentiation.

Examples of quantitative methods are given by the rough Index-method of Aulitzky (1973), Hampel (1980) and Nakamura (1980). These techniques need further evaluation in view of our limited experience with them.

Hazard evaluation of natural debris cones and fans is possible with the torrent-index (Aulitzky 1973), provided the debris source area consists of residual colluvium (Stiny's "Altschutt" 1931). Not all questions on the check list need to be answered for every point on a debris fan (see Appendix). However, the evaluation loses its relevance with a decreasing number of questions answered as the weight of the individual questions in the comprehensive survey differs. Questions 1 to 6 concern the debris cone and should be answered from as many points as possible so that the hazard zones can be drawn as accurately as possible. Questions 7 to 11 apply to the whole torrent basin and are answered only once for each basin. The choice of points on the cone cannot be perfectly random, because "silent witnesses" (hazard indicators) of past extreme events tend to be unevenly distributed. Despite the fact that a hazard image of the cone can be derived from maximum grain size (question 1), thickness (question 2) of relief debris layers, cone-micromorphology (question 5) etc., the examination has to be generalized. Not the specific mechanisms of the great event, but the correct long range evaluation of hazard zones for practical decisions is the target.

As an example of the specific processes of large events, the debris flows of 1970/1971 of Mühlbach/Niedernsill/Salzburg illustrate the difference between two extreme flows: the second event already encountered a curving diversion dam near the head of the debris cone that had been constructed after the first event (Hofmann 1972).

By comparing present and past debris potential of the source area recent events on debris cones can be evaluated in their long-range context rather than for their short term impact on the debris cone alone. Bergthaler (1975) is correct in saying that an index developed for residual colluvium has limited applicability elsewhere. Only certain lithologies permit preservation of large blocks on the cone; distinct debris layers are better preserved in calcareous debris than in schistose debris; buildings may have been placed deliberately in areas of high risk for purposes of energy generation (i.e. mills, blacksmiths etc.) and their past function and accepted professional risk may have differed from the present context (question 7 of index).

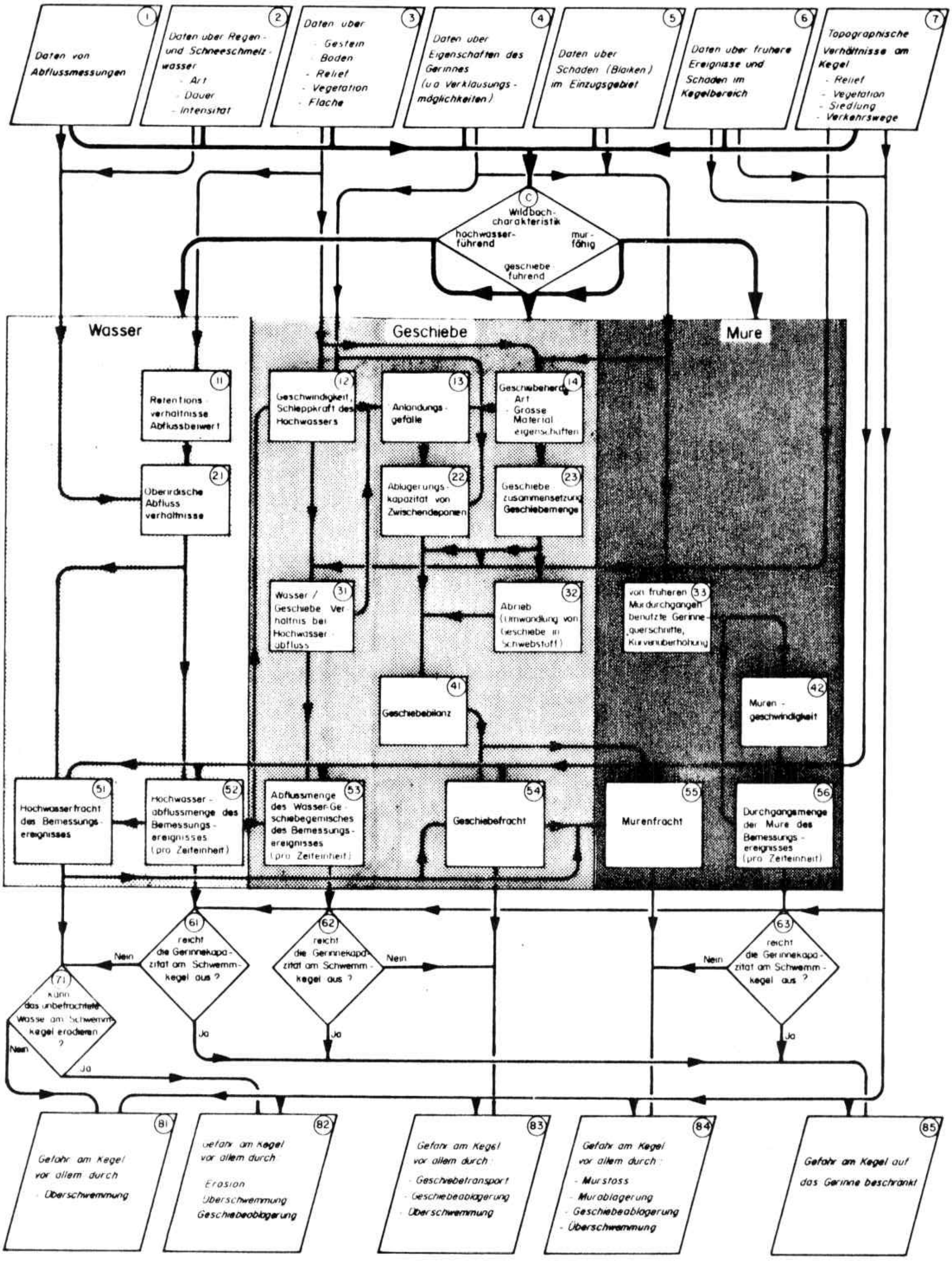

Fig. 3. Provisional flow-chart for estimating the degree of danger of a torrent (Kienholz 1981)
Vorläufiges Flußdiagramm für die Beurteilung der Wildbach-Gefährlichkeit (Kienholz 1981)

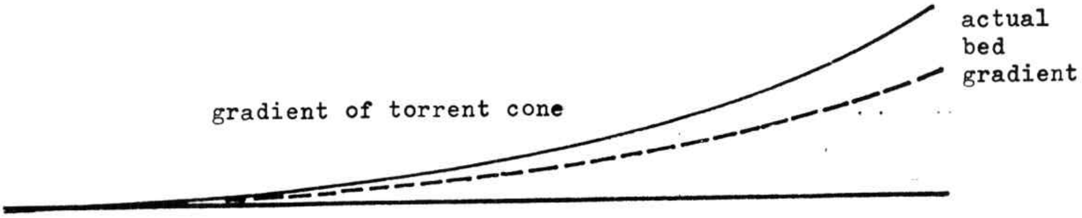

Fig. 4. Comparison of the gradient of a fossil debris cone without important debris sources with the actual natural channel gradient which has developed due to a lack of debris during flood discharge

Vergleich der Schwemmkegelneigung eines fossilen Schwemmkegels, dessen Einzugsgebiet keine bedeutsamen Geschiebeherde mehr aufweist, mit der aktuell ausgebildeten Neigung des Naturgerinnes am Schwemmkegel, die wegen der eingetretenen Geschiebeentlastung des Hochwassers nun flacher verläuft

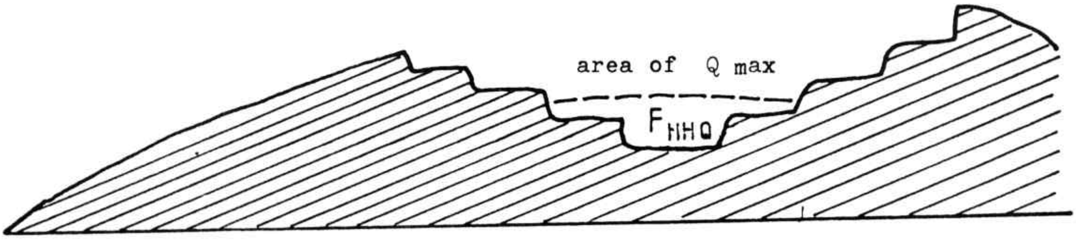

Fig. 5. Flood discharge section of a fossil debris cone, characterized by persistent depth erosion of a torrent into its own deposits along the cone

Hochwasserquerprofil am fossilen Schwemmkegel, gekennzeichnet durch anhaltende Eintiefungstendenz des Wildbaches in die eigene Alluvion

Table 4. *Practical basis for torrent hazard zoning in Tirol* (*Bergthaler 1979*)

In der Praxis verwendete Grundlage für die Durchführung der Wildbachzonenplanung in Tirol (*nach Bergthaler 1979*)

Criteria for the differentiation of the red zone (according to § 6a of the decree concerning hazard zoning maps (BGBl. 435/1976) in torrents and debris flow areas.

As proposed in a workshop at Flachgau/Salzburg/Austria one has to differentiate a 30-year catastrophe from a 150-year catastrophe:

a) for standing bodies of water:
   HQ_{30} limit of the red zone at 1.0 m water level
   HQ_{150} limit of the red zone at 2.0 m water level

b) for running water and bedload band:
   HQ_{30} 1.0 m water and debris load
   HQ_{150} 1.5 m depositional height or water level

c) for debris flows:
   HQ_{30} 0.7 m thickness of debris layer
   HQ_{150} 1.0 m thickness of debris layer

d) erosion:
   HQ_{30} 2.5 m erosional depth
   HQ_{150} 3.0 m erosional depth

The most important consideration concerning a debris cone is whether it is active or fossil. With the progressive removal of a debris source or a reduction of debris potential in the source area, the debris cone ceases to grow and the torrent begins to dissect its own deposits, thus reducing the gradient of the channel.

The comparison of the old and the new torrent gradient in conjunction with a test on whether a flood event will affect the surface of the cone by breaking out of its new incised channel is of considerable significance in the torrent evaluation of "silent witnesses" (hazard indicators) on the cone. It is only significant with respect to "silent witnesses" (hazard indicators) to what extent an extreme flood event affects the new profile (Figs. 4, 5).

As a rule for practical work, a recurrent design event of 150 years is used in torrent control in Austria (1976); unfortunately related flood control work is carried out with a different recurrence interval (Bundesministerium für Land- und Forstwirtschaft 1972 and Republik Österreich 1976). The author would consider it preferable to use the largest possible and recognizable flood event for areas of permanent settlement. Good discharge records are generally not available for torrents, but permanent communities ought not to be destroyed, today or tomorrow. This approach again makes use of the criteria listed above, including the thickness of debris layers, flood levels, and depth of erosional scour (see Tab. 4 by Bergthaler 1979).

2. Genetic Classification Related to the Type of Erosional Processes in the Catchment Basin

The behaviour of a torrent on the debris cone is the integrated result of a variety of processes in the catchment basin including its size, the geological substratum, and the distribution of precipitation which may differ from one segment to another. The most important parameter is the geological substratum and its specific reaction to a variety of precipitation events. The character of a torrent may be uniform with regard to its geology, hydrology and hydrogeology – but this need not be the case. Therefore the subdivision of torrents as to the type and trend of erosion in the source area may be relevant only for certain parts of the catchment basin (watershed). The classification proposed below is based on the types of erosion (vertical and lateral) induced by surface runoff and on the types of embankment failure induced by subsurface water pressures and gliding layers. Further subdivision can be achieved as to natural and artificial release mechanisms. Stiny's (1931) idea of deriving the mechanism of debris generation from features in the source area has been retained, although only those mechanisms have been considered that are significant for a larger section of the catchment basin or source area.

In the attempt to characterize the mechanism of certain debris sources, new words had to be introduced which might, on first inspection, appear unusual (Tab. 5).

2.1 Torrents with Erosion from Surface Runoff

These torrents can be subdivided into two groups: one group is characterized by erosion of the whole discharge section with considerable depth scour (scour torrents); the other group is dominated by local lateral erosion due to concentration of isotachs along the outer channel bends (lateral erosion torrents). Both types may be represented in composite catchment basins. The first group is more dangerous than the second one. From dominant grain size one could distinguish debris and mud torrents.

2.1.1 Scour Torrents (*Torrents with Depth Erosion*)

In these torrents the channel bed possesses insufficient strength to resist exceptional stresses (e.g. along reaches of high gradient) and thus cannot assure bed stability. The torrent strives to establish a balanced profile between the stable reaches approaching a hyperbola. The subgroupings differ by the character of the substratum.

Table 5. *Genetic characterization of torrents (individual sections of torrents) with respect to the origin of debris, the development potential, and the appropriate protective measures in the debris source area*
Kausale Typisierung von Wildbächen (oder einzelnen Wildbach-Abschnitten) nach den vorherrschenden, durch die Art des Wasserangriffs bestimmten Geschiebebildungsursachen und der danach zu erwartenden Entwicklungsfähigkeit, sowie zu den angepaßten, wichtigsten Schutzmaßnahmen im Bereich dieser Geschiebeherde

Origin of debris	Resulting type	Development potential of torrent	Appropriate technical measures
A) Erosion by surface discharge	2.1 Torrents with erosion from surface runoff		
Excessive traction forces along the whole discharge section	2.1.1 Depth erosion torrents (scour)		
	2.1.1 Natural depth erosion (scour) torrents		
In unconsolidated materials (colluvium)	2.1.1.1.1 Colluvial scour torrents	Great dynamic	Stacked arrays of check dams between fixed points
Erodible ash beds	2.1.1.1.2 Volcanic scour torrents	Very great dynamic	Check dams and biological techniques
Erosion in bedrock	2.1.1.1.3 Bedrock scour torrents	Stable	Not necessary
	2.1.1.1.4 Partial scour torrents	Small	Local check dams (block throw embankments)
Permeable channel beds	2.1.1.1.5 Torrents with strong infiltration	Small	Redistribution of discharge
Fine grained surficial deposits	2.1.1.1.6 Gullies	Great dynamic	Stabilisation of gully head and unstable gully walls
Erosion of redeposited debris	2.1.1.1.7 Debris accumulating torrents	Moderate	Spurs, debris retention basins
	2.1.1.2 Induced scour torrents	Variable	Control of cause grading of channel
Lateral erosion	2.1.2 Lateral-erosion torrents		
	2.1.2.1 Natural lateral-erosion torrents		
In predetermined valleys	2.1.2.1.1 Torrents with predetermined channel bends	Moderate	Spurs
Redeposited materials	2.1.2.1.2 Free meanders	Small to moderate	Spurs, straightening
Erosion by flooding	2.1.2.1.3 Grass scar torrents	Small	
Confinement	2.1.2.2 Induced lateral-erosion torrents	Variable	Control of cause or grading
B) Slope failure	2.2 Torrents with embankment failures		
Large scale slope sagging and creep	2.2.1 Slope creep	Very dynamic	Surface and subsurface drainage, flexible check dams
Conchoidal retrogressive failure	2.2.2 "Muschelanbruch"	Dynamic	Drainage, variable check dam patterns
	2.2.3 Slow earth-debris flows	Moderate	Drainage, piles, revegetation
C) Special processes	2.3 Special torrents		
Ice avalanches, glacial lake bursts	2.3.1 Ice-debris flows and snow-debris avalanches	Very dynamic	Drainage
Runoff delay in caves	2.3.2 Karst torrents	Small	Convex rakes
	2.3.3 Glacial torrents	Moderate	Block throw embankments
Earthquakes	2.3.4 Earthquake torrents	Dynamic	
D) Varied causes	2.4 Composite torrents	Variable	Variable

2.1.1.1 Natural Scour Torrents

2.1.1.1.1 Colluvial Scour Torrents. Colluvial scour torrents are characterized by rapid and dangerous growth of scars with V-shaped cross sections. The process may affect long stretches of the channel and extend over considerable time intervals until general degradation and bedrock spurs combine to develop a balanced profile. The trend of erosion is towards a steady distribution of the erosional parameters in the sense of Sternberg's Law (1875) and in the sense of an equation for a longitudinal profile put forward by Hampel (1969, 1970). With the great or even excessive gradient of the bed as the principal genetic factor, the scouring forces of the torrent exceed the shear resistance of the bed. Debris generation by downward erosion is the essential process of valley formation, requiring check dams in stacked arrays as typical counter measures.

2.1.1.1.2 Volcanic Scour Torrents. Volcanic debris flows originate along V-shaped scour ravines of volcanoes. The ravines may also guide intermittent lava flows. Complexities arise due to the intercalation of erosion-resistant lava and erodible ash deposits. The control of such composite scour ravines by means of stacked arrays of check dams is difficult because the foundations of transverse structures tend to set off continuous minor mass movements leading to the eventual failure of the entire check dam arrays. During intense rain storms masses of water may combine with hot ash deposits to produce dense mud flows ("Lahar mud flows" in Indonesia). A more sandy matrix creates a less dense debris flow ("Baujir" in Indonesia or "Dosharyn" in Japan according to the Japan International Cooperation Agency 1979).

2.1.1.1.3 Bedrock Scour Torrents. Bedrock scour torrents are characterized by a very slow evolution because of the great resistance of bedrock channels to erosion, even along steep reaches. In general it is not worthwhile to control such torrents by engineering works.

2.1.1.1.4 Partial Scour Torrents. These are torrents which in general do not show characteristics of torrents, but possess reaches with substantial depth erosion, such as the "Danube torrents" in Nibelungengau and Wachau in Austria, which drop steeply from the plateaus of Mühlviertel and Waldviertel districts towards the Danube and Kamp rivers. Scour along these steep reaches is induced by the large discharge of water derived from extensive catchment basins on dense granitic terrain. Along torrential reaches erosion is limited to wedge-shaped scour depressions below waterfalls and ravines.

The generation of debris along these torrents is limited and rarely exceeds a moderate volume. Measures against scour are confined to masonry revetments rather than stacked arrays of check dams.

2.1.1.1.5 Torrents with Strong Infiltration. Torrents with strong infiltration are limited to permeable terrain and/or high catchment basins normally. In the case of catastrophes the discharge and erosion decrease in a downstream direction, channels become narrower and occasionally disappear altogether. The geological substratum is predominantly fractured and stratified carbonate rock, talus, or permeable sands (e.g. "Wadis").

In the area of erosion stacked arrays of check dams would only help in exceptional cases. In the depositional domain diversion structures (dams and gabions) might aid infiltration. Application of flood formulas have to be absolutely avoided in this type of torrent.

With increasing size of the catchment basin the amount of HQ may decrease (or stay constant). In addition discharge sections, flood levels, and cumulative debris load diminish and can best be evaluated in the field.

2.1.1.1.6 Gullies. Gullies produce mud flows along steep-walled channels in generally gentle terrain. At the head of the gully material is derived from deeply incised walls from where it is carried to the mouth (Fig. 6). Gullies are the result of extreme flood discharge and traction forces on poorly consolidated, fine-grained (often aeolian) channel bed materials. The abrupt incision at the head of the gully owes its origin to scouring of water into homogeneous packed fine sediment; stepped profiles develop in stratified deposits. Gully formation is particularly common in arid and semiarid zones (Heede 1980). Erosion is retrogressive and proceeds rapidly at the head of the gully in times of extreme rainfalls (discontinuous gully). In the uppermost parts of the gully system more gentle gradients are also found (continuous gully according Heede 1980). The evolution of gullies eventually tends towards extremely low gradients. It is therefore important to control the head of a gully and its branching network of tributary runnels. In the lower sections of a gully and on gentle fans damage arises mainly from mud accumulation. Due to the small grain size of the substratum buildings and control works are easily undercut or bypassed and have to be protected accordingly.

Gullies are also common where runoff from roads attacks loose side or where agricultural activity (corn, hops, vines etc.) uses too steep slopes with fine granular soils.

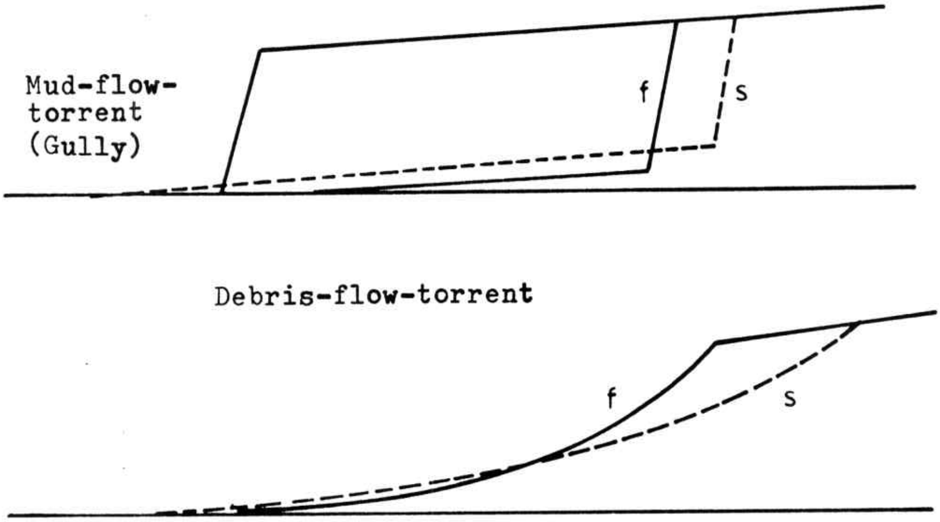

Fig. 6. Schematic development of longitudinal channel profiles in mudflow torrents (gullies) (upper Fig.) (supplemented after Ireland, Sharpe, Eargle 1939) and debris-flow torrents (below Fig.). (f) indicates an earlier stage than (s). Due to comminution of debris longitudinal profiles of debris-flow torrents tend to follow Sternberg's (1975) law

Schematische Weiterentwicklung der Talbildung: Schematische Längenschnitte von Schlammwildbächen (Gullies) (oben) (Gullies oder Racheln) (unter Benützung von Irland, Sharpe, Eargle 1939) und Geschiebewildbächen (unten) (wobei (f) das frühere und (s) das spätere Stadium zeigt), deren Längenschnitts-Ausbildung (im Gegensatz zum Gully) durch den Abrieb des Sternbergschen Gesetzes (1875) bestimmt wird.

2.1.1.1.7 Debris-Accumulating Torrents (*Stiny 1931*). In these torrents debris is accumulated "on call" along wider and low-gradient reaches – and can be remobilized during extreme events. Among debris-accumulating torrents in mountainous terrain there are transitional types towards free meanders and thus embankment erosion may supply part of the debris. Stiny (1931) pointed out that torrents characterized by such intervening depositional reaches tend to "clean" themselves in intervals of 35 years. Counter measures include provision of sufficiently voluminous debris retention basins.

2.1.1.2 Induced Scour Torrents

Such torrents develop due to artifical confinement of the channel to the extent that its discharge section is unable to handle flood discharge. Confinement of channels may develop as a result of forest-roads, haulage along topographic depressions, artificial increase of discharge or new water channels in erodible materials and extensive cultivation on formerly natural terrain. According to the geological substratum the resulting erosional forms vary (e.g. gullies in finegrained materials); transitional forms to torrents with lateral erosion exist. Counter measures include the establishment of a new erosional balance along the channel or control of the disturbance.

2.1.2 Lateral Erosion Torrents

Under this heading fall torrents whose traction is insufficient to cause major depth erosion (scour) and whose activity is limited to lateral erosion due to a concentration of isotachs along the outside channel bends resulting in embankment erosion.

Lateral erosion may be the result of a forced directional change or that of free meanders along the valley floor.

2.1.2.1 Natural Lateral-Erosion Torrents

These torrents and their directional changes are determined by the lithology and structural geology of the underlying terrain.

They are found in mountainous regions where repeated changes in the direction of the valley impose bends and abrupt embankment breaks. Even the torrents of gentle terrain (Salzer 1886) which develop redepositional reaches rather than debris fans can produce embankment scars along shifting meander bends.

2.1.2.1.1 Torrents with Predetermined Channel Bends. These torrents derive their debris from embankments which are undercut during excessive discharge, thus endangering roads, buildings, and cultivated terrain. Steep slopes may be converted into menacing sources of debris. The evaluation of hazard and evolution of a debris source has to start at the principal points of erosional attack – using vegetation as a guide. The development of debris cones or, more often, debris fans depends on the quality of erodible debris along the torrent. Technical counter measures include block-throw spurs, channel reinforcements, and, less commonly, stone masonry revetments, check dams, channel cuts. In conjunction with embankment controls biological improvements should be carried out.

2.1.2.1.2 Torrents with Free Meanders. During the development of meanders in low-gradient valley reaches only finer grained materials are reworked. Accordingly, only fine grained debris accumulates along the bottom of the valley during flood events. The main preventive measures include the exclusion of permanent settlements, careful industrial site planning and diking. Near existing settlements the development of safe "islands" with erosion-resistant block buttresses prevents excessive scour. The level and design of basements have to accommodate a design flood. Technical measures include channel straightening and flat sloped embankments, combined with biological techniques.

2.1.2.1.3 Grass-Scar Torrents. This type, proposed and reported by Stiny (1931) cannot be discussed in detail here. Grass torrents erode only a tenuous grass-soil cover which establishes itself in between flood events along the channel. The damage caused by this type is normally harmless.

2.1.2.2 Induced Lateral-Erosion Torrents

These torrents originate from the confinement of channels by roads. They may even evolve into scour torrents. Smooth embankment controls along roads may similarly increase the discharge velocities and thus increase the potential for scour and lateral erosion. Bridges and culverts with narrow cross sections tend to be blocked by drift wood and thus force channel abandonment.

2.2 Torrents with Embankment Failures

These torrents do not create their own debris but receive it from landslides (slope creep, slumps, conchoidal failures, earth flows, debris avalanches). Blockage by slide debris is the main hazard associated with these torrents if discharge is insufficient to carry away the accumulated material harmlessly. Dependent on the type of debris supply different segments of the torrent tend to pose different hazards and growth patterns. Sagging or creep of entire mountainsides tends to shift the torrent channel and thus set the stage for enormous debris flow potential. Similar hazards arise from bursting blockages of the channel caused by slide masses or debris flow from tributary ravines. Voluminous debris slumps and conchoidal failures[1] (= "Muschelanbruch" by Stiny 1931) tend to be more dangerous than surficial planar debris slides. Large scale translation slides, however, such as those of the Jasnitzgraben/Allerheiligen/Mürztal/Styria/Austria, are exceedingly dangerous. Geomorphological tests (e.g. Moser 1973) may give an indication of the failure potential of embankments. Embankment failures can also be induced artificially by defective drainage works, insufficient storm drains, runoff from parking lots, ski runs etc. Remedial measures along the mountain sides include drainage, reforestation, stabilisation of slide debris, retaining walls, flexible check dams (Ofner 1977), debris retention basins and channel works.

2.3 Special Torrents

This group encompasses torrents with a great variety of erosional processes. There are connections with other types, but it seems better to divide for a better understanding.

2.3.1 Ice-Debris Flows and Snow-Debris Avalanches

Mixtures of ice and debris, and mixtures of snow and debris can attain great velocities, as demonstrated by the ice-fall-debris-flow of Huascaran on May 31, 1970 (Welsch/Kienzl 1970), which descended with an average velocity of 250 to 300 km/h accompanied by extensive development of much dust and an airblast. Snow-debris mixtures, as they occur during springtime rainstorms (as in April 1975 in Lungau) are also dangerous because the saturation of snow and soil with water enables the avalanches to reach great velocity, jump their natural ravines, and ascend the opposite valley walls. Not only the flowing material but also the airblast has destructive potential and is not governed by the laws of hydraulics. The volume of erosion of these processes may be small; neverless they may carry large blocks of bedrock.

2.3.2 Karst Torrents

Karst torrents flow partly through cave systems, and thus experience a reduction of the flood wave. A diversion of Karst torrents into cave systems may reduce their damaging impact, as demonstrated by the "Katavotrone" (upward convex rakes) of the k.k. Wildbachverbauung in the old Austrio-Hungarian Monarchy.

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[1] The "Muschelanbruch" (Stiny 1931) originates from the forceful explosion of retained groundwater along the point of a slope from where a conchoidal retrogressive expansion of the erosional feature takes place. The reduction of shear resistance below the point of water discharge also contributes to the widening of the feature.

2.3.3 Glacial Torrents

Glacial torrents are dominated by the concentration of discharge (and bedload transport) in the summer months. Debris that has been accumulated along a channel during the year is carried off in this short period of peak discharge (see Fig. 7, Type 1). Coincidence of rapid snow-ice melt and thunderstorms may set into motion damaging masses of debris from the forefield of the glaciers. Such flood events are best countered by block throw dikes reinforced by internal cable systems to protect oversteepened banks and maintain a straight course of the channel.

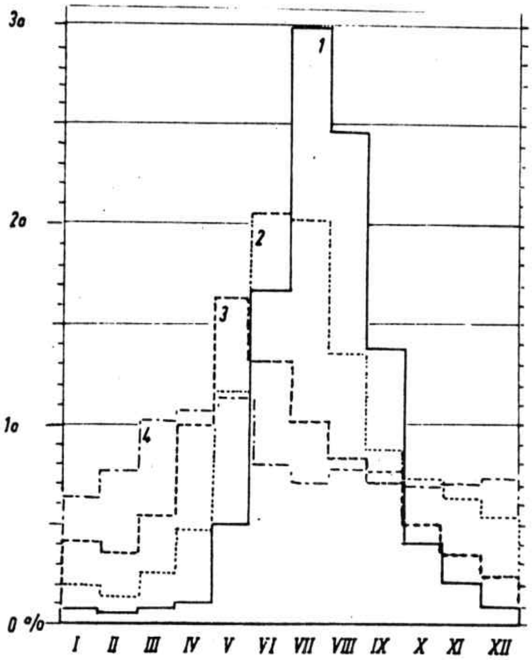

Fig. 7. Types of torrent and river water discharge in some Austrian river-basins (from Kresser and Güntschl 1970). 1 = glacial type (Venter Ache/Tirol), 2 = mountain river with high glacial contribution (Inn River/Tirol), 3 = mountain river without glacial contribution (Mur River/Styria), 4 = foreland river (Ybbs River, Lower Austria)

Abflußtypen (nach Kresser und Güntschl 1970) österreichischer Gewässer. 1 = Gletscherbach (Venter Ache/Tirol), 2 = Gebirgsfluß mit Gletscherwasseranteil (Inn), 3 = Gebirgsfluß ohne Gletscherwasseranteil (Mur), 4 = Vorlandfluß (Ybbs)

2.3.5 Earthquake Torrents

Repeated earthquake activity in a certain region may add to the instability of bedrock slopes. Technical counter measures along torrents have to consider this specific parameter (Querini 1980). Historical sources and documentation of recent events are significant aspects of this approach. The direct effects of an earthquake (i.e. rock avalanches, torrent blockages, colluvial slides, and collapse of buildings) contribute to the phenomena along the torrent channels that are covered adequately by the classification parameters discussed above.

2.4 Composite torrents

As pointed out in the introduction, it is not always possible to characterize an entire catchment basin with one parameter or one type only without creating a bias. Distinct segments of a torrent

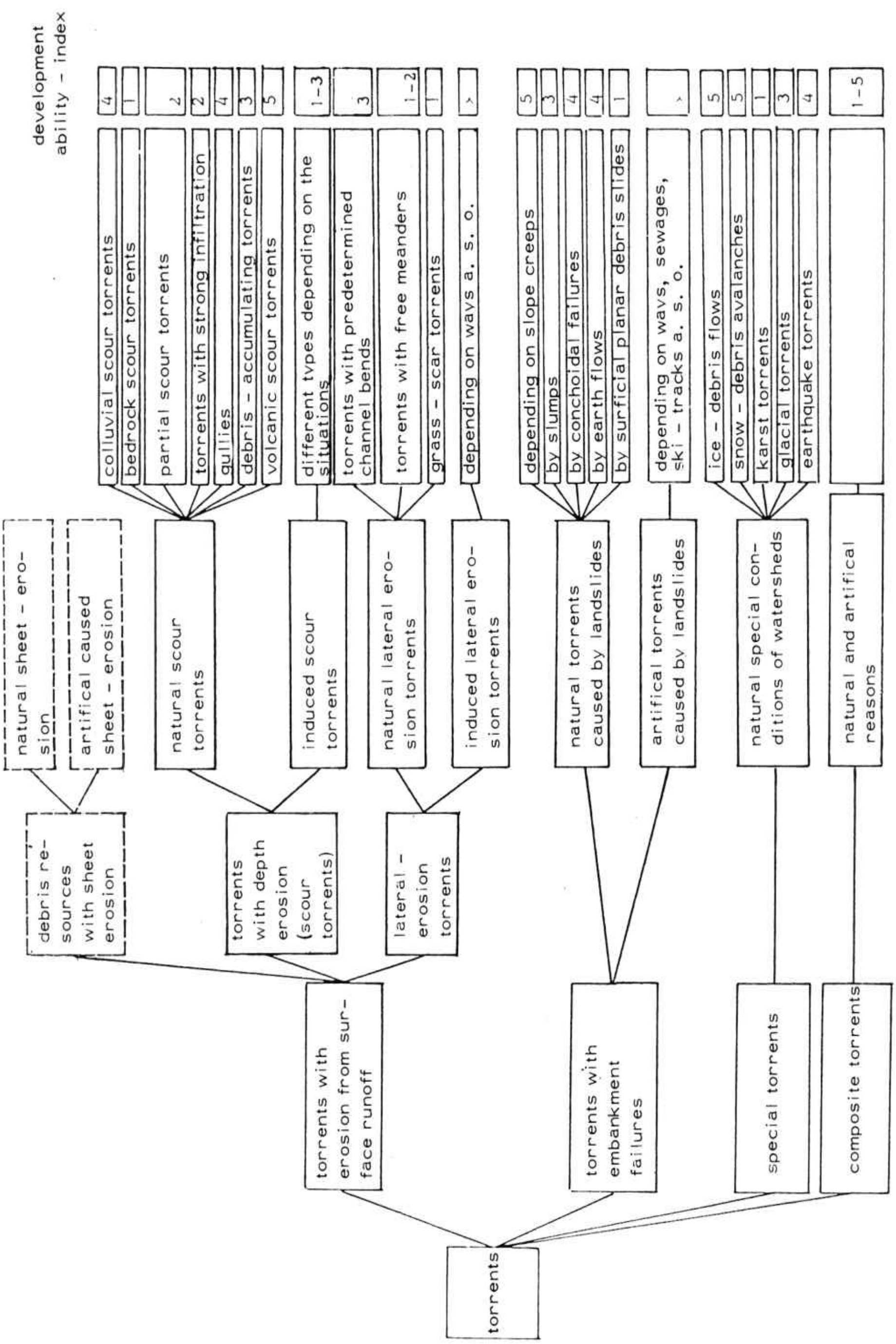

Fig. 8. Scheme of torrent classification inside the catchment basins and segments of catchment basins. Legend of the development-index: 5 = very dynamic developing potential, 4 = dynamic developing potential, 3 = moderate dynamic development, 2 = small development, 1 = virtually stable, x = different possibilities

Schema der Wildbachgliederung nach Einzugsgebietstypen und Einzugsgebietsabschnitten. Legende: 5 = sehr dynamische Entwicklungsfähigkeit, 4 = dynamische Entwicklung, 3 = mäßig dynamische Entwicklung, 2 = geringe dynamische Entwicklung, 1 = nahezu stabil, x = unterschiedliche Entwicklung can be concisely described as to their torrent and slope dynamics – but the catchment basin may be a composite of different types identified along individual segments.

Therefore, in contrast to the debris cone, where processes are integrated into the image of an extreme event, the source area is characterized in the description of a composite torrent which is characterized by its individual segments (Fig. 8).

2.5 Conclusions

The summarizing Fig. 8 gives an overview of the genetic classification of torrents, based on past experience, and is probably subject to further testing and correction. Nevertheless it seems that with a view to the forest-management of catchment basins, and the application of active or passive measures on the cone, the five genetic categories of debris movement are an adequate beginning.

With regard to sheet erosion, a phenomenon transitional to rill erosion, view points and management practices are somewhat different (watershed management). In principle, damage arises from surface runoff which is considered in Fig. 8 (broken lines).

Appendix Preliminary Torrent Hazard Classification of Debris Cones

(Torrent index for the establishment of torrent zoning maps in the context of land use mapping)

The first part of the classification (Questions 1 to 6) serves to determine the local level of hazard in different areas of a debris cone, using so called "silent witnesses" or hazard indicators that can normally be found on "natural" debris cones. The second part characterizes the projected torrent activity by differentiating roughly (according to Aulitzky 1973) between debris flow torrents, bedload torrents, and flood creeks (Questions 7 to 11). By arranging the questions in this manner the investigator may gain a reasonable picture of the hazard gradients even if time does not permit a more comprehensive investigation. The questions are graduated in such a way that if they are answered with (a), i.e. 4 points, destruction and human casualties are to be expected. Questions answered with (b), (c), and (d), i.e. 3, 2, 1 points respectively, indicate a progressively smaller hazard. The point sum, resulting from an addition of the points entered in questions 1 to 6, is divided by the number of questions answered. The number gained by this procedure is the hazard index for the area under consideration.

If this index is greater than 2.6 the area should be included in the most endangered "red zone" on account of possible destruction and casualties; no building permit should be given. If the index is between 2.6 and 1.6, the area would be included in the "yellow zone"; certain building restrictions have to be imposed which are to be defined according to the hazard to be expected, e.g. elevated doors, main entrance on downstream side of buildings, no basement windows or other openings, reinforcement of inevitable low openings, rotation or buttressing of foundations, block throw buttresses, reinforcement of walls, provision for emergency exits etc. With an index below 1.6 construction may proceed without special protective measures (formerly designated as the "green zone" and now as the "white zone" drawn inside of the dotted line on the hazard maps). Areas not investigated are also white on the map but are separated by this line from the safe white zone. Access to the building land ought to be considered separately by similar procedures.

The test sum of the questions 7 to 11 is also divided by the number of questions answered: a torrent with potential for debris flows is to be expected if the index is greater than 2.7; if the index is between 2.7 and 1.9 much bedload transport is to be expected; if the index is below 1.9 only floods are characteristic of the creek. From this only hints can be derived, and gradations from one type to the other have to be considered. The range of indices for potential debris flows is probably between 2.4 and 4.0, for bedload transport of debris between 1.6 and 3.0, and for creeks with flood potential between 1.0 and 2.2.

In the case of major engineering works against torrent hazards the indices have to be modified or possibly reduced to zero.

Torrent Index

(for the differentiation of endangered areas of torrent hazards on the debris cone)

Question 1

Maximum grain volume of recently eroded material.	points
a) 1 m^3 and more.	4
b) 0.2 to 1.0 m^3.	3
c) 0.01 – 0.2 m^3.	2
d) Less than 0.01 m^3.	1

Remarks: The maximum grain volume is an indication of the transporting forces in a debris flow or the water and thus also an expression of the velocity and momentum of the processes. Misinterpretations may arise from gradual downcone displacement of individual blocks or in the case of remainder from the Pleistocene glaciations.

Question 2

Maximum thickness of single debris layers that can be differentiated by the soil horizons or the textural breaks.	points
a) 1 m and more.	4
b) 0.5 to 1.0 m.	3
c) 0.1 to 0.5 m.	2
d) Smaller than 0.1 m.	1

Question 3

Inclination (gradient) of the debris cone domain under study.	points
a) More than 15‰.	4
b) 7 to 15‰.	3
c) 2 to 7‰.	2
d) Less than 2‰.	1

Remarks: Inclination of the surface of deposition influences the rate at which a catastrophic event takes place, and the depositional tendency decreases with increasing gradient.

Question 4

The present vegetation cover is:	points
a) pioneer vegetation of alnus, salix, myricaria on stony terrain to patches with first succession of larch, pine, and spruce;	4
b) advanced succession of even aged larch, birch, pine and spruce stands on coarse gravelly terrain;	3
c) characterized by the predominance of meadows and pasture broken by stone fences and stony soils;	2
d) characterized by fields without stone fences or terraces and only minor stony material in the soil.	1

Question 5

Are the erosional features and surface irregularities on the debris cone domain	points
a) debris ridges and erosional furrows with coarse blocks, that can be identified as domains with concentrated high-velocity debris flows;	4
b) poorly defined depositional features created by spreading debris flow or by its redeposition;	3

c) elevated surfaces along the incised torrent which could only be affected by a blockage of the channel; points 2

d) distinctly elevated surfaces above the incised torrent channel, that cannot be reached by debris from the channel, but to which access could be interrupted? 1

Question 6

The discharge situation on the debris cone is: points

a) characterized by the presence of blocking structures above the domain of interest (e.g. bridges, culverts of small diameter, narrows, dams etc.) or other structures that inhibit the free discharge above, laterally or below the point of reference (flat reaches with less the 3‰ gradient, sharp bends, restrictions along the receiving river) which would force channel abandonment even with a minor debris load; 4

b) similar situation as at (a) except that only broken logs and very coarse boulders would force channel abandonment; 3

c) characterized by absence of significant obstacles but only moderately incised flat channel and a relatively free debris discharge potential of the receiving river; 2

d) channel works on the lower course which could easily handle the design flood. 1

Remarks: In the case of discharge impediments by buildings and preexisting features the local domain with serious impact will have to be considered separately.

Number of questions answered ....
Total points ....
Therefore torrent local index ....

Second Part: Characterization of Torrent Type

Question 7

Debris flow and flood disasters have in the past: points

a) caused considerable devastation and casualties in the old community, peripheral to the torrent or on uninhabited terrain nearby; 4

b) caused only material damage without complete destruction of buildings; 3

c) caused devastation of newly constructed buildings along the channel; 2

d) caused only material damage in recently builtover areas in the vicinity of the torrent channel. 1

Remarks: The old centres of the communities usually reflect an instinctive and traditional experience and represent safe areas. They are only rarely affected by destruction through torrent activity, except in the cases of mills, where sporadic damage is accepted as a professional risk.

Question 8

The potential one-day maximum precipitation (taking into account the average elevation of the catchment basin and a long record): points

a) exceeds 200 mm (or 2 mm/min for at least an hour); 4

b) is between 150 and 200 mm (or 1,5 to 2,0 mm/min for at least an hour); 3

c) between 100 and 150 mm (1.0 to 1.5 mm/min for at least an hour); 2

d) less than 100 mm (or less than 1.0 mm/min for at least an hour); 1

Remarks: Since retention capacity of the vegetation cover and the soil is probably completely exhausted at 200 mm precipitation, greater precipitation values per day (e.g. in Austria up to 650 mm) have not been taken into account.

Question 9

Location and potential debris volume in the source area of the upper basin: points

a) Is the debris source directly above the cone and can the voluminous debris be moved along a steep (more than 20%) course that can be blocked between its erodible flanks, and is the greatest debris mass that can be expected to be mobilized more than 100 000 m^3? 4

b) Are the large debris sources separated from the cone by a steep but relatively open gorge that cannot be blocked, and is the greatest debris mass that can be mobilized in the uplands between 10 000 and 100 000 m^3? 3

c) Are the closest debris sources separated from the cone by a flat torrent reach that may also serve as a redepositional area without a potential for blockages, and is the expected debris volume during an extreme event between 1 000 and 10 000 m^3? 2

d) Are the closest debris sources separated from the cone by several gentle torrent reaches, and is the greatest single debris load less than 1 000 m^3? 1

Question 10

Role of the unrooted trees or logs in the debris flow (or flood): points

a) Can, in the extreme case, parts of old mature forest reach the debris flow along embankments by erosion, slumps, debris avalanches etc.? 4

b) Can single trees of mature stands reach the torrent channel along eroded embankments or slope failures? 3

c) Can only stumps and short logs reach the debris flow or flood channel? 2

d) Can only young and short trees reach the torrent in a case of debris flow or flood channel? 1

Question 11

Water-storage potential of the bedrock and surficial materials (according to the hydrogeological parameters the effective percentage of the area has to be considered in the point grading): points

a) massive bedrock or slate-marl beds without colluvial cover, or clay-loam and clay-loam-sand-rock surfaces with a predominance of finegrained materials, moraine; 4

b) strongly weathered near-surface bedrock, inclined shale-marl units or residual colluvium with clay-sand mixtures; 3

c) jointed rock or sand – gravel beds without fines; 2

d) strongly jointed bedrock, karst or unconsolidated coarse surficial materials and talus, highly permeable. 1

Number of questions answered ....
Total points ....
Therefore torrent-type index ....

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