Erosion, Debris Flows and Environment in Mountain Regions (Proceedings of the Chengdu Symposium, July 1992). IAHS Publ. no. 209, 1992.

A catastrophic flood/multiple debris flow in a confined mountain stream: an example from the Schmiedlaine, southern Germany

C. DE JONG

Institut für Physische Geographie, Freie Universität Berlin, Grunewaldstrasse 35, 1000 Berlin 41, Germany

Abstract The dynamics of a catastrophic flood/multiple debris flow on 30 June 1990 was reconstructed along a 2 km stretch of the River Schmiedlaine. The upper bedrock reach was mainly subject to sediment transport and erosion, giving way to an erosionally and depositionally interactive boulder-bed reach with confined bedrock meanders and finally to a well-sorted purely aggradational braided reach. Sediment was delivered from several major slumps and broken check dams, combined with two major debris flows. Resulting deposition consisted of log jams, levees and small end lobes. During the flood's rising limb, flows were highly viscous and hyperconcentrated, with flood-water reworking following near the end. Reconstruction of the flood maximum allowed determination of varying velocities and flood mechanics. Up to 1 m of vertical water level difference occurred in areas of high stream curvature. Flood power, bed resistance and bed friction varied markedly according to gradient and stream curvature.

INTRODUCTION

Aims

This study aims to reconstruct longitudinal changes in hydraulic geometry and flow processes during the passage of a catastrophic flood. It will assess the geomorphological impact of the flood on three varying reaches, namely, a straight bedrock reach, a gravel/boulder meandering reach and finally a braided meandering reach.

Study area

The study area (Fig. 1) consists of a 1.8 km long stretch of the Schmiedlaine, an alpine mountain torrent that drains the northern Alps, 60 km south of Munich before confluencing with the Lainbach which drains past Benediktbeuern. The geology is very diverse, consisting mainly of cemented marls, sandstones, conglomerates, breccias, dolomites, slates and Quaternary morainic deposits. The stream has a peaky discharge with the mean flow lying around 1 $m^3 s^{-1}$ and with floods of 10 $m^3 s^{-1}$ recurring four-five times annually. The flood under discussion had an estimated discharge of 75 $m^3 s^{-1}$. The Schmiedlaine's average gradient lies around 0.08, interrupted twice by minor waterfalls. Reaches are constrained by local bedrock, enforcing high angles of stream curvature. Sediment sorting and river geometry vary considerably down the long profile. The highly incised bedrock/boulder reach below the waterfalls gives way to a boulder/gravel reach, which in turn merges into a meandering gravel-bed reach and finally into a low gradient braided gravel reach prior to its confluence with the River Lainbach.

Event characteristics

The flood/multiple debris flow which occurred on 30 June 1990 was triggered by heavy rainfall (80 mm in 30 min) and by the rapid transportation of large volumes of slope material, in the form of landslides and debris flows, into the Schmiedlaine. In the main Lainbach River, a highly destructive flood ensued. This resulted in the blocking of one bridge and the destruction of the associated road. Highly hyperconcentrated flows on the rising limb of the flood were modified by the occurrence of two closely spaced debris flows after the flood peak in the boulder/gravel reach. After this, the main flood wave rapidly reworked the material, eroding in the upper reaches and aggrading in the lower.

METHODOLOGY

Surveying

The Schmiedlaine was surveyed using a theodolite and distomat and documented photographically from its confluence with the River Lainbach up to the waterfalls. Long profiles were plotted and compared using both the lowest point in each cross section, the main gravel bar and the left and right bank high water marks. Forty-eight cross sections were drawn from approximately 15 surveying points, and at each there was an indication of present water levels, dry channels, terrace levels and high water levels.

Calculation of cross-sectional areas

Maximum cross-sectional areas immediately after the flood were calculated together with the local gradient on a bar to bar basis. In order to calculate approximate volumes of material eroded or deposited during the flood, river sections unaltered by the flood were used as reference points. These included

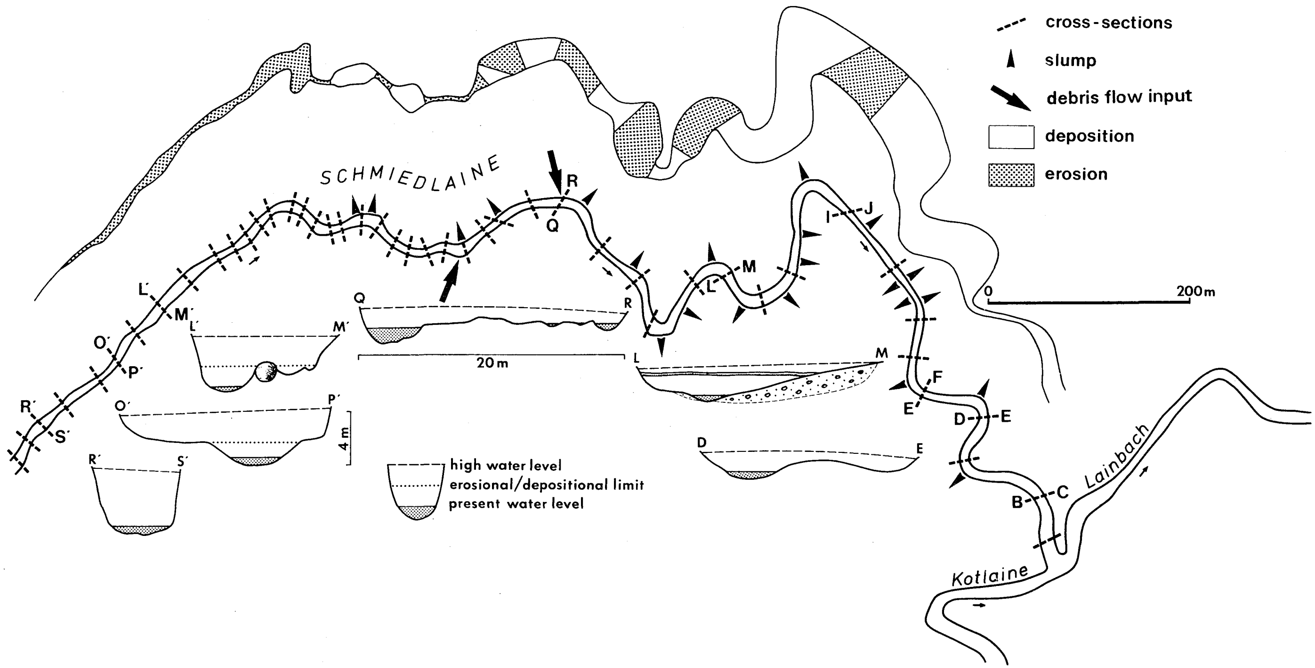

Fig. 1 Detailed geomorphology of the study area indicating erosional and aggradational zones, major valley-side sedimentary inputs and post-flood geometries.

minor waterfalls, bedrock reaches and manmade control structures. Assuming good hydraulic relationships between cross-sectional area, gradient, and velocity (Leopold & Maddock, 1953) a line that decreased exponentially with gradient was plotted through the unaltered sections. By plotting the post-flood cross-sectional areas on the curve for each of the 48 cross-sections, the actual area just after the flood maximum could be determined. The validity of this method was checked by investigating photographs and the cross-sectional diagrams. Areas of erosion could be determined from various terrace levels and deposition from large boulder deposits and log jams. By inserting approximate flood base levels into the cross sections, the remaining area subject to erosion or deposition after the flood fitted closely with the graph.

Flow velocities

Velocities were estimated after Johnson (1970) from the radius of curvature of the river bends and the elevation differences that persist between high water marks on either side of the channel:

$$\tan o = v^2/r_c\, g \cos S$$

where:
$\tan o$ = high water elevation difference,
v = mean velocity,
r_c = radius of curvature,
g = gravity,
S = channel slope.
The approximate discharge during the flood could be calculated from sections with unaltered cross-sectional areas and their velocities.

Hydraulic geometry

Flood effectiveness within the different types of reaches were calculated. Unit stream powers were derived form the standard formula:

$$\omega = QpS/w$$

where the undefined terms are:
ω = unit stream power,
Q = discharge,
p = density,
w = river width.
The Darcy-Weissbach friction factor was obtained from the gravity, hydraulic radius, inclination and velocity values for the corrected depths. Froude numbers were determined simultaneously.

Sediment analysis

Sediment samples were taken at four sections. Surface counts of maximum *b*-axes clasts were taken at cross section QR just below the second debris input, at boulder-log jam IJ and at the debris flow end-lobe at EF, and a 500 kg bulk surface and sub-surface sample was taken at BC (Fig. 1). Sedimentary sections were investigated within the three different representative reaches.

RESULTS AND DISCUSSION

Sedimentology

The largest boulders were found in the upper bedrock reaches and in the boulder-log jams (Fig. 1). Log jams were coarser than debris end lobes (Fig. 2). Whilst the largest material should have been found below the debris input, it actually occurred at the levee at BC.

In the meandering reaches the deposits had been deeply incised by the post-debris flow flood often creating three terrace levels. Vertical sections revealed a massive layer of clast-supported material deposited by hyperconcentrated flows (Costa, 1986) with a total absence of fines (Fig. 3). It is suggested that they were moving as a "high density traction carpet" (Todd, 1989) which on deposition is drained of the wet fluid matrix, causing the clasts to settle. Turbulence is in this case dampened out and grain interaction provides the dominant means of momentum transfer. Overlying this was an abrupt discontinuity, followed by a thicker matrix layer of stratified material, unsorted and interspersed with boulders over 1 m in size. This corresponds with the debris flow input stage causing even higher density flows. Newtonian flood waters would have been incapable of transporting material of such size. The sections were draped with very large boulders on the surface which would have settled out during the final stages of flood reworking after being moved ahead by dispersive forces. The origin of the deposits was further complicated by complex reworking in the waning stages of the flood. Iseya *et al.* (1992) found that smaller grains tend to pass through the interstices leaving the coarsest on the surface. Their time sequential model of aggradation and degradation can be applied to some locations where roughness is dampened out by deposition and which are subject to bed load flows.

Flood dynamics

Flow velocities decelerated from the deep flows (4 m) in the upper bedrock reaches (Fig. 4) to the shallower flows (0.5 m) in the distal reaches. Bedrock and narrow, high curvature reaches were subject to the highest stream powers during the flood (Fig. 5) decreasing in the lower braided and meandering

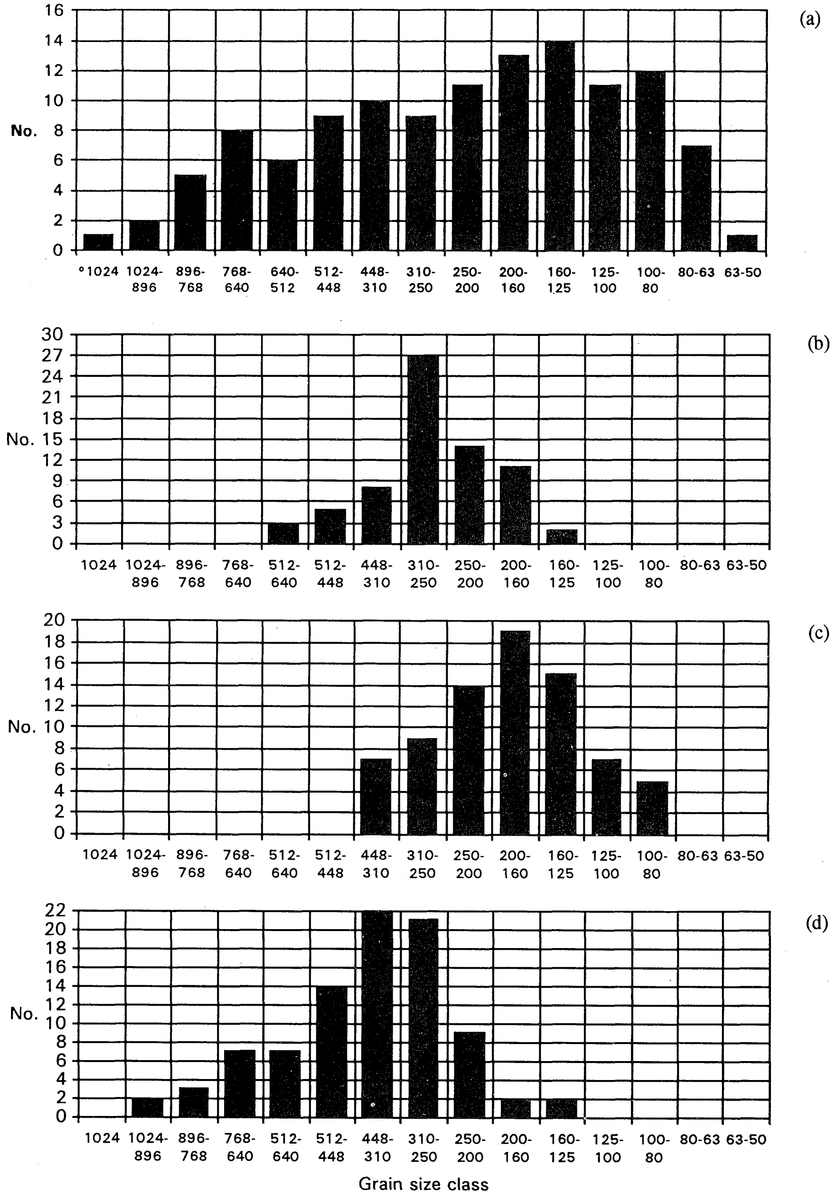

Fig. 2 Grain size distributions (mm): (a) below main debris input (QR), (b) at the log jam (IJ), (c) at the debris end lobe (EF), (d) at the levee (BC).

gravel-bed reaches. The boulder-bed reaches generally had stream powers twice as high. Volumes of erosion and accretion did not always correspond with the stream powers locally, but flood powers below 1.2 generally caused high amounts of deposition whereas those above 1.4 normally eroded.

Average Froude numbers (Fig. 6) did not fluctuate much along the river's course and even remained sub-critical. Pierson (1980) describes this behaviour

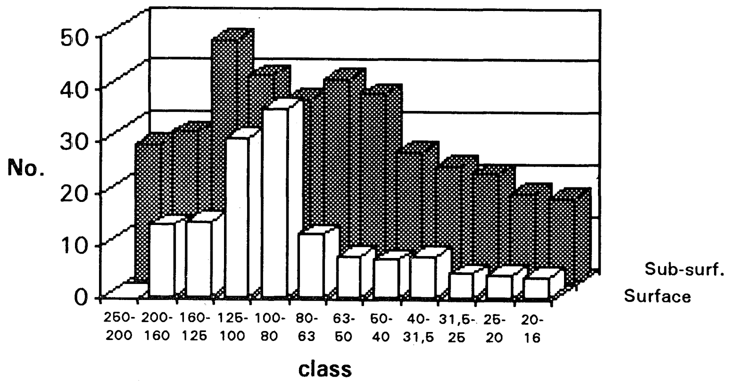

Fig. 3 Surface and subsurface grain size distributions (mm) at BC.

as representing the result of increased viscosity and the flow being characteristically laminar. In the lower reaches, the broad river widths, low flow depths and low velocities matched the extremely high flow depths and narrow channels with similar velocities in the bedrock reaches. Froude numbers remained relatively low throughout the flood peak. This is not unexpected since they are an indication of hydraulic state and are strongly related to geometry.

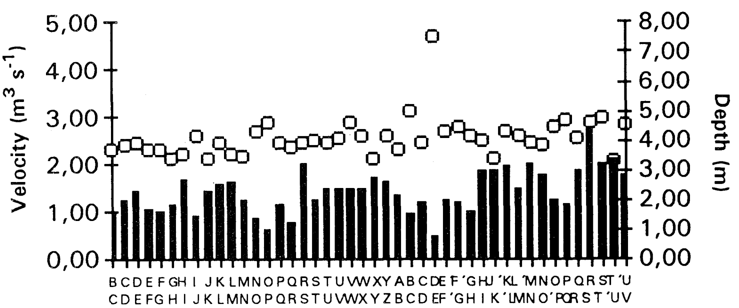

Fig. 4 Downstream variability in hydraulic geometry (water velocity and depth).

Bed resistance decreased steadily downstream (Fig. 6). As expected, the boulder-log jam at IJ, the main debris flow input at QR and the upper bedrock reach posed particularly high resistances to flow. Coarse woody debris played a major role in bed and flow resistance, since it was the equivalent of channel size or larger and managed to divert flow in at least two locations.

Flow bends

Flow bends governed the nature of flow and locations of erosion and deposition through their resistance to flow. The detailed geomorphological map (Fig. 1) shows areas of erosion and deposition as influenced by debris flow and valley sediment inputs as well as valley meanders. Processes of

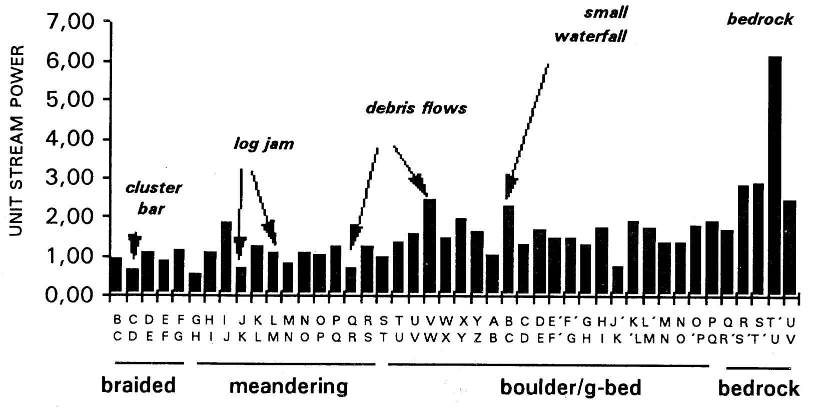

Fig. 5 Stream power variability.

deposition were governed by the properties of the hyperconcentrated flow. At five distinct locations, depositional lobes or snouts with considerably larger grain sizes than their downstream counterparts occurred (Fig. 2). Log jams also acted as major sediment traps, though depositional patterns were complex. At the log jam IJ, upstream of the end-snout EF, grain sizes were much larger. Congested zones (Iseya & Ikeda, 1987), produced by the log jams allowed the trapping of large amounts of woody debris and very coarse sediment. Erosional zones were invariably located in the straight reaches with finer sediments.

A lack of turbulence and normal secondary circulation during the hyperconcentrated flows (Costa, 1986) allowed deposition of a series of levees at the edges of sharp channel curves. River bend resistance played an essential role in the reworking of material, depending on the length and angle of curvature. With a decrease in flow energy and centrifugal force towards the end of the event, the radius of flow curvature gradually decreased, producing the sequence of levees at the channel sides. Flow bends also influenced the structure of the water surface topography.

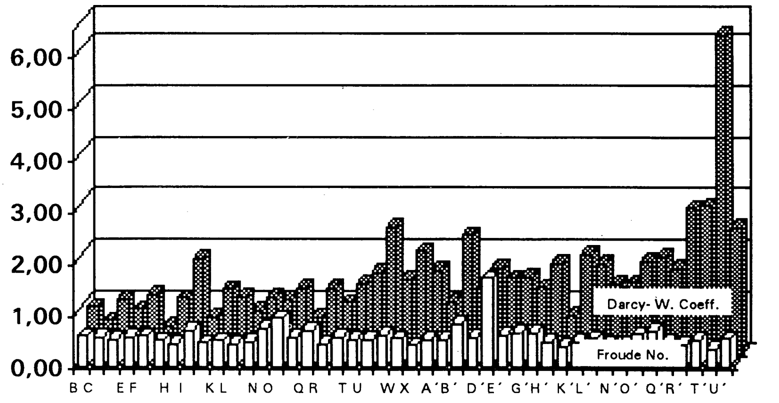

Fig. 6 Bed resistance factors.

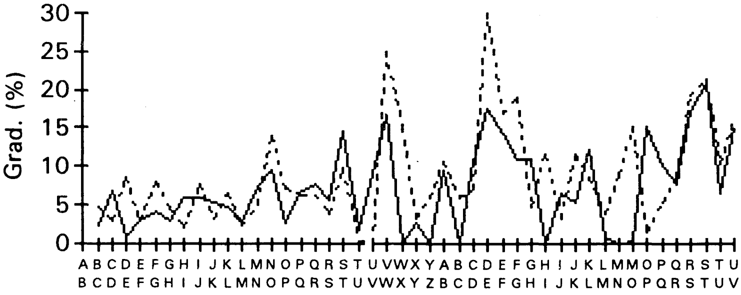

Fig. 7 Variations in right (dotted line) and left (continual line) high water level gradients during the flood maximum. Notice divergence.

Water surface topography

In the upper reaches, bed material was often the size of the channel itself, and with correspondingly high flow depths, water levels were forced into asymmetrical patterns onto the channel edges around the obstacles (Fig. 7). In reaches with large amounts of in-bend deposition, such as log jam locations, water levels became laterally convex or asymmetrical in the cross sections (see Fig. 1). The highly meandering reaches had vertical water level differences of up to 1 m.

Acknowledgments I am grateful for the help Peter Ergenzinger has given me both in the field and by providing new ideas for this study. I would also like to thank Neus la Roca, Magarita Cruz Almanza and Marzelus Holzmann for assistance in the field. The research was supported by the DFG and a Studienstiftung scholarship.

REFERENCES

Costa, J. E. (1986) Rheologic, geomorphic, and sedimentologic differentiation of water floods, hyperconcentrated flows and debris flows. In: *Flood Geomorphology* (ed. by V. R. Baker, R. C. Kochel & P. C. Patton), 113-122. Wiley-Interscience, New York.

Iseya, F. *et al.* (1992) Fluvial deposits in a torrential gravel-bed stream by extreme sediment supply: sedimentary structures and depositional mechanisms. In: *Dynamics of Gravel-bed Rivers* (ed. by P. Billi, R. D. Hey, C. R. Thorne & P. Tacconi). Wiley and Sons, Chichester, UK.

Iseya, F. & Ikeda, H. (1987) Pulsations in bedload transport rates induced by a longitudinal sediment sorting: a flume study using sand and gravel mixtures. *Geogr. Annal.* **69A**, 15-27.

Johnson, A. M. (1970) *Physical Processes in Geology*. Freeman and Cooper, San Francisco, California.

Leopold, L. & Maddock, T. (1953) The hydraulic geometry of stream channels and some physiographic implications. *USGS Prof. Pap.* **252**, 1-57.

Pierson, T. C. (1980) Erosion and deposition by debris flows at Mt. Thomas, North Canterbury, New Zealand. *Earth Surf. Proc.* **5**, 227-247.

Todd, S. P. (1989) Stream-driven, high density gravelly traction carpets: possible deposits in the Trabeg Conglomerate Formation, SW Ireland and some theoretical considerations of their origin. *Sedimentology* **36**, 513-530.