PART 3

WATERSHED RESEARCH IN EUROPE

CHAPTER 8
NEGLECTED ASPECTS OF WATERSHED MANAGEMENT

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INTRODUCTION

Integrated watershed management should not only deal with water balance or focus on the needs of stakeholders, land use and forestry but should also integrate aspects such as water and sediment sources, slope stability and sediment transport, especially in young, active mountain belts.

This paper will concentrate on:
- high alpine regions in the United States, Germany, Switzerland, Austria, France and Italy;
- stakeholders, mainly from forest services, small farms, alpine clubs, villages and small towns downstream;
- the treatment of watershed management as a comprehensive problem covering issues that range from precipitation to runoff, from ecology to evapotranspiration and from slope instability to sediment transport.

STATEMENT 1: WATER BUDGET AND EVAPOTRANSPIRATION

Water budget

In mountain watersheds, there is little sense in carrying out water balance studies in the traditional manner of calculating evaporation losses from the deficit between precipitation and discharge because precipitation is too inaccurate a factor to act as the main determinant. Instead, an alternative approach is suggested in which regional precipitation is back-calculated from the sum of the losses incurred by discharge and evaporation (Figure 1; de Jong, List and Ergenzinger, 2002; Schädler and Weingartner, 2002). This is more accurate than determining the regional precipitation with standard extrapolation procedures from few point stations. Because the losses by evapotranspiration in high mountains are relatively small, the relative error of accuracy of evapotranspiration models can also be kept minimal. Accordingly, integrated watershed management in high alpine regions should pay far more attention to the determination of evapotranspiration in forested zones and in those covered by alpine meadows and shrubs. Due to its ecological importance and potential for change in the near future as a consequence of climatic perturbations, the zone above the tree line, which interacts with alpine meadows, shrubs and the forest border, should no longer be neglected by hydrologists.

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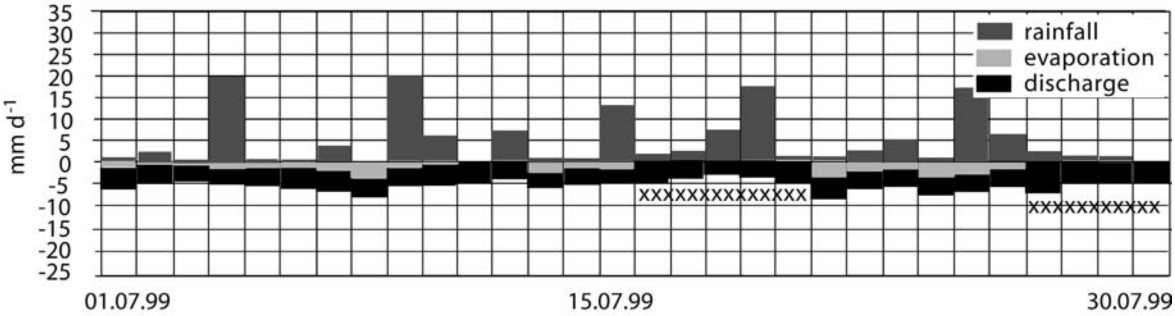
Another factor that is often neglected in watershed management in mountains is the hydrological role of avalanches within the water cycle. Avalanches are agents for the internal water movement within a basin and should therefore be investigated. Snow transfer into the lower valley zones near water route ways causes faster melt at different temporal and regional scales owing to higher temperatures. If snow melt occurs more rapidly and at an earlier stage seasonally, local soil moisture conditions can be influenced and water discharge into the streams is accelerated, so water can be transported away more quickly, and discharge increases. Any change in the frequency of avalanches through changes in climate or vegetation cover will be reflected in these hydrological processes.

FIGURE 1

Measured evaporation (from evaporation pans), discharge and rainfall in the Dischma valley for the wet month of August 1999.



x = no evaporation measurement

Evapotranspiration

The regionalization of evapotranspiration requires a suitable description of the physical characteristics of the watershed. It is suggested that the regional differentiation of temperature as detected by remote sensing, e.g. from light aircraft or satellite, is the most appropriate approach for validating evapotranspiration model results in mountain terrain. Because there is no simple evapotranspiration approach that can be transferred from the lowlands to the alps, well-known meteorological functions that have been developed for flat terrain and non-turbulent conditions, such as the Penman or Bowen ratio, are not applicable (de Jong, Collins and Ranzi, 2005). On the other hand, the Priestley-Taylor function has proven to be a robust approach.

A profound knowledge of evapotranspiration processes of single trees and tree stands in alpine areas already exists from long-term experimental studies such as those carried out by the WSL Birmensdorf in Davos, Switzerland (Häsler, 1982). In contrast, little is known on evapotranspiration of the high alpine belt above the tree line, especially those areas covered by pasture and dwarf shrubs. The hydrological interactions between this zone and the lower-lying alpine meadow zone in relation to its role as meadow or pasture for milk production has been largely neglected. In alpine catchments, the amount of evapotranspiration increases significantly from the colder, windier meadow on the valley floor to the sheltered, highly insulated shrub zone on the lower valley slopes (de Jong, Migala and Mundelius, 2005). It is these zones that are most highly frequented by grazing cattle. Should they undergo strong land-use change, this will not only have important impacts on the water balance in terms of ecology and biology; for example, once alpine meadow is abandoned, a rich and valuable deposit of fertilizer is developed locally (Körner, Hoflacher and Wieser, 1978). As a result of this extensive organic cover and the limited weathering capacity of the parent material, soil development is modified over many decades. No natural soil development will be possible for a long time, and any soil development that does occur will be strongly dependent on antecedent land-use conditions. Such modifications of the soil and vegetation cover influence the storage capacity of the soil and the amount of evapotranspiration.

STATEMENT 2: SEDIMENT BUDGETS AND RIVER BED STABILITY

During the International Year of Mountains 2002, the principal focus in natural sciences was narrowed down to problems of the hydrological cycle in mountains. However, in these extreme regions, watershed management has to be far more comprehensive and should include new focal points such as:

- river bed stability;
- general aspects of flooding;
- sediment transport.

River bed stability has an important causal relationship with the floodplain zones where land use and infrastructure are intensive. It is therefore important to understand and predict potential destructive changes in terms of erosion and deposition by flood flows in these zones (Dunne, 2000). During and after floods, large woody debris and coarse sediment play a dominant role in restructuring river beds, and this can have disastrous effects on areas with traditional land use. The stakeholders concerned include farmers with property in riparian river zones and administrators, especially of forest roads that are prone to erosion during floods. Locally, the hydraulic conditions and the river morphology are quite often altered by the impact of eroded trees and/or log jams (de Jong and Ergenzinger, 1995). Wood-induced river bed formations are common in mountain torrents and – apart from step-pool systems –are responsible for major habitat diversity. In contrast to hard check dam structures, these natural breaks in the longitudinal development of a stream enable far higher connectivity of the fluvial system (Figure 2).

It is commonly assumed that the probability of floods changes with land use, especially in relation to forested and agricultural land. However, during extreme thunderstorms with high intensity rainfall, the influence of land use on flood discharge rapidly loses significance. Forests, for example, can reduce average flood flows, but where extreme precipitation occurs during single precipitation events with magnitudes of 40 to 80 mm per day, extreme floods will develop independent of the vegetation cover. Liniger and Weingartner (1998) indicate that the influence of forest ceases as soon as soil is saturated, as was the case in the extreme rainfall–flood events in Switzerland in the last century. Naef, Sherrer and Weiler (2002) describe how storm runoff cannot be significantly reduced by land-use changes, unless they occur in the runoff generation areas where runoff is rapidly produced. Thus, for hazard assessment of extreme floods the question of whether catchments are forested or not is not nearly as important as how much water can be stored and transmitted in rapid runoff production areas such as slopes, scree fields or river beds. Good geomorphological and hydrogeological maps that coherently describe the sub-surface conditions are therefore necessary, in addition to land-use maps. From a hydrological point of view, predictive tools will fail if prognoses rely only on forest cover maps.

It is often overlooked that the hazard potential of floods is not merely a function of the amount of peak flow but also of the amount of sediment mobilized (de Jong, 1997). Large-sized sediments are usually only set into motion during floods, and will then cause considerable river bed changes (de Jong, 1994). Such changes can have long-lasting effects on forests and other types of land use along the valley floor. This is especially true for Mediterranean mountain areas, where farmland and fruit orchards are closely tied to riparian areas. The danger of river bed change increases significantly in zones of slope instability. During extreme events, there is a high potential for slope degradation by mass movements; slope degradation, in turn, generates very large sediment point sources. Mass movements that block river courses can even create temporary lakes and act as source areas of coarse sediments for a considerable time after an event, thereby temporarily elevating the river bed (Ergenzinger, 1992). It can take decades for former valley conditions to be restored after disruption by fluvial erosion.

In order to obtain a comprehensive understanding of the dynamics of mountain torrent beds, appropriate observation systems should be applied. Apart from standard geodetic cross-sections or longitudinal surveys, remote sensing from tethered balloons or via helicopter using digital cameras or video systems is suggested for streams in the order of 5 to 10 m width

FIGURE 2

Damaged and sedimented check dams in the Bavarian Alps, Lainbach River after the 1990 extreme event.

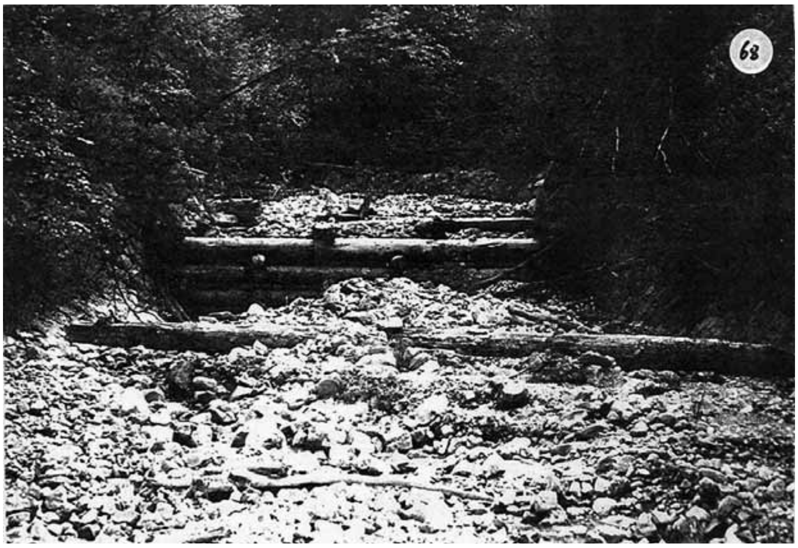
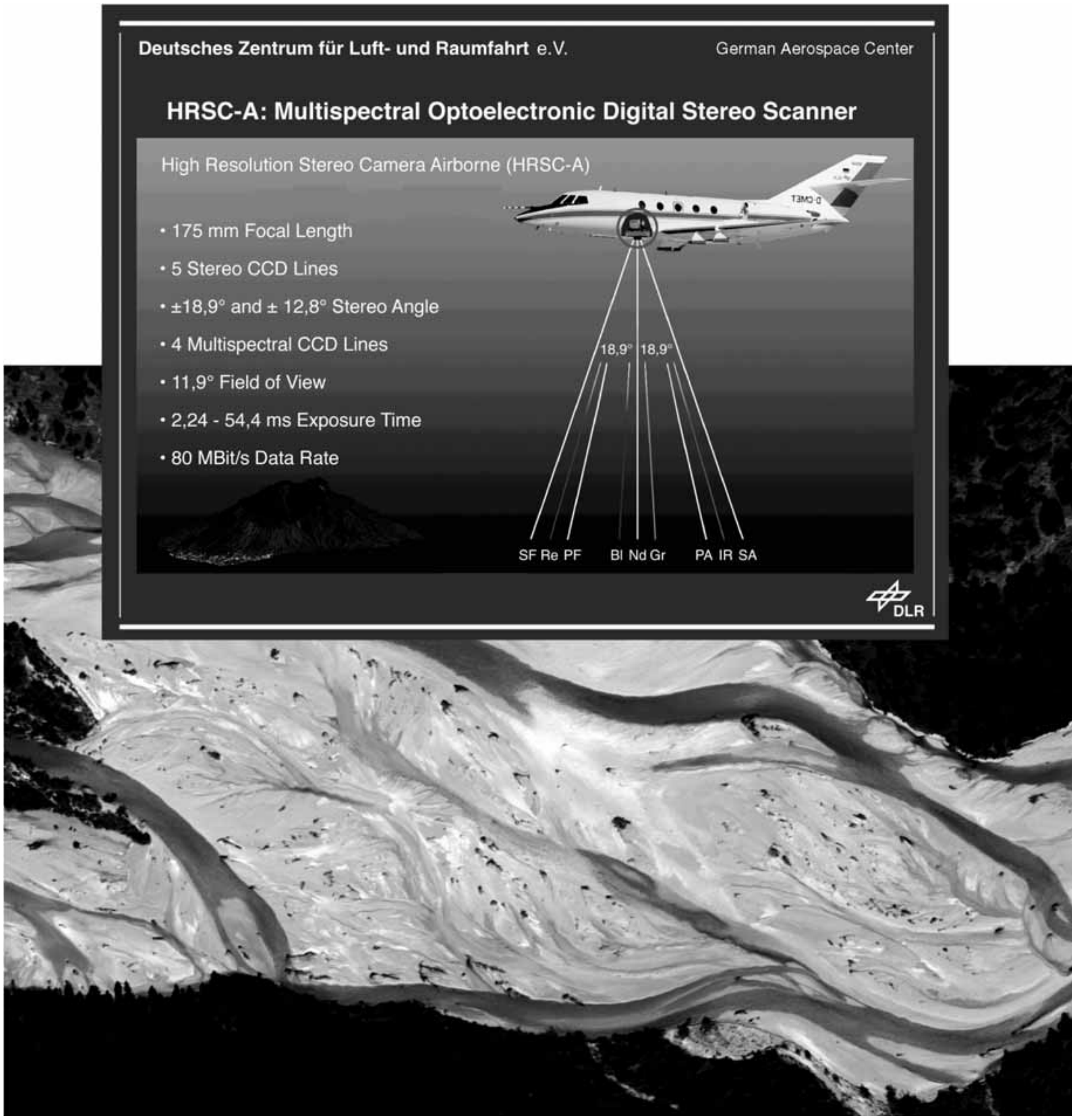


Photo: Thilo Schmalfeld.

(Ergenzinger and de Jong, 2003). For larger rivers (> 200 m in width), river bed changes can be determined with the help of drones or light aircraft and scanning stereo techniques (Figure 3), such as the HRSC system (Bucher and Lehmann, 2000). In addition, the velocity of representative bed particles during bedload transport can be measured with radio tracers (Figure 4) (Ergenzinger and Conrady, 1982) or magnetic tracers (Ergenzinger, de Jong and Christaller, 1994).

FIGURE 3

New possibilities of investigating morphological changes of river beds with HRSC scanner from light aircraft. Example of the Rissbach 400 m above its confluence with the Isar River, Upper Bavaria in 2000. The 3-D resolution of the river bed is 15 cm.



Deutsches Zentrum für Luft- und Raumfahrt e.V. German Aerospace Center

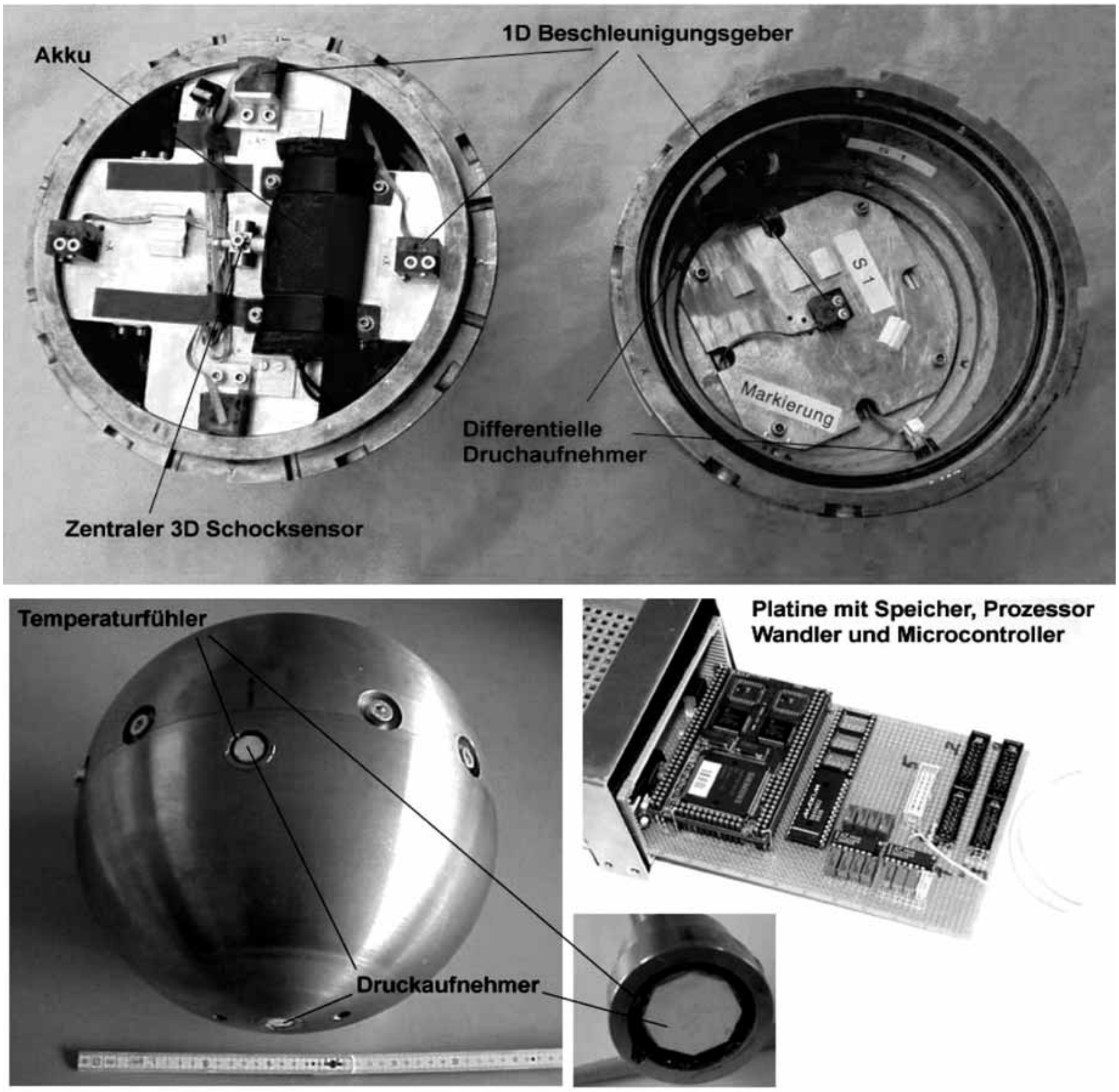
HRSC-A: Multispectral Optoelectronic Digital Stereo Scanner

High Resolution Stereo Camera Airborne (HRSC-A)

- 175 mm Focal Length
- 5 Stereo CCD Lines
- ±18,9° and ± 12,8° Stereo Angle
- 4 Multispectral CCD Lines
- 11,9° Field of View
- 2,24 - 54,4 ms Exposure Time
- 80 MBit/s Data Rate

FIGURE 4

Instrumented mobile measuring probe for quantifiying pressure differences and velocity of sediment transport during natural debris flows and floods in high mountain streams. The probe is fitted with pressure transducers and memory module (developed by J. Hanisch, BGR Hannover and P. Ergenzinger, FU Berlin 2001)



STATEMENT 3: SEDIMENT RETENTION STRUCTURES AND SUSTAINABILITY

Over the past 150 years, special problems caused by human intervention have arisen in alpine catchments (Habersack and Piégay, in press). Modifications in the sediment source areas of catchments have had considerable impact on river channel dynamics. Considerable effort was undertaken to retain sediment in the source areas, on the one hand through slope stabilization (reforestation and technical measures) and on the other by torrent control work (Wildbachverbauung). As a result, sediment delivery was strongly altered, and new protective measures were required in the downstream areas, e.g. to counteract excessive channel incision resulting from sediment deficit further downstream (Liébault and Piégay, 2002).

One procedure for sediment retention in the nineteenth and early twentieth centuries was the construction of small check dams, mostly of wood, in high density along the upper river reaches (Bravard and Peiry, 1993; Habersack and Nachtnebel, 1995). The check dams store sediment until they are full, when the surplus is conveyed over the sill. Although the concept of check dams is to reduce the longitudinal river profile and associated sediment transport, the dams have proximal as well as distal effects. Small check dams in river channels are potentially dangerous nowadays because they have stored large quantities of sediment over long time periods and are weakening owing to a shortage of maintenance budgets (Figure 2). Disaster in terms of excessive sediment release and the consequent destruction of human-made structures downstream can result from the so-called "check-dam domino" effect (i.e. sudden failure of one check dam after the other resulting from the impact of sudden sediment release from the upper check dams). Whereas the sudden failure of check dams has strong local effects, long-term sediment retention in check dams alters the river dynamics over longer distances (hundreds of kilometres) by causing continual channel deepening. As a result of decreasing sediment supply over many years, it is possible that the active channel width decreases and the channel narrows. In the Rhone catchment, 70 percent of braided reaches have disappeared owing to the combination of torrent regulation, sediment trapping upstream and gravel mining (Bourdin, 2004). The financial costs of the effects of such measures are considerable (Bravard, Kondolf and Piégay, 1999).

The widespread claim that forests act as protectors against such sediment-dominated disasters is often a myth. The protective role of the forest is dependent on the soil porosity, slope gradient and rainfall intensity. Where flatter slopes dominate, runoff does not concentrate as much as it does on steep slopes, and in these zones the forest can reduce the impacts of sediment transport or the passage of debris flows. However, such conditions are rare in steep alpine areas, and forests cannot protect against the concentration of runoff during storm flow. In highly porous areas, such as steep debris flow cones within the forest, infiltration capacity is higher than rainfall intensity during storm events. Surface runoff does not occur except where the rapidly rising groundwater table reaches the surface and initiates small debris flows. Forests may dampen the effects of extreme events during the first 15 mm/hour of effective rainfall (without interception), but for rainfall exceeding 80 mm/hour, surface runoff dominates and sediment stored over decades on the forest floor is rapidly transported into the river. Thus, the capacity of the forest as a sediment trap is limited. This is also true for the occurrence of debris flows (Figure 5). Debris flows can either be generated above the tree-line or as a result of bank failure of streams within the forest, and their tracks can directly traverse the forest downslope. Again, the forest cannot help in protecting the passage of the debris flows. An example was the flood/debris flow disaster in the Lainbach valley in 1990 (de Jong, 1994) in which small, zero-order streams in the forest were rapidly enlarged to transport large debris flows. After this event small, turned-over grass patches provided evidence that groundwater had surfaced locally under high pressure in hollows, reactivating channels in the source areas. All these processes should have a significant impact on the way in which hazards are assessed in mountain catchments with major transport infrastructure and villages below forested slopes.

FIGURE 5

Multiple debris flows traversing dense forests at Piz Madlain in Prätigau (Lower Engadin) Switzerland.

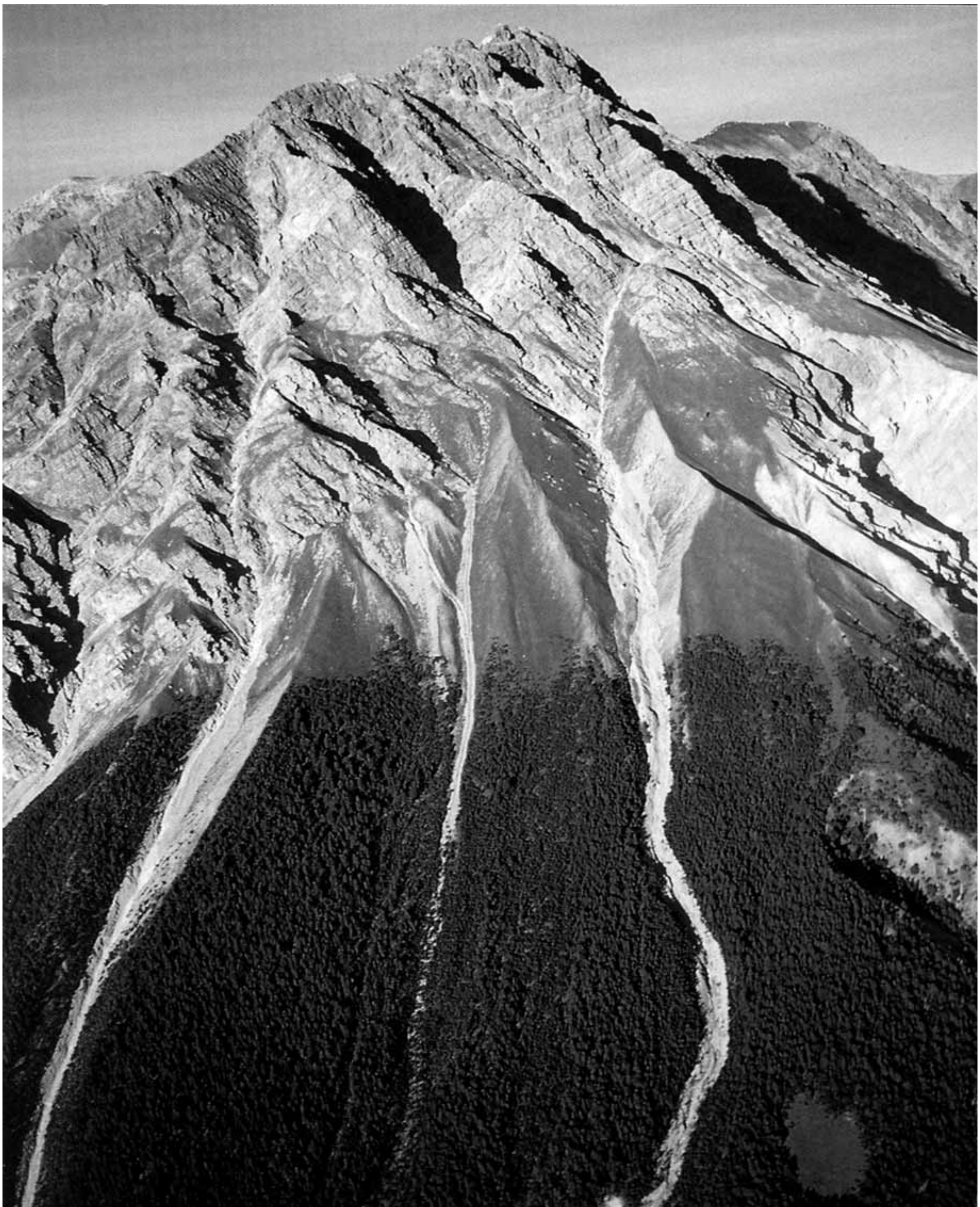


Photo: Donatsch and Pult in Ikarus über Graubünden, 1995.

Other problems are the unwanted side-effects of sediment retention of large dams or dammed catchments (Kondolf and Swanson, 1993). Because the majority of sediment cannot be removed from the dam reservoir (Verstraeten and Poesen, 2000), sedimentation behind dams, whether minor or major, can be compared to a time bomb. However, the number of new dams being built in high mountain catchments is still increasing, and the sedimentary problems associated with them are largely ignored. By reducing flood magnitude, dams decrease or eliminate bedload transport and cause major ecological change downstream. Minimum discharge released from dams is not well regulated from an ecological viewpoint, and can completely extinguish ecosystems that depend on a certain flow velocity and river bed morphology. Not only is the limited life expectancy of all technical solutions to nature a challenge for us in the near future, we are already being confronted with the problem of how to react to large quantities of – at times, polluted – sediments that have been stored within dammed basins over many decades and centuries.

CONCLUSION

This paper has shown that there is no single solution that is suitable for mountain watershed management. It is therefore not advisable to discuss only the procedures of hydrological top-down or bottom-up strategies or of combinations of the two methodologies. Problems cannot be solved by applying single-discipline approaches, but require profound inputs from hydrology, meteorology, biology, geomorphology and related sciences. The neglected aspects of watershed management will remain neglected if there are no interdisciplinary means for controlling the success or failure of watershed programmes. In order to enable more sustainable solutions for the future, further technical developments, possibly from cross-cutting disciplines, are necessary to substantiate our understanding of the dynamics of high mountain basins.

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