NEW CONTRIBUTIONS OF RESEARCH IN ORDER TO ACHIEV A SUCCESSFUL WATERSHED MANAGEMENT

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SUMMARY

In order to achieve a successful watershed management, a thorough knowledge of the different erosion phenomena is a prerequisite. The spectrum of these phenomena ranges from normal geological erosion to accelerate or man made erosion and, especially in steeper mountainous areas, to all kinds of torrent erosion, such as gullying and land slides up to deep reaching mass movements, as well as bed load transport, mud flows and sedimentation. Since it is difficult to estimate quantitative data of floods and of combined forms of erosion and sediment transport from small mountain watersheds, it is often necessary to carry out special research and measurements in such cases. In order to explain the different research methods, their benefits and application in practice, some examples are described in detail in this paper.

In the Trattenbach watershed, different methods of mapping were tested and led to an example of quantitative estimation of a torrent. In the experimental watershed Gradenbach, intensive nine-year investigations and measurements have now led to an equation for the functional dependence of the slope movement from precipitation. The results and the discovered relationship allow a better understanding of the mechanism of the deep reaching slope movements with valley narrowing by mass creep, facilitate the choose of control systems and enable forecasting and warning too. Due to the need of flexible control constructions, new elastic and prefabricated steel crib dams have been tested in the experimental watershed of the Dürnbach.

The newer findings and research results are summarized and discussed in view of the application for other, particularly for developing countries.

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Zusammenfassung

Eine gründliche Kenntnis der verschiedenen Erosionserscheinungen ist eine Voraussetzung für eine erfolgreiche Bewirtschaftung von Gebirgseinzugsgebieten. Das Spektrum dieser Erosionserscheinungen reicht von der normalen geologischen Erosion oder der sogenannten Bodenerosion (man made erosion) bis zu allen Arten der Wildbacherosion,wie Grabenbildung, Rutschungen, tiefreichende Massenbewegungen, als auch Geschiebe- und Feststofftransport, Murgänge und deren Ablagerungen. Wegen der Schwierigkeiten Hochwässer oder kombinierte Formen der Erosion und des Feststofftransportes aus kleinen Wildbachgebieten mengenmäßig einzuschätzen, ist es meistens notwendig, in bestimmten Fällen spezielle Versuche und Messungen anzustellen. Im gegenständlichen Beitrag werden solche verschiedene Forschungsmethoden, deren Anwendung und Nutzen für die Praxis an Beispielen eingehender erläutert.

Im Einzugsgebiet des Trattenbaches wurden verschiedene Kartierungs-Methoden getestet, die zu einem Beispiel für die mengenmäßige Einschätzung eines Wildbaches führten. Im Mustereinzugsgebiet Gradenbach konnte aufgrund neunjähriger Untersuchungen und Messungen ein Zusammenhang zwischen Niederschlägen und Hangbewegung gefunden werden. Die ermittelte Abhängigkeit vermittelt ein besseres Verständnis über den Bewegungsmechanismus der tiefreichenden Hangbewegung in Form eines Talzuschubes, erleichtert die Wahl der Verbauungsmethoden und ermöglicht auch Voraussagen und Warnungen. Aufgrund des Bedarfes an flexiblen Verbauungswerken wurden neue elastische und vorgefertigte Stahl-Korb-Sperren im Mustereinzugsgebiet Gradenbach getestet.

Die neueren Versuchs- und Forschungsergebnisse werden anschließend im Hinblick auf die mögliche Anwendung in anderen, insbesondere Entwicklungsländern diskutiert.

INTRODUCTION

The knowledge of the dangers and possible damages by torrent erosion is one of the most important preconditions of sensible land-use planning especially in densly populated, mountainous countries. Painful experiences of several centuries demonstrate that hasty and careless human activities are able to increase harmless natural erosion to disastrous proportions and often are bound to the utter destructions of land and soil. Since forest, in most cases, is best suited to prevent, counteract and repair erosion , in most countries the control of erosion up to torrent erosion has been the domain of foresters from the beginning. Therefore at many Forest Research Stations special Institutes are engaged in this field, in order to improve the knowledge of erosion phenomena and their quantitative assesment as well as further evaluating of biological and technical control measures.

Torrent erosion here generally includes the whole process of excessive erosion (soil erosion, land slides, gully erosion), bed load transport and deposition of torrent debris on debris cones or on valley alluvions. While the knowledge of soil erosion is brought to a high standard, the quantitative estimation of torrent erosion and bed load transport of torrents, used for all plannings in mountainous regions, is much more difficult. Qualitative describtions of erosion phenomena are manifold, but quantitative data are rare. The causes are wellknown: the problems of quantitative estimation of torrents (including floods, erosion, bed load transport, accumulation and alluvium) is very complex and accordingly special research results are extensive and manifold. Also it is very difficult to apply the various results above all because of the accidental and casual characteristic and the enormous local and temporal scattering of erosion phenomena.

Consequently the Institute for Torrent and Avalanche Control of the Federal Research Station of Vienna tries to improve knowledge and methods for the estimation of torrents by special investigation, measurements and mapping especially in experimental watersheds as well as by systematic collection of data of all extreme torrent events (Kronfellner-Kraus 1967, 1971, 1974, 1975, 1976). In the following chapters the existing basic facts should be summarized and confronted with newest findings and observations. A synopsis should be achieved for the sake of argument. Here we shall reduce the problem to the estimation of special kinds of torrent erosion and of debris transport of torrents in the East Alps. Nevertheless how far the findings are applicable to other countries and continents will also be examined. Until now the discussions have shown that the different findings and especially research methods are much more applicable to other countries then one would expect.

FUNDAMENTALS

The assesment of torrents depends on its purpose and on the locality to be rated. It is not the same if the quantitative estimation is needed for the purpose of control, or for mapping of danger zones, or for problems of hydraulic power utilization (sedimentation of storage basins) and either to the locality: either erosion or debris transport or deposition or alluvium is predominant. Not only the recurrance probability but also the manner of origin (if the flood is caused by snowmelt, continous rainfall or by heavy storms), the way of flood process and the knowledge of complete discharge of a flood are important for the bed load transport.

Lakes and storage reservoirs may devide a watershed and influence flood discharge and bed load transport. The transport of debris and suspended load is almost brought to a complete standstill - until the lakes or reservoirs are silted up completely. Such sedimentation gave the oldest data as gauge of the fluvial degradation. This is the quotient from annual sediment discharge of a catchment and the catchment area. This expression gives a rough comparative value for an average degradation - which increases with the altitude and steepness of the catchment or watershed. The annual degradation for river catchments(from the removal of dissolved solid material as suspended and debris load) amount from hundredth to some centimillimeters for large streams.

Water power experts computed degradation depth, respectively specific annual discharge (for sq.km) from observed sedimentation from centimillimeters to millimeters in comperatively small catchments in crystalline rock. The computation of the erosion rate in crystalline rock was exactly possible in the Margaritzen-storage at the foot of the Großglockner (the highest mountain of Austria), where the runoff from the Pasterzen-glacier is caught. The Pasterzen-glacier retreats today and the further sedimentation takes place in a little natural lake behind a natural rock-sill. The sedimentation volume amounts appr. 35.000 cbm per year. This gives an annual degradation(or general erosion or denudation) rate of 1mm per year. In other cases, in limestone, the degradation or erosion depth amounts to 10 mm or centimeter(s).

The average degradation depth in erosion scarps of "ancient debris" or stable erosion scarps in alluvium respectively moraines ("Altschutt" by Stiny) were computed in several cases from centimeters to decimeters - as an example until 120 mm in the shell shaped erosion scarp of the Schesatobel torrent. These are mean values, because in such cases of large erosion scarps combined erosion phenomena take place, especially longitudinal or gully erosion. Also in other isolated cases, on slopes and so on, longitudinal erosion cut in in meter and decameter dimensions, which can be noticed distinctly when started with waterfall effect. The same values of erosion depths were found in rocky ditches caused by heavy mud and rock flows, for example in the Wollinitzbach during the catastrophy in 1966.

Even smaller wash-outs on slopes may influence debris transport. It is a sort of "nomadizing shell shaped erosion scarps" (according to Stiny 1910), similar described by Swanston (1974). In the densely populated Alps such erosion scarps on slopes, respectively the mud flows originating from them, destoyed numerous houses and killed many people. Often enough of such mud flows are "man made", when after road building concentrated road dewatering can attack former stable slopes. Mud flows of larger dimensions and such which containe timber to a greater extent can not only be important suppliers of debris, but may also cause a damming up of the flow. Ensuing burstings of dams increase the danger of mud flows. Avalanches have a similar effect. As they damage the vegetation cover they contribute to erosion and are much greater suppliers of debris and timber to torrents as it is generally assumed. The erosion depths of such new scarps may amount to meters and decameters as an example from the shell sharped erosion scarp in the Wollinitzbach. The moved masses of even deeper slidings and slope movements (with depths from deca- to hectometers) are, on the whole not transported at one time - as, for instance, - during a single flood. They receive notice insofar, as they produce bed load material for long periods constantly,again for the above mentioned erosion phenomena (especially vertical and lateral erosion), which they also draw close to the eroding water. That are the cases, where intensive studies must be undertaken and often by research institutes.

NEWER RESEARCH RESULTS AT EXAMPLES

As mentioned above experimental watersheds have been installed with rainfall samplers and ombrographs, weirs or channels to find out the specific hydrographs related to the special, local conditions which have to be mapped accordingly.

Mapping of the Trattenbach-watershed

A minimum is the mapping in regard to size and place of sites exposed to gliding as a prerequisite for drawing up a sediment load balance. Because it is comparatively difficult to realize deep seated unstable sites precise ascertainments in the field are necessary. The methods employed shall not be dealt with here in this paper,because the numerous authors concerned with this problem mentioned are cited in the former, more special papers,as an example the description of the done work in the Trattenbach (Jeglitsch at al., 1975). There were carried out all known methods of mapping in order to test the applicability in practice. The Trattenbach lies in the Southern Limestone Alps of Austria and covers 1,6 km2. A shematical graph gave general information about the watershed. A forest site mapping was more specific for silvicultural use, such as afforestation and so on, as well as a vegetational map. For the special problem the geohydrologic investigation delivered a more special support. All these mappings were useful supports to the futher planning of reforestation and of control works and so on. They also resulted in informations on normal and possible amounts of debris load during catastrophic conditions.

By the mapping of a torrent and its entire watershed, the debris sources and the various sites are precisely determined in regard to place and size. The possible depth of erosion, however, can, on the whole, only be estimated and, in regard to the expences, seldom precisely determined by drilling, etc. The studies in the Graden torrent deliver such an example.

Newer research results and statements from the Gradenbach watershed

The problems which arise regarding the control of complex erosion phenomena, such as valley narrowing by mass creep in rock, deliver probably the best example for suitable close cooperation between both, the practical torrent control service and geotechnical forestry institutes. Therefore the intensive invetigations about such an area on the Berchtold-slope in the Gradenbach watershed in the upper Möll valley, Carinthia, may be described in detail. The precise field research and continued measurements there are necessary as a basis for planning of the control work and for warning purposes. An accelaration of the slope movement can probably endanger the inhabitants below.

The autor has reported about these problems repeatedly and in detail at earlier times, referring to observations and measurements of five- and seven-year periods (Kronfellner-Kraus 1974, 1976). The continued measurements proved the started supposition to be true and now make further statements possible. With the help of the most important (but removed) graphs first published in 1974 (which have since been brought up to date), the newest results of measurements should be attached to a nine-year period (1969 - 1977) and are summarized and discussed below.

As earlier reported, the valley narrowing by mass creep in rock takes place at the left lower end of the Gradenbach. There the South-East oriented so-called Berchtold-slope is slowly moving downwards to an extent of about 2 sq.km and that at a breadth of 1 km at the foot of the slope (1200 m sea level) 2 km up to the ridge (2200 m sea level). On the slope there is a little tributary, the so-called Berchtoldbrook, and there are many springs too. Both the Gradenbach and the Berchtoldbrook as well as the whole Berchtold-slope function as an experimental watershed (Mustereinzugsgebiet). In order to find the necessary knowledge of the mechanism and causes of the slope movement and probable relationships, the investigations deal with above all, precipitation, temperature, runoff, slope deformations and mountain pressures. Some of these measurements for precipitation, temperature, slope deformation as well as mountain pressure, were able to be continiously carried out over the whole nine-year period other measurements are not so complete. The previous measurements of the various spring discharges have had to be and must be interrupted according to the progress of drain work on the slope. The further measurements of the spring discharges are now taking place at the end of a drainage system in v-notch weirs, at the same time facilitating the continous control of drainage functions. The so-called "ditch-weir" began operating in 1975. In the same year the discharge measurements began in the Berchtoldbach, the small brook draining the Berchtold slope. For both there are now three years of results available. First an attempt was made to measure the runoff from the Berchtoldbach by a flume, but this had to be abandoned, because of the large amounts of bed load during floods and mud flows. The flume was buried again and again. Since 1975 a so-called "Tirolerwehr" has enable runoff measurements to be made exactly in a v-notch weir. While bed load or mud flows pass through a flume the normal runoff falls through a grill in a canal which leads to the weir.

The geodetic surveys have also been extended in the meantime. Besides the three former profiles on the Berchtold slope at about 1300 m above sea level and 1800 and 2050 m respectively two further profiles at an altitude of appr. 1450 and 1650 m have been surveyed since 1976. Moreover an intensive geodetic control of two bore holes was undertaken this spring.
Whereas the measurements of mountain pressures by telepressmeters can be continued within the lower chek dam No. 13 the others within the upper check dam No. 22 had to be given up after the complete rupture. There are still other various special investigations such as torsion measurements on the moving slope and of

forest-hydrological nature mainly in regard to snow cover and snow melt and so on. But these were started relatively late and are not in direct connection with the problem handled in this paper.

The results of these studies may be explained by the following drawings. These drawings correspond essentially to the previous one but had to be brought up to date, considering the extended programm of investigation and measurements and progess.

The precipitation at the base station in Egg on the Berchtold-slope is shown in fig.1 as yearly cumulative precipitation curves and in fig.3-a in monthly values. After the years with heaviest precipitation (1972 and 1975) the years 1976 and 1977 were the next with heavy precipitation within the nine-year period. The winter of1976 was of light precipitation, so that the heavier rainfall in summer and autumn possibly effected the following year 1977. The precipitation rate of the year 1977 can be compared with the one of 1972, and in these two years the slope movement increased similarly. As mentioned above the mesurements of precipitation were extended for different additional purposes.

The fluctuations of temperature, shown by monthly mean values in fig.3-b, are of interest insofar as it may help to explain the different degrees of slope movement.

As mentioned above the runoff measurements of the different springs were transferred into the drainage system. Fortunately the results of the former measurements seem to have found a good continuation in the newer weirs, as the fig. 3-c shows for the "ditch-weir". The peak values of spring runoffs generally occur in advance of the peak values of greatest slope movement. The runoff peaks measured in the Berchtoldbach weir appear even earlier, that is to say one or two month before. In 1976 two runoff peaks took place, in April and in November, according to the rainfall and temperature conditions (fig.3-c).

After the extreme maximum in 1975 the amount of slope movement was relatively less in 1976 and relatively great in 1977, i.e. more than six times greater than 1976 but similar to the value of slope movement in 1974 (fig. 2 and 3-d). And that the slope movements of the signal 11 in the lowest profile were comparable during May to September in 1976, 6 cm, in 1977, 39,5 cm and in 1975, 300 cm.

Due to the complete rupture of the check dam No. 22 the furhter measurements of mountain pressure are only possible in the lower check dam No. 13 (fig. 3-e). Like the years 1972 and 1975 the curve of pressure values in fig. 3-f shows a distinct peak value in 1977, although to a lower extent. Here in this stretch, the mountain pressure measured lies within the allowable range of compression stresses for concrete. Nevertheless the combination of different types of stress, mainly compression and shear stress, have also led in this areas to the well-known instances of damage at the dam wings.

Since 1975 the vertical components of the slope movements have also been surveyed in three slope profiles and over the chain of check dams, and since 1976 in two additional slope profiles. This has enabled us to make a kinetic study in a longitudinal section

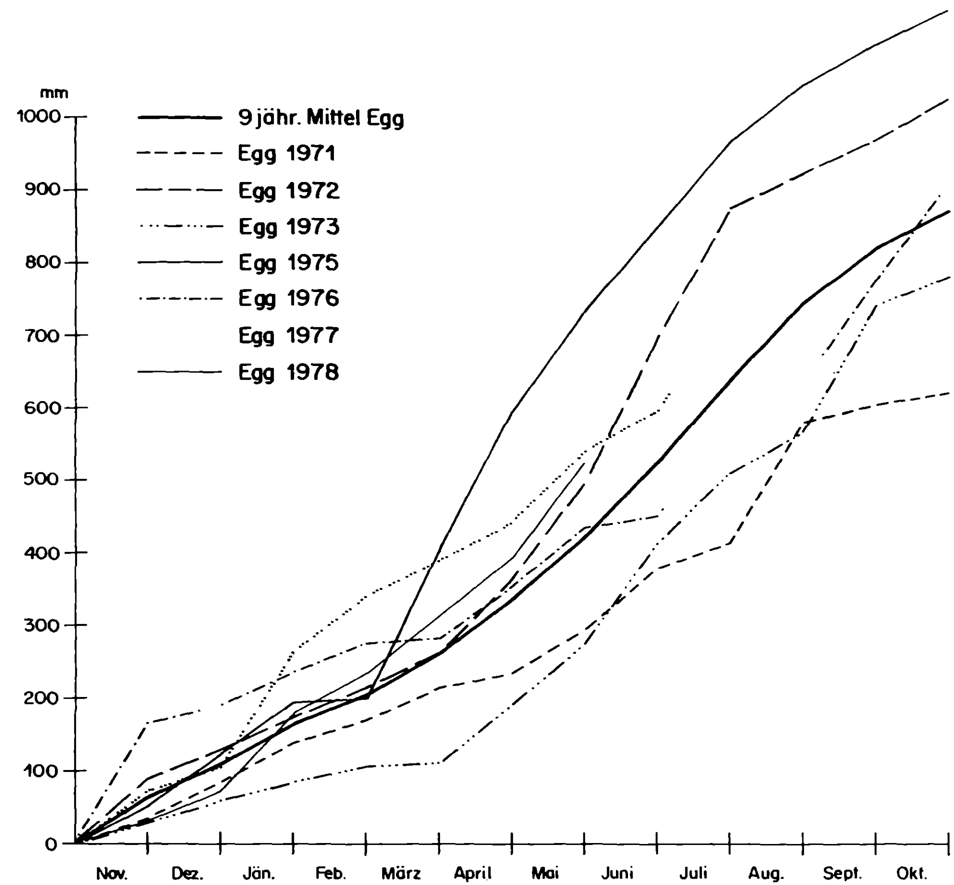


Fig.1: Some characteristic cumulative precipitation curves of the base station in Egg on the Berchtold slope.

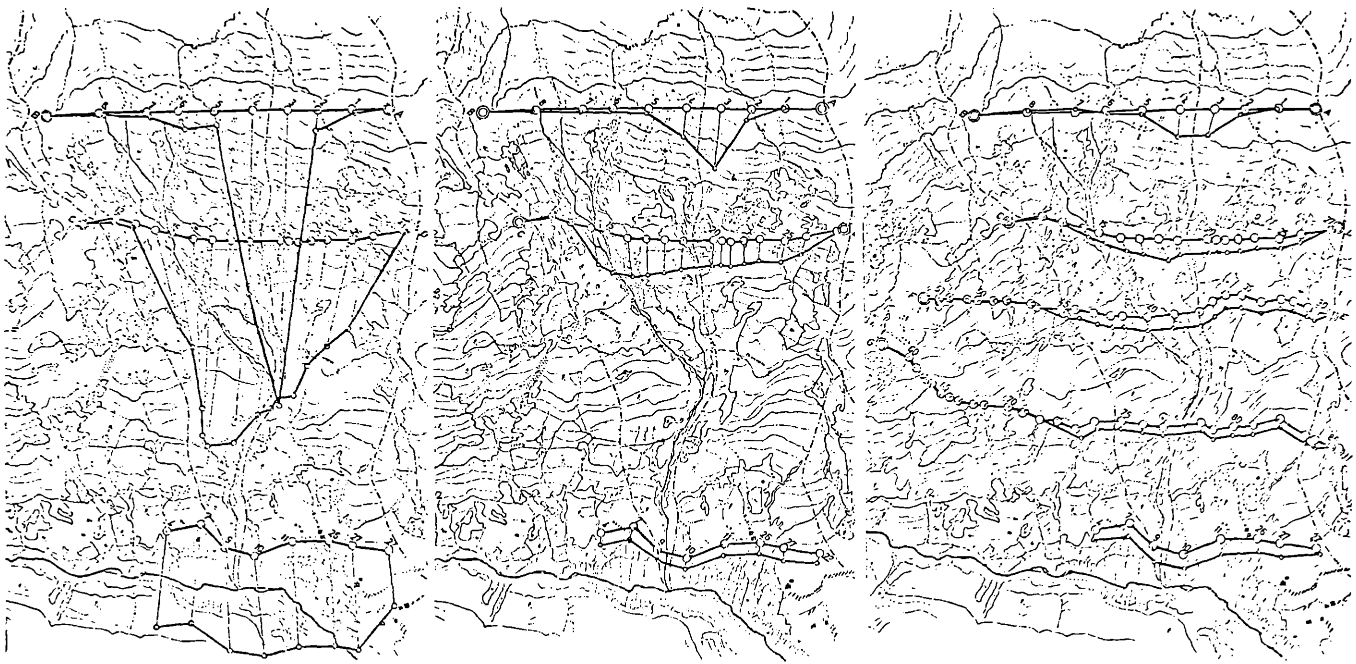


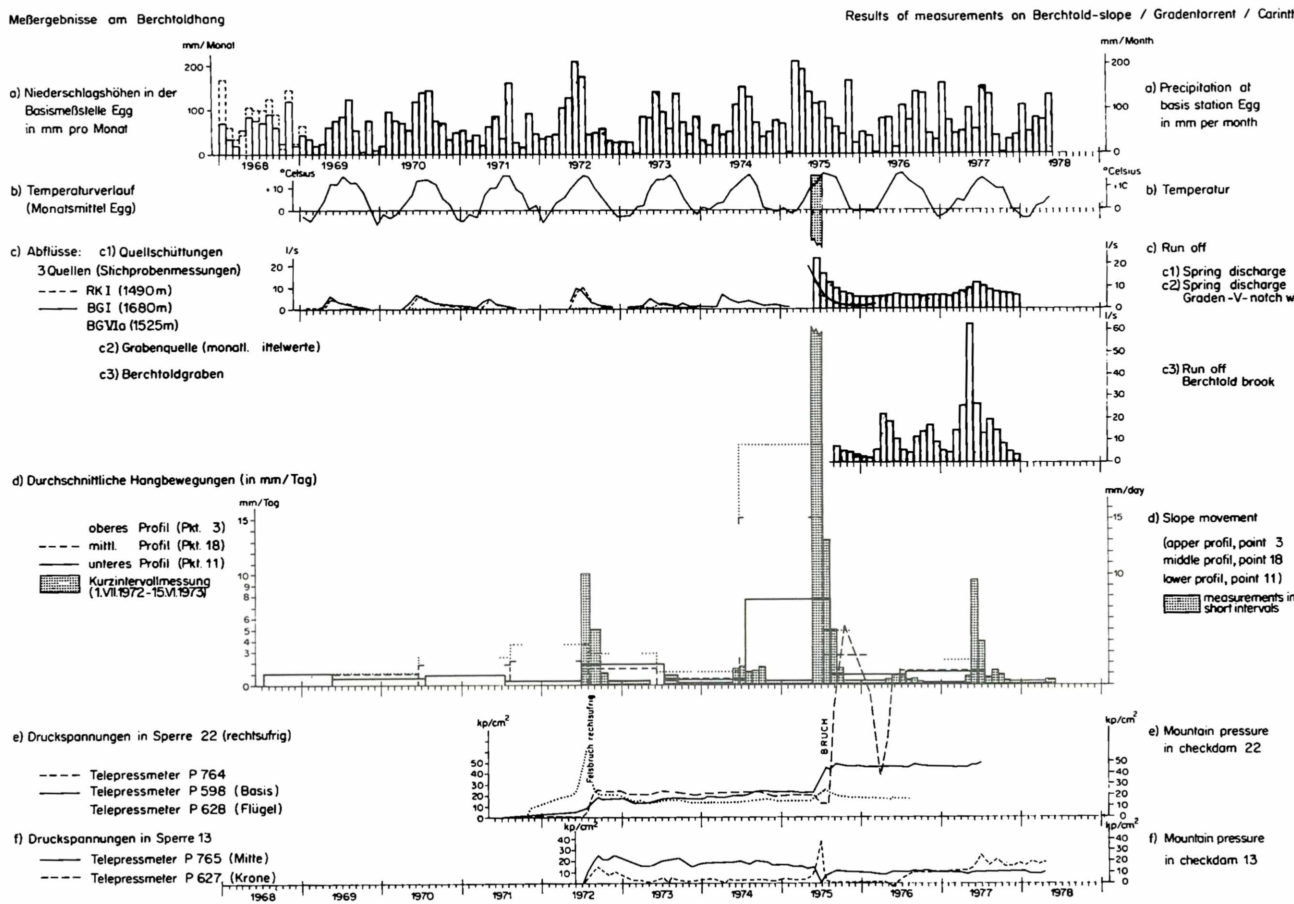
Fig. 2: Amounts of the annual slope movements from the geodetic measurements of three, respectively five profiles on the Berchtold slope in the Gradenbach during the last three periods:

a) slope movement from (June/July) 1974 until (July/August) 1975

b) from (July/August) 1975 until (June/July) 1976

c) from (June/October) 1976 until (June/July) 1977.

Fig. 3:


Meßergebnisse am Berchtoldhang
Results of measurements on Berchtold-slope / Gradentorrent / Carinthia
mm/Monat
mm/Month
a) Niederschlagshöhen in der Basismeßstelle Egg in mm pro Monat
a) Precipitation at basis station Egg in mm per month
b) Temperaturverlauf (Monatsmittel Egg)
b) Temperatur
°Celsius
c) Abflüsse: c1) Quellschüttungen
3 Quellen (Stichprobenmessungen)
RK I (1490m)
BG I (1680m)
BG VIa (1525m)
c2) Grabenquelle (monatl. ittelwerte)
c3) Berchtoldgraben
c) Run off
c1) Spring discharge
c2) Spring discharge Graden-V-notch weir
c3) Run off Berchtold brook
l/s
d) Durchschnittliche Hangbewegungen (in mm/Tag)
mm/Tag
oberes Profil (Pkt. 3)
mittl. Profil (Pkt. 18)
unteres Profil (Pkt. 11)
Kurzintervallmessung (1.VII.1972-15.VI.1973)
d) Slope movement
mm/day
(apper profil, point 3
middle profil, point 18
lower profil, point 11)
measurements in short intervals
e) Druckspannungen in Sperre 22 (rechtsufrig)
Telepressmeter P 764
Telepressmeter P 598 (Basis)
Telepressmeter P 628 (Flügel)
e) Mountain pressure in checkdam 22
kp/cm²
Felsbruch rechtsufrig
BRUCH
f) Druckspannungen in Sperre 13
Telepressmeter P 765 (Mitte)
Telepressmeter P 627 (Krone)
f) Mountain pressure in checkdam 13
1968
1969
1970
1971
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1974
1975
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1977
1978

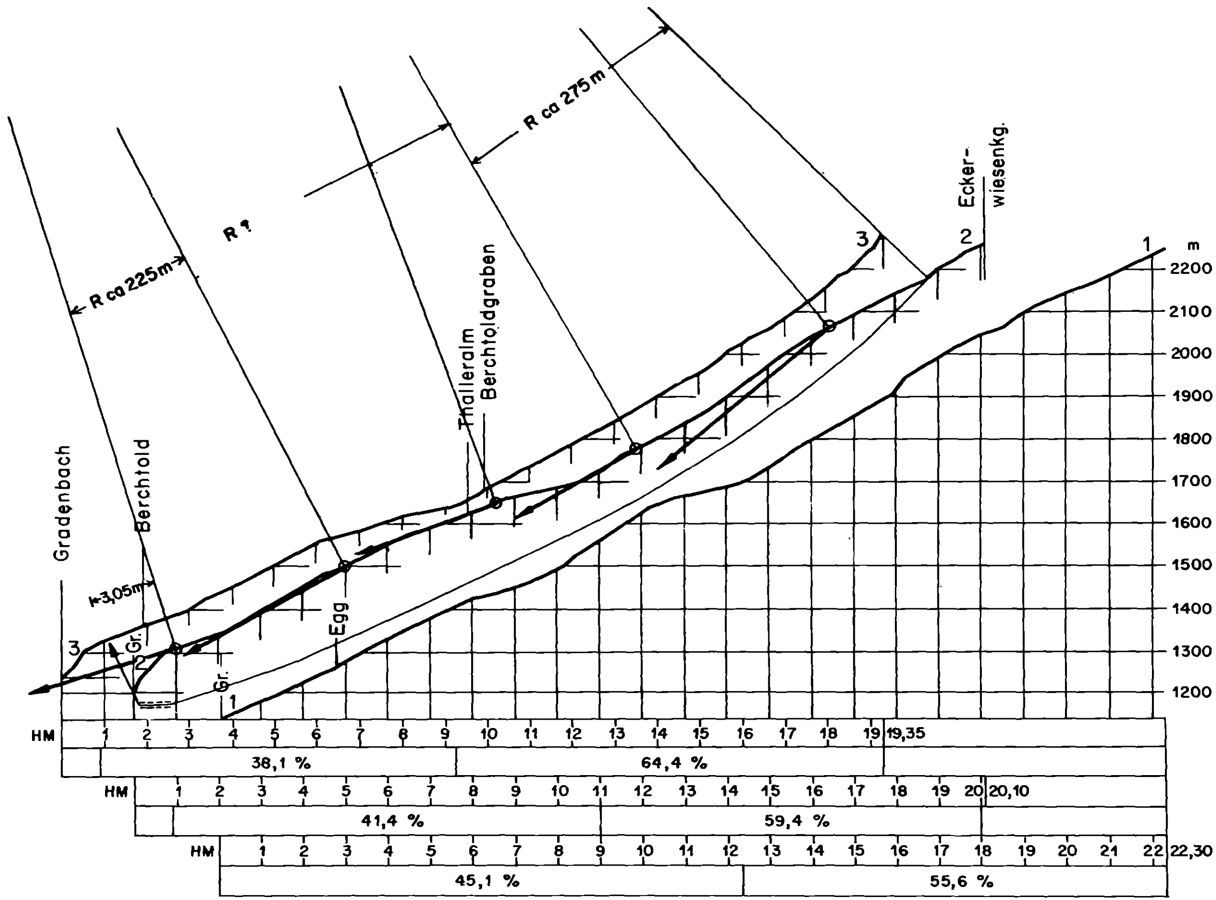

Fig. 4: Kinetic study for the longitudinal section "2" of the Berchtold slope based on the three-dimensional displacements of point 3 at the highest, the points 17/18, 36a/37a, 79/80 in the next lowest and 11 in the lowest profile.

(fig. 4) of the Berchtold slope. Whereas in the first observation year (1976/77) only four points were at one's disposal, six points for this study are now available (point 3 at the highest, the points17/18, 36a/37a, 79/80 in the next lowest and 11 in lowest profile. The sixth point lies at the foot of the slope in the ditch of the Gradenbach. The results found, based on the surveys of the last two years have proven the supposition stated at that time to be true. As it may be observed, the inclination of the three dimensional movement vectors decreases constantly from the upper part to the lower part of the slope (from about 45^{o} to $17,5^{o}$). This phenomenon bears out the theory of a deep reaching movement with a curved boundary of slope deformation below. Only the points 36a/37a in one of the newer profiles show a slight deviation tendency, which may be explained by a localized sliding. Such deviations are partially possible all over the slope according to the investigations of geologists, who have been engaged (Moser 1978). On the whole, the picture of the deep reaching slope deformation is not impaired by this local deviation, which is also corroborated by two bore holes which were drilled this winter (the results of these explorations works and inclination measurements are not yet completely available).

After the appearance of two extreme deviating slope movements in the short time of the following two years, but with similar yearly sums of precipitation, the connection between rainfall and slope movement seemed to be only qualitative but not quantitative or regular. Only when the precipitation and slope movement of the year 1977 showed a similar extent to the year 1974 a regular correlation seemed to be possible and therefore more intensive studies and analyses with different combinations were undertaken, which led, finally to the following, provisional results.

The yearly slope movement takes place above all following the late spring thaw and in summertime. After beginning the slope movement increases quickly and soon reaches the maximum movement and then slacks off gradually. The prolongation in the summertime varies, depending on the various rain fall, but the whole amount of the yearly slope movement does not seem to be essentially influenced. If one compares the whole slope movement during May to September with the former sum of precipitation, one gets the best relation, if one takes into consideration the precipitation amount from 10 month earlier, from November until and including August. Under these conditions they following linear regression for a semi-logarithmic curve was found (fig.5):

$$V = 0,194 \;.\; e^{0,897 \quad N}$$

(V deformation in mm, e base of natural logarithms, N = precipitation sum in dm) with a correlation coefficient of r 0,988.

But also if one takes into consideration only 8 months from November until June, a correlation coefficient of r = 0,96 was found (for a corresponding equal computation). The result shows the enomours importance of the amount of precipitation in wintertime and of the melting of snow in spring and may facilitate forecasting and warning in the future. But at the same time, it indeed be noted, that the amount of available basis data (only 5 years) is still very small. The relation found may better explain some appearances but it should not be overrated. Further investigations and measurements are still necessary.

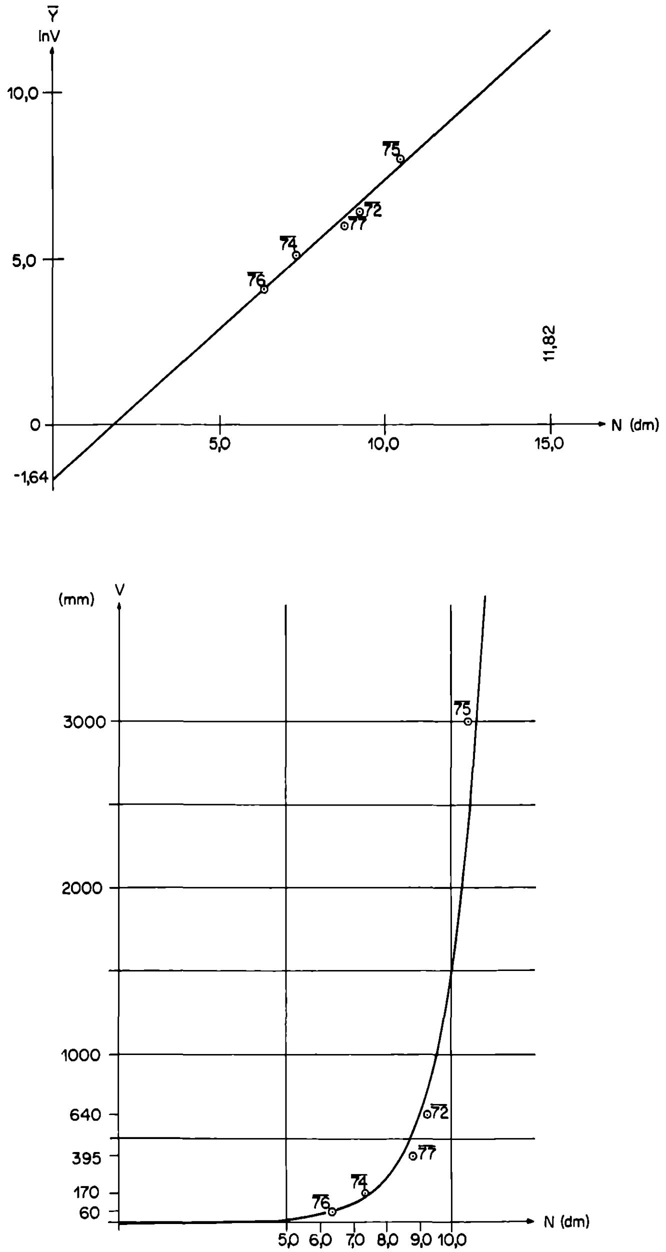

Fig. 5: The slope movement (V) during May until September in dependence on the former sum of precipitation (N) 10 month before, from November until and includin g August, as linear regression for a semi-logarithmic curve:

$$V \quad 0,194 \quad e^{0,897} \quad N.$$

These intensive observations, investigations and measurements over a nine-year period allowed further studies, which may contribute to a better understanding of the moving mechanism of the area considered of the valley narrowing by mass creep in rock. They showed, especially, the enormous influence of all precipitation during the whole wintertime until the melting of snow. The well-known principles of torrent control and slope stabilization may have been generally steady. On the other hand there seems to exist a newer viewpoint insofar, as in forest-hydrological measures, that is to say through afforestation, a higher degree of snow interception may contribute to the whole drainage systems, especially in the endangered wintertime. After nine-years' experience and special analyses one is tempted to say, that the possibility of the progressive rupture of the moving slope should be in future taken more into consideration than up to the present time. The further investigations of measurements will have to taken these facts including the problem of warning into consideration. For the estimation of bed load potential, valley narrowing by mass creep may be regarded as a debris source on a long term basis. By the crushing deformation of rock masses, new debris is constantly produced and transported close to the river again and again by the downward movement of the slope. When the eroding forces are sufficient, corresponding bed load transports may develop according to flood discharges. From the mass creep area of the Gradenbach we may expect (according to measurement results of the last nine-years) an annual yield of debris in the range of about 25.000 cbm. After 20 years a peak discharge may, therefore, encounter a mass of debris of about 500.000 cbm and transport it. Thus new erosion and slope movement can continue. The control techniques must correspond to such bed load production for a longer period. Flexible construction types have to be chosen which function even during heavy ground movements. The elevation and widening of torrent bed (which has, in addition to drainage work, a stabilizing effect by the superimposed debris at the foot of the slope), ought to be planned for longer term according to the yield of debris and continued until a sufficient consolidation is achieved.

New control methods in the Dürnbach watershed

Evaluating the bed load transport of torrents, conditions of transport and sedimentation may be estimated by measurements of longitudinal and cross section of the whole water courses and lines of the debris grading curves. The obvious stages of the development of torrents and their debris cones or alluvial fans allow conclusions about manner and size of erosion, accumulation and alluvium. The debris production of a torrent becomes only partly effective according to the means of transport and streamflow. Material is dislodged according to the existing tractive force of the flow and stored at different periods and again transported. Also the abrasion and the crushing of gravel pieces on their way downstream is of great importance. For this reason "retention coefficients" have been calculated, which can hardly be applied in general, but calculated for special torrents or for types of torrents. The experimental watershed "Dürnbach" is an other example, which may illustrate both this view point and the effort in finding of new special types for torrent control in areas of valley narrowing by mass creep.

A geological map shows mass creep in rock on both slopes of the Dürnbach. As a result of the deep reaching mass movement, extensive escarpments can be found as sources of debris load. In this experimental watershed the necessary instruments are intalled which allow to register mainly precipitation, runoff and bed load transport (by desposition in debris basins). The valley narrowing by mass creep in rock makes necessary flexible types of control works, for example gabion check dams or a steely open dam like a grill. Some steel beams were deformed by the side mountain pressure, but the dam is still in function, while other types in concrete or masonry were broken.

In 1972 a large rock fall took place: about 60.000 m3 bed load blocked up the torrential bed and were partly transported downwards. In order to retain these masses, the open dam was closed by wooden beams. Further check dams were built and were silted up in short times. The transport of bed load, the abrasion, and the crushing of gravel pieces on the way, could be studied exactly until both debris basins at the end of the ditch and on the beginning of the alluvial fan. There is also a gaging station to measure the runoff from the whole watershed.

One of the new check dams serves as a test for a steel crib dam. This crib dam was also an "open dam" in the beginning, although this construction was silted up in a short time. The bended beams allow a high degree of deformation by side pressure and raise the flexibility The construction was also a test for prefabricated material.

Observed data of mud flows

In literature and practice data were hardly to be found. The autor has collected all extreme values mainly since 1965 and some older data from literature. The interpretation of the most significant data is given by a graph, relating the transported debris masses to the correspondent catchment areas, which illustrate the order of magnitude. As far as the frequency of mass movements is concerned, it must be stated that six Austrian torrents have already transported more than 100.000 cbm into the valley twice during ten years. Here we are dealing with temporarely limited individual events and not with the sums of succeeding floods and mud flows, which may also amount to millions of cubic meters. In the case of Schesatobel-torrent the whole mass moved from the shell sharped erosion scarp during 1796-1958 was 40 Million cmb!

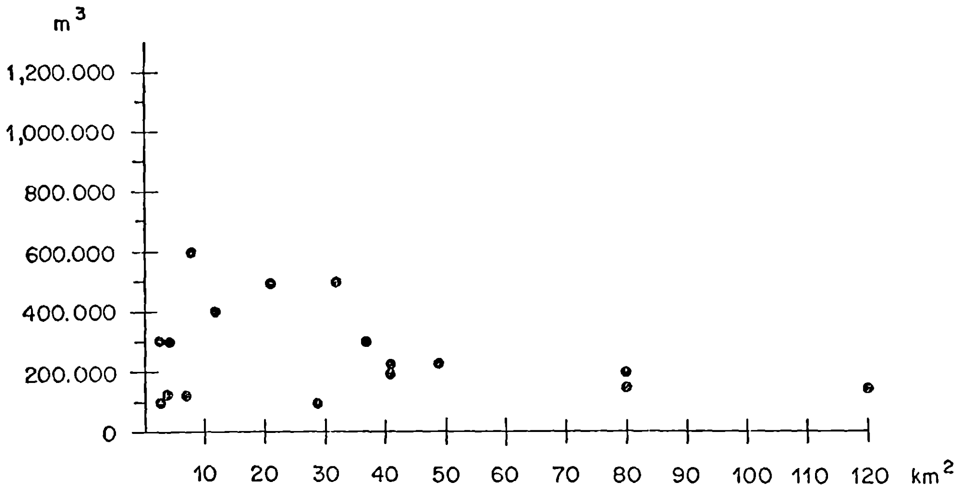

Fig.: Peak values of bed load transport (m^3) of singular torrent events in Austria, related to catchment area (km2).

CONCLUSIONS AND THEIR APPLICATION

Findings in the East Alps

As mentioned above we can conclude, that big mass transports in torrents do not represent isolated cases. They are, however, erosion phenomena which occur irregularly but nevertheless within certain periods of time. The recurrence probability of debris mass transport depends, above all, on the intensity of erosion in the existing debris sources. There the mean annual erosion amounts to the following dimensions: in sources of detritus production by weathering from millimeters to centimeters: in sources of ancient debris from centimeters do decimeters. Vertical and lateral erosion amounts to meter and decameter dimensions. Deep reaching movements as land slides and mass creep in rock in dimensions of deca- to hectometers have, above all, the function of preparation for the above metioned erosion phenomena. By means of the continuous streamflow of the torrents, parts of these debris volumes get into the effluent streams and are transported further. This may be estimated at 25 per cent for smaller catchment areas with low streamflow and at 50 (and more) per cent for larger catchment areas with steadier streamflow. The rest of debris is stored until it is carried off by high flows. This explains, especially in torrents delivering detritus from weathering, a certain periodicity.

In addition to this also completely new sources of debris may develop. Vegetation, especially forests, can protect the soil from surface erosion to a great extent, but cannot avoid vertical and lateral erosion or slides completely under unpropitious contitions. It must be added that even under vegetativ soil protection a certain disposition for erosion remains which only can be recognized by precise mapping and further intensive investigations. Especially in difficult cases a close cooperation between practice and research can lead to satisfying solutions as showed by examples. Drawing up a balance of bed load discharge, it is necessary to take into consideration not only hydrological conditions but also size and distribution, disposition to erosion and the specific connection of all potential debris sources within drainage system. The remaining uncertainty in regard to the temporarely varying disposition to erosion in the watershed, the irregular charging of debris and the changing transport conditions, that is to say the randomness of the torrent activities, exclude the drawing up of a precise sediment discharge balance. On the other hand many years experience, calculations, observations and precise mappings allow one to estimate the continuous and periodical sediment discharge, according to the magnitude of erosion. This enables us to establish - in regard to control technique and planning, that is to say by measures - a sediment balance allowing for eventualities. Historic examples, the Schesatobel and the Klausenkofelbach (in which watershed clearcuts started the following torrent erosion), prove impressively where destructive developements, originating from disturbance and damage of the vegetation cover, can lead too. Therefore, it is necessary to realize unstable sites and to treat them cautiously, to preserve the protecting vegetation cover and to control developed sources of debris instantly by technical means and to revegetate them. The inevitable sediment discharge and the remaining risk can be encountered by creating sedimentation areas (or debris basins) for mud and debris flows and by keeping danger zones clear.

Applicability to other countries

To apply the given methods and results to other countries it is necessary to adapt the spectre of possible erosion to the particular climatic, geological and other natural conditions. In principle it seems to be sensible also here to differenciate between torrents of detritus and torrents of ancient debris as moraines can be found in other continents as well as in Europe (Alps, Andes, Himalaya, Rocky Mountains, etc.). Due to much higher rain intensities and the much greater frequency of occurrence detritus and rock erosion in tropical countries, particularly under monsoon conditions, often exceeds erosion of ancient debris in temperate zones.

An other major difference exists in the forest condition in different countries. While in most countries of Europe the protection value of forest have been recognized and forests have protected for centuries, in many developing countries this recognition occured only recently and the forest destruction still goes on at the same rate at which the population increases. In arid areas, where vegetative protection is often very weak and the debris of weathering can accumulate over long periods of time between floods, the very heavy floods can have disastrous effects.

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The presented studies in this paper are intended as examples for good functional cooperation between practical services, research organizations and other specialists. There the autor is indebted to them all.

As already mentioned in 1974 numerous specialists of different departments from two institutes of the Federal Forest Research Station of Vienna are engaged in common projects. From the Institute for Torrent and Avalanche Control Dipl.Ing. Ruf with two co-workers, Platzer and Weissenbeck, are measuring precipitation and runoff. Dipl.Ing. Jeglitsch is engaged in spring discharge and convergence measurements, while Ing. Schweighofer continues the measurements of mountain pressure. Own local observers in the different watersheds,and above all Zirknitzer at the Gradenbach, render valuable assistance. From the Research Institute for Fundamentals Dipl.Ing. Mayer and Dipl.Ing.Tiroch survey slope movements. I am grateful for Ing. Schieler's assistance with mathematical questions. I own my deep appreciation not only to the above-mentioned specialists but also to all other co-workers engaged in common projects.

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The given acknowledgements may at the same time illustrate the wide range of engaged fields in complicated cases of torrent erosion. Both practice and research benefit from each other. The positive results may contribute to successful management of watersheds.

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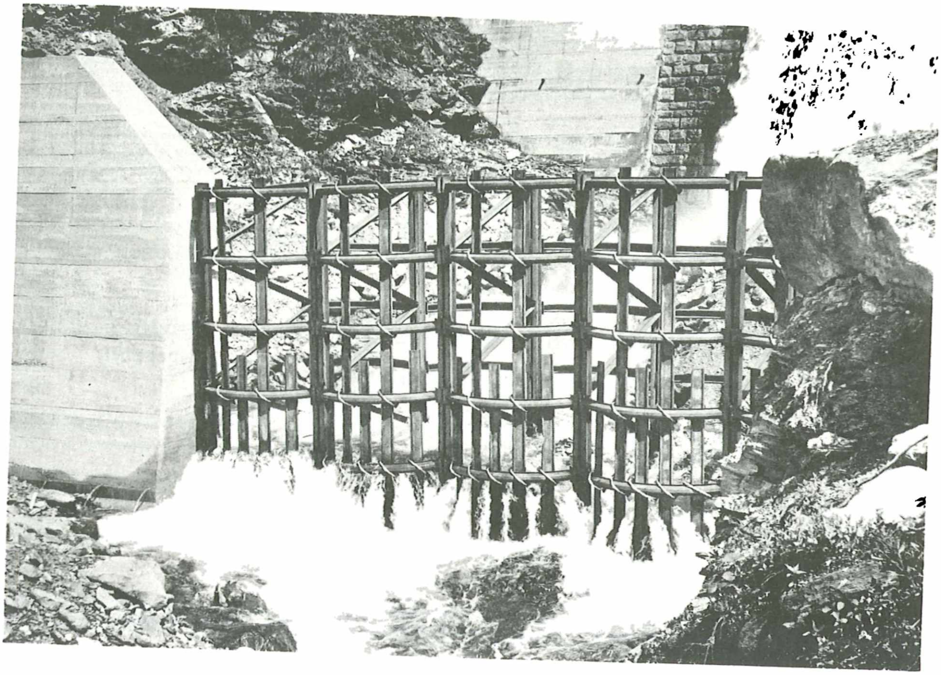

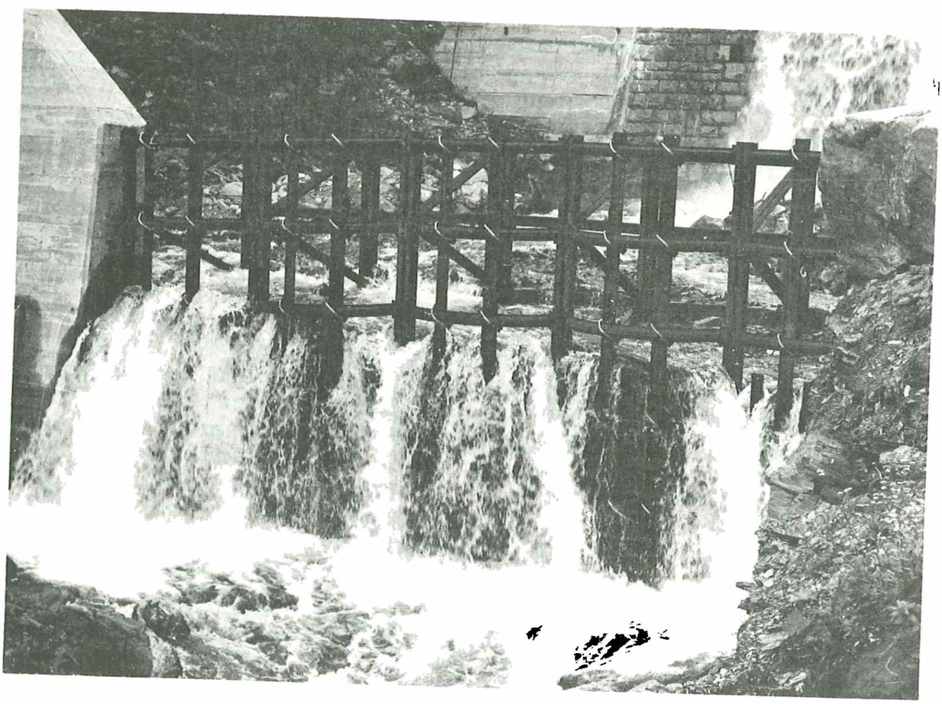

The eleastic, prefabricated steel crib dam in Dürnbach.