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GUIDE OF FIELD EXCURSION

March 7, 2002
around Lake Thun, Switzerland

INTERNATIONAL CONFERENCE ON FLOOD ESTIMATION

March 6-8, 2002
Berne, Switzerland

Federal Office for Water and Geology (BWG)
Institute of Geography, University of Berne (GIUB)
Commission for the Hydrology of the Rhine Basin (CHR)

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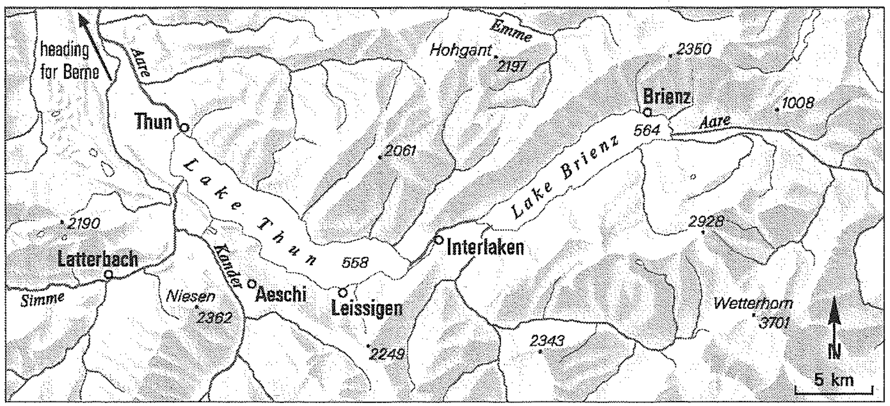
Introduction

The field excursion is organised by bus and conducts to places around Lake Thun. Several stops will introduce important sites of current projects of the Federal Office for Water and Geology (BWG) and the Hydrology Group of the Department of Geography of Berne University (GIUB). Topics of the various stops are:

◆ **Geology of the Berner Oberland (Aeschi)**
Geological aspects will be presented. As there is the sedimentary and tectonic evolution. Moreover it will be given some comments on the glacial and postglacial history of region Lake Thun with valley and lake formation. The participants will be introduced also to the anthropogenic geology (Kander deviation, AlpTransit tunnel).

◆ **Flood Generation in Mountain Torrents (Leissigen)**
The Spissibach-torrent has been investigated extensively by the Department of Geography of Bern University over the last ten years. The processes of flood generation and the mobilisation of bedload in a changing environment have been especially addressed. This kind of studies is very important taking into account that there is a lack of data in small alpine torrents. In the frame of the excursion some new measurement techniques as well as results of the analyses and modelling work and their implications for daily practice are presented.



Region of Lake Thun and Lake Brienz
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- **Hydrological forecast for the Lake of Thun and flood hazard assessment in the City of Thun (Thun)**

In 1999 several rivers and lakes flooded all over Switzerland and the discussion about protection and risk management got an up-to-date topic. The expert of this stop will point to the problem of water level prediction in case of flood. Also the change of this knowledge into risk maps will be presented.

- **Selected Hydrometric Methods used by the Swiss National Hydrological Survey (Latterbach)**

The Swiss National Hydrological Survey presents an alpine stream gauging station. A discharge measurement by cableway will be demonstrated. An exhibition with discharge measuring equipments by tracers and acoustic doppler current profilers will be added.

Texts were collected and arranged by Judith Dobmann and Simone Hunziker
Please note authors are responsible for consistency in spelling.

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Geology of the Berner Oberland

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How many years must a mountain exist
Before it is washed to the sea?
Bob Dylan

Introduction

The viewpoint of Aeschi near Spiez in the Berner Oberland is situated on the northern shoulder of the Alps with a marvellous view towards the high mountain chain in the south and towards the Swiss Plateau in the northwest.

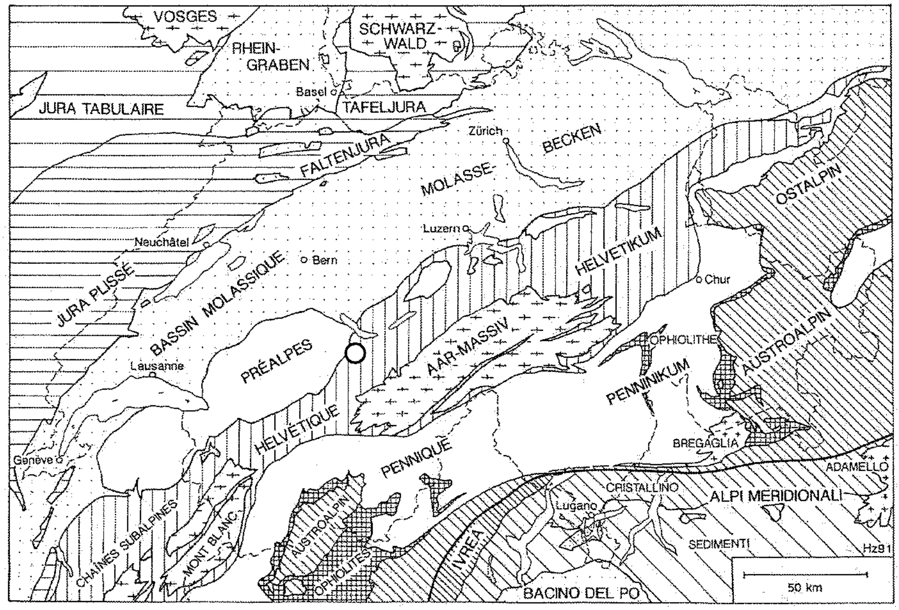


Fig 1: Switzerland – Geological/tectonic units
O = Viewpoint Aeschi

Alpine evolution – a short summary

The Alps are a typical collision belt (Pfiffner et al., 1997), and the following evolution steps can be distinguished:

210 million years ago (Triassic):
Europe and Africa form a single plate. The two continents are separated only by a shallow sea.

150 million years ago (Jurassic):
The two continents are separated by a deep ocean. At the plate boundary, marked by submarine volcanoes, new oceanic crust is formed.

100 million years ago (Cretaceous):
The two continents converge, the oceanic crust in between is subducted. The continents then collide, and the African plate overrides the European one. Crustal packages in dimension of tens of kilometers, called tectonic nappes, are overthrust one over the other.

30 million years ago (Tertiary):
The collision reaches the maximum. Due to rapid uplift, the morphological mountain chain is formed. In the forelands north and south of it, huge accumulations of clastic sediments form the Molasse.

20'000 years ago:
During the climax of the last glaciation, wide areas of Switzerland are covered with ice. Drift deposits in the Swiss Plateau.

The Alpine evolution can be compared with some events of human history:

290 years ago:
Deviation of the Kander river towards the Lake of Thun.

90 years ago:
Construction of the first Lötschberg tunnel (length 14.6 km).

1 year ago:
Start of the construction of the second Lötschberg tunnel (length 35 km).

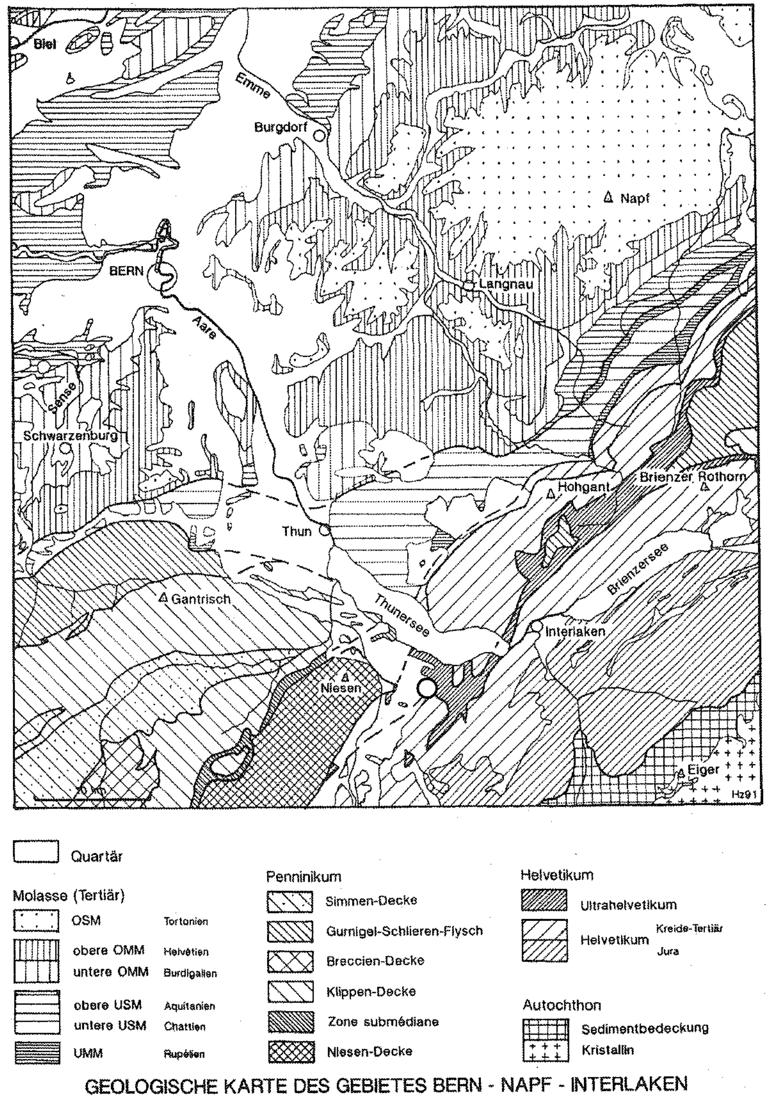


Fig. 2: Geological sketch map of the region between Bern and Interlaken.

The geologic-tectonic units of the Berner Oberland

From a geological point of view four units can be distinguished, each with its own geological history (Fig. 2). In a paleogeographic order from south to north, these are:

Northern Penninic unit:
The main part of the Penninic unit, which has its origin in the oceanic domain, is situated today more to the south and is composed both of continental and oceanic crust. Only few smaller sedimentary nappes of northern Penninic origin were thrust northwards over the Helvetic units.

Helvetic unit:
The Helvetic unit originally formed the southern margin of the European continent. A sedimentary pile of Mesozoic limestones and marls with a thickness of up to nearly 5 km was deposited on the crystalline basement. Only the sedimentary cover was thrust over the "Autochthonous unit".

"Autochthonous unit":
Originally situated in the north of the Helvetic domain, this unit is a slightly overthrust basement-cover complex in which the sedimentary cover itself is partially detached from its original basement and thrust northward ("Parautochthonous units").

Molasse basin:
A thick pile of clastic sediments of Tertiary age were deposited during the uplift phase of the Alpine evolution in the subsiding northern foreland. The underground of this basin is formed by a basement–cover unit similar to the "Autochthonous".

Stage 1: Formation of the Mesozoic sedimentary cover

The Triassic consists of a thin series of shallow-marine sediments, such as sandstones, dolomites and evaporites. Towards the Penninic domain the series is slightly thickening.
During the Early and Middle Jurassic, two basins, probably limited by normal faults (crustal extension), were formed in the Helvetic domain, where series up to 1000 m of shales and siliceous were deposited (Fig. 3). In the northern Penninic realm, shallow-water sediments dominate.

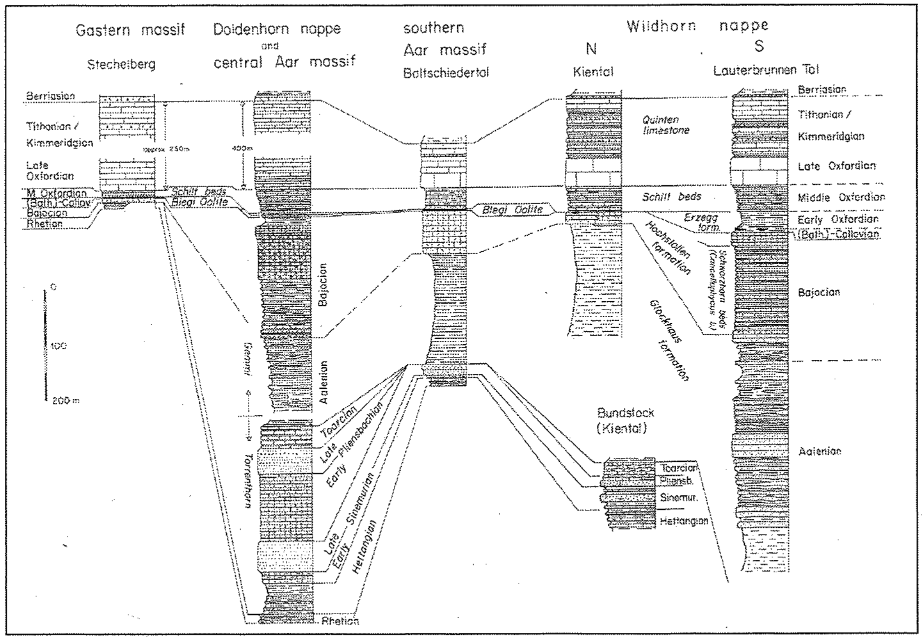


Fig. 3: Jurassic stratigraphy of the "Autochthonous" and Helvetic nappes in the Berner Oberland (by R. Herb, Geology of Switzerland 1980)

In the Autochthonous and Helvetic domain the Upper Jurassic is characterised by a thick series of micritic limestones, which form prominent cliffs in the High Calcareous Alps. Towards the south the facies becomes increasingly oceanic with limestones and flysch-like sediments.
The Cretaceous mainly consists of marls and limestones, indicating different influences from the northern continent. In general the sea was deepening from north to south (stronger subsidence in the south), and the complete series is much thicker in the southern domain (Fig. 4). At the end of the Cretaceous the whole Helvetic domain emerged. In the northern Penninic unit, flysch deposits are indications of the first compressional pulses, which lead to the subduction of large parts of the southern Penninic realm with its oceanic crust. Only few slices were obducted and are found today as ophiolites in the Penninic nappe pile.
The Tertiary series are characterised by a general transgression from south to north. Therefore, in the Penninic unit the sedimentation of flysch sediments continued throughout the Cretaceous. This is in contrast to the Helvetic-"Autochthonous" domain where the stratigraphic gap between the

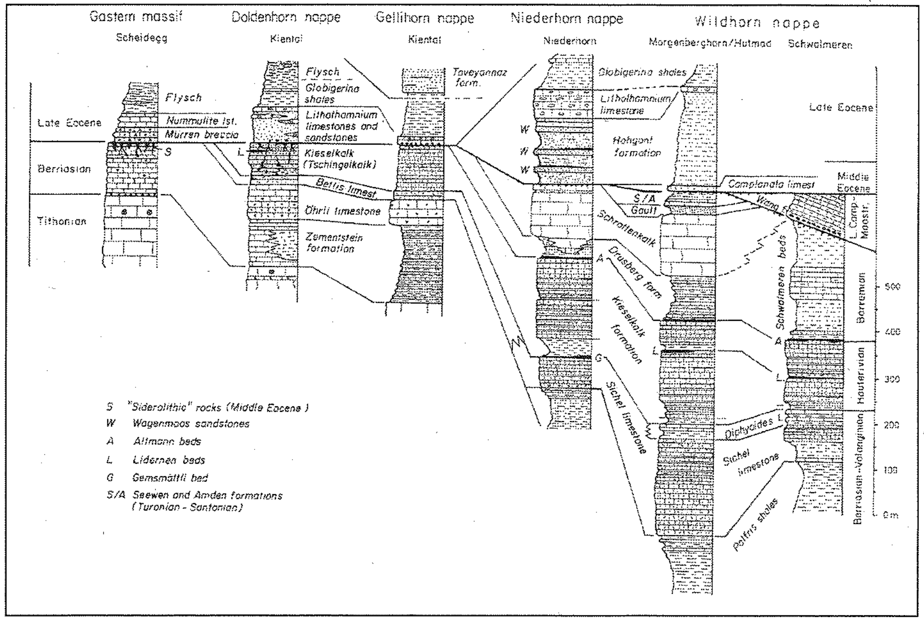


Fig. 4: Cretaceous and Tertiary stratigraphy of the "Autochthonous" and Helvetic nappes in the Berner Oberland (by R. Herb, Geology of Switzerland 1980)

Cretaceous and the Tertiary is increasing from south to north. As a consequence, the oldest Tertiary deposits in the north are much younger than those in the south. Beginning usually with shallow-water limestones (with Nummulites) and shales, the sedimentation continues towards flysch deposits. In the northernmost domain the sedimentation changed in the Oligocene from flysch to Molasse facies (see stage 2).

Stage 2: Formation of Tertiary Alpine Chain and the deposition of the Molasse

With the change of the plate motion directions during the early Cretaceous the compressional stage of the Alpine cycle was initiated. Indications of the first orogenic phase about 90 million years ago are the interruption of sedimentary successions by thrust planes and the dating of (high pressure) metamorphism.

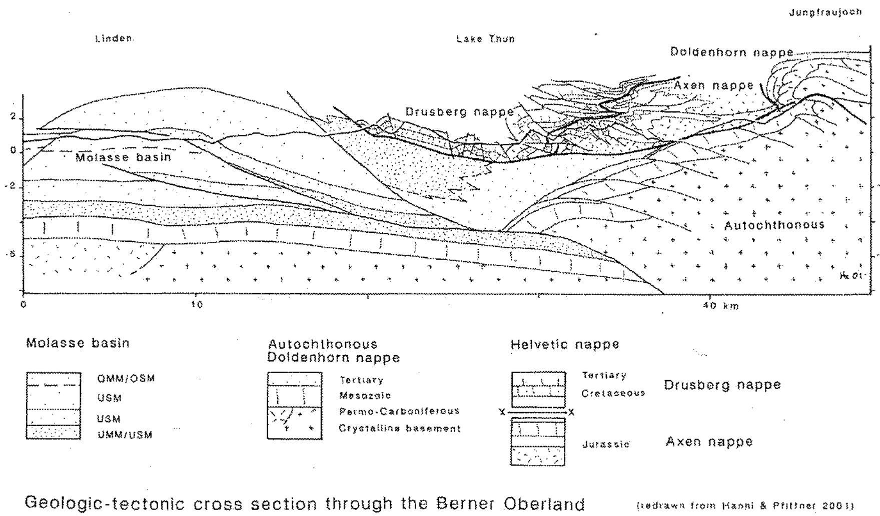


Fig. 5: Geologic-tectonic cross section through the Berner Oberland

The climax of the Alpine orogeny occurred during late Eocene/Oligocene time when the different units were thrust one over the other. In general this process set off in the south, whereby already overthrust higher units were transported on the back of the lower units further north. As a consequence of the compressional deformation, thrust faults inside the nappes and huge folds were formed, often affecting the whole sedimentary pile.

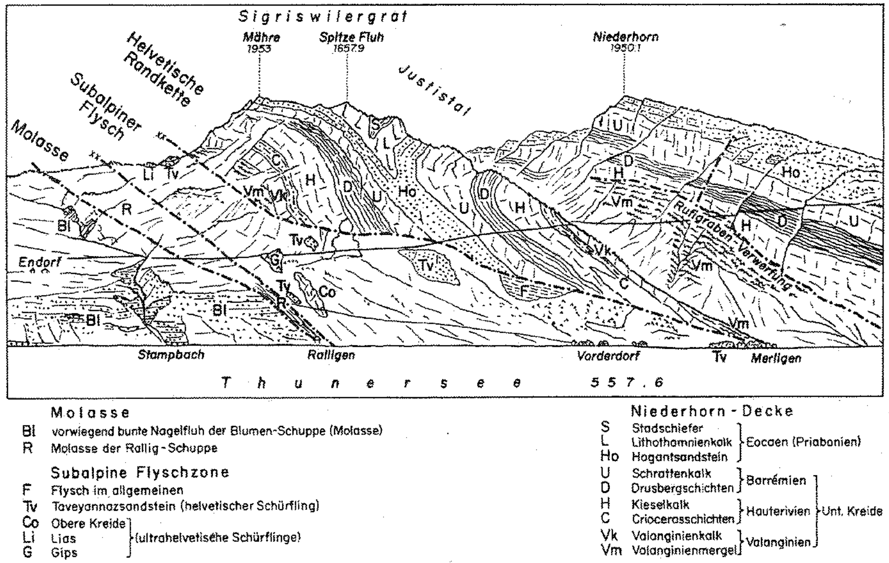
In the Berner Oberland only some relicts of the Penninic nappes resisted to erosion and are found today lying at the frontal part of the Helvetic nappes (Fig. 2). The most significant are the Klippen and the Niesen nappes.

The Helvetic nappe of the Berner Oberland includes sediments ranging from the Lower Jurassic (Lias) to the Lower Tertiary (Lower Eocene); it was thrust from its roots south of the Aar Massif to its present position on top and in front of the "Autochthonous" unit. Forming in the western part of the Berner Oberland a huge double fold nappe complex (Wildhorn nappe) the tectonic style is changing eastward (the double fold disappears), and in the Lake of Thun profile a separation between the lower (Jurassic; Axen nappe) and the upper (Cretaceous/Tertiary; Drusberg nappe) part can be observed (Fig. 5). The detached upper part was thrust much further north and forms the Border chain (Randkette, Fig. 6).

In the synform between the two parts of the Drusberg nappe we find the Penninic nappe relicts.

The "Autochthonous unit" is divided into numerous autochthonous/ parautochthonous slices, which were slightly thrust one over the other; the most important among them is the Doldenhorn nappe originating from the back of the Aar Massif. The whole complex is thrust onto the foreland.

Synchronous with the deformation inside the Alps, detritus of the rising Alps was deposited in the subsiding Molasse basin. The infill of the Molasse basin consists of two cycles ranging from marine to freshwater deposits. The marine Molasse consists of very shallow-water deposits, such as sandstones, silitites and limestones. The freshwater Molasse is dominated by huge debris fans at the border of the rising Alps, where most of the material eroded in the mountain chain was deposited. Towards the Swiss Plateau, the sediments become finer grained; there we can find sandstones, siltstones, clays and some intercalated freshwater limestones. Similar but smaller debris fans were also formed during the deposition of the Upper Marine Molasse.



Figur 2. *Der Alpenrand von Ralligen–Merligen, von Spiez aus gesehen.* Nach P. BECK (1911, Tafel IV).

Fig. 6: The Alpine border north of Lake of Thun (Geologischer Führer der Schweiz, 1934)

In the Swiss plateau the Molasse deposits are generally flat-lying or gently dipping towards south. At the Alpine border, they are incorporated into the thrust belt and cut into slices thrust one over the other (Fig. 5). This situation gives an indication of the latest thrust movements, which occurred after the deposition of the middle Miocene Upper Freshwater Molasse.

The Cretaceous–Tertiary orogenic cycles are responsible for the inner structure of the mountain chain, which can be described as a thrust belt, whereas the formation of today's morphology of the Alps is the result of processes which were active during the last two million years, and which are described in the following chapter.

Stage 3: Formation of the Alpine relief – the Glaciations

During the last two million years several advances of the Alpine glaciers into the northern and southern forelands occurred, synchronoulys with the great glaciations in Scandinavia. During this time the advancing glaciers eroded deep valleys into the Swiss Plateau and the large inner alpine valleys are now reaching partly far below the sea level (e.g. Valais Rhone valley, Lake of Thun). During the glacier retreats extended lakes were left behind, which were subsequently filled with the debris brought by rivers; during the following glacier advance the entire valley filling was usually removed again. Therefore, seismic profiling through these valleys give evidence only of the last valley filling after the last glaciation.
Some of the large lakes which were formed after the last glaciation are today completely or partially filled with postglacial fluvial debris. A good example are Lake of Thun and Lake of Brienz in the Berner Oberland. Here a long lake between Thun and Meiringen developped after the glacier retreat. The tributary rivers (Aare at Meiringen, Lütschine at Interlaken, Lombach at Unterseen and Kander in the Thun area) restricted the original lake surface to the present one with their debris input. The Lütschine and Lombach rivers even divided the orginal lake into two smaller ones with a huge double delta in the Interlaken region.

Other postglacial processes are the mass movements from very steep valley slopes. Many of the Alpine valleys (e.g. Kander valley) are filled with extensive postglacial landslide deposits. This processes continue today and are one of the important hazards for the population in the mountain regions.

Stage 4: Man and Geology

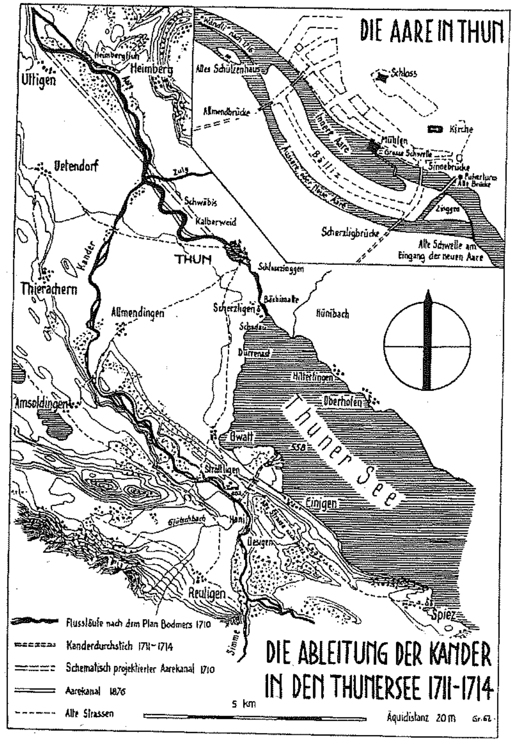


Fig. 7: Kander deviation in the Lake of Thun

Three major constructions in the Berner Oberland are in direct relations with the present geology: the Kander deviation and the two Lötschberg railway tunnels.

Originally the Kander river ran from the Kander valley southwest of Lake of Thun and flew northwest of Thun into the Aare (Fig. 7). Extended flooding of the plain near Thun and of the villages along lake Thun occurred several times. Between 1711 and 1714 the Kander was therefore deviated through a canal constructed through the hill (Strättlighügel) along Lake of Thun. The huge amount of clastic material brought by Kander and Simme in the last 285 years is clearly visible in the Kander delta in the Thunersee.

Between 1906 and 1913 the Lötschberg railway line from the Berner Oberland to the Valais with a tunnel (length 14.6 km) connecting Kandersteg and Goppenstein was constructed. On 24th July 1908 a breakthrough occurred because the tunnel pierced from massive limestones into the postglacial filling of the Gastern valley. The deviation of the tunnel is a consequence of this accident.

Today the new Lötschberg tunnel is under construction with a planned length of 35 km. For the Geology of the Berner Oberland/Valais region a profile from Helvetic Drusberg nappe through the Doldenhorn nappe, the autochthonous Aar Massif into the sediments lying on this crystalline basement will be displayed during this construction. The opening ceremony is planned for 2007.

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Flood Generation in Mountain Torrents – UoB Project Spissibach Leissigen

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Introduction

The fear of torrent flood disasters is revealed in the familar language of the local population:
«...Our grandma aptly knew: Strict rules had to be respected in crossing small bridges over mountain torrents. "Firmly walk down the bridge without looking into the water, otherwhise the hookman (troll) comes up and grips you and pulls you down with his large hook", she used to say when the sky was dark over the mountains. In any case grandma felt a strange pressure in her head: That was the sure-fire indication of an oncoming attack of the hookman...» These lines quote an article in «Oberländisches Volksblatt» of 22 May 1999 written by Sarah Anderegg. She wrote the article after the heavy rainfall and snow melting that caused dangerous high water in the torrents and floods in large areas round the Lake Thun in May 1999.

The high-water-event of 27 June 1969:
«A woman of the village [Leissigen] remembers the unforgettable night: "Sky and earth seemed to collapse. The rumbling noise was so tremendous that you could not understand a word of people talking together. We thought the village had come to its end, and what was still standing would fall within the next moments."
Heavy rain followed flash after flash of lightning... the torrents quickly rose, carrying stones and bed load, loose wood and rooted trees down the mountain, and reached the village with dirty earth-coloured water... Soon the passages under the bridges and the railwayline were blocked and the water discharged into gardens and through the narrow and steep lanes of the village in the direction to the lake... All the help was in vain; the violence of the elemental force of nature was beyond any human measure...»
(according to the newspaper reporting the event of 27 June 1969 in «Oberländisches Volksblatt» under the title «The water disaster in Leissigen»).

As the two examples show, fast rising torrents following extreme weather conditions can cause considerable damage to settlements and cultivated fields. In a country with a territory of over 60 % covered with Alpine ranges detailed studies on torrent processes are therefore indispensable. Vital interest must also be taken in investigating the possible relationship between climate fluctuations [climate change] and increasing extreme flood events. Nevertheless, only data of two pre-alpine test areas exist in Switzerland: Test area Rotenbach [cf. Fig. 1 R] and test area Erlenbach in the east of the country [cf. Fig. 1 E], both maintained by the Swiss Federal Institute for Forest, Snow and Landscape.

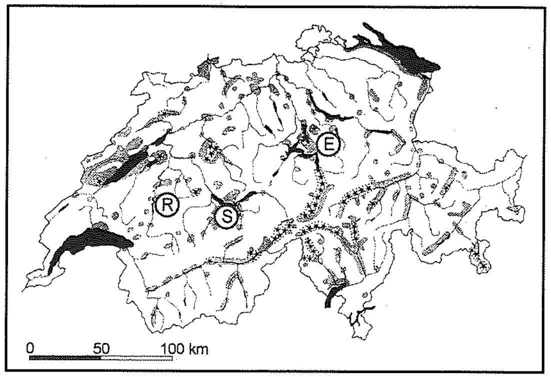

Fig. 1: Damage areas resulting from the extreme events in disaster year 1987. The star-symbol [**] indicates heavy catastrophic damage [Gotthard-Region], grey-marked areas signify regions of further damage [e.g. region of Lake Thun].

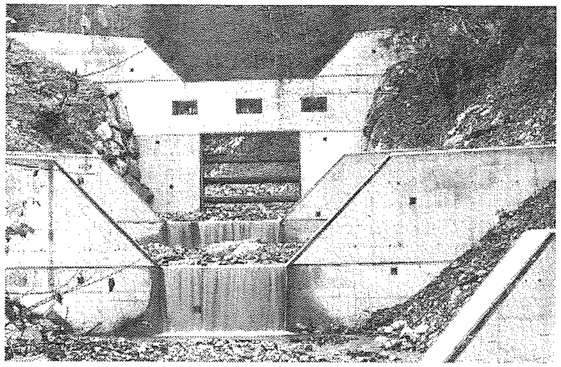

Fig. 2: After the heavy damage caused by a series of extreme thunderstorms in 1987, the Community of Leissigen decided to replace the old bedload collector by a new much larger and stronger, with concrete barriers of 0,80m thickness.

Torrent Studies on the Spissibach Catchment [Leissigen, Bernese Oberland] at the Department of Geography, University of Berne

Based on the previously described aspects, the two Groups of Hydrology and Geomorphology at the Department of Geography have built up and maintained a test area to study the torrent processes at the Spissibach catchment in the Bernese Oberland over the last ten years. The project name is «Torrent Systems, Project Leissigen» [location cf. Fig. 1 S and Fig. 4].

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WILDBACH SYSTEME PROJEKT LEISSIGEN

The Spissibach catchment covers an area of 2.6 sq. km, beginning at Morgenberghorn with 2249 metres a.s.l. and ending at 558 metres altitude at Leissigen village that is situated on a small torrent fan at the left shore of Lake Thun. With an altitude difference of 1691 metres and a mean slope of 28° the Spissibach represents a truly steep mountain torrent and perfectly amplifies the two other test sites mentioned before.

In addition to the main gauging station at Leissigen three gauging stations are installed for permanent use in concrete material in the upper part of the catchment. They are equipped with measuring instruments such as water level recorder [pressure probe], water temperature and electric conductivity measurement tools.

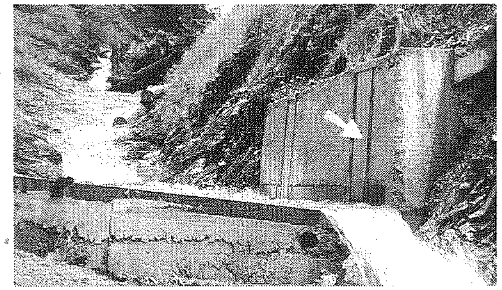


Fig. 3: Discharge station No. 260 in the upper part of the Spissibach, in solid concrete construction at an altitude of 1197 metres. All the measuring instruments are fixed in the channel in the side wall of the station, protected by a strong iron sheet [cf. arrow in Fig. 3]. The picture provides an impression of the steepness of this site.

Owing to steepness and turbulent water flow the current meter cannot be used in mountain torrents [cf. explanations in chapter Hydrometry]. The salt delution method was therefore applied. A self-developed injection mechanism is installed at Baachli gauging station to measure the high water runoff after precipitation events: fixed at a cable above the torrent a barrel filled with a defined volume of salt solution will be emptied following the computer-signal immediately after the high-water-wave-peak has passed [further descriptions of the instant-injection-method cf. chapter Hydrometry].

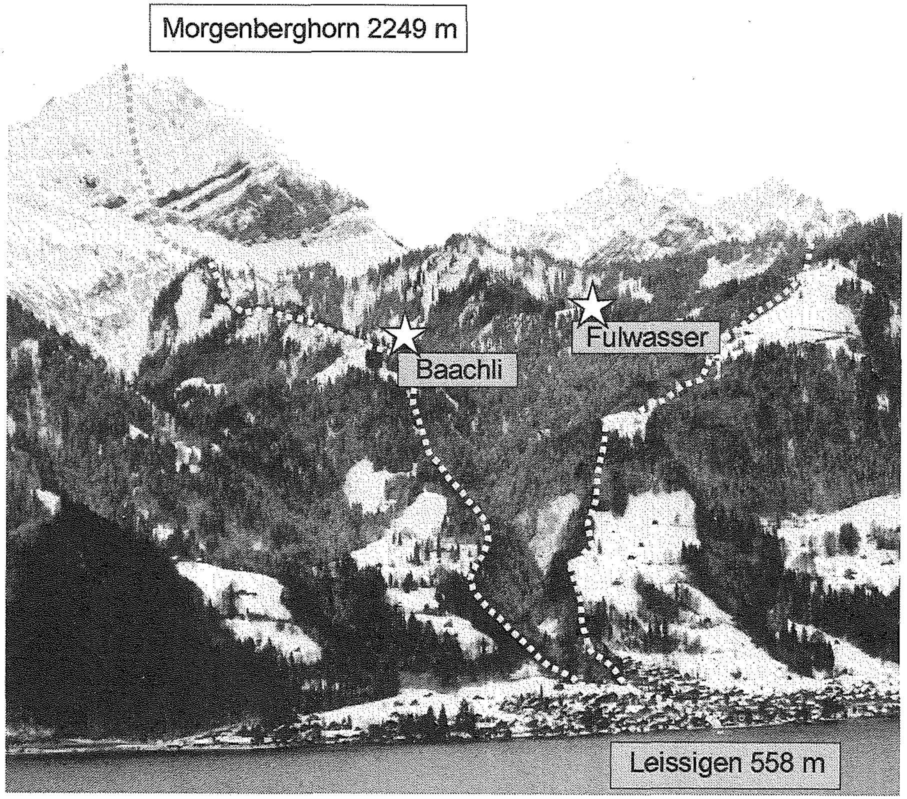


Fig. 4: The Spissibach Catchment, winter-photograph taken from the opposite side of Lake Thun, view to the south. The dotted line indicates the catchment borderline. The approximate locations of the two weather stations Baachli and Fulwasser are marked by a star symbol .

The two fully equipped automatic climate stations at Fulwasser [1388m] and Baachli [1350m], connected with tipping buckets for rainfall measurement, provide some of the necessary data for calculating the water balance [Evaporation, e.g., is calculated by means of Penman-Monteith or Makking methods]. Data from weather stations as well as those from gauging stations are captured at 10-minute-intervals in a data-logger at high temporal resolution and stored in special data archives called project information system [PIS Leissigen].

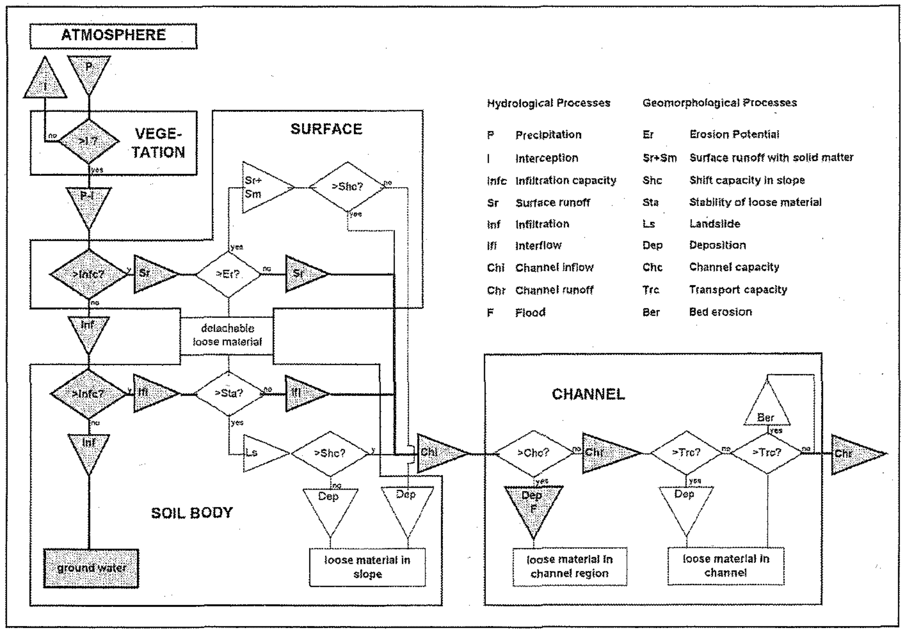


Fig. 5: Sketch of the structural torrent system [by Weingartner and Kienholz].

Investigations of the Hydrology and Geomorphology groups are aimed at a detailed analysis of runoff processes to allow the generation and calibration of a reliable and practical model of mountain torrents. This model can be used to investigate the impacts of climate and environmental change in mountainous regions. As described in Fig. 5 the main processes of torrent systems are briefly explained as follows: Hydrological processes [water flows] and geomorphological processes [shifting of solid matter] are linked in so far as solid matter may be loosened by surface runoff or in water saturated soils. However, this is a non-linear process.

Consequently, the interest is directed towards the hydrological processes which in Fig.5 are made visible by thick-lined symbols on grey background. Five main elements are involved in torrent water processes: atmosphere, vegetation, soil-surface, soil-body, channel. Precipitation as the input normally falls on vegetation first, is partly kept by interception [I] and evaporates. The remaining water [P-I] reaches the soil surface. If the infiltration capacity is large, the water penetrates [Inf] the soil body, if it is low the surface runoff [Sr] flows directly into the channel. The different soil body layers are decisive for the further process: either the water continues to infiltrate vertically until it reaches the saturated zone [ground water] or it flows off as interflow [Ifl].
Both surface runoff and interflow form the channel inflow [Chi] and flow down as channel runoff [Chr]. When the channel capacity [Chc] is exceeded, flood occurs [F] with deposition of loose material [Dep].

Measurement concept

Study of specific processes cannot be achieved for the whole catchment area because steering parameters are likely to vary considerably from one site to another. Studies must therefore be assessed to micro-scale catchments with homogeneous conditions [e.g. land use and vegetation, slope, exposition, geology]. In this nested approach the manifold results of the small catchments are then summed up to form the overall torrent model.

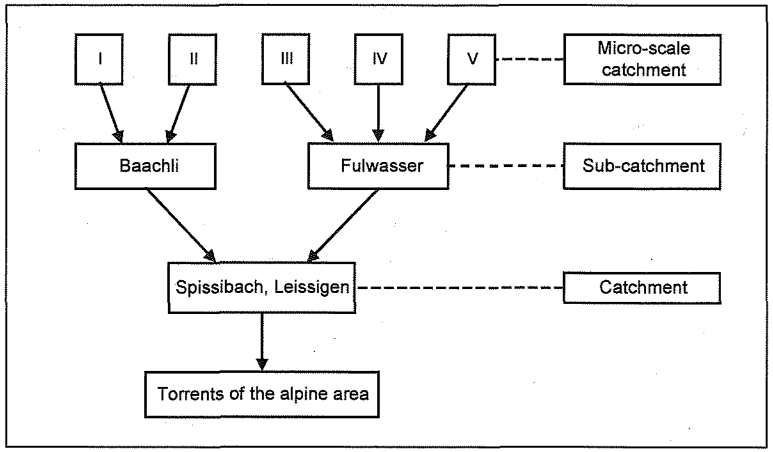


Fig. 6: General measurement concept.

Results

A number of studies have been carried out over the last ten years. In this frame, three of them are briefly presented:

A theoretical approach: Use of TOPMODEL combined with a Geographical Information System GIS [Brünisholz, M. (1999). Publication Gewässerkunde No. 228, Bern.]

A hydrological comparison of the two sub-catchments Baachli and Fulwasser [cf. Fig. 6] was drawn on the basis of a hydrological model. TOPMODEL is assigned to the «physically based semi-distributed models» developed at the Centre for Research on Environmental Systems and Statistics at the University of Lancaster [GB]. A topographical index [topo-index] is derived from the Digital Elevation Model; it describes possible surface runoff in consequence of saturated soils. With this index the whole catchment area could be subdivided into classes with similar runoff conditions. The parameters precipitation, evaporation, soil-water in the root-zone, soil-transmission and mean velocity of the channel runoff were therefore required.
With the combination of TOPMODEL and the GIS-system ARC/INFO the simulation of the spatial-temporal development of surface runoff in saturated zones can be made visible. Long-term [months] as well as short-term simulations of a singular rainfall event [hours] can thus be done.

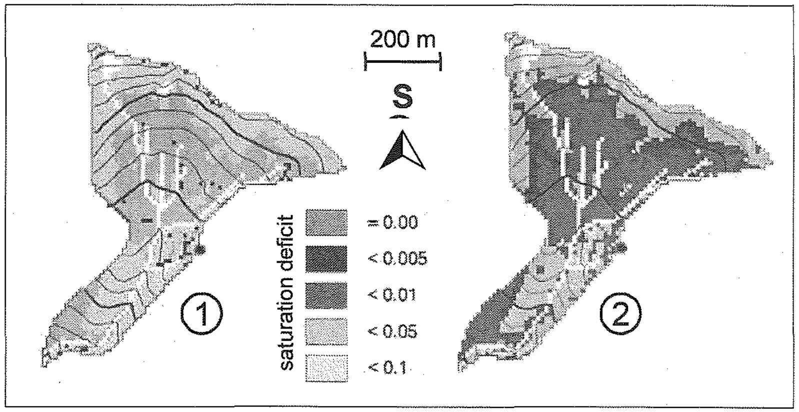
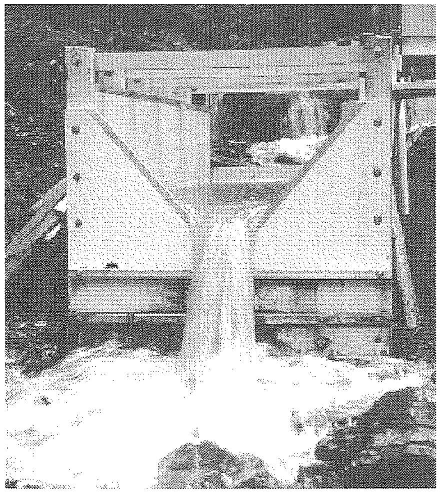


Fig. 7: Dynamics of saturated areas in the sub-catchment Fulwasser after the rainfall event of 11 July 1995. ① shows the situation before the beginning of rainfall, ② represents the situation 7 hours later after the end of rainfall.

Simulation results of Fulwasser [0.26 km²] and Baachli [0.62 km²] can be compared: After the rainfall event of 11 July 1995 with 59.6 mm precipitation within 4 hours the percentage of saturated areas in Fulwasser is much higher with a maximum of 59 % [cf. Fig. 7] than in Baachli with 23%. The simulation results show that soil saturation in Fulwasser is quickly attained, a fact that confirms the field observations: The less steep slopes remain marshy even in dry periods.

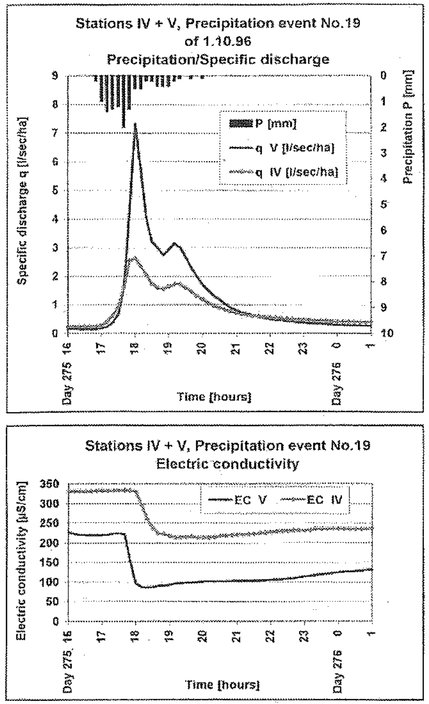
B Empirical approach: Comparative hydrological investigations in three micro-scale catchments of Fulwasser torrent [Lämmli, M. (2000). Publication Gewässerkunde No. 250, Bern.]

Three homogeneous micro-scale catchments which, however, differ in natural conditions were defined in the upper part of Fulwasser [cf. Fig. 6]. Three wooden weirs with a calibrated notch had to be built first and equipped with instruments for water level and electric conductivity measurements, automatically taken in the same temporal resolution as from the weather stations.
These three catchments are numbered as follows: III [0.024 km²], IV 272 [0.056 km²], V [0.044 km²].
58 rainfall/runoff events of 1996 and 1997 were selected. After the separation of the hydrographs base flow/direct flow every event was described with 20 parameters such as rainfall intensity and peak flow.



Despite the close vicinity the three micro-scale catchments reveal a different hydrological behaviour which is represented in Fig. 9 by the hydrographs and electric conductivity. Catchment V especially shows a fast and intensive reaction to rainfall. Runoff close to surface dominates and leads to a much higher specific discharge than in catchments III and IV. The very fine-porous material [gley above flysch layers] hinders the water to infiltrate the soil.

Fig. 8: The notched weir No. IV.



On the other hand, catchment IV must have a fairly large storage, i.e. water can infiltrate much easier than in catchment V, the dry-weather hydrograph does not sink so briskly and the base flow remains on a high level. Seismic measurements identify a deep depression [caused by a local glacier during the last ice age] filled with thick layers of coarse-grained loose material.
The described facts are additionally underlined by the data of electric conductivity. The usually far higher electric conductivity rates in catchment IV indicate that the water remains in the subsurface over a long time.

Fig. 9: Discharge and electric conductivity stations IV and V during a precipitation event.

C Empirical approach: Investigation of processes of runoff generation by means of sprinkling tests, soil moisture measurements and hydrological classification of Baachli and Fulwasser by vegetation and soil mapping [Judith Dobmann and Simone Hunziker (master thesis in preparation)]

Based on results gained by mapping out vegetation and soils as well as by investigations on soil hydrology the thesis of Judith Dobmann and that of Simone Hunziker aim at the generation of a map on runoff processes.

Simone Hunziker attempts to classify sub-catchments Baachli and Fulwasser into units that differ in view of hydrological reaction and underlies her study with findings in the frame of soil and vegetation mapping. Analysis of these results obtained is a crucial part within the investigation whether botanic families and soil types are suitable indicators for hydrological research.

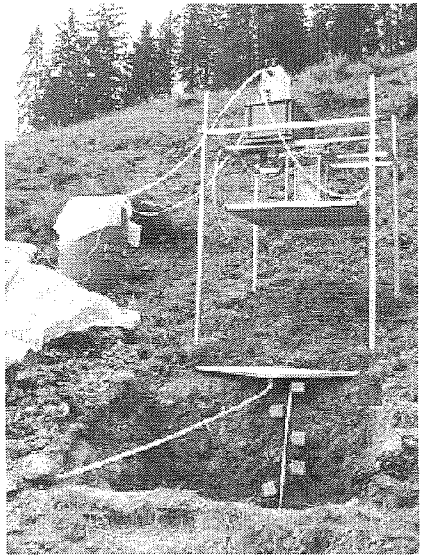


Fig. 10: Site of sprinkling tests, collector of surface runoff (iron sheet), 5 TDR-sondes in profile hole

Fig. 11: upper part: Typical spring-vegetation occurring in the marsh-land Fulwasser [Eriophorum angustifolium]; lower part: soil profile of the same site

Judith Dobmann carried out sprinkling tests at seven sites. Soil moisture was captured by means of TDR-sondes and the surface runoff measured in an automatic gauging system. The total of these data will provide suitable in-situ-information on surface runoff, infiltration, short-term retention capacity and in-depth-percolation.

Based on Simone Hunziker's thesis point-results from Judith Dobmann can be extrapolated to the surface and the outcome will be represented in a map on different hydrological units. This map will help to assess the reaction behaviour of torrent catchments as well as to optimise inputs for hydrologic models and to distinguish the areas that are likely to contribute to floods.

Hydrological forecast for the Lake of Thun and flood hazard assessment in the City of Thun

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Introduction

The Swiss and French Alps experienced extraordinary snowfall in February 1999. In the Canton of Bern the event had approximately a 50-years recurrence interval. As early as March the Cantonal Authority discussed the possibility of flooding during the melt season (April and May). A forecast system (which had to be developed beforehand) was established for the Lake of Thun (Mani 2000) and an operational monitoring and warning procedure was set up. Beginning in late April, strong snowmelt caused river and lake levels to rise considerably. From 11 to 14 May an above average rainfall occurred and caused maximum stage for the Lake of Thun and the Aare River downstream (Fig. 1; cf. BWG 2000). Flood damage of approx. CHF 60 million resulted. In the light of these events the City of Thun initiated a hazard assessment. The present paper highlights some aspects of the hydrological simulation procedures and the establishing of a hazard map.

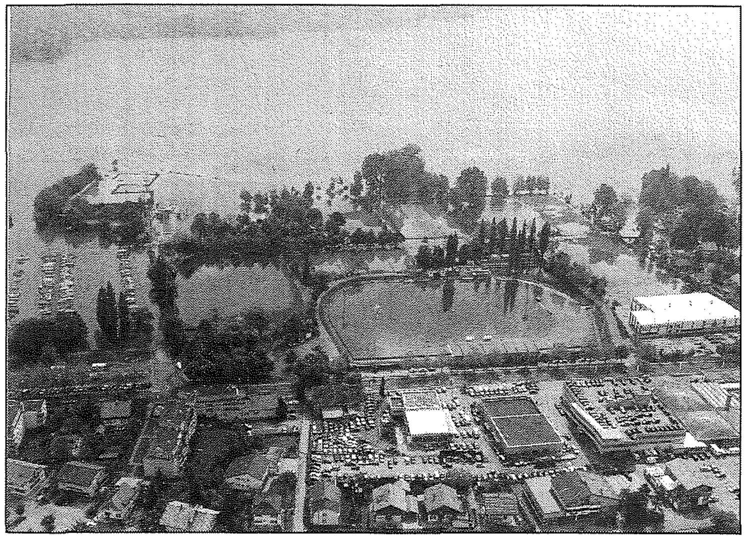

Fig. 1: Thun, 14 May 1999: Flooded city district along the lake shore.

Modelling approach

The simulation of the hydrological conditions in the Aare system (Lake of Thun, its affluents and Aare River downstream) is based on three modules representing the main processes:

- Simulation of water supply from rainfall and snow melt.
- Simulation of discharge in main tributaries.
- Simulation of the level of Lake of Thun.

An extended degree-day model developed by Braun (1985) simulates snow melt. A linear storage model transforms the water supply into discharge of the main rivers. The lake level was simulated using a volumetric approach. The parameters for the snow melt simulation were chosen according to information found in the literature. Runoff coefficient and storage constant required calibration before the simulation could start. The cantonal water and energy administration provided the stage-discharge function for the Aare River at the outlet of the Lake of Thun.

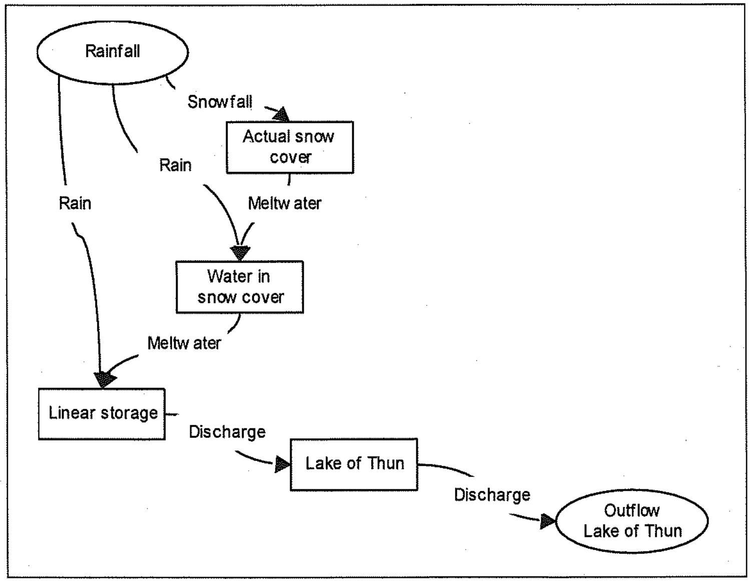

Fig. 2: Conceptual simulation scheme

This simulation approach was transformed into a semi-distributed model. The whole catchment basin of the Lake of Thun (2000 km^2) was divided into a number of major regions and altitudinal zones (200 m each) for the simulation of snow melt. Satellite imagery provided the distribution of snow

cover (as start condition and for the occasional calibration of snow melt simulation). In addition, the avalanche service provided data of the water equivalent of the snow cover. The simulation of runoff in the main rivers could be calibrated with few gauging stations.

Forecasting and sensitivity analysis

The forecast system was operational from April 1 onward. A weekly prognosis of the development of the water supply was performed based on a 5 to 7 days weather forecast (rainfall, air temperature, temperature gradient). The simulation results could be checked using rainfall and runoff data of the past period (Fig. 3).

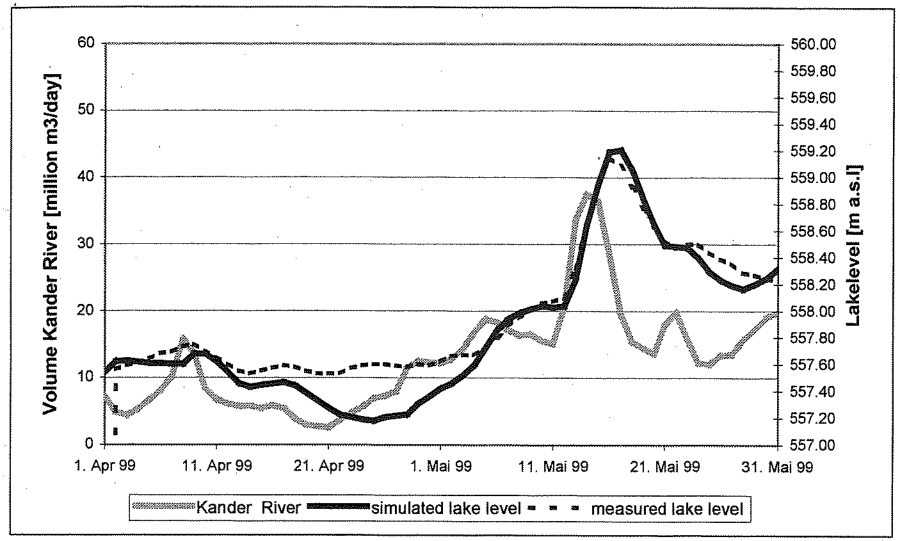

Fig. 3 Lake of Thun: Simulated and measured lake level, compared with the inflow (represented by the discharge of Kander River)

In general, the model represents the conditions in the basin of the Lake of Thun satisfactorily. In most cases inaccurate weather forecast explained the deviation of the modelled from the measured discharge and lake level. It is clearly visible in figure 4 that the flow into the Lake of Thun (represented by the hydrograph of the Kander River) increased considerably long before the rainy period from 11 to 14 May started.This was primarily due to snow melt as indicated with Simme River at the

Oberwil gauging station (Fig. 4). The 70 to 100 mm of rainfall between May 11 and 14 caused the rapid rise of the lake level.

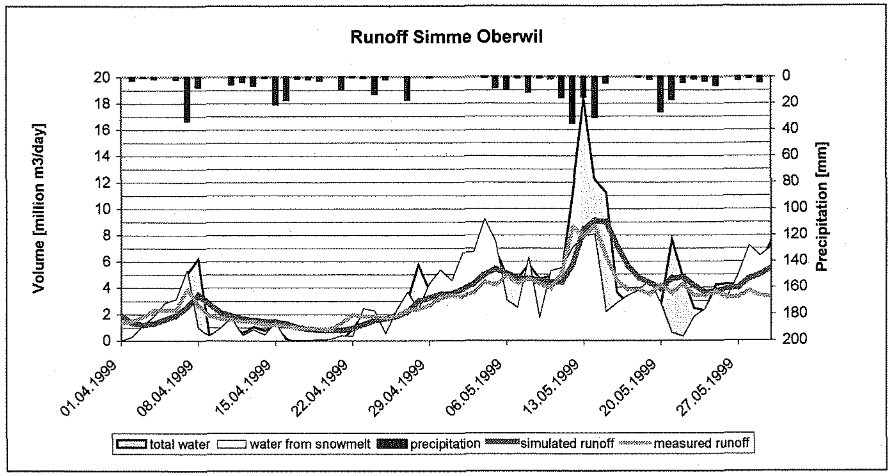

Fig. 4 Snow melt and discharge simulated for the Oberwil gauging station (Simme River)

In addition to the weekly prognosis the simulations were used to perform some sensitivity analysis. A number of rainfall and temperature series of past years or synthetic data series served as input parameters. The comparison of two scenarios considering different temperature and water equivalent data is given in figure 5. The results of the sensitivity analyses in general show the following results:

- The presence of a high amount of water in the snow cover between 1300 m and 2000 m is most important for a high water supply to the lake (large areas of the basin are located in this altitudinal zone).
- The water equivalent itself is less sensitive for the rise of the lake level, because the energy input, and therefore, the snow melt is limited.
- Air temperatures are very sensitive for the snow melt in the basin, particularly when large snow amounts occur in lower altitudinal zones.
- A high water equivalent causes a prolonged period of high river and lake levels, and therefore, the probability of a coincidence with a strong rainfall event is increased.
- Extended rain can result in a rapid increase of the lake level, particularly when the soils are saturated by melt water.
- The lake level can easily raise to the limit of damage (558.3 m a.s.l.) only due to snow melt.

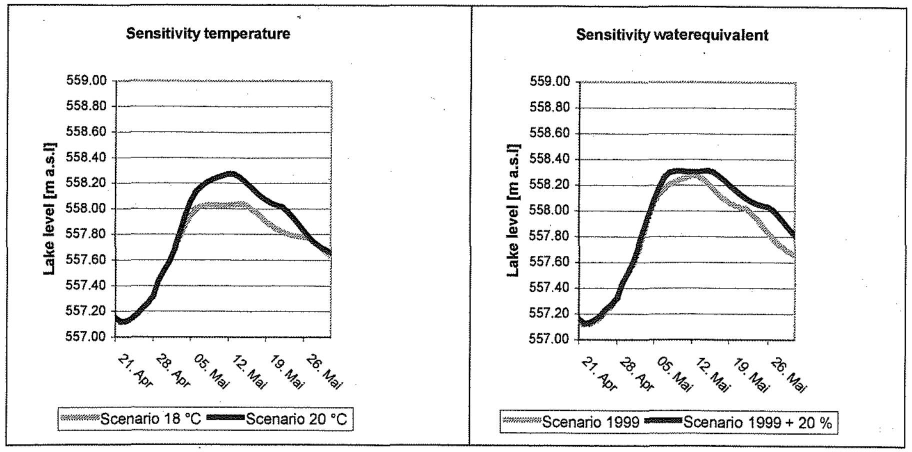

Fig. 5: Sensitivity analysis for the lake level
Left: variation of air temperature, right: variation of water equivalent

The monitoring and forecast system was further evaluated and developed. Today, the monitoring and warning procedures can easily be implemented and a dangerous situation monitored.

Frequency analysis of the lake level

The level of the Lake of Thun is measured for more than 130 years. Since the 1880s the outflow of the lake is controlled by gates. Under normal conditions the stage is maintained within relatively narrow margins enabling navigation, protecting fish habitats and providing storage for flood water. The yearly maximum stages are given in figure 6. The 1999 value of 559.12 m a.s.l. is by far the highest ever measured level. From a statistical point of view the 1999 event has a recurrence interval of about 800 years (fig. 7). However, due to the control of the lake level (e.g. lowering of the stage before major rainfall events occur) an extrapolation of rare events should not be done. The distribution function should be used only to a level of about 558.7 m, which represents approximately a 50-years event. Taking into account the processes which result in high lake levels (strong snowmelt, extended and prolonged rainfall) it can be concluded that the 1999 value represents a 80 to 200-years event.

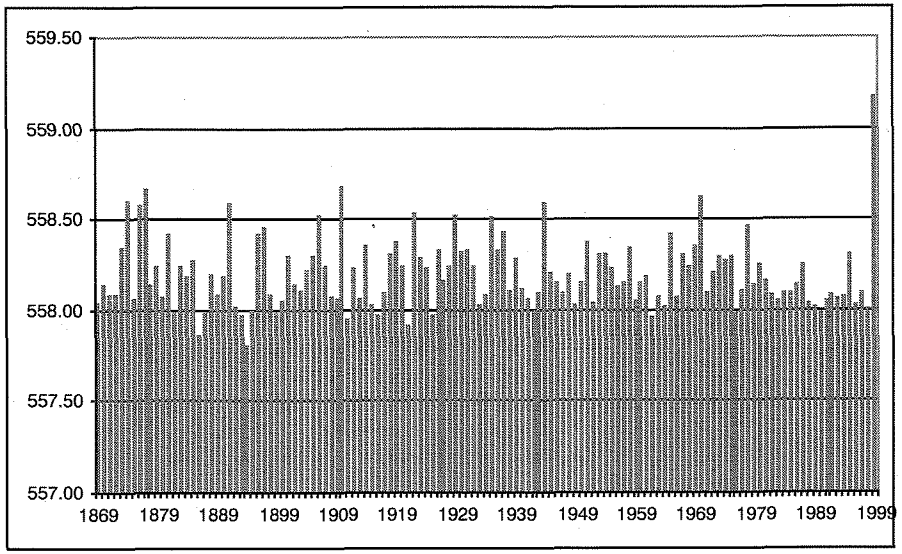

Fig. 6: Maximum stages of the Lake of Thun. The level above which damage occurs is 558.3 m a.s.l.

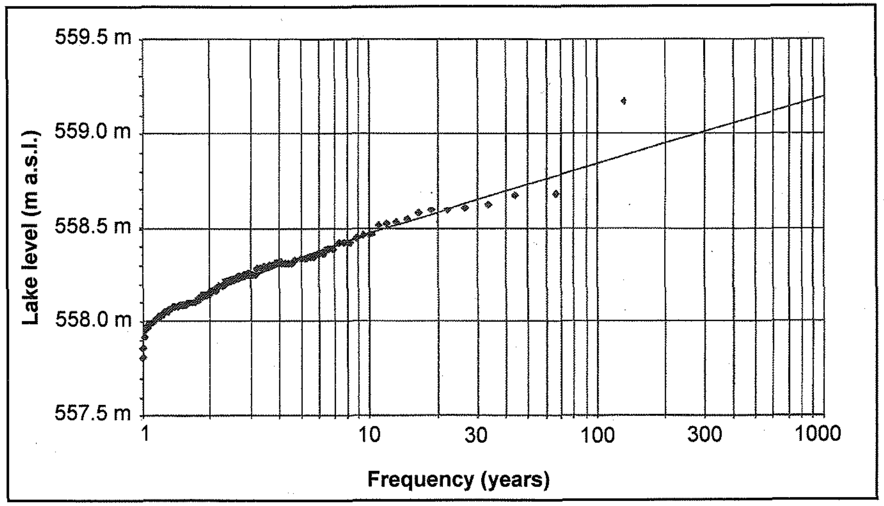

Fig. 7: Frequency-stage relation for the Lake of Thun. The level is controlled by gates. Therefore, a statistical extrapolation of the 1999 value is not appropriate.

Hazard assessment and hazard map

Following the 1999 floods, the City of Thun, with support from the cantonal and federal administration, initiated a comprehensive hazard analysis and the preparation of a hazard map for the whole territory of the municipality (Stadt Thun 2000). Hazard maps in Switzerland are established following recommendations given by the Federal Office for Water and Geology (BWW/BUWAL/BRP 1997). The degree of hazard is determined by classes of probability (recurrence interval for 30-, 100-, and 300-years event) and by classes of intensity. Floods, for instance, are classified according to water depth: low intensity: < 0.5 m, moderate intensity: 0.5 – 2 m; high intensity: > 2m. Three colours represent the degree of hazard using probability and intensity as follows:

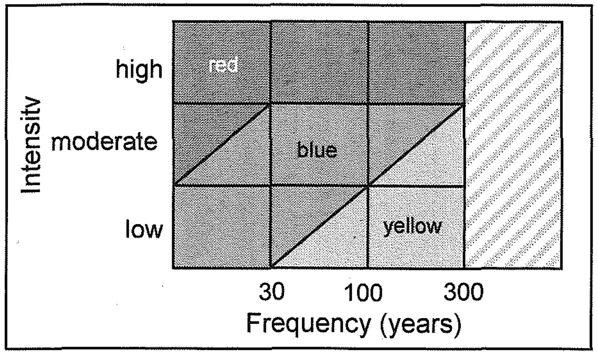

Fig. 8: Intensity / Frequency Diagram for the determination of the degree of hazard.

The May 1999 flooding along the lake shore served as prime information for the hazard zones. In spite of major uncertainties about the recurrence interval of the 1999 flood it was decided to consider this event as the 100-years flood (see above). For the preparation of the hazard map the following probability/stage relation was used:

Recurrence interval	Lake level m a.s.l.	Explanation
30 years	558.65 m	statistical value
100 years	559.12 m	stage of May 1999
300 years	559.32 m	20 cm above the 1999 stage. Possible value according to sensitivity analysis.
Extreme (1000 years)	??	further hydrological investigations required to determine stage.

Flood simulations showed that many areas which were not affected during the 1999 flood are additionally considered to be flood-prone. The whole hazard map is integrated in the "Zonenplan/Hinweisplan" and available on the web: http://thunhinweisplan.city-info.ch

The new hazard map of the city of Thun was used to change the building codes (mandatory building restrictions in blue areas and optional building regulations in yellow areas). The building code is available on the web with the relevant paragraph no. 46, considering the natural hazards: http://www.thun.ch/offizielles/aemter/planungsamt/br.pdf. Unfortunately, there were not many options for further land use restrictions in the hazard zones since almost all housing lots are already built up along the lake shore.

Conclusions

An integrated flood risk management requires long-term and short-term measures. The latter ones consider for instance monitoring, warning and alert procedures as well as precautionary flood defence works (emergency services) in order to limit damage. On the other hand land use regulations prevent the further increase of vulnerability in flood-prone areas. The case of the Lake of Thun and the City of Thun serve as a good example where the responsible agencies made the relevant steps.

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Selected Hydrometric Methods used by the Swiss National Hydrological Survey

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Introduction

The main purpose of stream gauging stations is to provide systematic record of stage and discharge. Continuous streamflow records are necessary in the design of water supply and waste water systems, in designing hydraulic structures, in the operations of water management systems, and in estimating the sediment or chemical loads of streams, including pollutants.

Since continuous measurement of discharge is not usually feasible, records of discharge are computed from the relationship between stage and discharge, as defined by systematic record of stage and periodic discharge measurements.

A continuous record of stage is obtained by installing instruments that measure and record the water surface elevation in the stream. Discharge measurements are initially made at various stages to define the relation between stage and discharge. Discharge measurements are then made at periodic intervals to verify the stage–discharge relation or to define any change in the relation caused by changes in channel geometry and/or channel roughness.

The Swiss National Hydrological Survey (SNHS) at the Federal Office for Water and Geology uses different methods to measure discharge in small creeks, in rivers as well as in streams. The basic instrument most commonly used is the current meter. In torrents and mountainous rivers, the discharge measurements are made by tracers (salt, fluorescent dyes). For the last 4 years, our survey has used Acoustic Doppler Current Profilers (ADCP) for measuring the discharges in rivers with deep profiles. These primarily used methods of discharge measurement and the measuring equipments will be shown at the hydrometric station Latterbach at the river Simme. Furthermore, a discharge measurement with current meter mounted on a cableway will be demonstrated.

Hydrometric Station "Simme-Latterbach"

The river Simme at the location of the hydrometric station Latterbach has a catchment of 564 km^2, 2.2% of which is glacier area. The horizon of the station is 665 meter above sea level, while the average height of the catchment is about 1598 meters above sea level. The seasonal variation of the discharge is influenced by snowmelt between March and July. But more than by the seasonal fluctuations, the discharge of the river Simme is dominated by thunderstorms. Figure 1 shows the daily averaged discharges of 1999. The discharge is observed since 1984. The highest observed discharge at the station Latterbach occurred in May 12th 1999 with a value of 225 m^3/s. Discharge measurements, establishing the stage-discharge relation range from 1.9 m^3/s to 105 m^3/s and were made by current meters mounted on a cableway.

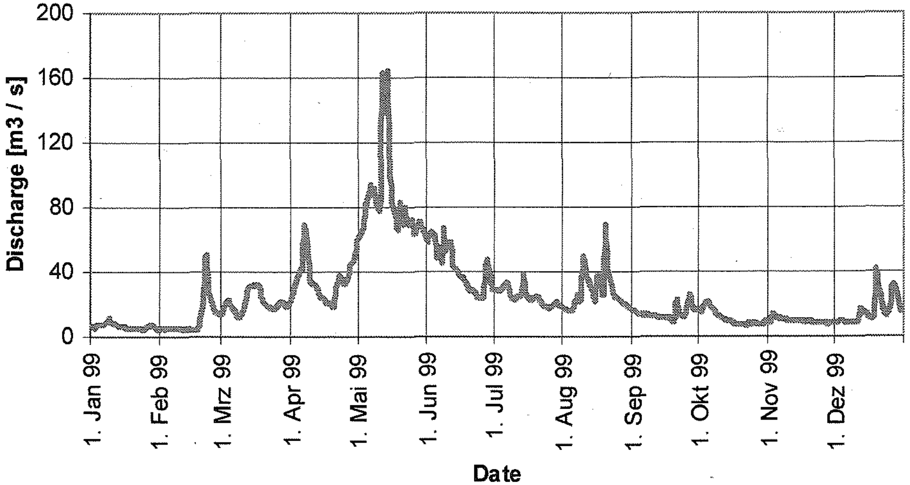

Figure 1: Daily discharges in m^3/s of the river Simme at the station Latterbach for the year 1999.

Discharge measurements with current meters

A current meter measurement is the summation of the products of the partial areas of the stream cross-section and their respective average velocities. The cross section is defined by depths at verticals 1, 2, 3, 4, ..., n. At each vertical the velocities are sampled by a current meter to obtain the mean of the vertical distribution of velocities.
Current meters, timers, and numbers of counting meter revolutions are needed for the calculation of the discharge, along with different equipment that depends on the manner in which the measurement has to be made, whether by wading, from cableways (Fig. 2), or from bridges.

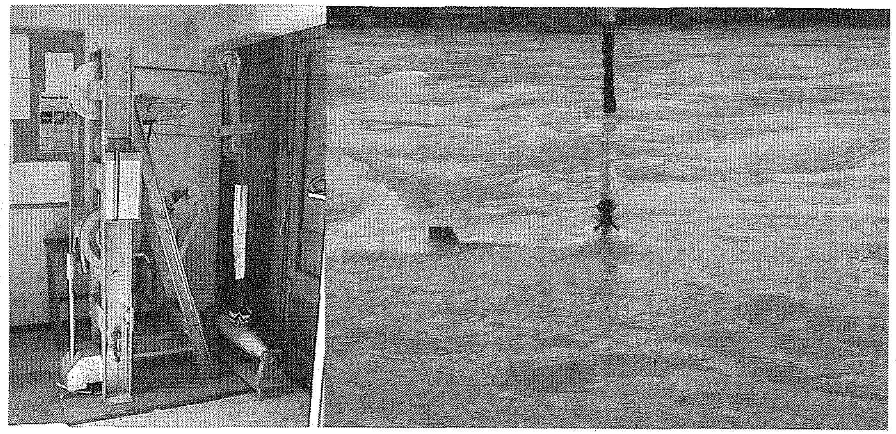

Figure 2: The self-developed cabelway installed by the Swiss National Hydrological Survey (SNHS).

A current meter is an instrument used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at a point in a stream and measuring the necessary time for a given number of revolutions of the rotor, the velocity of water at this point is determined.
To determine the velocity of the water from the revolutions of the rotor of a current meter, a relation between the angular velocity of the rotor and the velocity of the water that spins the rotor must be established. The rating is established by first towing the meter at a constant velocity through a long water-filled tank, and then relating the linear and rotational velocities of the current meter. Our rating tank in Ittigen near Berne is 140 m long and 4 m wide, and the measuring cat can calibrate velocities up to 10 m/s. In the

SNHS the current meters are recalibrated after every 40 discharge measurements. But if the engineering staff suspects that the calibration of the current meter is not valid any longer (for example due to a crooked axis or a twisted rotor from a hard stroke on a stone), the current meter is recalibrated earlier.
The current meter measures the velocity at a point. The method of making discharge measurements at a cross-section requires the determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained from velocity observations at many points in the vertical, but it can be approximated by making a few velocity observations and using a known relation between those velocities and the mean velocity in the vertical. The SNHS determines the mean velocity in a vertical by the five-point method. With this method, velocity observations are made in each vertical at 0.2, 0.5 and 0.8 of the depth below the surface, and as close to the surface and to the stream-bed as practical.
In Latterbach, there is a cableway installed. This type was developed by the SNHS in the sixties of the last century. The weight of the sinker used in our discharge measurement stations with cableway is 55 kg. The depth is measured by using a sounding reel.

Discharge measurements with Tracers

Discharge measurements with tracers may be divided into two categories. The methods with a constant injection of the tracer at an exactly known injection rate over a long enough period of time to ensure a constant concentration of the tracer at the location where the sampling is done or where the probe is located. On the other hand there are methods where an exactly known mass of tracer is dissolved at once in the river. This method with an instantaneous injection of the tracer is called integration method.
The constant injection method is operationally used by the SNHS with fluorescein sodium as fluorescent dye, which is injected with a Boyle-Mariotte bottle (Fig. 3) into the river. The injection rate of the fluorescein sodium may be varied between 0.0035 and 0.0184 l/s in order to be capable of measure a wide range of discharge rates. Downstream of the injection location samples of the discharge water are collected. From each side of the torrent or the mountainous river 7 samples are taken at a chosen interval. This procedure ensures the control of a homogeneous dissolution of the fluorescent dye over the whole width of the river (by comparing the tracer concentration of the right and the left bank) as well as over time (constant tracer concentration of successive samples).

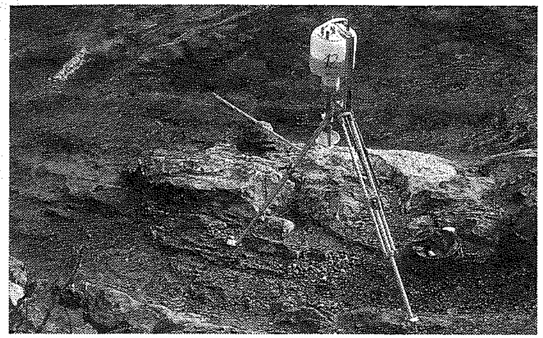

Figure 3: Constant injection of tracer with the Boyle-Mariotte bottle.

As instantaneous injection method two different tracers are used by the SNHS. First the injection of salt (NaCl) and the corresponding measurement of the electric conductivity (μS/cm) of the water in the stream. To record and integrate the electrical conductivity a conductivity meter may be attached to a portable PC, and a software programme called "Salz" records all data and calculates the corresponding discharge (SNHS measuring box). Alternatively the instrument "Salinomadd" is used to conduct instantaneous injection measurements with salt. The "Salinomadd" device records the conductivity of the water in the stream and provides the rate of flow in litres per second at the end of the operation. Figure 4 shows the SNHS measuring box and the "Salinomadd"-equipment used for the measurement of the electric conductivity.

Figure 4: Equipments for the measurement of the conductivity.

The other instantaneous injection method uses fluorescein sodium as tracer and the corresponding in-situ measurement of the fluorescent of the water in torrents or mountainous rivers. The fluorescence of the water in the stream is measured by a Fibre Optic Fluorometer called LLF-M. The LLF-M is a portable, multichannel fluorescence spectrometer with integrated fibre optic probe for online- and in-situ monitoring of fluorescent dyes in the water. Figure 5 shows the injection of fluorescein sodium in the river Worble (left side) and the Fibre Optic Fluorometer LLF-M (right side).

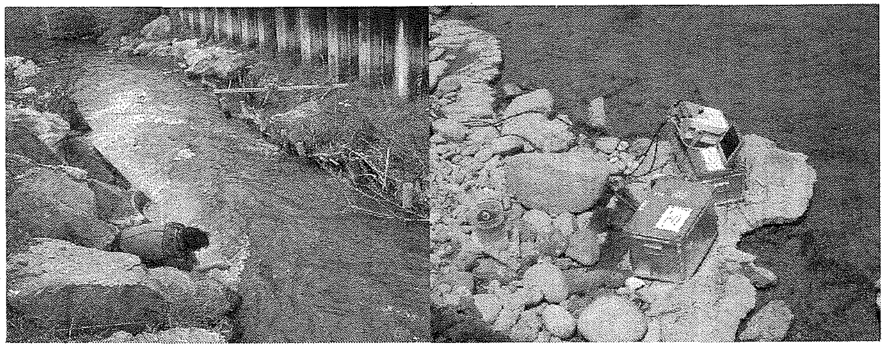

Figure 5: Instantaneous injection of fluorescein sodium (left side) and the Fibre Optic Fluorometer LLF-M with the laptop (right side).

Discharge measurements with ADCP

The operational hydrometric service of SNHS also uses an Acoustic Doppler Current Profiler (ADCP) to measure discharges in deeper rivers, such as the Rhine, the Rhone and the Aare. Figure 6 shows an ADCP measurement at the river Rhone. The broad-band ADCP with a frequency of 1200 kHz is suited to measure streams with a water depth more than 2 m, thus the possibility to use ADCP in Swiss rivers is limited. The use of the ADCP is especially limited in rivers where a considerable amount of water flow passes near the bank in rather shallow water. In this way the "extrapolated" discharge by means of the estimated discharge near the riverbank and the estimated part of discharge near the water surface may become a considerable part of the total discharge. A new ADCP "Rio Grande ZedHed", which is able to measure even shallow water depths down to 25 cm, was recently tested. The development of such a "shallow water ADCP" could considerably enhance the possibility to measure discharges in Switzerland with ADCP techniques.

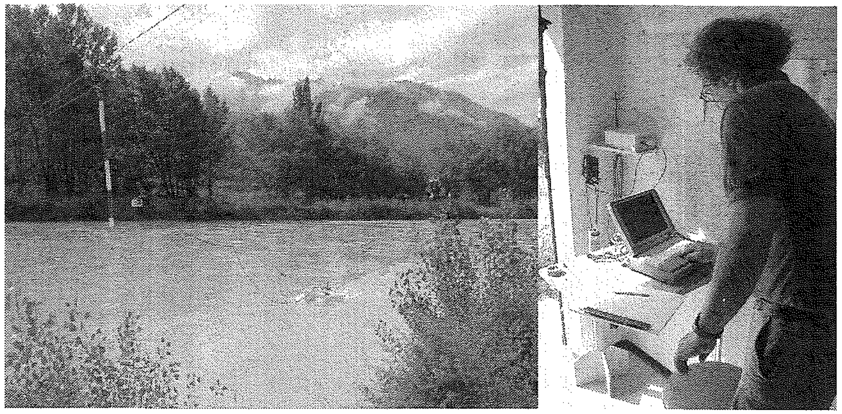

Figure 6: ADCP measurement at the river Rhone.

Applicability of the different discharge measurement methods

Of the above mentioned methods for discharge measurement, each is suited best to measure a certain type of discharge by means of water depth, water velocity, width of the river, amount of discharge and turbulence of water flow. Figure 7 shows, among others, the mentioned discharge measuring methods and their applicability by means of water depth and ranges of discharge.

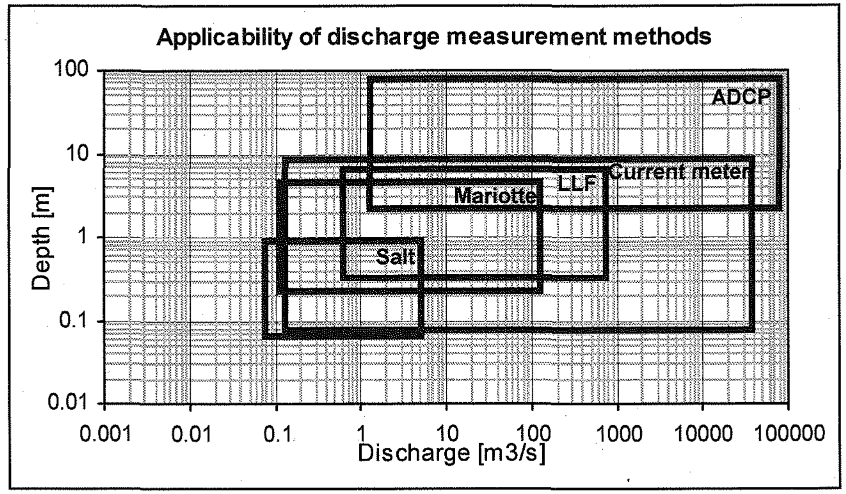

Figure 7: Discharge measurement methods for different ranges of water depth and discharge.

The measurement with current meter is obviously a technique, which is applicable to a wide range of water depth as well as discharge. This is one reason why this technique is the most often used method in the SNHS today. The ADCP could become much more important in the future when the limitation of the necessary water depth vanishes by the new development of the "Rio Grande ZedHed".
Comparing the suitability of Salt and LLF-M measurements it becomes obvious that these two instantaneous injection methods are complementary by means of their applicability in different ranges of discharges. Thus, both methods are used operationally in SNHS in turbulent water where current meters are not applicable any more, for example in torrents or mountainous rivers.