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Hydraulic Research at the Swiss Federal Institute of Forestry Research

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Summary:

The activity of the Forestry Research Institute in the field of hydraulic research is outlined. The commission and historical development of the Institute, the facilities available to our department, and our collaboration with other institutes are described, as well as the problems on which we are currently working. An example illustrating our activity is given.

Résumé: Recherche sur l'hydraulique à l'Institut fédéral de recherches forestières

L'activité de l'Institut de recherches forestières, dirigée vers le secteur «Hydraulic Research», est brièvement présentée dans ce texte. Le but poursuivi, le développement historique, les moyens dont nous disposons, les problèmes qui nous préoccupent et la coopération avec des tiers y sont décrits. Un exemple illustrant notre activité figure aussi dans ce travail.

Résumé: «Hydraulic Research» an der Eidg. Anstalt für das forstliche Versuchswesen

Die Tätigkeit der Versuchsanstalt wird im Teilbereich «Hydraulic Research» kurz vorgestellt. Erläutert werden Auftrag, historische Entwicklung, zur Verfügung stehende Mittel, Probleme, die uns beschäftigen, und Zusammenarbeit mit Dritten. An einem Beispiel wird die Arbeitsweise dargestellt.

What does a forestry research institute have to do with hydraulic problems? A very understandable question! The fact is that the forest engineer comes into contact with questions of hydrology and hydraulics at many points. Precipitation, surface runoff, gully runoff, seepage flow, soil erosion, gully erosion, soil water balance, drainage systems, and specific aspects of hydraulic engineering are some of the items the forest engineer has to deal with; especially if he works in the mountains. This concern with hydraulic-hydrological processes becomes less surprising when one considers that the mountain forester has to devote some 50% to 80% of his time to constructional problems.

1. Commission and past history

In 1884/85 the Swiss Federal Forest Research Institute (now SFIFR) was commissioned by government decree to study problems of forest maintenance, forest effects, and protection against natural hazards. The Institute took up its task in 1886, with a small staff; today its personnel numbers over 250. After only a few years the Institute's commission was broadened to include questions of control and reclamation in mountain torrent areas, stabilisation of creep and slide slopes, protection from soil erosion, and, more recently, from rockfall. All these problems are studied at the Institute's research department "Protection Works and Hydrology". (Avalanche research is conducted at the Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch/Davos, founded in 1942.) The first gauging stations for the study of water balance, flood flow, and sediment transport were installed in the Sperbelgraben and the Rappengraben in the Emmental in 1902. The results from those studies achieved worldwide recognition.

2. Facilities

At present the Department "Protection Works and Hydrology" comprises 11 graduates (civil engineers, reclamation engineers, forest engineers, and biologists), 6 trained technicians, and a number of assistant staff varying according to need. In addition we have access to the infrastructural elements of the SFIFR: remote sensing and photogrammetry; the computer science and mathematics advisory section; a very extensive library with a comprehensive catalogue; the central chemical analytical laboratory; the efficient photographic service; various workshops; and a well-endowed fleet of vehicles.

From the middle of this year we shall have at our disposal laboratories including a small hall for diverse experiments and laboratories for studies on soil mechanics and soil physics, analyses in water chemistry, and hydrological measurements.

The majority of our investigations are conducted in the field (in situ). Soon it will be possible to supplement them with laboratory trials. Our department owns also 3 up-to-date gauging stations in small catchment areas; 3 which it shares with other institutions; and a number of non-permanent ones.

3. Collaboration with other institutes

Our department works in close collaboration with practical foresters in Switzerland. They commission various studies and provide important impulses for research. We also collaborate closely with various university institutes both at home and abroad, in particular with the Hydraulic Research Station and the Institute of Foundation Engineering and Soil Mechanics at the FIT Zurich. Close contact is maintained with federal departments, including the Federal Office for Forestry and Landscape Protection, the Federal Office for Water Economy, the National Hydrological and Geological Survey and the Federal Directorate of Land Survey. Equally close contacts are maintained with the corresponding cantonal authorities.

4. Problems on which we are working

In the field of hydraulics/hydrology, besides the numerous elements necessary for analysing natural processes, we are currently studying the following topics:

Figure 1. Erlentobel gauging station, Alptal (upstream views): upper gauging station, chute, debris storage basin, lower gauging station for discharge containing no bed load.

Figure 1. Station de jaugeage Erlentobel, à l'Alptal (sur l'image, de haut en bas): station de jaugeage supérieure, goulotte de déversement, bassin récepteur de sédiments, station de jaugeage inférieure destinée à «l'écoulement d'eau pure» dépourvue d'alluvions.

Bild 1. Abflussmessstation Erlentobel im Alptal (im Bild von oben nach unten): obere Messstation, Schussrinne, Geschiebeauffangbecken, untere Abflussmessstation für den geschiebelosen «Reinwasserabfluss».

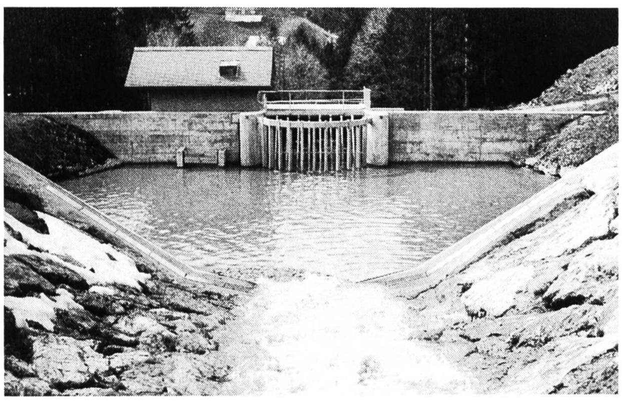


Figure 2. Erlentobel gauging station: measuring sill with nine built-in hydrophonic sensors to determine beginning and end of sediment transport, and to estimate thickness of sediment bearing layer.

Figure 2. Station de jaugeage Erlentobel: seuil de mesure équipé de neuf émetteurs hydrophones afin de déterminer le début et la fin du transport de sédiments et d'estimer «l'épaisseur» des sédiments contenus dans la couche aquifère.

Bild 2. Abflussmessstation Erlentobel: Messschwelle mit neun eingebauten Hydrophongebern zur Bestimmung von Beginn und Ende des Geschiebetransportes und der ungefähren «Mächtigkeit» der geschiebeführenden Schicht.

- flood discharge in mountain torrents during extreme events
- precipitation runoff processes in small catchment areas
- water balance on "small sites" and in catchment areas
- sediment transport problems in mountain torrents and their tributaries (sediment discharge, sediment load, sediment transport capacity, and debris flows)
- hydraulics of mountain torrents (special problems)
- hydraulics of drainage systems
- protective effects of the forest (currently of great importance in mountain torrent areas because of extensive forest damage)
- constructions and designs for mountain torrents and their catchment areas; check dams, bank stabilisation, gully control, protection against soil erosion, biotechnical engineering, drainage of landslides.

Only in exceptional cases do we conduct hydraulic research in the sense of basic research and hydraulic model tests; in those fields we depend on assistance from university institutes. Our work is rather concentrated on applied research. We also seek to process "abstract" scientific findings in such a way that they can more easily be applied in practice.

Example: Sediment transport in small mountain torrents

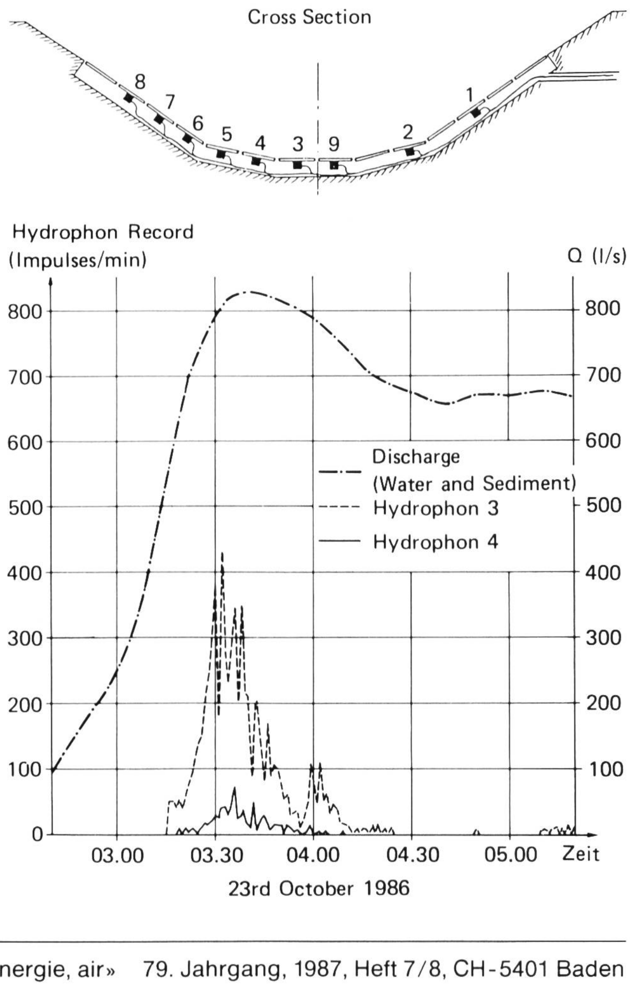
Knowlegde of sediment transport conditions during extreme events is a decisive fundamental in mountain torrent control. As the sediment transport equation of *Meyer-Peter/Müller* commonly used in Switzerland cannot be applied to mountain torrents with a gradient of $J > 5\%$, we use a new equation [1] for sediment transport capacity in steep gradients ($J \leq 20\%$) provided by the Federal Institute of Hydraulic Research, Hydrology and Glaciology. It is based on laboratory tests and theoretical considerations.

We are currently testing its applicability and validity. Among the aids available for this study is our newly installed gauging station in the Alptal (figure 1), which allows fairly accurate measurement of clear water runoff and sediment load during flood events. Acoustic measuring devices ("hydrophones") allow determination of the beginning and end of sediment transport and also – though only roughly – of the depth of the "sediment-bearing layer" (figures 2 and 3). That in turn permits an estimation of the sediment transport hydrograph during high flow. Calculations of sediment transport capacity (after *Smart/Jäggi*) [1] have, in comparison with actual measurements, generally given figures

Figure 3. Hydrophon readings (sound level) synchronised with plain water discharge during minor flood. Please note that sediment transport ends at a flow rate considerably higher than the rate prevailing at the beginning of sediment transport (ca 450 l/s). Hydrophonic sensors no 1, 2, 5 and 8 did not record, which means, sediment transport took place near the channel bottom only.

Figure 3. Lecteur hydrophone (niveau sonore) synchronisé avec «l'écoulement d'eau pure» au cours du passage d'une petite crue. On remarquera que le débit d'eau est considérablement plus élevé (env. 450 l/s) en début de transport des sédiments qu'à la fin de celui-ci. Les émetteurs hydrophones nos 1, 2, 5 et 8 n'ont rien transmis, ce qui signifie que le transport de sédiments n'a lieu qu'aux endroits les plus profonds du radier.

Bild 3. Hydrophon-Aufzeichnungen (Geräuschpegel) kombiniert mit dem «Reinwasserabfluss» während des Durchganges eines kleinen Hochwassers. Man beachte das Ende des Geschiebetransportes bei einer Wasserführung, die weit über derjenigen bei Geschiebetransportbeginn (zirka 450 l/s) liegt. Die Hydrophongeber Nr. 1, 2, 5 und 8 haben nicht angezeigt, das heisst der Geschiebestransport fand nur an der tiefsten Stelle der Sohle statt.



which are too high, for instance for the flood of August, 1984 (ca. 100-year flood flow event). We presume that as long as loose sediment is available on the torrent bed, the calculated values equal the actual conditions, but that as soon as channel bed scouring starts, that is, as soon as the soil characteristics of the underlying material come into play, the volume of transported sediment may decrease considerably, depending on the soil mechanical properties (shear strength etc). In this particular case the torrent lies in flysch and its bed consists of a mixture of clay-sized to gravel-sized particles, that is, cohesive material. The discrepancy between the calculated and the measured values shows that the *erosion processes* in cohesive and non-cohesive material in steep gullies should be studied as soon as possible. In order to perform the relevant calculations we are currently developing methods permitting representative definitions of the following flood runoff parameters: channel gradient, channel cross section, channel roughness, and irregularities, grain size distribution of gully material and transported sediment, etc. Another aspect concerns the nonsteady flow of the flood flow (incl. sediment), a flow which we so far have assumed to be quasi steady.

This problem regarding sediment transport is a typical example of our diverse activities. Especially at present we are continually being confronted with new problems, and the focal points of our research are shifting accordingly. Above all, the rapid increase in forest damage is stimulating, even forcing us, to work more and more intensively as time progresses. In that respect we are facing a most uncertain future.

[1] *G. M. Smart* and *M. N. R. Jaeggi* (1983): "Sediment transport on steep slopes". Mitteilung der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich, Nr. 64.

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Hydraulic machinery model testing

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1. Introduction

The use of model tests is of considerable importance in the context of hydraulic machines. In fact, flows are so complex that it is still impossible to do a complete calculation taking into account the viscous effects. Because of this, the final configuration of a hydraulic machine is always defined using the results of model tests.

We shall also see later that it is very difficult to perform a field acceptance test, and that in many cases the most accurate and most economical method is to do acceptance tests on a model. This technique also has the great advantage that it can be employed before the prototype is manufactured.

Model tests are also very important to verify the results of flow calculations specially with three-dimensional flow analysis programs.

2. Description of the IMHEF installations

The Hydraulic Machines and Fluid Mechanics Institute (IMHEF) of the Swiss Federal Institute of Technology, Lausanne, has an extensive installation for model testing of hydraulic machines and it can be used for all types of reaction machines, i.e. [1], [2].

Table 1. Main characteristics

Head	H	= 2 m to 100 m
Discharge	$Q_{max.}$	= 1,3 m
Dynamometer power	P_D	= 300 kW
Pump power	P_P	= 900 kW
Speed	$N_{max.}$	= 2500 RPM

- Francis *(figure 1),* Kaplan and bulb turbines
- radial, diagonal and axial pumps and pump-turbines.

The installation has two test platforms which are used alternately. This feature permits installation of a model on one test platform when the other one is in operation. The time available for testing is accordingly larger. The hydraulic energy (head) is supplied to the models by a single 3-stage diagonal pump: its particular feature is that both closed-circuit and open-circuit machine tests can be done with a large 1000 m³ tank. *Figure 2* shows a perspective view of the circuit.

The main characteristics are given in *table 1.*

To calculate the efficiency of a machine, which is the most important guaranteed factor, the head, flow, torque and speed of rotation must be measured. Of these four, flow and torque are particularly difficult to measure.

The IMHEF installation comprises two series transducers for flow measurement, i.e. an electromagnetic flowmeter and an ultrasonic flowmeter. These two instruments are calibrated on the spot using a high-precision volumetric tank.

For vertical axis machines, torque is measured using a hydrostatic pivot and strain gauge load cells. The friction torque of the bearings and seals of the model is also measured. The accuracy obtained is better than $\Delta T / T = 0.1\,\%$.

IMHEF has two torque measurement techniques for horizontal axis machines (bulb turbines):

- using a generator cradle-mounted inside the bulb (Neyrtec system);
- using a right-angle gearbox cradle-mounted (Aströ system).

The two systems have their advantages and disadvantages. The maximum power of the Neyrtec system is about 30 kW while that of the Aströ system is 150 kW.

With the Neyrtec system strict geometric similitude can be obtained, while the Aströ system has a bearing under the bulb.

The measurement of cavitation phenomena and pressure fluctuations requires a number of additional measurement systems to establish, for example, dissolved oxygen and nuclei content, and instruments such as quartz pressure gauge, strain gauge torquemeter, FFT signal analysis system, etc.

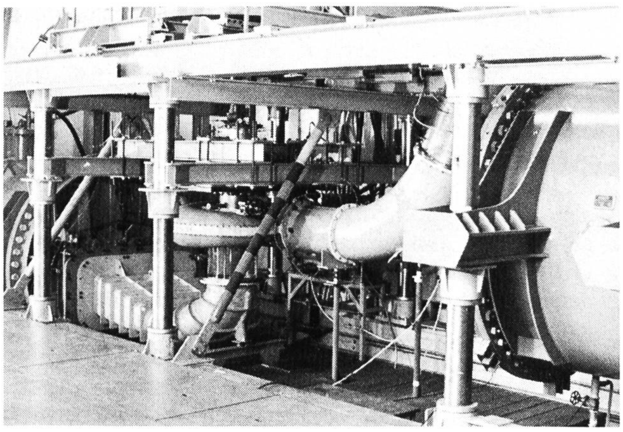

Figure 1. Model of Itaipu (Brazil) Francis turbine (outlet diameter 400 mm) during acceptance tests at IMHEF.