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type of results obtained with the model. Under these conditions, the results of a model test transposed to the prototype will very often be considerably more accurate than a field test on a prototype.
Other tests such as those for cavitation, runaway, mechanical efforts are also very accurate and, in spite of the transposition difficulties, the results of these tests are also very reliable.
It is clear that all these tests require a rigorous geometric similitude. Special attention must therefore be paid to checking the dimensions of the model and the prototype to ensure homology.

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EAWAG

Swiss Federal Institute for Water Resources and Water Pollution Control

Eidg. Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz

Institut fédéral pour l'aménagement, l'épuration et la protection des eaux

The EAWAG, founded in 1936, is Switzerland's principal institute of water protection research (figure 1). *Associated with the Swiss Federal Institutes of Technology it has a status similar to a university institute. The mandate comprises the research, teaching and consulting in the field of water resources, water pollution control and waste management. The advisory services are provided to the government, to communities and to industry. The EAWAG has no regulatory functions.*
Some 170 staff collaborate in the several departments of EAWAG. Approximately half are academically qualified chemists, biologists, physicists, geologists, computer scientists, and civil, environmental, chemical and mechanical engineers. Additionally, there are 20 to 30 doctoral students and several visiting scientists. Some 80 percent of the finances stem from governmental funding and 10 percent each from research foundations and contractual work.

Objectives

The main role of the EAWAG is to act as an interface between science and the implementation of environmental protection. Its primary objective is to serve as a research and educational centre for developing improved concepts for environmental protection, water resources and waste management. In doing so, EAWAG is oriented by the objectives of the Federal laws on water protection and on environmental protection.
Establishing effective environmental protection policies demands a comprehensive understanding of natural processes and ecological relationships. Thus, primary research areas concern
- the physical, chemical and biological processes that occur in both natural systems and engineered systems for waste, water and sewage treatment and
- the material cycles connecting water, soil and air which are increasingly influenced by man.

EAWAG maintains extensive contacts to foreign research institutes and its own research activities are strongly motivated by the findings of international basic research.

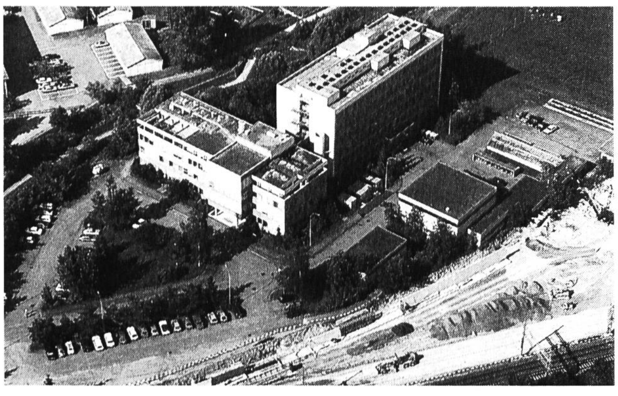


Figure 1. Main facilities of EAWAG in Dübendorf.
Bild 1. EAWAG-Hauptgebäude in Dübendorf.
Figure 1. Vue générale des bâtiments de l'EAWAG.
(Foto: Militärflugdienst Dübendorf)

Thereby, a special characteristic of EAWAG may be seen in the cooperation of several scientific and engineering disciplines and the experience EAWAG has gained in multidisciplinary projects. Furthermore, it is also involved in problems of water distribution and the hygienic disposal of solid and liquid wastes in developing countries.

Research areas

Due to the interdisciplinary character of EAWAG, its research activities cover a wide range from aquatic ecology, limnology and environmental chemistry to urban hydrology, planning, process engineering, solid wastes and anthropogenic influences on material fluxes. The wide spectrum of areas involved in any particular research activity is seen in the following selection of research programs and projects, which directly or indirectly relate to hydrology:

1. Aquatic ecology and limnology

Aquatic ecology deals with the interactions of organisms with their biotic and abiotic environment, as determined by physical, chemical and biological processes in rivers, lakes and groundwater. It includes the analysis of the effects of physical and chemical stresses on organisms and communities.

With regard to *river ecosystems* the prime objective at the limnology department of EAWAG is to further increase the knowledge and understanding of the structure and function of benthic communities. Field investigations are mainly carried out in the river Thur, one of the few still largely natural streams of the Swiss Pre-Alps. The main physiographical parameters (e.g. hydrology, channel morphology, temperature) are of central importance for the animals and plants which form the benthic biocoenosis. Among these parameters hydrology plays a special role because it is widely affected by hydroelectric power production, which often reduces the ecological state of the streams. The same is true if streams are flow-regulated or straightened to decrease the danger of flooding. Two dissertations dealing with these problems will soon be started. One will investigate the effect of a significantly (unnaturally) altered discharge regime (by power production) on the biology of the stream, whereas the other one will look at the ecological damages caused by man-made alterations of the channel morphology. In addition, an interdisciplinary group has recently started work on the effect of reduced discharge on the ecological quality of streams and rivers (see section 1.7).

Research in physical limnology at EAWAG started with mainly empirical investigations on the transport in *lakes* of heat, chemical and biological components as well as on the physical aspects of lake restoration. The interest focused on the study of transport phenomena on the hypolimnion of deep lakes and at the sediment-water interface. In the future, physicists – as well as those in other scientific fields at EAWAG – will also have to deal with questions of environmental science in general. Future research will be more broadly based, reflecting the awareness that our impact is not limited each time to only one compartment, such as the hydrosphere, atmosphere, lithosphere or ecosphere.

Several groups within the EAWAG are involved with analysis of inorganic and organic compounds in *groundwater;* from the point of view of hydraulic research, the Geology and Radiology Sections are pursuing two main directions: The effect of sedimentary structures on the dispersal of contaminants and isotope hydrology of mixing zones.

Outlines of selected research projects:

1.1 Vertical mixing in lakes

At the early stage of the development of eutrophication models it became clear that – at least in the deep lakes which are typical for Switzerland – understanding of hypolimnic oxygen concentrations and internal nutrient loading (the remobilization of nutrients such as phosphorus from the sediments and subsequent migration through the thermocline into the surface waters) would not be possible without some quantitative knowledge of vertical (or rather diapycnical) mixing. Computation of vertical eddy diffusion coefficients began by using the vertical distribution of radon-222, a naturally occuring radionuclide (half-life 3.8 days) diffusing from the sediments into the lake water. Later, other natural isotopes were also employed such as tritium or the ratio of the stable isotopes helium-3 and helium-4. (The later measurements were only possible due to the co-operation with the Institute of Environmental Physics of the University at Heidelberg, FRG.) Yet, with the availability of high-precision temperature sensors the temporal evolution of the vertical temperature distribution became the standard method for the calculation of vertical eddy diffusivity [1].

In the future, the focus of the research will be more on the *understanding of processes,* that is on the direct measurement of turbulent currents. This opens a new field with respect to both instrumentation and theory (see section 1.3).

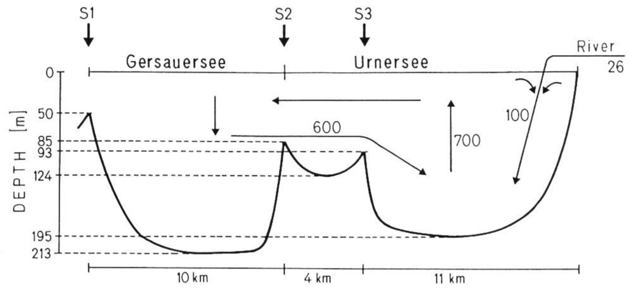
1.2 River-driven and density-driven mixing in lakes

The temperature data collected within the framework of the investigations described in section 1.1 have demonstrated that water exchange in the hypolimnion, especially in the deepest layers of a lake, can often not be explained in terms of a simple one-dimensional diffusion scheme. In some occasions the intrusion of water with distinctly different temperature and chemistry into the deep hypolimnion was observed, leaving layers in the upper hypolimnion unchanged. Such processes are often called "mixing around the edge". Investigations in Urnersee, the southern fjord-like basin of Lake Lucerne, allowed to quantify the different mechanisms responsible for the renewal of hypolimnic water [2]. *Figure 2* gives a summary of the major processes: While wind-induced mixing and mixing by inlets have long been identified as important mechanisms, it came as a surprise that horizontal density currents caused by slight differences in the vertical heat distribution in the two adjacent basins, Urnersee and

Figure 2. Schematic representation of water exchange processes in Urnersee (part of Lake Lucerne).

Bild 2. Schematische Darstellung der Wasserbewegungen im Urnersee (Vierwaldstättersee).

Figure 2. Schéma représentant la circulation des eaux dans l'Urnersee (Lac de Lucerne).



Arrows indicate total water fluxes in 10^6 m^3 in May/June 1986. The river discharge to the hypolimnion increases from 26 to 100 × 10^3 m^3 at 65 m depth by entrainment of lake water. Entrainment continues for those cases in which the plume reaches further down into the hypolimnion. Due to horizontal density gradients a significant amount of water flows from intermediate depths of Gersauersee into the bottom of Urnersee. The intruding waters cause a slow upwelling in Urnersee. S1 to S3 indicate sills separating the different basins. From [2].

Gersauersee, could induce a significant lateral flow into the bottom of Urnersee.

1.3 Measurements of small bottom currents

Physical limnologists are faced with the problem of measuring hypolimnic currents. Unlike in oceans and large lakes, currents in small to medium lakes are usually smaller than 1 to 2 cm/s and thus below the threshold of mechanical current meters. Yet, these currents, in spite of their smallness, probably represent the main source of mixing and transport in the hypolimnion and are therefore of direct ecological relevance. Besides using accoustic current meters (they have higher resolution and practically no threshold but pose the new problem of zero-point stability), new instruments for the detection of small currents have been developed. The pendulum current meter, where the movement of the water is made visible by a floating object with a density slightly different from the water, has been used in several small Swiss lakes [3]. Based on these measurements a direct relation between standing internal waves at the thermocline (so-called internal seiches) and bottom currents was found. At the moment, this instrument is being combined with a video camera and an in-situ microcomputer which will automatically register the position of the floating ball and then store its coordinates as a function of time in a solid-state memory. Furthermore, another instrument is under construction in which the water currents will be determined from the movement of a small artificial dye patch.

1.4 Vertical temperature models and heat exchange at the water surface

The work on vertical temperature models was started in connection with two applied studies, one dealing with the effect of cooling due to heat pumps operating with lake water, the other dealing with the possible effect from the pumpback phase of a pumped storage hydropower scheme operating between the lake and a higher reservoir. Existing models such as the models of the University of Western Australia or of Massachusetts Institute of Technology, MIT, concentrate on the processes occuring at the surface and the upper thermocline. In deep lakes however, the description of vertical mixing below the thermocline is at least as important as the computation of the thermocline depth. The information on vertical eddy diffusitivy described in section 1.1 sets the basis for the development of a new thermocline model which describes vertical eddy diffusivity as function of wind forcing and in-situ density stratification. This model has been combined with a heat flux model which was calibrated against a very large and detailled set of meteorological data collected at the lake surface of two Swiss lakes by instruments mounted on a buoy.

1.5 Internal methods for lake restoration

Since EAWAG has been involved in lake restoration projects for many years, the physical aspects of internal restoration methods such as artificial vertical mixing, aeration or drainage of hypolimnic water have long been of interest [4]. In collaboration with the Institute of Hydrodynamics and Water Research at the ETH in Zurich a project on the dynamics of vertical bubble plumes in a stratified lake was started. Such plumes are used in several Swiss lakes for artificial mixing and for hypolimnic oxygen input.

1.6 Effects of storm events on receiving waters

The understanding of the effect of combined sewer overflows on the water quality of the receiving water should be the main criterion for future renewings and extensions of urban drainage systems. Measurements of the behaviour of several pollutants during a storm event may lead to important conclusions concerning the different behaviour especially of dissolved and particulate compounds [5, 6]. Because of the high expense of such studies, it is useful to use the results also for the calibration of mathematical sewer system models (see section 3.1). Together with river transport and process models (see section 2.2) the effect of water pollution measures on the receiving water may then better be estimated in advance.

1.7 Ecological effects of reduction in stream flow

Water stored in reservoirs in the alpine regions of Switzerland plays an important role in the energy production of the country. As is well known from the literature the resulting reduction of stream flow affects the biocoenosis of the rivers in those areas. The hypotheses are

- that the biocoenoses are directly affected by the geometry and roughness of the river bed, changes of the water regime, and the chemical condition of the river water,
- that the physico-chemical conditions (i.e. the distribution and quality of river habitats) and thus the biocoenosis may be predicted as a function of the changes in the flow conditions.

The goal of the project is to find ecological criteria on which minimum discharge recommendations may be based. Such criteria are derived from the literature and from a field study conducted at a river in the Swiss Midlands and Pre-Alps, respectively, which is affected by water withdrawal. Samples of fish, macro-invertebrates and microbenthos are taken from both above and below the withdrawal sites and are examined in connection with those parameters, which are expected to be affected by the above stated hypotheses.

1.8 Prediction of contaminant dispersal in inhomogeneous aquifers

Fluvio-glacial sediments form the most important aquifers of the Swiss Midlands. Outcrops of these deposits in gravel pits display a complex pattern of sedimentary structures in different scales. The porosity within individual structures is highly variable. Parallel bedded and cross stratified layers lead to local anisotropy. These directionally controlled hydraulic parameters are not of major concern in the search of water supplies, but become critical when predictions of contaminant dispersal are needed. A minor portion of the sediment sequence comprises sand-free gravel stringers or beds. The permeability of these thin zones is several orders of magnitude higher than the host sediment. The degree of

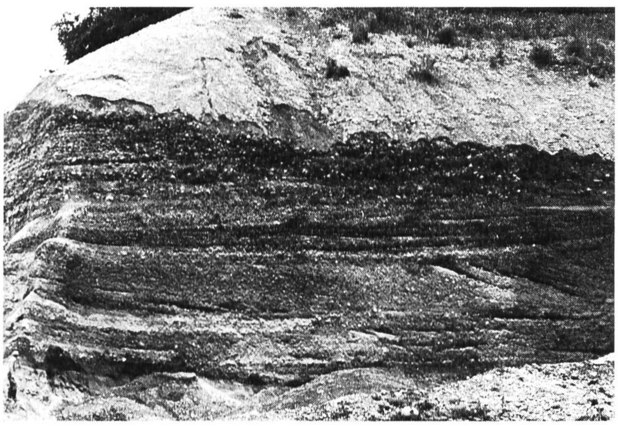


Figure 3. Sedimentary structures within fluvio-glacial gravel deposits of the Northern Swiss Midlands (Pit Hüntwangen, Profile E-W).

Bild 3. Sedimentstrukturen in fluvio-glazialen Schotterablagerungen (Kiesgrube Hüntwangen, Profil E-W).

Figure 3. Structures sédimentaires dans des alluvions fluvio-glaciales en Suisse de Nord (Hüntwangen, coupe Est-Ouest). Foto: *P. Huggenberger*

networking of these zones determines the most rapid transport path. The goal is to integrate the field observations with numerical modelling in order to show the significance of sediment structures in contaminant propagation. *Figure 3* shows a field example of the sedimentary structures from a braided glacio-fluvial system typical of the northern Swiss Midlands. The outcrop is idealized into a matrix of permeability and anisotropy. Simulation experiments show how flow is greater in the sorted gravel stringers and slowed by sand lenses. Up to three orders of magnitude differences are common. Model predictions of the local behaviour of contaminant plumes are highly dependent on structural and facies interpretations of such glacio-fluvial gravel deposits. Such integrated research on groundwater modelling, with the aim to add chemical behaviour equations, is the object of an ongoing interdisciplinary project with the Institute of Hydromechanics and Water Research at the ETH in Zurich.

2. Environmental chemistry

Environmental chemistry deals with specific chemical analyses and chemical dynamics of pollutants in aquatic systems and in the atmosphere, and with material exchange between water, soil and air. The assessment of potential toxicological and ecological effects of pollutants in the environment necessitates an understanding of qualitative and quantitative relationships between sources, transfer into air, water and soil, transformation and potential for bioaccumulation in the food chain, residence time, and ultimate distribution of pollutants in the ecosystems.

The development of the biocoenosis in an aquatic ecosystem is primarily and causally determined by intensity factors such as concentrations or activities of chemical compounds, temperature, velocity gradients, productivity, light and redox intensity. At EAWAG the effect of these factors on the biocoenosis and water condition is analyzed by a combined experimental and modelling approach:

- Effective values of the intensity factors are determined analytically at representative sites of the river ecosystem. For many chemicals this requires that additional analytical methods have to be developed.
- Expected values of intensity factors are estimated by simulations based on mathematical models as described below. This requires that for each chemical under consideration the strength of the sources and the rates of the various processes by which it is transformed or eliminated are to be determined. For organic compounds these processes usually are biological degradation, hydrolysis, photolysis, chemical oxidation, and incorporation into biota and suspended solids. For heavy metals the dominant processes are adsorption on biota, on suspended particles or on sediments.

Outlines of research projects by which the fate and distribution of chemicals in the environment are analyzed or predicted:

2.1 Modelling of spatial and temporal dynamics of chemical compounds in lakes

Simple mass balance models for chemical or biological species were originally developed in order to predict the response of lakes to different eutrophication control measures. Later, the models were refined by introduction of the vertical axis as a continuous coordinate, so that the description of vertically structured components became feasible. At the moment, a program with a set of hierarchical models for the description of anthropogenic organic compounds such as organic solvents, detergent components or pesticides is developed [7]. The aim is to provide the lake manager with a tool for assessing the possible impact of anthropogenic compounds in lakes and to interprete data with respect to origin and reactivity of the measured compounds. This work is supported by the Swiss Environmental Protection Agency and the European Community within the COST (Coopération scientifique et technique) program 641.

2.2 Simulation of transport and transformation processes in river ecosystems

To quantify processes and to simulate complex interactions in river ecosystems, a mathematical model has been developed. Since the dominant processes depend on the specific substances or organisms which are investigated, various process models are necessary. The common part of all these models is the simulation of the hydraulic discharge of the river and of the transport by advection and dispersion in the river. The hydraulic calculation may describe a steady state situation, characteristic for dry weather, or it may include the simulation of the propagation of a flood wave caused by an intense storm event [6]. For the transport calculations an estimation of the mixing processes is crucial. In a zone near the inflow, mixing over depth and width is important. Further downstream longitudinal dispersion of transversally mixed concentration distributions becomes the most important mixing process in case of varying input sources. It can be shown that besides the usual approach to longitudinal dispersion with a one-dimensional advection-dispersion equation, exchange processes with stagnant zones of water may also be of importance [8]. It is planned to extend the present model to calculate deposition and resuspension processes of particles in order to estimate sediment transport rates and concentrations of suspended solids. Consideration of chemical and biological processes allows the use of the models for chemodynamical investigations. Figure 4 shows an example of such a calculation.

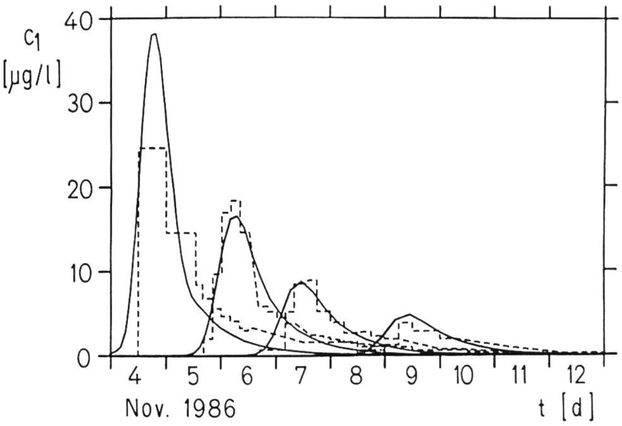


Figure 4. Time series of concentrations of an insecticide accidentally spilled into the Rhine river.

Bild 4. Konzentrationszeitreihe eines bei einem Unfall in den Rhein gelangten Insektizids.

Figure 4. Représentation des concentrations en fonction du temps d'un insecticide répandu accidentellement dans le Rhin.

The dashedlines, which represent concentrations measured by the German authorities at four sites in the Rhine, are compared with a calculation considering advective transport, lognitudinal dispersion, dilution and biological degradation [8].

2.3 Isotope hydrology

A recent industrial accident released 500 Ci of tritium into the Glatt river system. The amounts did not pose a threat to communal health. The accident provided as a useful side-effect, a largescale experiment for tracing the rate and amount of infiltration of river water into groundwater [9, 10]. It has been possible to follow the ^3H plume in groundwater

for over 2 years and up to 30 km from the input source. A few wells showed effects of "short-circuit" routing. Knowing the input amount has also provided a quantitative estimate of infiltration and mixing on a grand scale. Predictions of tritium residence time and concentrations based on Darcy's law and measured hydraulic conductivities generally differed from those observed by an order of magnitude; arrival times in the drinking water wells however, were closely approximated by stochastic models. The development of these models benefited from the experimental set-up and tritium data from the test field of EAWAG near the infiltrating river. Future research will now also follow the input of Tschernobyl radionuclides into the groundwater system.
As a newer approach to determine mixing of surface and groundwaters, or the exchange of groundwaters and lake waters, stable isotopes of hydrogen, oxygen and carbon are used in experiments. In mountainous areas of the temperate zone, oxygen and hydrogen isotopes are shown to be dominantly controlled by the altitude of precipitation. Once out of the evaporation cycle and into groundwater, the signals of $\delta^{18}O$ and δ H/D provide a sensitive and mostly conservative tracer of point sources and mixing. Carbon isotopes have been little studied in groundwaters but are closely linked to the biological cycle. $\delta^{13}C$ can be a useful indicator of biodegradation of organic compounds from surface sources and thus pollution. It can also help to show the interaction of groundwater with the solid matrix of the aquifer. Where instrumentation is available, stable isotope measurements are quick and very reliable. The industrial quarter of Zurich City provides a testing ground for the first phase with a network of over 30 wells. Limmat river water with the isotopic values of the large reservoir of Lake Zurich infiltrates and mixes with a local groundwater and a tributary stream showing seasonal variations. Initial results confirm the value of $\delta^{18}O$ as the most conservative natural tracer and characterizes each of the three sources.

3. Urban hydrology

Traditionally, the Engineering Department of the EAWAG has a strong influence upon the progress in the urban drainage techniques in Switzerland. The evaluation of rainfall data for the design of sewers Intensity-Duration-Frequency curves for different places in Switzerland [11] , the design procedure for the combined sewer overflow and storage structure [12], and textbooks for urban drainage design and performance [13, 14] are only some examples of past activity of the EAWAG in this area.

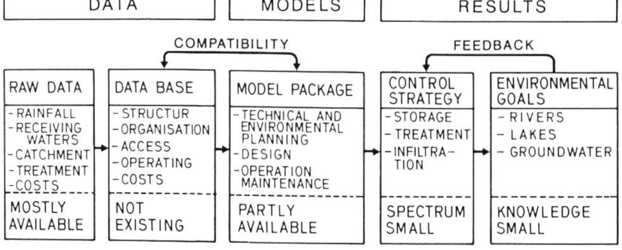


Figure 5. Interaction of different aspects of modeling design and operation of urban drainage systems.

Bild 5. Schema der möglichen Anwendung siedlungshydrologischer Modelle in der Schweiz.

Figure 5. Schéma d'interaction entre les différents modèles traitant des opérations d'écoulement des eaux urbaines.

Among the experimental investigations conducted in the seventies are quantitative and qualitative descriptions of urban surface runoff, of highway surface runoff and of combined sewer discharge during wet weather [15, 16]. Recently, the importance of the water pollution problem during rainfall runoff and the efficiency of different water pollution control measures during wet weather have been studied with the aid of models and with experimental investigations [17].
The research interests dealing with problems in urban hydrology at the Engineering Department are the following:
- Introduction and application of modelling in urban hydrology in Switzerland, especially assessing the possibility of introducing a "Swiss Model Package" for the different planning, design and operational tests in urban drainage and water pollution control *(figure 5).*
- Identification and characterization of the water pollution problems in receiving waters and in groundwater caused by urbanization and by urban drainage.
- To apply additional alternatives for the treatment of combined sewer overflow (e.g. infiltration, real time control, screening, etc.), in addition to the customary storage and clarification in "overflow tanks".
- Suitable rainfall data and methods for the application of these data for many different tasks in urban hydrology are not available yet. This lack of data in suitable form and lack of methods limits the wider application of mathematical modeling by the practical engineers.

As of 1986 projects in urban hydrology became one of the priority research topics at EAWAG. Most of these projects will be conducted by the urban hydrology group of the Engineering Department. One research project which touches all four topics discussed above is the development of a simulation model SASUM for the planning of urban drainage.

3.1 System analysis and simulation with an urban drainage model (SASUM)

The most significant pollution effect in receiving waters caused by drainage networks in Switzerland is the combined sewer overflow. However, it is common practise in Switzerland to develop overflow concepts of drainage systems which hardly consider any pollution effects. With the aid of SASUM it should become possible to optimize the urban drainage system and to choose efficient measures with regard to the pollution problems in receiving waters.
The SASUM is able to simulate the origin, transport and transfer of the pollution load in an urban drainage catchment during rainfall runoff. The simulation allows to identify the contribution of different sources (dry weather flow, surface runoff and scours from deposit in sewers) to the total pollution load and to investigate the efficiency of different water pollution control measures.
SASUM is a simple deterministic model. It is not suitable for the detailed design of sewers and of other structures but it does allow to investigate their efficiency. For this reason the input data of the catchment area and of the drainage networks are much less detailed than the input data for sewer design modelling.
The computer program allows both the fully interactive simulation for the optimization of the drainage system and of its elements as well as a batch calculation for the investigation of rainfall series and of the seasonal or annual pollution amount, frequency distribution, etc. The user-friendly handling and the format of the output (graphics, etc.) should support wide application by practical engineers in Switzerland.

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Strickler formula, a Swiss contribution to hydraulics

A short note on the 100th anniversary of Strickler's birth

Daniel Vischer

Albert Strickler was born in Wädenswil near Zurich on July 25, 1887, and died in Küsnacht near Zurich on February 1, 1963. I have not known him personally; indeed I never met him. But in 1983 I paid a visit to his widow in Küsnacht to get a photo of him *(figure 1)* and to ask a few questions. As a souvenir of him she gave me two things: his logarithmic table and his slide rule, both much used and worn.

Fig. 1. Albert Strickler, 1887–1963.

And then it struck me: A logarithmic table is useful to deal with products and powers; a slide rule is based on logarithm as well and is therefore also a tool to deal with products and powers, but it is normally confined to exponents of 2, 3 and thus ½, ⅓ and ⅔. Therefore, Strickler's formula, which reads

$$v = k R^{2/3} S^{1/2} \qquad \text{(Eq 1)}$$

with

v = mean flow velocity,
k = roughness coefficient (Strickler coefficient),
R = hydraulic radius,
S = slope,

can easily be handled with a slide rule, or what is more, it was probably adapted to the capabilities of a slide rule: *a typical slide rule formula.*

Two or three years later Strickler's widow sent me her only copy of her late husband's booklet "Beiträge zur Frage der Geschwindigkeitsformel und der Rauhigkeitszahlen für Ströme, Kanäle und geschlossene Leitungen" (Contribution to the problem of the flow formula and of roughness coefficients for rivers, channels and conduits), published in 1923 [1].

So I feel indebted to her and in a way bound to write this short note. As an opportunity I gladly choose the coincidence of Strickler's 100th anniversary with the XXII Congress of the International Association of Hydraulic Research (IAHR), held in Lausanne, Switzerland (see also [2]).

Power type formulae versus other formulae

Strickler's booklet comprises 48 pages of text with an important appendix of 14 tables and 39 plates. It is a masterpiece of clear and concise treatise writing. The first chapter consists of an enumeration of the then known flow formulae for turbulent flow. Strickler reproduces 34 of them but states that he could easily add another set of 34 or more. But what is perhaps more important, he arranges these formulae in four classes:

a) power type formulae for open channels
b) other formulae for open channels
c) power type formulae for conduits, and
d) other formulae for conduits.

All the power type formulae can be written in the form

$$v = C R^{a} S^{b} \qquad \text{(Eq 2)}$$

with

C = roughness coefficient
a, b = exponents.

The authors of such formulae, quoted by Strickler, are given in the *tables I and II* together with the exponents they suggest.

In contrast to these formulae the other formulae contain more than only factors with exponents. But it is difficult to generalize them with a simple expression. Thus, we reproduce here as an example another Swiss contribution to the field, namely the formula of *Ganguillet* and *Kutter* for open channel flow. It was published in 1869, that is more than 50 years before Strickler's booklet was published, and reads:

$$v = \frac{23 + \dfrac{1}{n} + \dfrac{0.00155}{s}}{1 + \left(23 + \dfrac{0.00155}{S}\right) \dfrac{n}{R^{1/2}}} \; R^{1/2} \; S^{1/2} \qquad \text{(Eq 3)}$$

with n = degree of roughness.

This somewhat cumbersome expression was very popular in its time. According to [3] the demand for copies of the first