UNESCO - IHP
International Sedimentation Initiative

ISI

Guidelines for Case Studies in Selected River Basins

First Draft
12.4.2005

Introductary Remarks

1) Editors
The draft of the guidelines has been prepared by Prof. M. Gavino, Prof. E. Gölz, Dr. C. Lehmann, Prof. M. Spreafico and Dr. E. van Velzen.

2) Objective of the guidelines
The objective of the guidelines is to define a structure and the contents of the case studies with the aim to allow a sophisticated analysis of methods and procedures used in different regions.

3) Procedure
The version of 12.4.2005 is a first draft. Figures and tables are only introduced as examples. The follow-up is proposed as follows

- Discussion and approval by the Rhine and Bermejo Commission
  April 20
- Discussion and approval by the ISI steering committee, End of April
- Revision of the English text and translation

Introduction

a. International Sedimentation Initiative of UNESCO

The International Sedimentation Initiative (ISI) has been launched by the United Nations Educational, Scientific, and Cultural Organization (UNESCO), as a major activity of the current Sixth Phase (2002-2006) of the International Hydrological Programme (IHP)[1]. In justifying the resolution, the Intergovernmental Council noted that:

i) Erosion and sedimentation processes and management in catchments, river systems and reservoirs are increasingly important in all parts of the world,
ii) Erosion and sedimentation processes have significant socio-economic and environmental impacts in river basin management,
iii) Sediment production processes are not sufficiently understood for practical use, while various sediment transport models are available
iv) Within the next few decades more than 50% of the world's reservoir storage capacity may be lost due to sedimentation, and realizing that appropriate storage sites of water are limited,
v) Sediment management practices should be improved.

What is the mission of ISI?
The International Sedimentation Initiative is expected to add a new dimension to ongoing efforts aiming at sustainable sediment management, in the context of sustainable water resources development at global scale.

Hence, its mission directly relates to the commitments of the international community expressed in major documents such as the Millenium Development Goals, the Rio Declaration of Sustainable Development, the World Water Assessment Programme, World Water Development Reports, etc. By its activity, the International Sedimentation Initiative aims to uphold the importance of sustainable sediment management within the context of the two United Nations decades that will take off in 2005: the "Water for Life Decade" and the "Decade for Education for Sustainable Development".

With direct access to stakeholders represented in the IHP National Committees and the Intergovernmental Council, ISI should be viewed as a vehicle to advance sediment management at the global scale.

What is the vision?
Sediment management is viewed as an important component of sustainable water resources management, and hence of the all-important enterprise of sustainable existence and development of the planet Earth. It seems therefore to be appropriate to include into this review a short message addressed to researchers and professionals dealing with erosion and sedimentation, stakeholders interested in sediment management, decision- and policy makers upon whom the planning and execution of the management depends.

Researchers and professionals should appreciate that each and every case of sediment management is site-specific and requires originality in approach and methodology. The complexity of issues must be looked upon from different angles and addressed through concerted collaboration of natural and social sciences.

Stakeholders should resist to be influenced by lobbies that often act on unfounded impulses based on incomplete information, motivated sometimes by conflicting private interests. They should rather rely on unbiased advice of the scientific and professional community.

[1] Resolution XV-8 of the Intergovernmental Council, Paris, 17-22 June 2002

Decision-makers should mistrust apparently attractive solutions that often result from the oversimplification of complex erosion and sedimentation processes.

Policy makers should respond to the views and wishes of actual stakeholders, but must not forget that the majority of water users have no voice and no vote, simply because they were not born yet. In the view of the inherent imprecision of long-term planning, they should care that sediment management rests adaptive to the inevitable yet vaguely predictable natural and social changes in the future.

What are the objectives?
The *overall objective* of the International Sedimentation Initiative is to promote and interact with activities that will result in:

- Increased awareness of sedimentation and erosion issues;
- Improved and sustainable management of soil and sediment resources;
- Better advice for policy development and implementation.

The *specific objectives* are in short recapitulated below:

1. Global Evaluation of Sediment Transport (GEST-Project). The Project will entail the development of a global repository for data, information and documentation on soil erosion and sediment transport, which can serve as a basis for global assessment of erosion and sedimentation problems and their social and economic implications. The data and information base will be developed in existing competent international institutions, such as the IRTCES in Beijing, China, GEMS-Water in Canada, ISIDE Observatory, in Italy, etc.

2. Initiation of case studies for river basins as demonstration projects: Case studies are seen as efficient means of raising awareness in different regions about erosion and sedimentation problems. They will offer examples of monitoring and data processing techniques, procedures and methodologies for analysis of environmental, economic and social impacts, and evaluation of management practices. It is decided to start with pilot river basins, such as the Nile, Zambezi, Rio Parana, Yellow River, Danube River, Rhine River. Other case studies will be included depending upon the circumstances.

3. Review of erosion and sedimentation related research; Information of ongoing research is an important contribution to the operation of the databases and information systems, bearing in mind the inadequacy of knowledge about various aspects of erosion and sediment phenomena for addressing key sedimentation problems. A substantial role could be assigned to associations such as ICCORES for reservoir sedimentation, as well as to the newly created World Association for Sedimentation and Erosion Research (WASER).

4. Education and capacity building for sustainable sediment management Within the medium term, the accent should be placed on identifying the modes of education at all levels, taking also into account regional priorities and interests in different socio-economic and eco-hydrological settings. The formulation of this task should consider the findings of the GEST Project, and the updated survey of sedimentation related research. In line with its educational commitment, ISI will encourage the involvement of young scientists in its activity.

What is the general strategy of the initiative?
In order to achieve such objectives, the International Hydrological Programme set up a Steering Group, which had several meetings and proposed an action plan that was approved by the Intergovernmental Council of IHP, at its 16th session, on 24 September 2004.
The International Sedimentation Initiative should achieve its goals through stimulating other actors in the field. ISI is open to collaboration with all interested institutions, international, regional, or national associations, in the interest of promoting sound and sustainable sediment management policies. ISI is eager to establish close working contacts with international, regional, and national projects, programmes and networks, such as SedNet, all over the world. In the above sense, the ISI is about to develop its strategy, focusing on those aspects of erosion and sedimentation problems where the UNESCO-executed action would be the most effective, filling in gaps that other organizations could execute less efficiently. Apparently, this would concern in the first place the organization and promotion of international information exchange on sediment related matters, ensuring a most direct access to the policy makers in the member states, as well as motivating and activating the scientific and professional communities in the interested regions and countries.

b. The "GEST" Project

Erosion, transport and sedimentation processes gain increasingly in importance in socio - economical and -ecological respect. Problems on the field of sediment transport occupy different institutions as well as the private enterprise worldwide. In particular, of big interest is the question of the origin of sediment as well as sediment transport processes of big river systems down to deposition processes and delta formation into the sea, including sediment quality aspects as well as social, economical and ecological impacts.
The individual processes are extremely complex. Therefore, each process is usually examined in an isolated manner. Depending on problem formulation, investigation projects and practical studies are carried out in well defined and specific areas or catchments. No actual coordination of activities as well as sufficient information about the relevant results exists on global level. Knowledge of sediment transport is general and theoretic (as result of e. g. laboratory investigations) or very specific (catchment, time – scale or event - related). Hence, results from practical studies are mainly unpublished and therefore not generally available.
To gain more information and to improve general awareness about sediment transport on global scale, the project GEST (Global Evaluation of Sediment Transport) as a program of the ISI has been introduced under the leadership of the UNESCO.

Objectives of the GEST project are:

- Introduce a list of previous global findings on erosion and transport processes. Inclusion of the available data and of investigations.
- Development of methodic and organizational general conditions for the assessment of erosion and transport processes on global level. Analysis of case studies in selected river basins as well as a global risk analysis in connection with sediment processes.
- Definition of the results to be expected within the framework of the IHP -ISI as well as the denomination of the most important key players.

c. Study for the Development of Guidelines of Case Studies in River Basins

The main objective of the study is the elaboration of guidelines for case studies in selected river basins. The respective work contains the following tasks:

- Compilation of essential sediment transport processes which occur from small mountainous catchments all the way down to the sea delta.

- Structuring of a case study for large river basins which aims at statements over erosion, transport – and sedimentation processes.

The tasks are executed by an international work group. Representatives from Holland, Germany, Argentina and Switzerland elaborated the draft guidelines for the preparation of case studies (Rhine basin and Rio Bermejo as examples).

Note:
It is an important goal of the development of guidelines to support the comparability of the individual case studies.

The study was financed by the Swiss Hydrological Survey of the Federal Office for Water and Geology
As an example, the Rhine River and Bermejo River have been selected (see fig. 1).

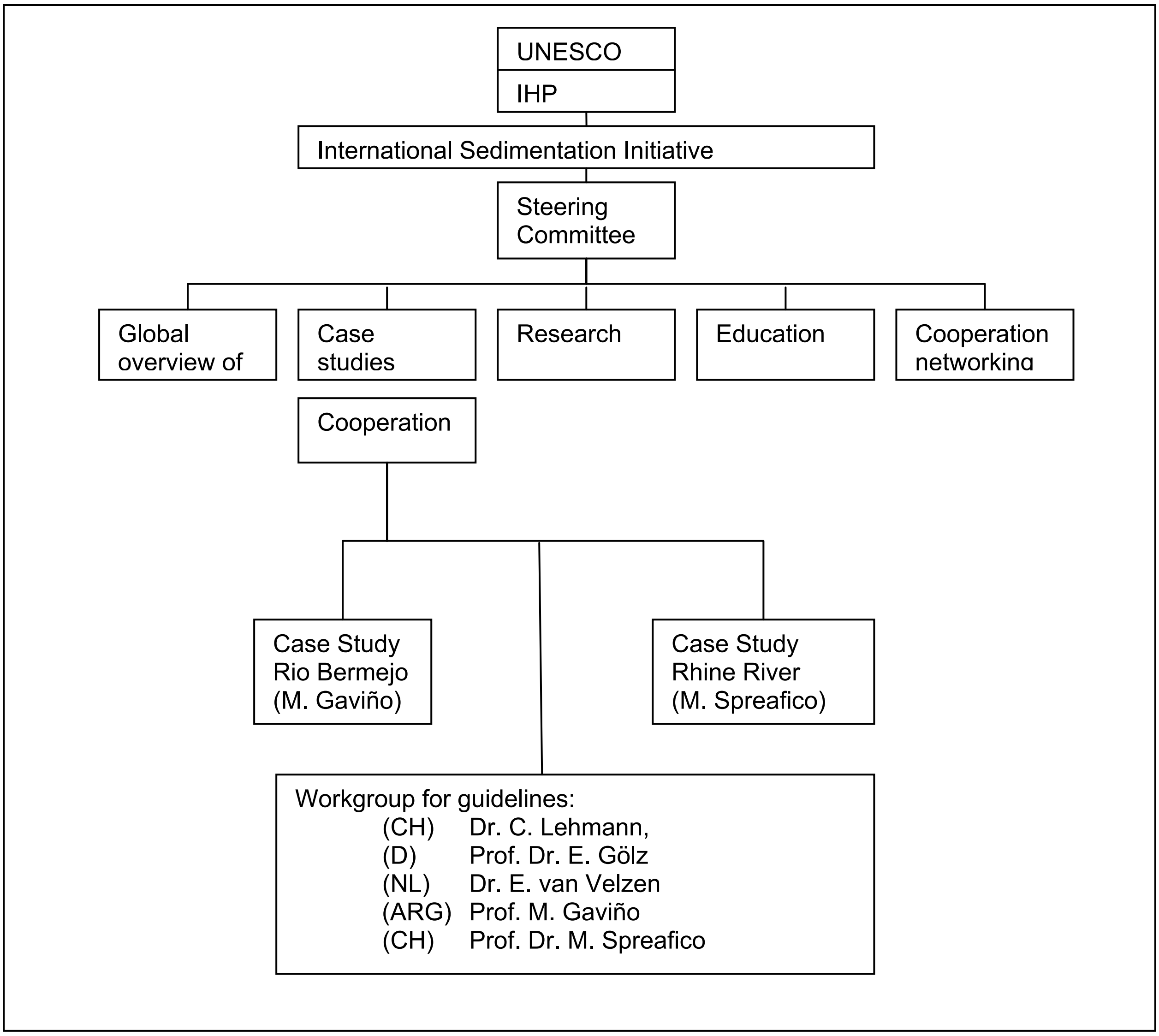

Fig. 1 Organization of the study

The contents of the guidelines includes the following:
All sediment related aspects, as comprehensive as possible, are illuminated: upper, alpine catchment areas, virtually identical with most of the Swiss part of the Rhine basin, catchment areas in the lower mountain range (as mainly found in Germany) as well as the flatlands (Holland). Different elements should be considered, as example:

- Description of catchments, including most relevant sediment related aspects: land use, soils, tectonic and geological aspects, topography, river channels, climatic issues…
- Mention of the most important stakeholders (see fig. 2)
- Identification of sediment sources (point sources, diffuse sources) and their importance to sediment budget
- Where applicable for problems with contaminants: Identification of main sources of contaminants and their effects on waters and environment
- Elaboration of a list with description of most important sediment-related processes (e. g. landslides, debris flows, delta formation, suspended sediment transport…)
- Identification of main pathways to deliver sediments to running waters.
- Presentation of the available documents / studies and findings in the catchment areas.
- Gathering information about available data. However, only data and investigations existing in this stage should be considered, so for example from the following elements:
- Sediment production and –mobilization
- Erosion and transport process in running waters

- Sediment budgets (per event, long-term)
- Sedimentation processes (reservoirs, natural lakes...) and delta formation
- Suspended sediment transport
- Studies about further aspects of sediment management.

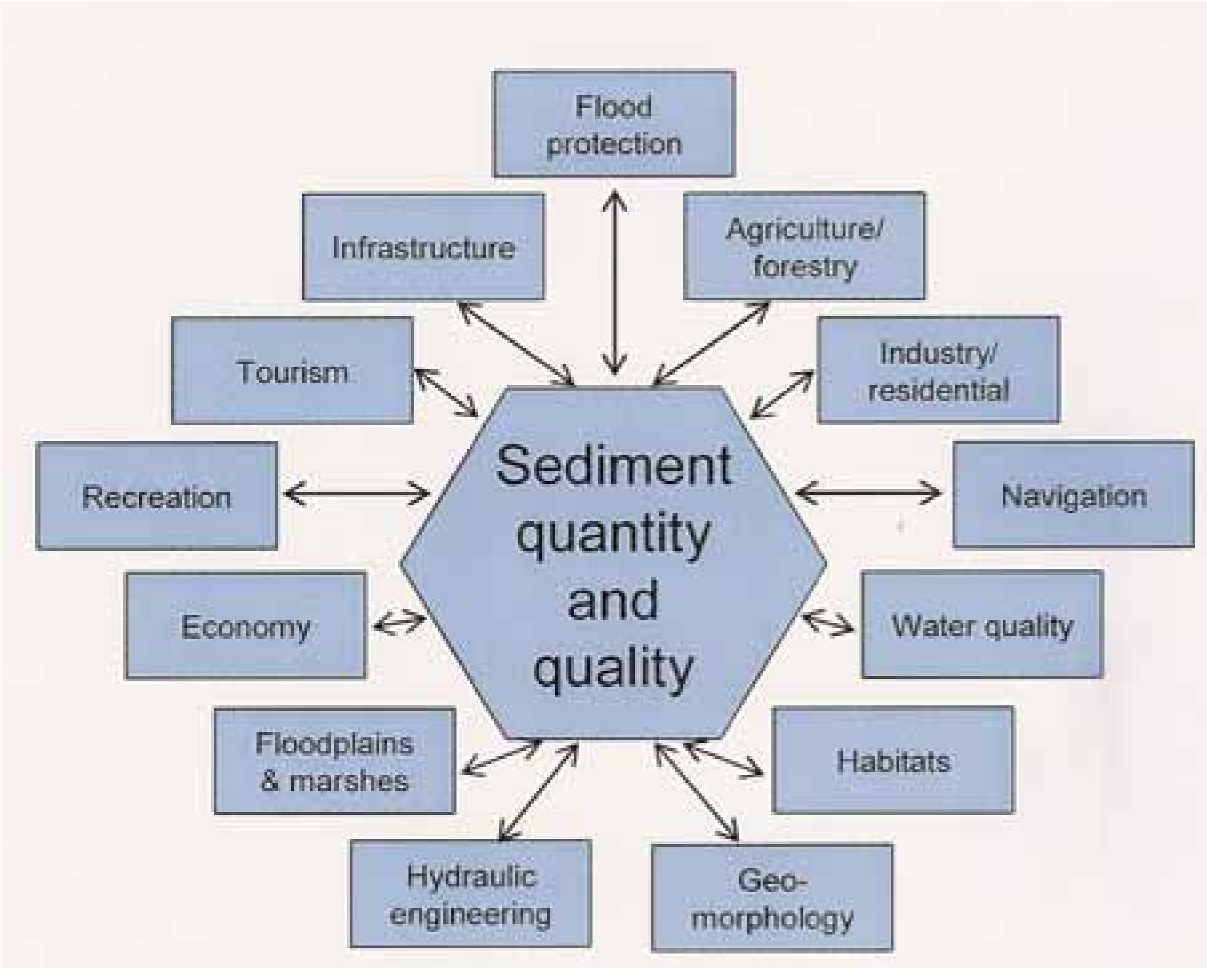

Fig. 2 General users and uses of sediment

Due to existing methodic problems, the global estimates mentioned above are at this time not yet possible in the originally planned sense. Besides the methodic problems, state of the art knowledge does not meet yet the requirements for such global assessments.
Therefore, it appeared reasonable for the time to work out the problems and knowledge by means of case studies. Rhine, Danube, Zambesi river, Nile, Parana und Yangtse rivers were selected as pilot catchments. The main reason for this selection was the fact that notable investigations have already been carried out in parts of these river systems or should be carried out in foreseeable future. The river basins mentioned will therefore serve as a model for further activities. Intentions to compile detailed information about sediment transport consist for example in the Danube river basin (SEDAN project). In the Rhine basin, sediment transport observation has a long time tradition, although the majority of sediment related problems are not yet sufficiently investigated and understood. An overall sediment transport assessment is not available for large river systems. But some comprehensive information exists on some midsize rivers or defined sections of larger rivers.

Close cooperation is planned and already implemented in first steps between the KHR/CHR[2] and the COBINABE[3]. Under the umbrella of the UNESCO, IHP and ISI, professional cooperation should

[2] Internationale Kommission für die Hydrologie des Rheingebietes (KHR). The International Commission for the Hydrology of the Rhine basin (CHR) is an organization in which the scientific institutes of the Rhine riparian states formulate joint hydrological measures for sustainable development of the Rhine basin.

among other things be supported and institutionalized. Further on, the elaboration of comparable case studies, which complement each other professionally and methodically, is planned.

The case studies should occupy a key position within the framework of the ISI. Moreover, case studies should serve as demonstration projects and model for the developing of a higher awareness building of stakeholders concerning sediment-relevant problems. Furthermore, the case studies should support communication as well as cooperation between the groups which work in the river basins. Finally, the case studies will also be used as guidelines for dealing with sediment – oriented problems.

[3] Commision Binacional para el Desarollo de la Alta Cuenca del Rio Bermejo y el Rio Grande de Tarija (in Argentina and Bolivia)

1. Description of the River Basin

1. 1. Overview

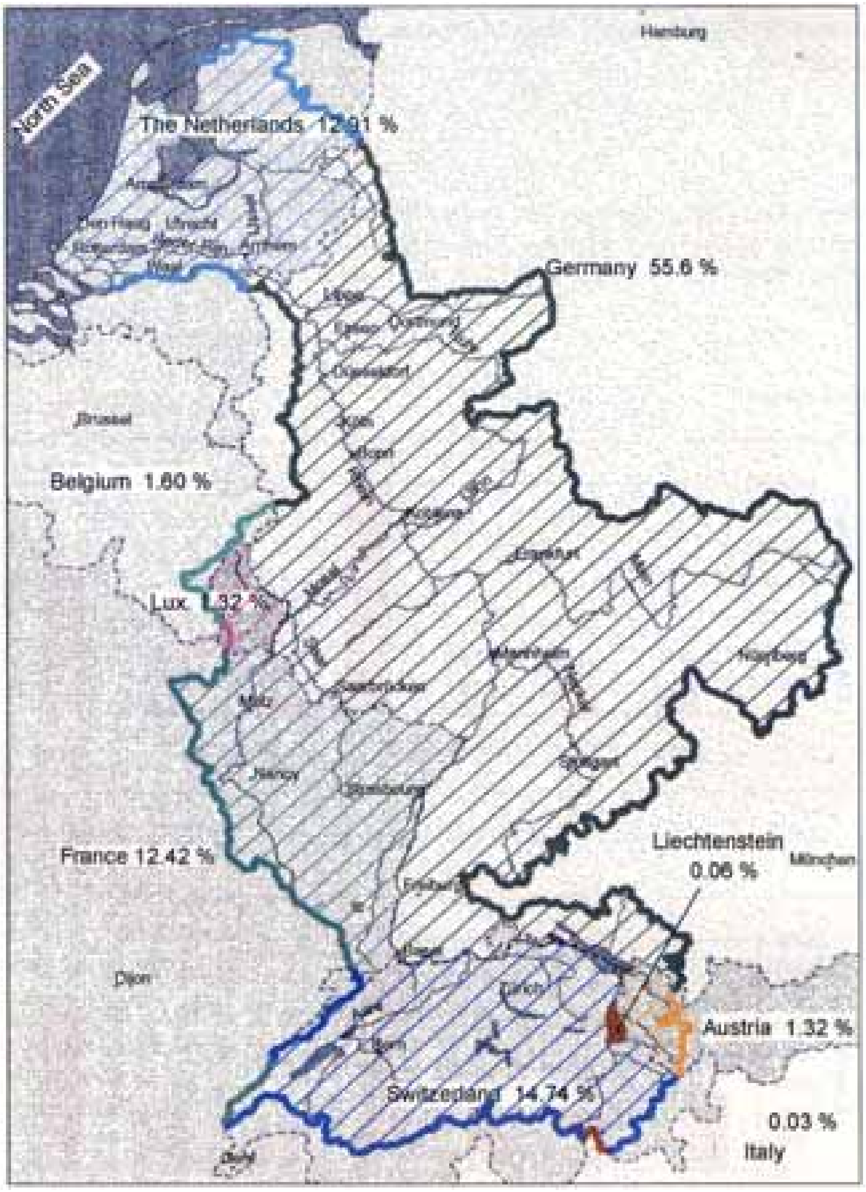

Figure 3 The Rhine basin

With a catchment area of 180’000 km^2 , the River Rhine ranks high among the European rivers that are most important and transport most water. As a shipping route it is one of the busiest in the world.
The course of the River Rhine, with a length of 1320 km, can be divided into 6 major parts:
The stretch from the confluence of the main source brooks, Vorderrhein and Hinterrhein, to the point where the river discharges into Lake Constance is called Alpine Rhine.
Between Lake Constance and Basel it is called High Rhine, downstream to Bingen its name is Upper Rhine and the next stretch to Cologne is named Mid-Rhine. From Cologne to Lobith it is called Lower Rhine and a few kilometers downstream the Rhine delta begins.
The main tributaries of the Rhine are:
Aare, Ill, Neckar, Main, Lahn, Moselle, Ruhr and Lippe.

The Rhine catchment area is distributed between 9 countries. More than half of the catchment area belongs to Germany. Switzerland, France and the Netherlands have nearly the same shares in the catchment (table 1). The width of the catchment area is strongly varying, from about 300 km in the Alpine region, 70 km on the southern end of the Upper Rhine Graben, to more than 500 km from the Lorrainian upland to the Fichtelgebirge mountains (figure 3).

Table 1 Areas of the Rhine basin shared by different states

Country	Area (km_2)	Percentage (%)
Germany	105,478	55.6
Switzerland	27,963	17.74
The Netherlands	24,500	12.91
France	23,556	12.42
Belgium	3,039	1.60
Luxemburg	2,513	1.32
Austria	2,501	1.32
Liechtenstein	106	0.06
Italy	51	0.03

1. 2. Longitudinal and cross – sectional profiles

The River Rhine shows a variety of longitudinal and cross – sectional profiles which are strongly marked by the character of the landscape by human influence.
The geological and morphological conditions cause specific conditions for the gradient of the river bed. When the High Rhine leaves Lake Constance the slope is 0.8 ‰, which is reduced at the end of the Upper Rhine at Bingen before the entry into the Rhenish slate mountains to 0.1 ‰. On the reach through the mountains the slope again increases to 0.4 ‰ and then approaches zero continuously towards the inflow into the North (see fig. 4).

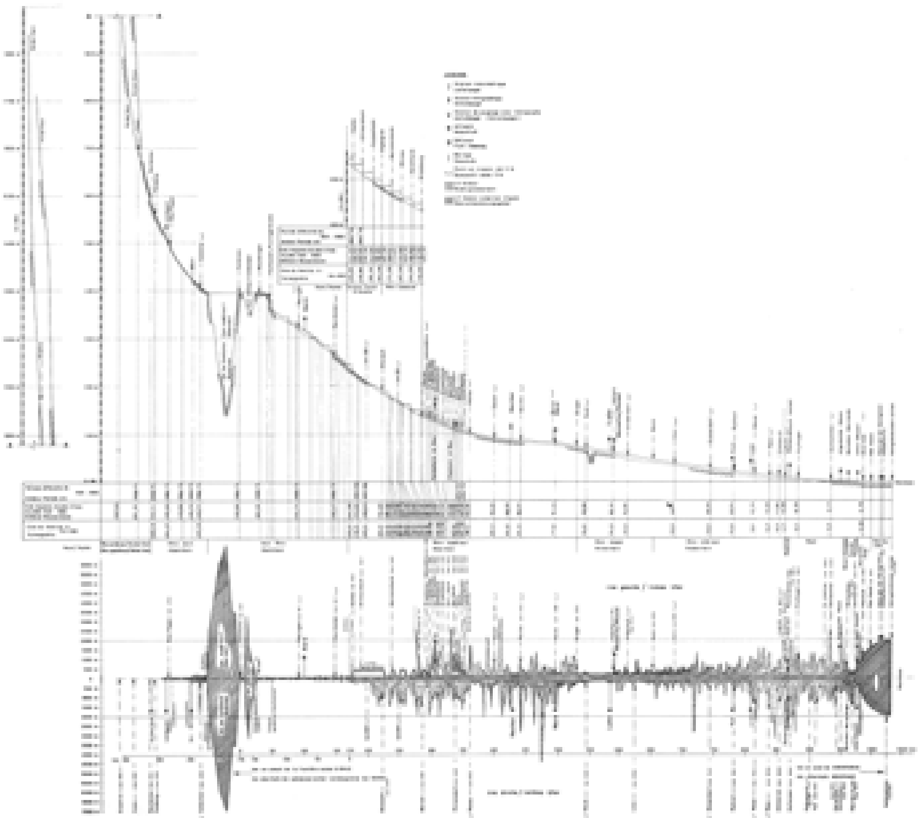

Fig. 4 Longitudinal profile of the Rhine and location of floodplains (after CHR 1987)

1. 3. Human impacts

1. 3. 1. Hydraulic Works

Regulation works were necessary, in order to protect the population from the harmful effects of floods and to come to a water management that enables optimum use of the water. Some of the most important measures have been: bed fixation, river-bend cut-offs to increase the discharge capacity, dyke building against flooding, expansion and stabilizing works in shipping channels (groynes, bank and bed fixations, short-cuts, widening and dredging of the channel) and complex construction works such as weirs, large canals, diversions of water courses and impounding reservoirs.

a. Vorarlberg, Austria

[Literature]

The state contract of 1892 with Switzerland concerning the regulation of the Rhine of Lake Constance up to the mouth of the Ill gave the impulse for the beginning of the protection measures in Vorarlberg. Article 19 of the 1924 and 1954 refreshed contract prescribes the partners in the Rhine catchment area to carry through defense works in torrents. They carried out structural and forest measures are checked every five years by the international Rhine commission. All pending problems are discussed at these meetings.
The Vorarlberg Rhine torrents include all torrents in the catchment area of the Ill, flowing river downwards Feldkirch into the Rhine.
Defense works of the Rhine torrents were made up to the second world war within the framework of the so called Rhine series. The first Rhine series lasted from 1896 to 1908, the second from1909 to 1924 and the third from 1925 to 1937, by allowing a special financing in each case. These moneys allowed the fulfillment of the obligations of the state contract, above all during the economically difficult times of the 1920 and 1930's, and secured many workplaces in the valleys.
After the second worldwar, a dynamic development took place in Vorarlberg. In the wake of the economical development, since the end of the fifties population grew from 150'000 to 330'000 inhabitants. That is a unique value for a mountains country with only 15% of flat lands. Among other things, the construction activities of these decades led to a gigantic grit requirement. Grit was to the greatest extent removed from the torrents in an order of magnitude of several million m^3. As at the same period no large floods occurred, natural sediment discharge was strongly reduced as well. As a result, a large extent bed erosion took place in the Ill, in Bludenz for example up to 4 m. Enormous dredging activities took place in the Swiss catchment areas, too.
In total, these activities led to large bed erosion in the regulation stretches of the Rhine. As a countermove, the grit withdrawals were mostly stopped. The defense work activities also reacted rapidly and have driven forward the construction of open check dams. Large hole check dams were built, also slit dams and beam dams. Applying such constructions, mid size floods might pass and sediments up to a certain grain size are retented. In the case of a catastrophic event, the orifices are blocked and the check dams will perform as conventional retention dams. After removal of the log jams, the retention basin is cleared again by normal water discharge. Otherwise, one must dredge. In the case of the present grit lack, clearance of retention basins is partly done free of charge by the gravel plants.
Doubling the population in the last 30 to 40 years would lead to a big settlement pressure in the valleys and therefore to uncontrolled advance of construction activities into the danger zones of torrents and avalanches. As a result, new desires for defense works were produced, which financially were no longer bearable. In 1975, as a counter measure in the forest law and within the framework of the forest introduced regional planning, the elaboration of danger zone plans was implemented.
Through danger zone mapping, construction activities could be regulated. From a contemporary point of view, the combination of forest and technical measures in the catchment area has proved to produce good results. The still valid law from 1884 was of its time a long way ahead and has initiated forest environmental control for more than 100 years.
The generous and extensive defense works in the torrents in the Austrian, the Liechtenstein and the Swiss Rhine catchment areas achieved an important contribution to the success of the Rhine regulation. During the last decades, thanks to the protective effects of the defense works, numerous local floods and debris flows passed the structures without causing any damage. The population in the

endangered valleys sees and recognizes this success. In the general public they are hardly registered, only disasters are media effective.

[schemes, pictures, tables]

b. Grisons, Switzerland

At the flood disasters of 1834 and 1868, the local municipalities were helpless to watch how local protection works in rivers and torrents were destroyed by the power of water. Immense damages to body and property of the inhabitants had to be lamented. In 1870, the "Wuhrgesetz" (defense work act) was accepted by Grisons population. Therefore the legal basis for a systematical procedure and financial support of protective measures was introduced. In 1877, the federal law of "Wasserbaupolizei" (water surveillance law) came into effect, enabling the financial support of flood defense works by the federal authorities. Thanks of technical and financial support by the Federation and the canton efficient protective measures could be carried out at the most dangerous torrents since end of the 19th century. In spite of numerous protection works implemented with considerable financial expenditures, floods and debris flows may still cause great damages in residential areas and to traffic lines. Natural conditions in Grisons do not allow absolute protection. The increasing requirements for settlement and traffic routes make sure that defense works keep on being confronted with problems.
At all rivers and torrents in the Rhine basin area of the canton, which suffered damages by extreme events, protection measures were carried out. Since the middle of the 19th century, a total of 825 defense work projects have been implemented. Among them, there are 593 torrent projects only. The expenditures invested amounted to 214 million Swiss Francs in total during the last more than 100 years. The Federal contributions mounted up to 105 million Swiss Francs (approx. 49%), the canton payed approx. 64 million Francs (approx. 30%). For the municipalities which are to the greatest extent financially weak mountain municipalities still resulted 45 million of Francs as remaining costs.
The constructions carried out in the last 100 years show continuous change in the defense technique. Instead of gravity dams made of dry and mortar masonry, slab dams of reinforced concrete are in use today. Open check dams allow sediment discharge regulation in the retention basin. Strong construction machines decrease the laborious manual work even in inaccessible canyons.
In former times, defense works were carried out in very urgent cases only. Today, environmental viewpoints are more in the foreground.

[schemes, pictures, tables]

c. St. Gall, Switzerland

With the law of the 12 August 1869 about the protection against torrents and also the postscript law dated April 3rd, 1877 as well as the corresponding execution arrangement dated November 16th 1877, the corner stone for comprehensive correction- and defense works in the waters of St. Gall was placed.
The federal law about water survey which was passed by the Swiss councils on July 22nd, 1877 was also of great importance.
If nothing else, the state contract between Austria and Switzerland of 30th December 1892 contributed to correction- and defense works in the torrents. Art.19 of this contract obliged the two countries to carry out protection works in the torrents of the Rhine catchment.
Late almost 100 years, at the 23rd March 1969, the "Grosse Rat" of the canton St. Gall passed the new law of hydraulic works. Today is already talked about a further revision of this law.
The main purpose of torrent control consists of the prevention of erosion damages in the upper course of torrents and aims therefore to avoid deposits in the lower course. The goal of all is controlled sediment discharge. Retention basins are an effective measure to protect the valley from uncontrolled accumulation. Almost all torrents in the St. Gall Rhine valley have such a retention basin.
From Bad Ragaz to Thal, there is a great number of torrents. Only two of them, the Tamina in Bad Ragaz and the Trübbach in the municipality Wartau, flow directly into the Rhine. All other torrents drain into the Werdenberger-channel, into the Saar channel, or into the Rhine channel.

[schemes, pictures, tables]

d. Principality of Liechtenstein

From time before 1835, no documents about defense works are available. It is however probable that already before this time small longitudinal constructions of stones for the diversion of debris flows had been made. The record of 1835 consists in the first place of descriptions about origin and effect of debris flows, but without being concerned of direct measures. It is pointed out that good success had achieved in the neighboring Tirol through different methods of measures. The Liechtensteinians however were discouraged against natural powers.
In an other record of 1860 can be proved that defense works already began in 1855. In 1855, people stood under formative impression of devastating debris flows. Obviously the first attempts to protect torrent beds from erosion were hesitant and executed with too weak wooden transversal structures. Failures occurring again and again led to scattered discouragement.
With the increasing application of heavy building materials, such as large bolders, success in defense works increased. The tasks were correctly recognized. It was a question of stabilization of torrent beds and fixing of landslides and of banks in canyons in order to reduce weathered material as much as possible. As however one still was far from stair like check dam constructions because of lacking financial means, damages by flowing about the check dams and scouring below check dams often occurred. As a result, the structures were destroyed or became inoperable.
The importance of the forest as optimal protection against erosion was soon also recognized and underlined with a clear cutting prohibition and the creation of avalanche forests.
1871 a first legal prescription for debris flow defense works was elaborated, which assigned the defense duty to the municipalities. For special cases, financial contributions werde made by the country. In the law of 1899, a Landesrüfenkommission (national debris flow commission) was originated as an advisory board of the government, in which the respective head of the government has the chairmanship up to now.
Through this, the great importance of the debris flow problem at that time is clearly attributed. In addition, a 50% support to all defense works was ensured. In the following years, countless frictions between the municipalities about kind and manner of constructions and cost distributions were hindrances for important hydraulic projects. For this reason, in 1937 an own technical authority of the country for debris flows was created and the country contribution was raised up to 70%. This would pave the way for an impressive reduction of debris flow damage.
The most important debris flow torrents drain their water to the Rhineside. The catchments are very steep and near the "Three sister" mountain range virtually without vegetation. To that, the catchments mainly consist of weathering prone material.
Between 1894 and 1990 almost 56 million Swiss francs were spent for torrent control in Liechtenstein. The State of Liechtenstein has supported the works since 1938 with a 70% contribution.

[schemes, pictures, tables]

e. Correction of Rhine river stretches downstream of Basle

In earlier times, the Upper Rhine did not have a bed as we know it today. The Rhine Plain was swampy, and malaria plagued the population. The river meandered over the whole width of the valley and changed its channels and created or swallowed islands after each flood event. About 1815, the training of the river began (see figure 5). The regulation of the Rhine was planned with view to the following aims:

- reducing the danger off floods;
- improving agricultural land use by lowering the groundwater table;
- reclaiming additional areas for settlements and agriculture;
- reducing the health hazards (malaria etc.);
- clarifying the position ofthe border between Germany and France along River Rhine; and
- improving navigation.

Fig. 5 serves as an example for Rhine river correction works.

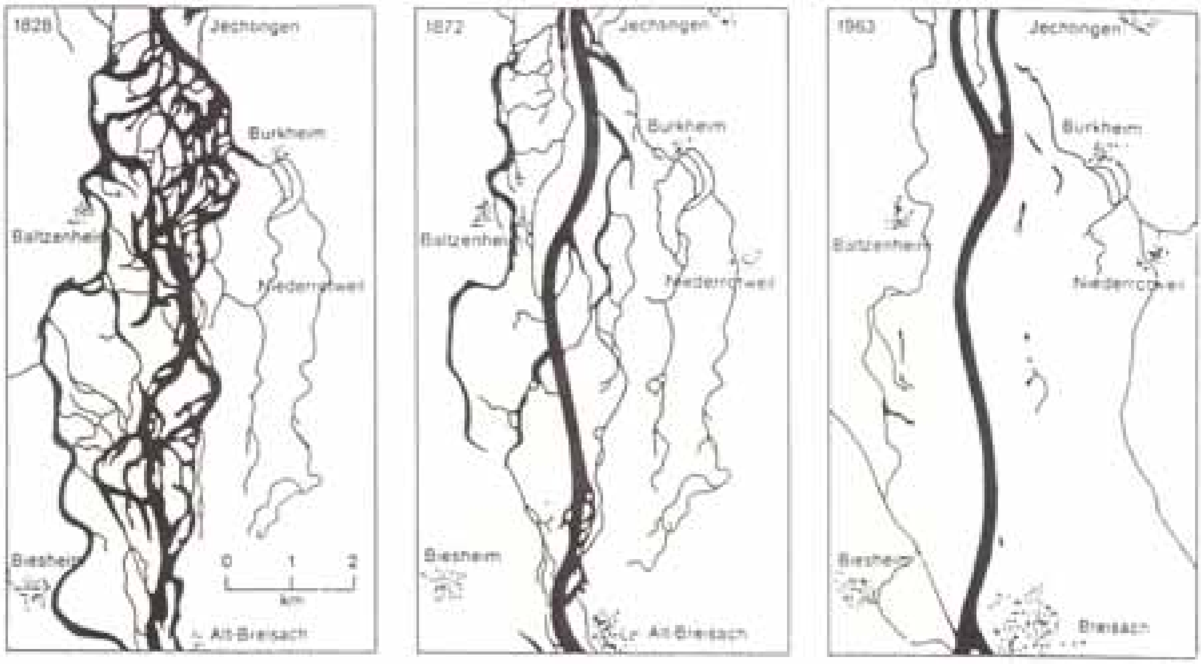

Fig. 5 Upper Rhine River at three stages: 1828 before regulation, 1872 after regulation and 1963 after regulation and canalization

The river training concept was based on the laws governing river discharge, which say that the hydrostatic behavior of a river is a function of discharge, of the cross section, of the longitudinal gradient, and of the depth of the water. Accordingly, the Rhine was forced into a self-deepening bed by building structures across and along the river. River bends and meanders were cut off. On the whole, the river bed gradient increased, and the river eroded its new bed. In the course of time the river bed cut down seven metes due to the increase in gradient and shortening of its course. The groundwater table dropped in the same order of magnitude.

In a treaty concluded between France and Germany, France was given the right to harness hydropower on the Upper Rhine. France then built a lateral canal which was lined with concrete slabs, so that interactions with groundwater were interrupted. The consequence was a further drop of the groundwater table. At some places, the habitats in the meadows dried up. Further river training projects were developed to mitigate and reverse the damages to landscape and river on the Upper Rhine. The adopted concept was the so called loop solution, which provided for returning the water through cut-offs into the bed of the River Rhine downstream of each impoundment weir with power station, thus restoring the interactions between river and groundwater (fig 6). However, downstream of the last impoundment, erosion set in again, so that the danger of further lowering of river bed and water table continued. A treaty adopted in 1969 provided for the construction of new impoundments. However, the ecological awareness among the public had increased so much that the implementation of this technical solution encountered severe resistance, although its main purpose was to avert further damages. After long-lasting investigations it was agreed to use artificial bed-load supply instead of building new weirs. This means that gravel of appropriate grain size is dumped into the river in order to prevent further erosion or to reverse the existing one.

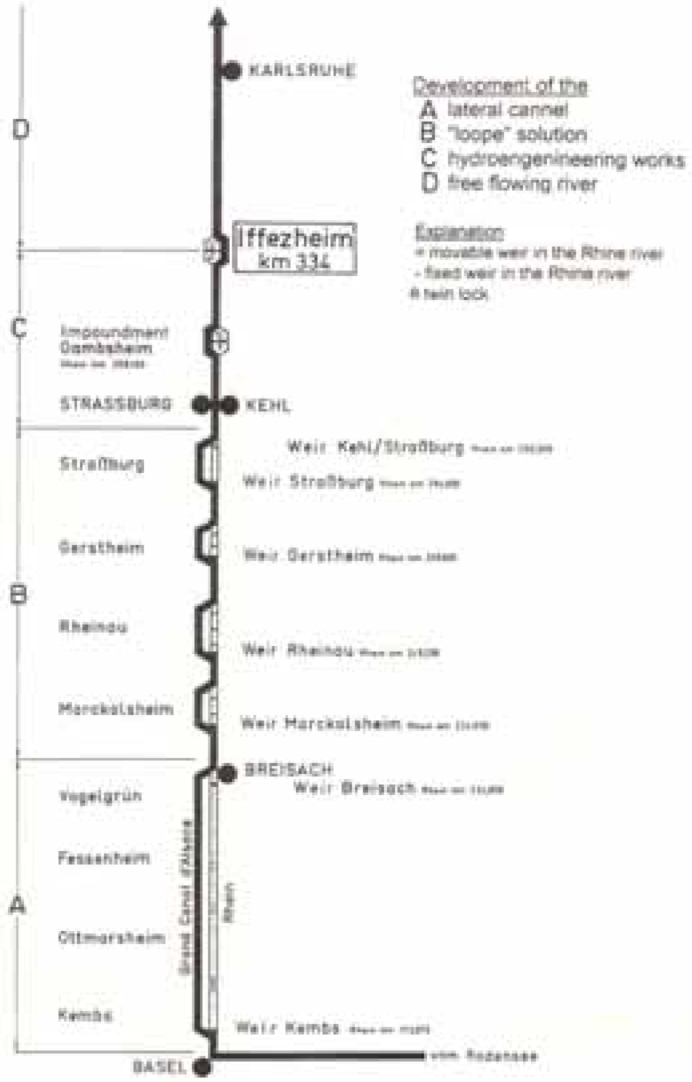

Fig. 6 River development scheme for Upper Rhine

In the regions of the Middle Rhine and the Lower Rhine the river bed had also repeatedly changed its position in earlier times. The river was braided with many islands and oxbow lakes, and it spread at mean flow over a width of 450 m. In the 18th century the first training works for flood protection were begun. The division of the river into several channels was removed and narrow bends were cut off.
From 1880 to 1900, the mean-flow bed was planfully trained, and the navigation channel was deepened between Bingen and Emmerich. This created the basis for the outstanding importance of the River Rhine as receiving watercourse and navigation channel in Europe.

Since 1900, the river training has been continuously improved. This included the construction of groynes, training walls, dredging in the fairway, and backfilling of scours.
The maintenance of the navigation channel in the Lower Rhine, as it resulted from the training works, is becoming increasingly difficult because of the continuing erosion of the riverbed and the lowering of the water level. Since the turn of the century, the equivalent water level at the gauge Ruhrort has declined by some 1.5 m. In the 1950s and 1960s the deepening rate reached 4 cm per year. When the river bottom is uneven, this process causes ever more shoals and narrows on many reaches. Simultaneously the depth of water in harbors and secondary waterways without flow-through decreases. Groundwater in riparian areas drops, so that water supplies are impaired and drying up of oxbow lakes and desertification of meadows is threatening. Some minor regulation projects in the 1970 could improve navigation locally, but the aim to establish and maintain a lasting river bed with possibly balanced bed load regime was not reached. The causes of bed erosion can be found mainly in the process of figure 7.

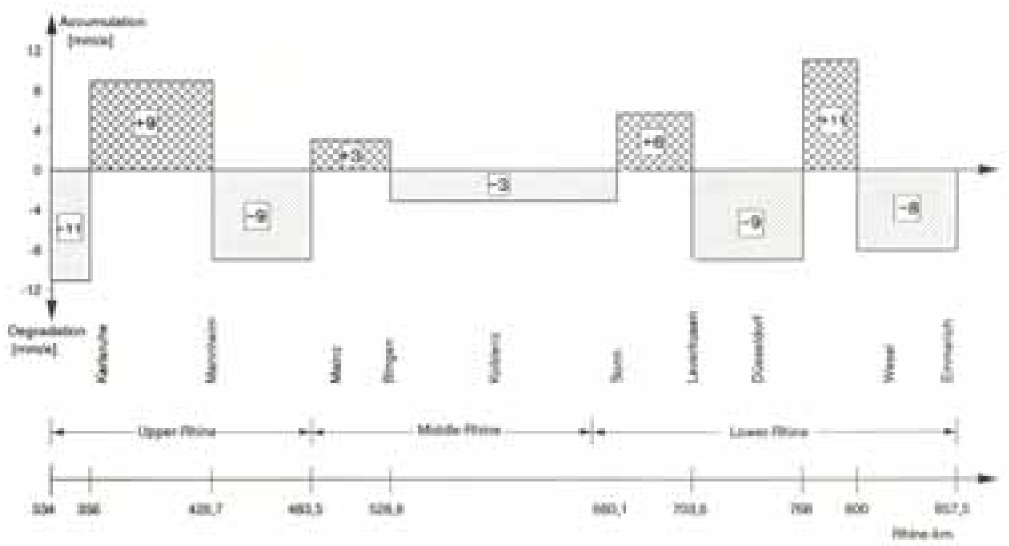

Fig. 7 Mean annual change of the average bottom level by bed load balance between 1981 and 1990

Figure 8 shows the Netherlands at the beginning of the 20th century. In the central embayment, called Zuyderzee, storm surges caused many inundations. The flood disaster of 1916 was the last impulse to carry out the long-cherished plan to close and partly reclaim the Zuyderzee. There were four main reasons to realize this plan: Flood protection, fight against salination, water supply in dry periods and reclamation to increase food production.

The closure dam with sluices was completed in 1932 creating the Lake IJssel. The IJssel, the north flowing branch of the Rhine, supplies the lake. The lake was transformed into a fresh water reservoir by the IJssel input. It supplies the northern parts of the Netherlands with fresh water during dry periods and discharges the surplus through sluices into the sea in wet periods.

By constructing four polders, parts of Lake IJssel were reclaimed and tumed into rich farmland. In the last reclaimed polder (Southern Flevoland) new towns are built for the expanding population on the old land, particularly Amsterdam. The water level in the remaining lake may vary with 20 cm creating a fresh water reservoir of 500 million m^3. Besides the supply of northern and north-western part of the Netherlands the lake also receives excess water from these areas in wet periods.

The south-western estuarine area of the country has islands, surrounded by deep tempestuous estuaries, into which the Scheldt, the Meuse and 90% of the Rhine discharge. The storm surge of February 1953 breached the dikes at 900 places, large areas became inundated, many people and livestock drowned. It gave the final impulse to the delta project with the aim of damming the estuaries in the south-west. Originally the Rotterdam Waterway and the Western Scheldt were excluded from the scheme because of their importance as entrances to the harbors of Rotterdam and Antwerp. Safety along these water courses is achieved by substantial reinforcement of the dikes.

The delta plan has been modified at two major points. According to the original plan the Eastern Scheldt was to be closed by one of the largest dams ever built in the Netherlands. In 1975 environmental considerations led to the decision to build a storm surge barrier dam, that leaves the tidal movement largely unmodified, but can be closed during storm surges. Due to the rapid development of the harbor of Rotterdam it proved to be necessary in 1987 to build a storm surge barrier in the Rotterdam Waterway. In contrast to the measures in the fifties, the deepest harbors of Rotterdam got a separate obstacle free entrance to the sea in 1975.

The main features of the delta project are as follows. There are five primary elements: the Rotterdam Waterway barrier (1998), the Hartel barrier (1997), the Haringvliet dam (1970), the Brouwersdam (1972) and the Eastern Scheldt barrier (1986). The last project was the most expensive enterprise. It costs almost 8000 million guilders (some 4500 million US dollars).

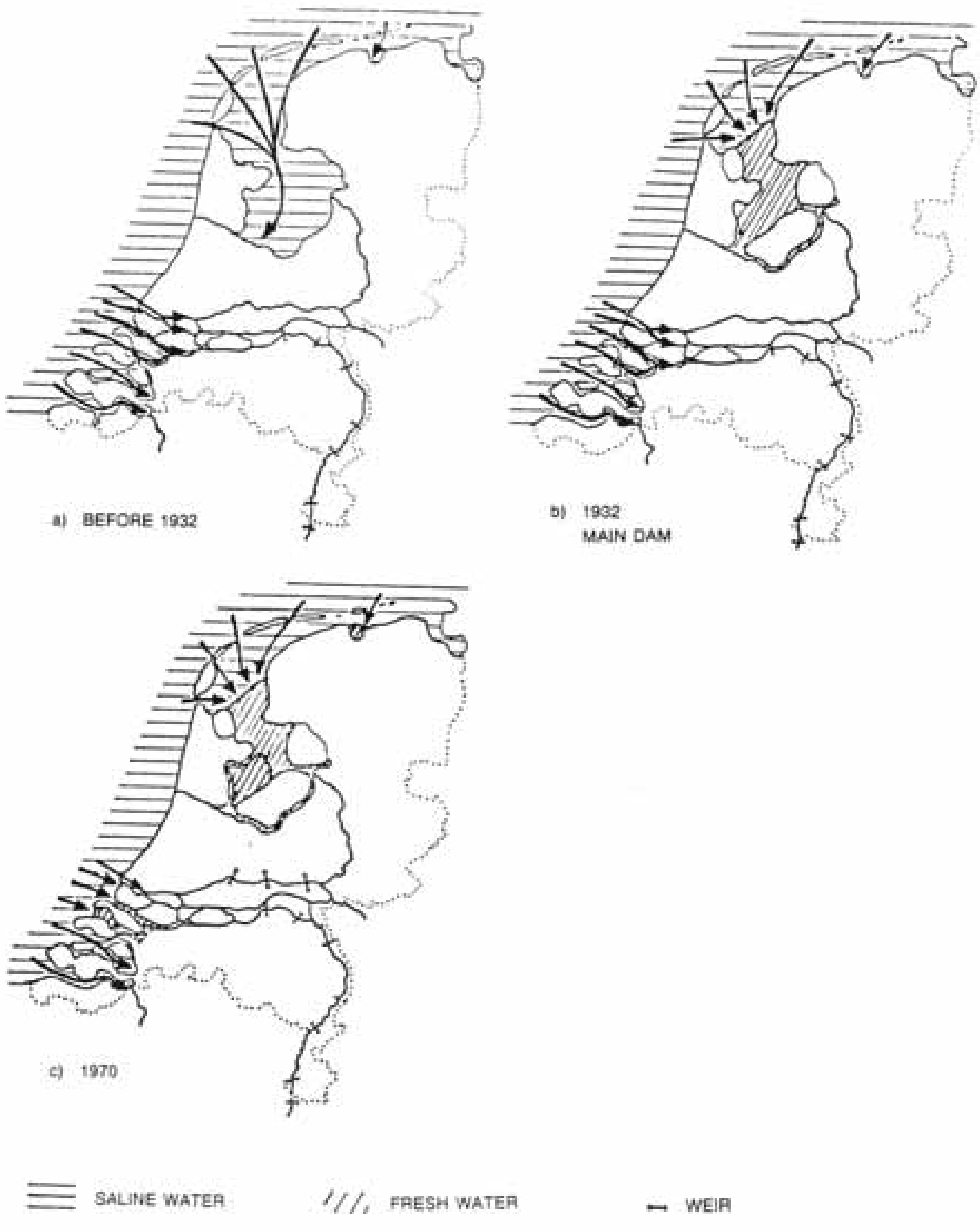

Fig. 8 Protection against storm surges and salinization in the 20th century in the Netherlands

Fig. 9 The weir at Driel in the Lower Rhine. The weir directs water to the north or let it pass to the west of the country.

Fig. 10 The 32 km long main dam separates the Wadden Sea from the fresh water of Lake IJssel.

1. 3. 2. Reservoirs and Hydropower

In the past a high number of hydropower plants have been installed, most of them with large retention basins.
Table 2 is an overview of retention basins in Switzerland.
The total retention volumes in the tributaries of the Rhine river can be seen in table 3 and fig. 11.

Table 2 Swiss Retention basins

Name of the dam Nom du barrage Name der Talsperre	Period of construction Période de construction Bauperiode	Dam – Talsperre – Barrage					Owner Propriétaire Nutzungsberechtigter
		Type*) Type*) Typ*)	Height Hauteur Höhe m	Crest length Longueur au couronnement Kronenlänge m	Volume Volume Kubatur 1000 m³	Elevation m a. s. l. Cote m s. m. Stauziel m ü. M.	
1. Lucendro	1942/47	G	73	270	154	2133	Aar e Ticino S. A., Olten/Bodio
2. Sella	1942/47	G	36	334	74	2256	
3. Rossens	1944/47	A	83	320	255	677	Entreprises Electriques Fribourgeoises, Fribourg
4. Egschi	1947/49	G	50	80	33	1181	Kraftwerke Zervreila AG, Vals
5. Göschenerreuss	1947/49	G	35	71	11	1084	Kraftwerke Wassen AG, Wassen
6. St. Barthélemy	1947/50	OG	87	420	400	2186	S. A. l'Energie de l'Ouest Suisse (EOS), Lausanne
7. Räterichsboden	1948/50	OG	94	456	279	1767	Kraftwerke Oberhasli AG, Innertkirchen
8. Salanfe	1948/52	G	52	616	330	1925	Salanfe S. A., Vernayaz
9. Molina	1948/51	G	32	70	14	697	Calancasca AG, Roveredo
10. Châtelot	1950/53	A	74	155	48	716	Soc. des F. M. du Châtelot, La Chaux-de-Fonds
11. Palagnedra	1950/53	G	72	120	85	492	Off. Idroelettriche della Maggia S. A., Locarno
12. Castiletto	1950/54	E	91	400	2 700	1680	Elektrizitätswerk der Stadt Zürich, Zürich
13. Oberaar	1951/53	OG	100	526	453	2303	Kraftwerke Oberhasli AG, Innertkirchen
14. Mauvoisin	1951/57	A	237	520	2 030	1962	Forces Motrices de Mauvoisin S. A., Sion
15. Grande Dixence	1951/62	G	285	695	5 957	2364	Grande Dixence S. A., Sion
16. Vieux Emosson	1952/55	AG	51	180	62	2205	Chemins de fer Fédéraux, Berne
17. Sambuco	1952/56	AG	130	363	775	1461	Off. Idroelettriche della Maggia S. A., Locarno
18. Les Clées	1953/55	G	32	100	21	743	Cie. Vaudoise d'Electricité, Lausanne
19. Zervreila	1953/57	A	151	504	635	1862	Kraftwerke Zervreila AG, Vals
20. Zervreila	1953/57	R	44	72	113	1729	
21. Zeuzier	1954/57	A	156	256	300	1777	Electricité de la Lienne S. A., Sion
22. Moiry	1954/58	A	148	610	815	2249	Forces Motrices de la Gougra S. A., Sierre
23. Fionnay	1955/57	R	37	100	40	1488	Grande Dixence S. A., Sion
24. Malvaglia	1956/59	A	93	290	162	969	Officine Idroelettriche di Blenio S. A., Olivone
25. Albigna	1955/59	OG	115	810	940	2163	Elektrizitätswerk der Stadt Zürich, Zürich
26. Göscheneralp	1955/60	R	155	540	9 350	1792	Kraftwerke Göschenen AG, Göschenen
27. Turtmann	1957/58	A	32	110	3	2177	Forces Motrices de la Gougra S. A., Sierre
28. Bärenburg	1957/61	G	64	115	55	1080	Kraftwerke Hinterrhein AG, Thusis
29. Valle di Lei	1957/61	A	143	710	824	1931	
30. Runcahez	1958/63	OG	33	180	35	1275	Kraftwerke Vorderrhein AG, Disentis/Mustér
31. Nalps	1958/62	A	125	480	500	1908	
32. Luzzone	1958/63	A	208	530	1 330	1591	Officine Idroelettriche di Blenio S. A., Olivone
33. Mattmark	1958/67	E	120	770	10 400	2197	Kraftwerke Mattmark AG, Saas Grund
34. Isola	1959/60	AG	45	290	71	1604	Misoxer Kraftwerke AG, Mesocco
35. Sufers	1959/62	A	58	125	22	1401	Kraftwerke Hinterrhein AG, Thusis
36. Limmern	1959/63	A	146	375	550	1857	Kraftwerke Linth-Limmern AG, Linthal
37. Les Toules	1960/63	A	86	460	255	1810	F. M. du Grand St-Bernard, Bourg-St-Pierre
38. Schiffenen	1960/63	AG	47	415	155	532	Entreprises Electriques Fribourgeoises, Fribourg
39. Sanetsch	1960/65	OG	42	210	40	2034	Kraftwerke Sanetsch AG, Gsteig
40. Carassina	1961/63	A	39	112	8	1700	Officine Idroelettriche di Blenio S. A., Olivone
41. Z'Mutt	1961/64	A	77	140	28	1970	Grande Dixence S. A., Sion
42. Roggiasca	1961/65	A	68	177	32	964	Elettricità Industriale S. A., Lostallo
43. Val d'Ambra	1961/65	E	30	105	55	603	Azienda Elettrica Ticinese, Bellinzona
44. Contra	1961/65	A	220	380	660	470	Verzasca S. A., Lugano
45. Curnera	1962/67	A	153	340	582	1956	Kraftwerke Vorderrhein AG, Disentis/Mustér
46. Gebidem	1962/67	A	122	325	210	1437	Electra-Massa AG, Naters
47. Gries	1963/65	G	60	400	250	2386	Kraftwerke Aegina AG, Ulrichen
48. Vasasca	1964/67	A	69	167	21	705	Società Elettrica Sopracenerina, Locarno
49. Robiei	1964/67	OG	68	350	152	1940	Off. Idroelettriche della Maggia S. A., Locarno
50. Cavagnoli	1964/68	A	105	310	221	2310	
51. Zött	1964/67	A	37	145	17	1940	
52. Sta. Maria	1964/67	A	117	560	640	1908	Kraftwerke Vorderrhein AG, Disentis/Mustér
53. Punt dal Gall	1964/69	A	130	540	775	1805	Engadiner Kraftwerke AG, Zernez
54. Hongrin	1964/69	A (2)	125	595	345	1255	F. M. Hongrin-Léman S. A., Château-d'Oex
55./56. Naret I + II	1965/70	A G	80 45	430 265	390 73	2310	Off. Idroelettriche della Maggia S. A., Locarno
57. Ova Spin	1966/68	A	73	130	29	1630	Engadiner Kraftwerke AG, Zernez
58. Carmena	1967/69	A	40	100	3	642	Azienda Elettrica Comunale, Bellinzona
59. Emosson	1968/72	A	180	555	1 100	1930	Electricité d'Emosson S. A., Martigny
60. Orden	1968/71	A	40	180	17	1798	Kanton Graubünden

*) A	Arch dam	Barrage-voûte	Bogenstaumauer
AG	Arch-gravity dam	Barrage-poids-voûte	Bogengewichts-Staumauer
G	Gravity dam	Barrage-poids	Gewichtsstaumauer
OG	Open-joint-gravity dam	Barrage-poids avec joints évidés	Gewichtsstaumauer mit Sparräumen
B	Buttress dam	Barrage à contreforts	Pfeilerstaumauer
E	Earthfill dam	Barrage en terre	Erddamm
R	Rockfill dam	Barrage en enrochements	Steindamm

Table 3 Retended water volumes in the tributaries of the Rhine river

Nebenfluß	Volumen in hm³	Summe d. Volumens (hm³)
Vorderrhein	253,14	253,14
Hinterrhein	289,36	542,50
Tamina	38,50	581,00
Ill (A)	183,40	764,40
Bregenzerach	8,40	772,80
Bodensee	1,40	774,20
Thur	0,60	774,80
Hochrhein (CH)	7,26	782,06
Aare	496,95	1279,01
Reuss	153,19	1432,20
Limmat	314,86	1747,06
Hochrhein (D)	112,85	1859,91
Oberrhein	27,63	1887,54
Ill (F)	24,29	1911,83
Neckar	37,99	1949,82
Main	59,64	2009,46
Nahe	14,05	2023,51
Lahn	6,63	2030,14
Moselle	103,58	2133,72
Mosel	50,53	2184,25
Saar	71,40	2255,65
Wied	4,45	2260,10
Ahr	0,73	2260,83
Sieg	123,10	2383,93
Wupper	140,43	2524,36
Erft	51,00	2575,36
Ruhr	496,06	3071,42
Lippe	50,01	3121,43

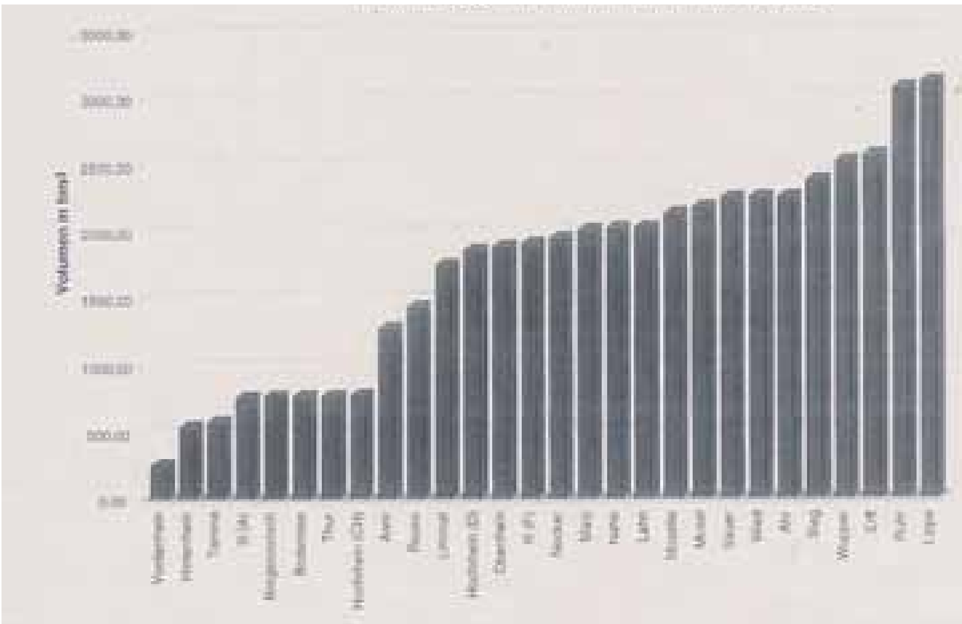

Fig. 11 Cumulative retention volumes in the tributaries of the Rhine river

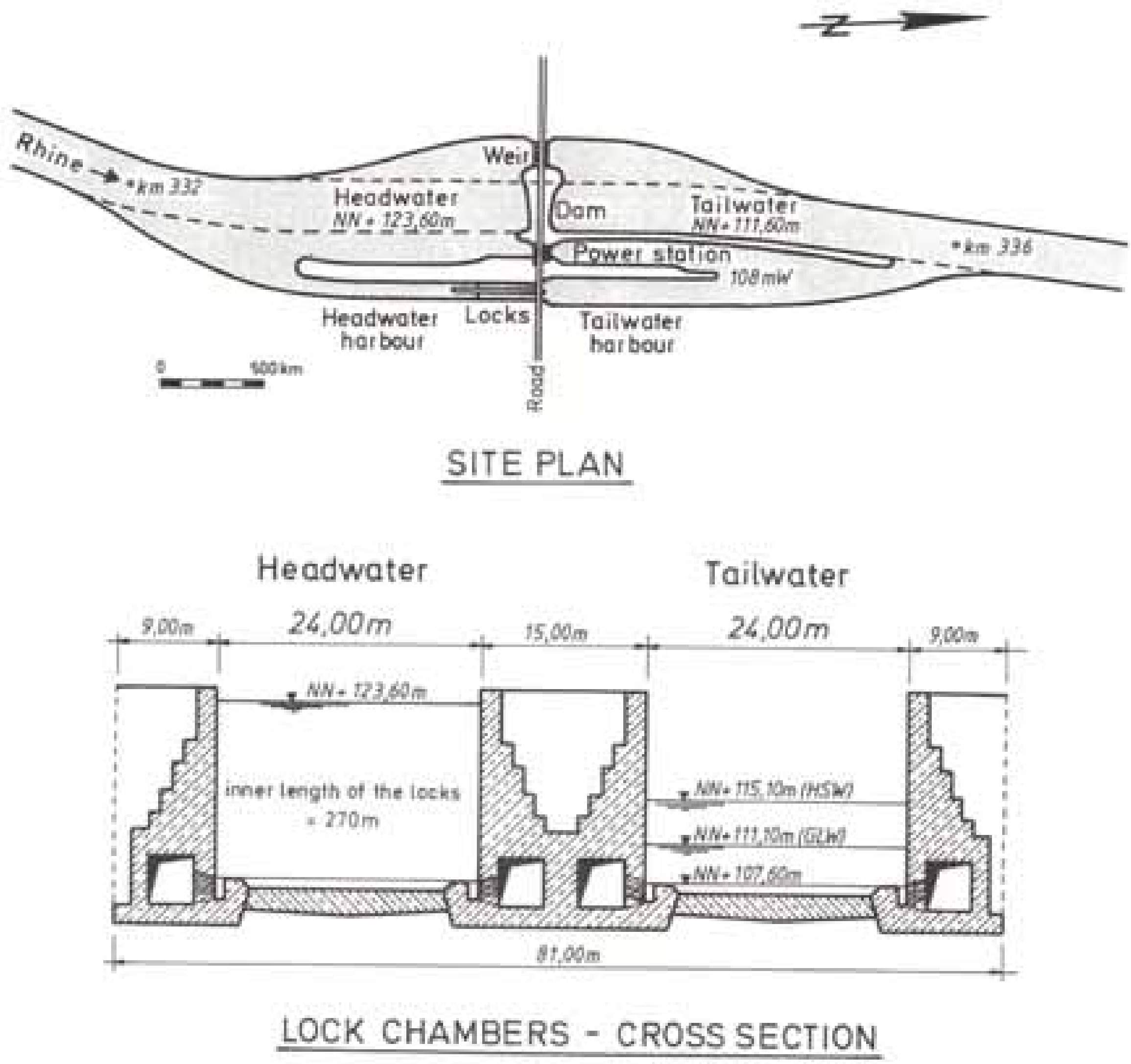

Fig. 12 Impoundment weir Iffezheim

The High Rhine with its slope of 150 m between Schaffhausen and Basel and its relatively narrow valley offers favorable conditions for hydropower generation. Moreover, streamflow there is relatively even because of the upstream lakes and reservoirs. Hydropower has been used on the River Rhine for more than 120 years. Altogether, there are twelve hydropower stations with capacities between 30 and 120 MW, while most stations have an installed capacity between 30 and 50 MW. The mean potential productive capacity of the twelve stations on the High Rhine is around 4,200 MWh.

By 1978, ten hydropower stations had been built on the Upper Rhine, some of them on lateral canals. They have installed capacities between 100 and 200 MW, with about 170 MW being the preferred size. The maximum output of these ten stations amounts to 1.5 million k W , and the mean annual power generation is around 8,500 rnillion kWh.

The power station Iffezheim for example was built in the same axis like the weir, the barrage, and the lock passage (fig. 12). It has four sets of tubular turbines in horizontal position which have a rotation speed of 100 revolutions per minute and a total throughput of 1,100 m^3/sec. The fall of water head is 11 m, and the maximum capacity reaches 112 MW. In the case of an emergency stoppage the turbines can be switched into an unloaded mode which ensures the passage of 60 % of their normal throughput. The remaining water is diverted over the weir by the automatic control system.

In former times, the impoundments on the High Rhine and the Upper Rhine were built exclusively for the purpose of hydropower generation. When mineral oil became a major source of energy and when nuclear power was utilized, the construction of hydropower stations on the Rhine and its tributaries only for energy production was stopped. However, whenever impoundments were built for other purposes like landscape protection or improvement of navigation, they were always combined with power generation.

1. 3. 3. Water supply

The Rhine has also great importance for water supply: However, the Rhine River catchment area is a conglomeration of high population density, accumulated high-tech industry and at the same time an area which is most intensively used for agricultural purposes. 104 chemical plants like BASF, Bayer, Ciba Geigy and Hoechst, and some 50 million people use the Rhine as the final Tecipient for their treated sewage (fig. 13).

Fig. 13 Waterworks in the Rhine area

Fig. 14 Water supply in the Netherlands

But where do cities like Zürich, Basel, Strasbourg, Stuttgart, Frankfurt, Mainz, Köln, Düsseldorf and Amsterdam get their drinking water from? Water withdrawal from ground water resources is restricted to the annual average natural recharge. This recharge does not meet the demand in areas that have high population density. The available ground water resource has to be increased for example by bank filtration. Therefore some 20 million people depend on the water of the Rhine, its tributaries and the lakes within the Rhine basin as sources
for their drinking water supply. Several measures have to be taken by the waterworks in order to ensure a safe supply. .
One hundred and nineteen waterworks in seven European countries the Netherlands, Germany, Belgium, France, Switzerland, Liechtenstein and Austria are represented by the International Association of Waterworks in the Rhine Basin (IA WR) (figure 13). This association was established in 1970 by three regional associations: RIW A (Samenwerkende Rijn- en Maaswaterleidingbedrijven), ARW (Arbeitsgemeinschaft Rhein-Wasserwerke) and A \VBR (Arbeitsgemeinschaft Wasserwerke Bodensee-Rhein). The waterworks realized that on1y international cooperation could eventually fight the deterioration of the Rhine water quality.
They demand the preventive protection of water resources and the sanitation of the Rhine to the point that natural treatment like bank filtration is sufficient to produce drinking water in sufficient amount and quality.
Bank filtration can be achieved due to ground water pumping. The depression cone in ground water table builds a gradient that allows surface water infiltrate into the underground. Such a well will gain both, bank filtered water from the river and natural ground water. The portions of both vary with the difference between the ground water table and the actual water level in the river, the pumping rate and the distance between well and river.
In places where geology or other factors do not allow to gain bank filtered water, treatment plants with several purification steps are needed to withdraw water directly out of the river. The purified water is infiltrated into the aquifer to allow natural purification within the underground before the water is extracted again and processed in filtration plants to produce drinking water (fig. 14). Al measures mentioned are sufficient to guaranty a safe yield in terms of quantity, provided that the quality of the river water allows its use for the production of drinking water.
The average drinking water consumption in Germany does not follow any of the prognoses in the past.Meanwhile one person needs 139 liters per day.
This amounts to one billion m3 each year for 20 million people and is negligible compared to the annual water flow of the Rhine of about 70 billion m^3. This volume though may arrive in different portions, causing flood in the city center of Köln as it occurred in January 1995.
Even at low water in the Rhine there was never a shortage problem but problems derived from declining water quality.

1. 4. Population

In antiquity and in the Middle Ages the Rhine basin was much less populated than it is today.
However, on rivers Rhine, Mosel and in the Main river basin agglomeration areas developed early. In the modern era, the Thirty Years' War caused a considerable decline in population in Germany. Afterwards, the increase was steady, reaching about five million inhabitants by 1800 in the German Rhine basin. On the whole the population figure increased to the sixfold over 160 years. Today, about 50 million people live in the whole Rhine River basin.
Their distribution among the riparian countries is shown in table 4.

Table 4 Population among the Rhine countries

	Inhabitants	
	(million)	Percent (%)
Germany	30	60
The Netherlands	10	20
Switzerland	5	10
France	5	10
Other countries	0.5	<1

The population trend in the modem era is characterized by increasing urbanization. In some parts of the Rhine basin agglomeration regions emerged. Nearly one third of the entire population is concentrated there. These agglomerations are located on River Rhine or are connected to it by channelized rivers and canals.
As the Rhine basin is very intensely used by commerce, industry and agriculture and because of its good infrastructure, its total population amounts to more than 50 million people. Some areas are very densely populated.
In the Swiss part of the basin they are the regions of Basel, Zurich and Bern; in the French territory the areas round Mulhouse, Strasbourg, Nancy and Metz. In Germany in the Upper Rhine basin the regions of Freiburg, Karlsruhe, Ludwigshafen and Mannheim stand out; in the Neckar basin the area round Stuttgart should be mentioned; in the Main basin the region of Nuremberg-Erlangen, Würzburg and particularly the lower Main basin from Frankfurt to Wiesbaden; on the left bank the area between Mainz and Bingen, as well as the Bonn-Cologne-Düsseldorf region may be distinguished. In the Moselle basin Saarland should be mentioned. The Ruhr area between Duisburg and Dortmund stands out as a purely urban and industrial region. The part of the Rhine basin in the Netherlands is very densely populated. Especially Arnhem and Nijmegen in the east, as well as the ports of Amsterdam and Rotterdam should be mentioned in this respect.

1. 5. Land Use

Far into the modern era land use in the Rhine basin was dominated by agriculture and forestry. Since the Middle Ages forests, which were the natural vegetation, have been widely cleared, especially on areas allowing easy cultivation. Timber was a major product, also in the trade with the sparsely wooded but economically active coastal areas to which it was brought by rafting. The wood was used there for ship building, housing construction, and as fuel. In the 18th and 19th centuries the clearing of forest became excessive and resulted in erosion damage and floods. The counter-action was reafforestation. Today, about one third of the Rhine basin is forested.
The transition from barter economy to money economy, the increasingly intensive and more rational cultivation practices, and the application of artificial fertilizers have mulitiplied the yields of major crops over the past 100 years. Agriculture had already early advanced into the riparian plains. There, it had to face recurring floods and was impaired by waterlogged soils which were caused by swamps and changing flow conditions. Thus, improvements in the soil water balance through flood protection and drainage have also played a role in the increase of agricultural yields.
The Rhine basin from Lake Constance to Bonn and the valleys of the tributaries have been wine-growing areas since ancient times. Through the high quality of the wines viniculture has gained great importance.

1. 6. Hydrometeorology

1. 6. 1. Climate and Meteorology

The annual amount of precipitation in the Rhine basin varies in the case of Kolmar of approx. 450 mm in the Alsace and also less than 500 mm in the triangle Mainz-Alzey-Worms up to almost 4000 mm in higher parts the Bernese Oberland. In the first case, the boundary from deciduous forest to the steppe is achieved, in the last case in some spots to the rainforest of middle latitudes. The second fundamental climate parameter, the annual mean temperature, sinks from about I0°, which is valid for almost the entire navigable Rhine, to below 0°C in the source areas of the alps.
If one considers the most important parameter besides the temperature, the precipitation, it is obvious that it has increased in the entire catchment area of the Rhine mainly in wintertime since 1961. As there is the same time an increase of mean temperatures as well, especially in the winter half-year, a tendency towards higher discharges in winter could result.
The increase of precipitation becomes especially clear regarding figure 15 for the parts of the Rhine basin upstream Cologne. Areal precipitation has increased around approx. 10% since 1890 mainly concerning the winter half-year.

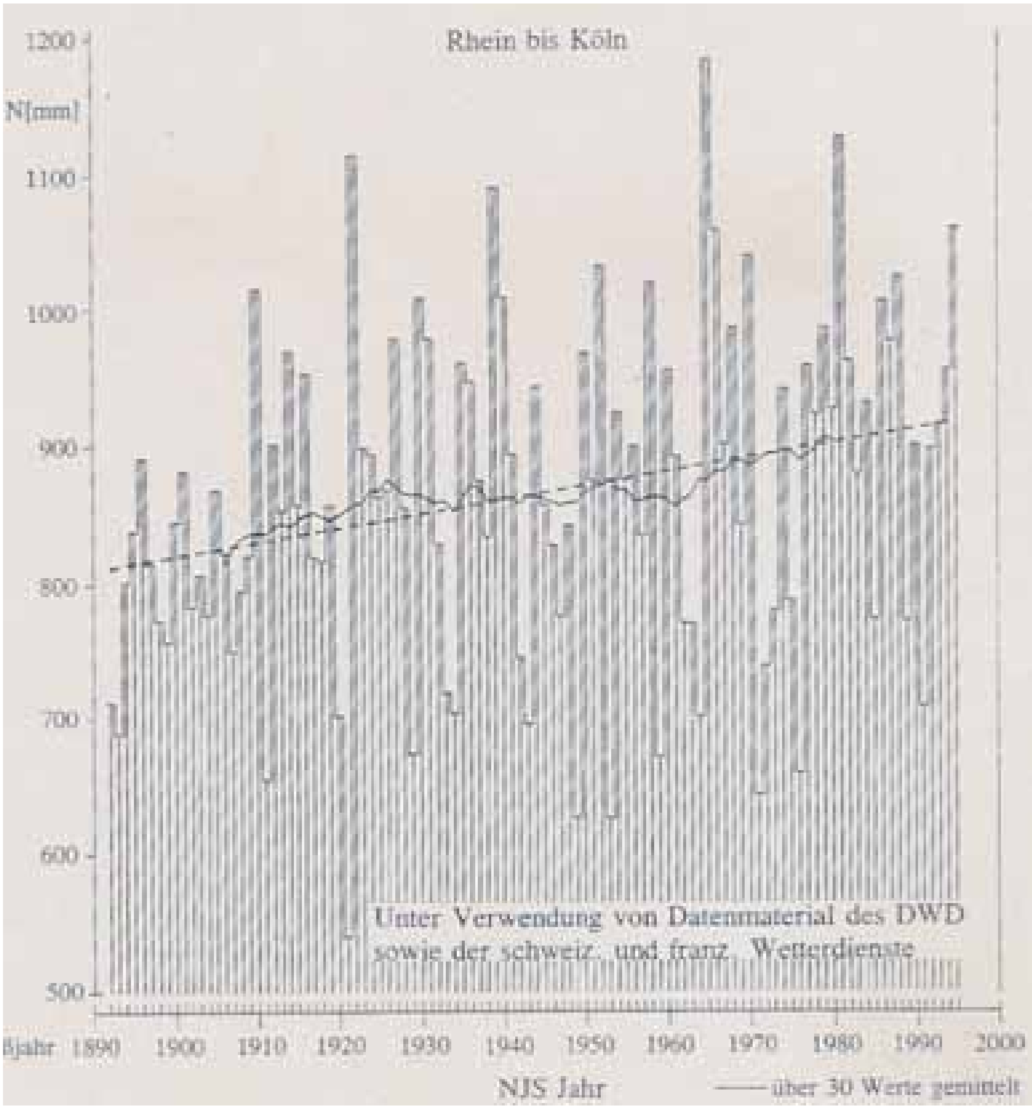

Fig. 15 Mean annual areal precipitation fort he Rhine basin upstream Cologne 1981 - 1995

1. 6. 2. Hydrology

a. Runoff regime of the River Rhine

The Rhine basin with an area of 185,000 km^2 and a mean annual discharge of 2200 m^3/s, is one of the most important river basins in Europe. The Rhine has its source in the snow and glaciers of the Swiss mountains and flows through Austria, Germany, France and Luxembourg to the flat lands of the Netherlands. On average, the Swiss Alps contribute 50 % of the total runoff of the Rhine. In summer, owing to snow and glacier melt, this contribution rises to 70%.
The components of the water balance in the Rhine basin are: precipitation 1100 mm, runoff 520 mm and evaporation 580 mm.
The runoff regime of the Rhine in the mountainous region is characterized by a large difference between low flow and high flow. The ratio between the lowest and the highest flow in the Swiss Alps is 1:68. Downstream the difference decreases noticeably, mainly owing to the storage capacity of larger natural lakes and anthropogenic factors such as artificial reservoirs.
At the border between Germany and the Netherlands the ratio is only 1:21. At Rheinfelden in Switzerland the Rhine has low flows during the winter months and high flows in June and July.
In Germany and France the Neckar, Main, Mosel and Lippe tributaries to the Rhine contribute low flows in the summer months and high flows during winter. The runoff regime at Rhine-Rees at the border between Germany and the Netherlands therefore shows high flows in January to March and low flows in August to October (figure 16). There is a great variety of runoff regimes within the Rhine basin. In Switzerland alone, 16 different natural regime types are recognized (figure 17).

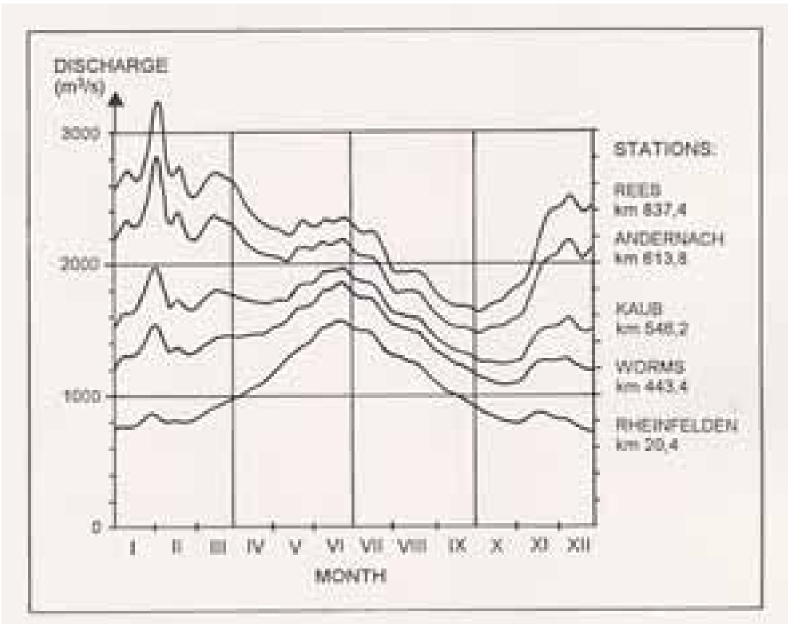

Fig. 16 Runoff regimes of the Rhine at selected monitoring stations

Figure 18 shows a hydrological profile of the Rhine from the Lake Constance to the Netherlands. It shows mean flood discharge MHQ, mean flow MQ and mean low flow MNQ for the sections of the Rhine between major tributaries. The pattern of mean specific flood discharge MHq is also shown. The mean specific discharge varies between 29 l/ km^2 in the Swiss mountains and 14 l/ km^2 in the Netherlands. These values are based on monitoring between 1951 and 1990.
In recent years the Rhine basin has seen more heavy floods than before, which have caused enormous damage. In 1987 a flood devastated large parts of Switzerland, causing damage in the amount of US$ 1,000 million. In 1990 and 1993/94 the countries along the Rhine suffered flood damage amounting to US$ 900 million. In January 1995 many towns along the Rhine and the Mosel were flooded. In the Netherlands, dykes were on the verge of breaking and several hundred thousand

people had to be evacuated. The damage incurred amounted to several billion US$. The reasons for these floods were:

- a long period of at times very heavy rainfall in many parts of the catchment area,
  insufficient retention of rain-water in the soil, which already held large quantities of water
- from earlier rainfall and/or, in the case of the winter floods, the fact that the soil was frozen and therefore impermeable,
- erosion, transport and deposit of sediments.

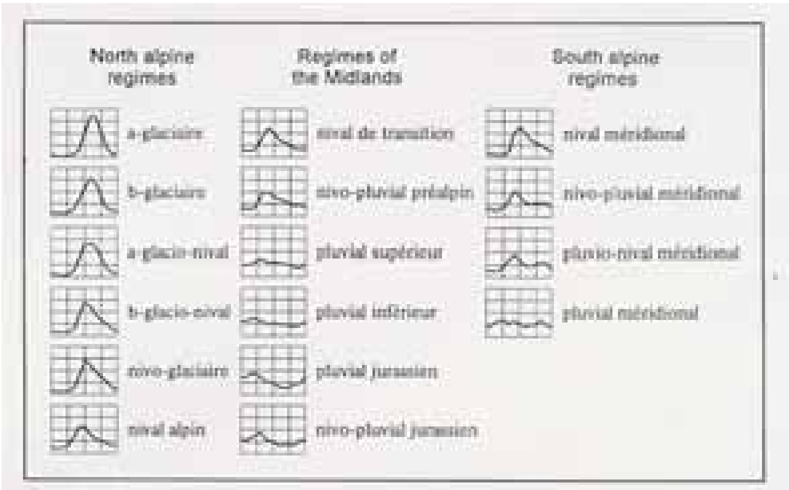

Fig. 17 Natural regime types in Switzerland

Apart from natural causes, floods are also influenced by man-made factors. The water balance can be upset by any changes made to the natural water retention of vegetation, soil and hydrographic systems, such as:

- sealing the surface through residential and industrial buildings and roads,
  reducing forested areas through clearance and damage to trees,
- damaging the ground water through agricultural practice which is unsuitable to local conditions,
- reducing water retention alongside rivers by canalizing them for the principal purpose of
- rapid drainage,
- reducing the area naturally flooded by building dykes.

On the other hand, flooding has been affected in a positive way in some areas through the construction of flood retention basins and the regulation of the water-level in lakes. The effects of these individual human-made factors on flooding vary for each section of the Rhine. They depend in particular on the size and characteristics of each local catchment area. Physical-deterministically reliable estimations of the effects of human intervention are only available in a few cases because of the complex correlations involved.

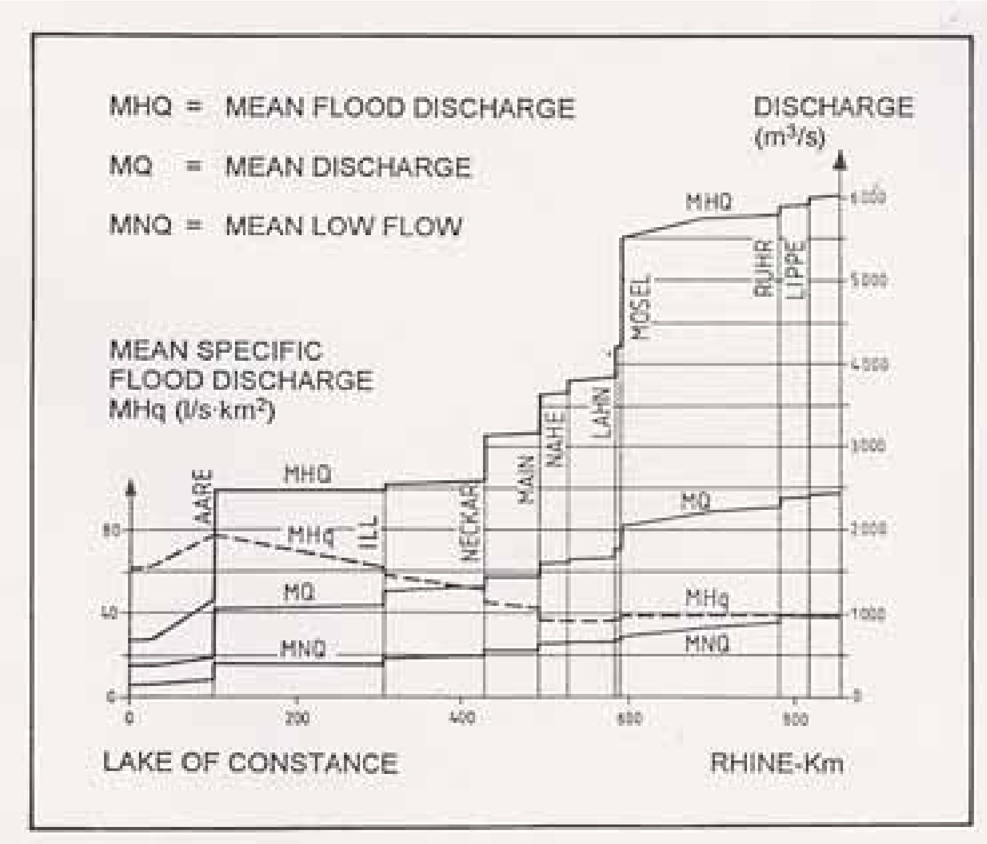

Fig. 18 Discharge of River Rhine

Table 5 Water-balance components of the extreme flood of 24th/25th August 1987 in the basin of the River Reuss

Component	Amount		
	mm	10^6 m³	%
Precipitation	182	151	100
Discharge			
– total	94	78	52
– direct runoff	49	41	
– from roads	0.6	0.5	
Evaporation			
– total	7	6	4
– interception by forests	0.6	0.5	
Storage			
– total	81	67	44
– snow	8	7	
– soil	60	50	
– flooded areas	4	3	
– reservoirs	9	7.5	

The causes and effects of the flood that occurred between 23 rd and 25th August 1987 in the 832 km^2 alpine catchment area of the River Reuss down to Seedorf have been examined in detail [LHG 1988; LHG 1991]. The water balance at the time can be described as follows:
From the rain that fell, 27 % flowed directly and 25 % indirectly, through soil transfer. The roads (sealed surfaces) in the catchment area contributed about 1 % of the direct runoff. The degree of interception of forest and, in particular, any possible modification of this effect owing to damage to the forest is not significant in relation to the water balance and in comparison with the mistakes incurred in measuring rainfall and runoff. The retention capacity of the soil was the most important regulating parameter for measuring the volume of the flood (see table 5). The following conclusions can be drawn:

- earlier rain, snow melt and temperature pattern all led to high runoff rates;
- total rainfall of 170 mm in 60 hours is rare in areas of over 800 km^2 in this region; the pattern of rainfall intensity played a decisive role;
- in comparison with previous weather patterns and the capacity of soil storage, which depend on the geological substratum, the influence of vegetation was negligible;
- the flood build-up was hardly influenced at all by human modification of the landscape.
- The rainfall levels and distribution created such unfavorable conditions that human-made factors could not alter the situation. Human intervention which reduces the retention capacity in the catchment area (deforestation, sealing the surface) can, however, drastically increase the frequency of average floods in the same catchment area. The storage of water in reservoirs helped to reduce peak discharge levels;
- debris flows and sediment brought down by the mountain rivers caused a large part of the damage.

Many investigations have been carried out in the Rhine catchment area to determine the medium and long-term changes in runoff in the area and to gain more knowledge concerning their causes. An example is given in figure 19 which shows the changes in water-balance components at Basle between 1901 and 1995. Average air temperature rose during the observation period by around 1.4 ac. Precipitation rose by approximately 120 mm, which constitutes around 8 % of the annual precipitation. A noticeable increase was observed in the I-hour maximum precipitation levels since the 1970's. Runoff increased on I y slightly (5 mm), while evaporation rose considerably (107 mm). An average annual rise of 1.5 pro mille was seen in flood peaks at Basle.

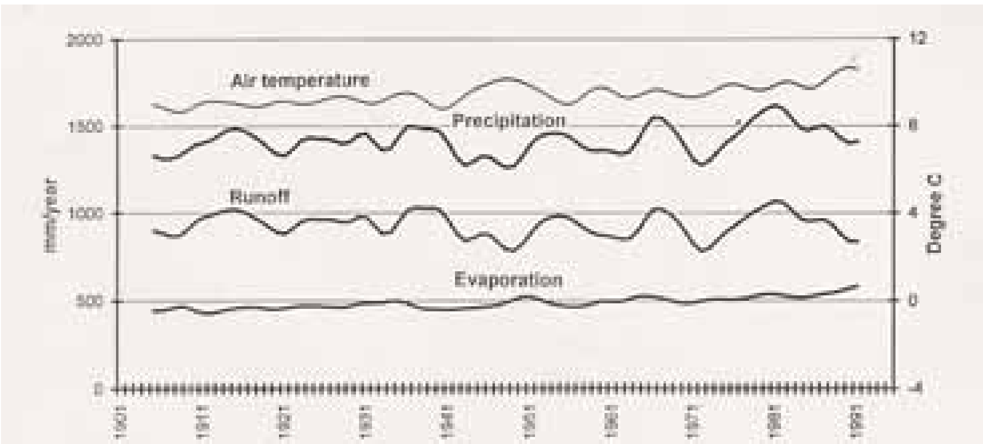

Fig. 19 Time series of air temperature and water balance components at Basle from 1901 - 1995

Similar trends have also been seen in long measurement series in Germany, where the rise in runoff was somewhat higher. As far as runoff is concerned, it must be added that it has risen at low and mean flow as well as flood flow.
The causes of these trends are changes in the river regime, climatic changes and human intervention. For example, it was observed that wind patterns have changed. A west wind is more common, which brings longer and more intensive precipitation. The increase in air temperature has led to a change in volume and temporal distribution of rainfall. It can also be seen that winter precipitation has risen and at the same time the frequency of snowfalls has decreased. The increase in air temperature has also

caused a considerable reduction in water reserves of glaciers and snow in the Alpine regions. The degree of frequency of flooding can of course also be considerably influenced, in a positive or negative way, by water management. For example, mountain reservoirs can reduce peak floods by retaining water.

2. Influence of climate change on the runoff regime

For several years, the International Commission of the Hydrology of the Rhine Basin (CHR) in co-operation with other hydrological institutions in Europe has been investigating the impact of possible climate change or land-use change on mean flow, flood and low flow occurrence. These projects should provide a basis for developing counteract strategies to the effects of global warming. Catchment models and a model for the entire Rhine basin have been developed or adapted for the studies.
In several catchments in Switzerland the repercussions of a CO_2 doubling on the water balance have been studied using the IRMB model [Bultot 1992]. This model is a daily conceptual hydrological model, developed by the Hydrology Section of the Royal Meteorological Institute of Belgium. It is able to simulate the components of the water cycle in medium-sized catchments with surfaces from 200 km_2 to 1500 km_2. It is not distributed, i.e. the input data must be considered as uniform over the whole area. The IRMB model is based on a sequence of sub-reservoirs representing the different main water storage of the catchments and transfer between them. The parameters of the model have been determined by fitting the daily values of the total flow at the outlet of the catchment. As input variables climate data (precipitation, net radiation, air temperature, air humidity, soil temperature at various depths, wind) and physiographical data (soil cover, albedo, leaf index, soil types, urban areas, maximum possible water content of the aeration zone) are needed (example table 7). The calculation of the daily increases in precipitation, temperature, radiation, water vapor pressure and cloud cover due to CO_2 doubling were calculated according to a method described in Bultot (1988).
The water balance components of the Ergolz catchment between CO_2 disturbed conditions and present climatic conditions for the years 1983 to 1990 are shown in table 5. The main conclusions are:

- Increased potential and effective evapotranspiration; consequential impact: a slight increase in biomass and agricultural production.
- Despite rising infiltration, decreased annual deep percolation water flow, the infiltration surplus being consumed by evapotranspiration.
- Increased seasonal runoff with no effect on the annual total flow at the outlet. Total flow is higher from December to February and lower from May to September.
- Increased daily maximum flow.
- Greater frequency of soil moisture content below 60 % of the saturation capacity in the aeration zone.
- Shorter spells with snow cover; consequently lower cost of snow-clearing operations but negative economical consequences for winter recreation areas.

The impact of human-induced global climate change on the Rhine discharge is simulated by the RHINEFLOW model. Changes in regional annual water availability and seasonal Rhine discharge have been estimated using climate scenarios. The climate scenarios are based on greenhouse gases emission scenarios. Two scenarios are used, which have been deve1oped for the Intergovernmental Panel on Climate Change: the Business-as-Usual (BaU) scenario in which current trends continue and a considerable growth in the use of fossil fuels is forecasted, and the Accelerated Policies scenario (AP), which represents adequate environrn~ntal policies and stricter international protocols. For both emission scenarios, three runs were carried out with the RHINEFLOW model. One uses the change fields for precipitation and temperature from the 'Best Guess". Best Guess uses the average expected change for temperature and the average precipitation from the weighed results for precipitation from the 7 GCM experiments.
In the two other runs the lower and higher 90 % confidence limit were used.

Table 6 Water balance of the Ergolz catchment. Increases between scenario 1 (CO_2 doubling) and scenario 0 (present)

Ergolz at Liestal scenariol -scenario O	Annual mean water balance (mm)								Mean
	1983	1984	1985	1986	1987	1988	1989	1990	
Precipitation	51.3	49.8	43.2	66.0	44.9	70.2	50.7	58.1	54.3
Potential evaporation	67.5	82.8	68.0	73.8	71.6	71.6	68.4	64.1	71.0
Effective evaporation	51.5	58.4	47.8	63.2	66.9	61.4	47.3	48.4	55.6
Directevaporation	10.9	12.1	4.0	11.4	16.1	18.3	7.1	9.2	11.2
Evap. upper aer.zone	25.3	27.9	27.7	37.1	38.2	27.9	23.4	26.2	29.3
Evap.lower aer.zone	15.3	18.2	16.1	14.6	12.6	15.2	16.8	12.9	15.2
Interception	10.9	11.5	4.6	10.4	16.6	17.9	7.1	9.2	11.0
Throughfall	40.3	44.2	33.5	54.5	28.0	52.1	43.5	48.8	43.1
Infiltration	14.5	26.7	21.7	35.9	27.7	3.8	32.1	17.7	22.5
Runoffwatersupply	26.0	26.6	11.8	20.1	-1.1	48.8	11.7	30.2	20.7
Deep percolation	-21.0	-22.0	- 22.8	- 13.7	- 27.5	- 36.2	-5.2	- 23.0	-21.4
Simulatedtotalflow	-5.0	-5.4	-8.8	6.4	- 27.8	- 13.2	8.2	17.8	-0.2
Direct surface flow	20.6	13.0	8.2	15.0	-2.2	36.9	9.0	20.9	15.2
Delayed surface flow	10.8	3.5	4.8	4.4	1.5	11.8	4.2	3.3	5.6
Percol.water flow	-36.4	-21.9	- 21.8	- 13.1	- 27.0	- 35.5	-5.1	.-6.4	-20.9
Extemalf1ow	-0.9	-0.5	-0.6	-0.3	-0.6	-0.8	-0.1	-0.2	-0.5

The RHINEFLOW model has been developed to investigate month to month changes in 'the water balance compartments in the Rhine basin. RHINEFLOW uses the standard meteorological input variables of temperature and precipitation and the geographical data on topography, land use, soil type and ground-water flow characteristics. These parameters are stored in a raster GIS with spatial resolution of 3 x 3 km. Calculations of evapotranspiration, runoff and snowmelt are based on the Thornthwaite-Mather method for actual and potential evapotranspiration and a temperature-index method for snowfall and snowmelt. The model separates monthly water surplus into direct runoff, which is discharged in the same month, and delayed runoff. Stream flow calculations are corrected by using data on lake water-storage changes and changes of water storage of glacier ice. The model produces time series for the river discharge. It also produces maps showing the temporal and spatial distribution of a number of hydrological variables such as potential and actual evapotranspiration, snowfall percentage and snow cover duration.

1. 7. Travel times

The travel time of a solute cloud in the river Rhine may be determined by different methods and models, all depending on the knowledge of mean velocities in the river. The more the information about velocities is known, the more the derived travel times are correct. By the means of a hydrodynamic model travel times in the river Rhine between the Lake of Constance and Bale were computed. These calculations were carried out for different steady flow conditions from low water to high water (fig. 20).
Diagrams allow the estimation of travel times between two river places (cross-sections). If there are unsteady flow conditions in the river, the travel time of a solute cloud is strongly influenced by the flow variations (fig. 21).

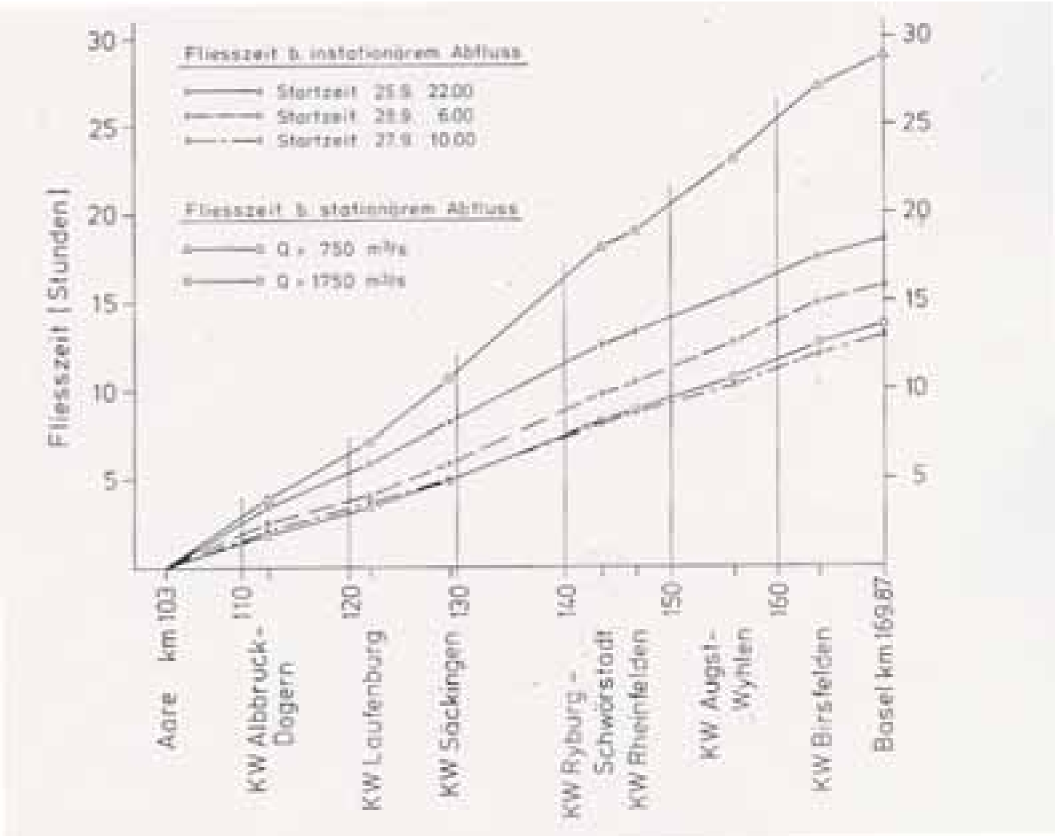

Fig. 20 Travel time compare calculations between the River Aare inflow to the Rhine and Basel

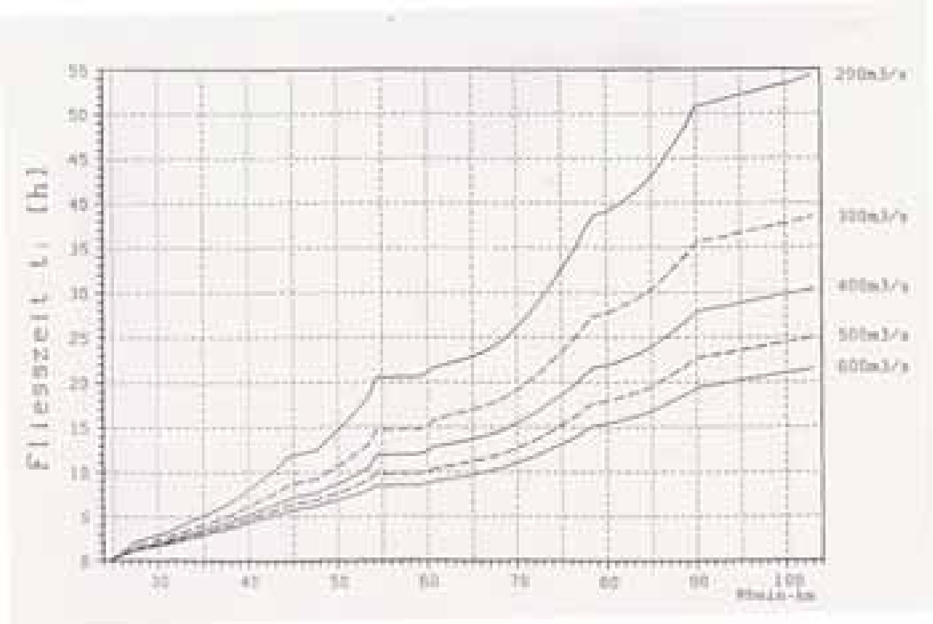

Fig. 21 Mean travel times of Rhine between Stein am Rhein and Aare inflow

1. 8. Hydrogeology

The morphological structure of the basin is somehow reflected in the structure of the groundwater provinces. Changing rock conditions cause also great local differences in groundwater flow. Only those groundwater provinces which play an important role in drinking water supplies are mentioned here.
In the Alpine region and partially also in the uplands, the long-stretched gravel-filled troughs in the valleys are exploited for water supplies.
The Upper Rhine Graben consists of Mesozoic strata with an overlying cover of marine, sandy-clayey Tertiary material of more than 2,000 m depth. The top cover in the central basin is formed by 200-400 m thick Quarternary deposits. These deposits contain extensive and productive aquifers.
A particularly groundwater-rich landscape in the Rhine basin is the Lower Rhine Embayment and the area of the eastern Netherlands. In the series of several groundwater storreys it is in the first line the upper one in the sands and gravels of the Pleistocene Rhine terraces that has the highest hydrogeological importance. The by far richest in water is the lower terrace on both banks of the present course of River Rhine between Bonn and the Netherlands consisting of 20 - 30 m thick sands and gravel that show good to very good water permeability. The lower terrace is in direct connection with the surface runoff in River Rhine so that besides groundwater abstraction from the 10-30 km wide terrace increasing use is made of bank ion in the vicinity of the river.

1. 9. Morphological Landscape Structure

In terms of elevation and morphologjcal structure the Rhine basin can be divided into the high mountain area (Alps), the Alpine foothills, uplands consisting of separate blocks of the Variscan peneplain and overlying Mesozoic strata, and the lowland. The mean elevation of the Rhine basin was calculated to be 483 m and the mean terrain slope 5°44'. The share of the Alpine high mountains amounts to more than 16,000 km_2. The highest peaks exceed 4,000 m above sea level. Several hundred km_2 are covered by glaciers, although glaciation is presently strongly receding.

Northwest of the high mountains the Swiss Midland stretches over some 220 km with an average width of 45 km and an area of about 10,000 km_2. The Swiss Midland consists mainly of Miocene molasse. In the north of the high mountains there is the basin of Lake Constance which is of glacial origin. Its centre is covered by Lake Constance. With an elevation of the water surface of 396 m above sea level the lake has a maximum depth of 276 m, so that the bottom of the lake at its deepest point is merely 120 m above sea level.

The Alps, the Alpine foothills, the Midland, and the Swiss Jura are the major landscapes of the Rhine basin downstream to Basel. Their share in the entire river basin amounts to some 20 %.

At Basel, River Rhine enters with a sharp bend the Upper Rhine Plain which extends from south to north. With an overall length of 300 km the Upper Rhine Graben has a mean width of 40 km. In the west and in the east along the Upper Rhine Graben, uplands extend which show over the foundation rock the complete series of Mesozoic strata such as Bunter Sandstone, Muschelkalk, Keuper, Lias, Dogger, and Malm of the Jurassic system.

North of a line Main-Rhine-Nahe, the Rhenish Slate Mountains cover an area of about 26,000 km_2 which drain nearly exclusively into River Rhine. In a 113-km long antecedent valley the Rhjne breaks through the Rhenish Slate Mountains between the towns of Bingen and Bonn. Simultaneously with River Rhine its tributaries Mosel, Lahn, and Sieg cut their antecedent valleys into the Rhenish Slate Mountains.

From north-west the Lower Rhine Embayment stretches into the Rhenish Slate Mountains. The landscape along the Lower Rhine is characterized by wide aggradation areas, remnants of the northern glaciation and sometimes thick loessial covers. According to its aggradation character the Lower Rhine Embayment is structured in the main terrace, the middle terrace and the lower terrace of River Rhine. On Dutch territory part of the river basin lies below the level of the sea.

1. 10. Soils

The formation of a soil type depends on a number of factors: parent rock, climate, groundwater conditions, soil humidity, land use, and relief influence on the development of a soil type. These factors vary widely in the Rhine basin, so that a variety of soil types occurs. Nevertheless, in the Alps, in the uplands, in valleys, and on the Lower Rhine larger areas of similar soils can be found. In the Alps soil-covers are mostly shallow, in the uplands braunerde soils prevail, and podzolic soils are frequent in the plains. How intensively the climatic conditions determine the formation of a certain soil is shown by the occurrence of chernozem soils in the area of Worms: Here favorable temperatures and relatively low precipitation have produced this soil type which usually occurs only in much more continental regions.

2. Users

In a larger basin, a large number of users have different needs and requirements. In small alpine catchments, uses and users of sediment related affairs might be different than those of larger lowland catchments. Below, stakeholders and their needs are presented for the two examples for small alpine and, and as a contrary, large lowland catchments.

2. 1. Stakeholders of small alpine catchments

In small and steep alpine catchments, interactions between uses and users and sediment related problems are mainly governed by the needs of protection against loss and damage (land, forests, settlements, traffic lines, etc.), power and water supply and construction. Other uses are conservation of nature like habitat protection and recreation (Fig. 22).

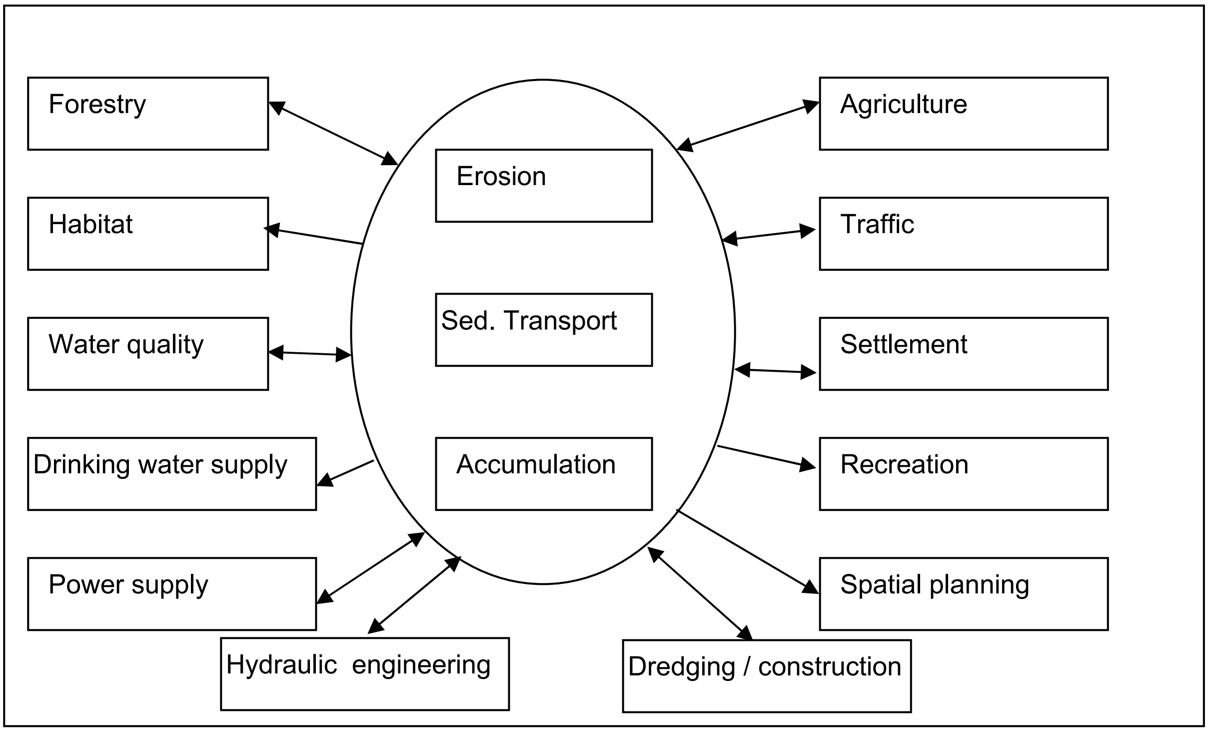

Fig. 22 Some of possible stakeholders in an alpine catchment; note that some relations are mainly one way relations (indicated by single arrow)

a. Needs for protection (mainly natural hazards, soil loss)

Sediment management because of protection requirements includes all stabilization and hydraulic works for erosion control, sediment retention and deviation and canalization. Also soft measures like forestation and bio – engineering are part of sediment management. Protection against natural hazards do also include measures like spatial planning (construction recommendations and restrictions, recently as a result of risk mapping). As all these measures except spatial planning influence the sediment flow as they are influenced by it as well (double arrow in fig. 22): size and design of a sediment retention basin for example is a function of sediment properties and inflow volumes (the construction of a basin is therefore influenced by the factor sediment). On the other hand, the basin interrupts sediment flow and might cause increased bed erosion downstream due to unsaturated sediment transport capacity (basin influences the factor sediment: erosion volume, accumulation and transport).

As a compare to natural hazard protection, soil loss as an agricultural damage is of minor importance, but needs special attention at places with relatively intensive agricultural production.

[Examples]

b. Power and drinking water supply (reservoir sedimentation, abrasion of turbines etc.)

In alpine regions, electricity is highly generated by waterpower. Therefore, users of water power face the following sediment related problems:

- Planning, construction and operation of water intakes (sedimentation, wood retention)
- Construction and operation of water power installations (choice of location, problems of accretion, wash out and erosion, bank protection measures)
- Infiltration and exfiltration

Turbines work properly only as they are driven by clean water. Sand and finer material result in abrasion and damage.

[Examples]

c. Construction (use of sediments, dredging)

Since ever, river sediments have been used for construction purposes. Dredging sediments out of river beds is a common practice to gain this popular raw material. Dredging is done where apparently enough sediment is available. Disadvantages of dredging are lack of sediment downstream, which often results in increased bed erosion with damage of hydraulic works, walls, bridge foundation etc. In the Rhine basin, dredging permissions have been treated restrictively in recent times. In addition, construction of infrastructural works is also essential:

- Planning of road and railroad construction (culverts, river crossings…)
- Planning, construction and operation of waterways for navigation and its infrastructure)

d. Other uses (habitat protection, recreation, environmental protection)

Natural river behavior with altering river banks and rich variety of sediment transport favors the development of diverse fauna and flora. Natural river stretches are also popular recreation spots for locals. Therefore, some specific uses might derived:

- Nature and landscape protection within the areas of influence of water
- Treatment of accretion problems in shallow waters (fishery)
- Watershed management (reforestation, stabilization of slopes)

2. 2. Stakeholders of large lowland catchments

Stakeholders of large lowland river systems have mainly the same interests and conflicts with sediment related problems as the population in alpine catchments. A supplement function is navigation for example (fig. 23), influenced by bed level alteration by erosion or accumulation of sediments.

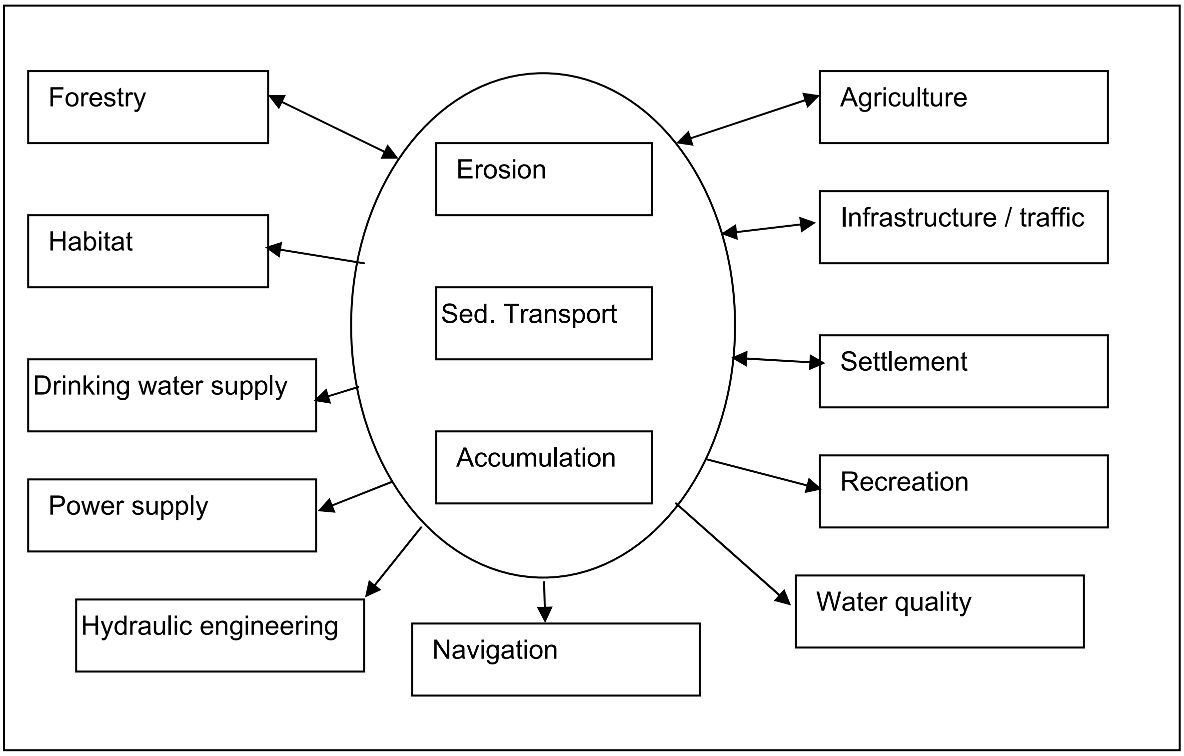

Fig. 23 Some of possible stakeholders in an lowland catchment; note that some relations are mainly one way relations (indicated by single arrow; altered after Owens et. al. 2004)

[Examples]

3. Problems related to Sediment Management

Problems that are faced by an efficient sediment management are described below. As sediment management varies depending specific question formulations, the following differentiation is made:

- Torrents and small alpine watersheds
- Large rivers at medium mountain range and lowlands
- Lakes and reservoirs

3. 1. Torrents and small alpine watersheds

Problem	Uses and solutions
1. Protection against damage Risk detection and -evaluation Flood protection by constructive measures Protection of receiving waters Assessment of sediment budget 2. Water conservation 3. Human impacts Intakes Roads, paths Watershed management Dredging Deposits 4. Research Basic research Applied research	Basic information to solve problems of planning, construction and operation in the following fields: Hydraulic engineering Stabilization works Retention Effects of torrents on their receiving waters Traffic routes River crossings narrowings bridges Sanitary engineering intakes, crossings, water protection Hydropower utilization intakes sediment and wood retention Watershed management conservation and improvement of the capacity of the watershed by measurements of agriculture and forestry drainage, afforestation Landscape protection, , planning of use and protection Risk detection Risk mapping Warning systems

3. 2. Larger River systems

Problems	Uses and solutions
1. Protection against damage Risk detection and -evaluation Flood protection by constructive measures Protection of receiving waters Assessment of sediment budget 2. Water conservation clogging 3. Human impacts Watershed use (e. g. road construction, bridges, power plants infrastructure for navigation) 4. Research Basic research Applied research	Basic information to solve problems of planning, construction and operation in the following fields: River control Stabilization of river bed and banks regarding tributaries and dredgings Traffic Roads and railways (river crossings, parallel tracks to rivers) Structures for navigation (waterways and ports) Sanitary engineering intakes, crossings water protection water purification water infiltration and exfiltration (groundwater) Power plants sedimentation and flushing, and erosion problems bank protection Fishery Passive flood protection flood warning (incl. flood wave warning) evaluation of danger zones (risk evaluation, risk mapping

3. 3. Lakes

Problems	Uses and solutions
1. Protection against damage Loss of volumes Sedimentation 2. Water conservation Clogging 3. Human impacts - Construction - Intakes of canals - Dredgings, earth deposits 4. Research Basic research Applied research	Basic information to solve problems of planning, construction and operation in the following fields: Hydraulic works Planning of structures (weirs, channel design) Hydropower Sedimentation Sand deposits and abrasion of technical structures Control of structures Fishery, traffic Sedimentation of ports and water ways Water supply Intakes Sediment and wood retention Sanitay engineering Supply of drinking water Wear of pumps Water intakes Clogging of filters Energy supply producing heat by heat pumps Recreation, sport Landscape and environmental protection

In the Netherlands the navigable depth and width is one of the main problems related with sediment management. So a description is needed of the requirements and the measures taken to fullfill these requirements.

Another important issue is the erosion of the riverbed. The upper part of the Dutch Rhine brances erode with appr. 2 cm/year. Untill now there are no measures taken to stop the erosion of the riverbed, but in the next years the erosion has to be stopped.

4. Necessary Sediment Observation

Sediment observations depend on the question formulation. The most common elements of sediment observation are lined out in (annex 1, still to be introduced). The table includes a list of most relevant processes, their influence by other factors, as well as considerations of human impacts. A short line out of methods to qualify and quantify the processes is also included. Besides the description of natural processes, methods to evaluate the processes are important as well.

Besides the methods, tools and devices enabling to qualify and quantify sediment processes and their effects as well as human interventions to sediment processes are an important component. Several categories of methods, tools and devices are therefore available, as there are among others (listing not complete):

a. Methods and tools:

- Assessment of sediment potential and sediment budget
- Sediment transport equations / programs
- Soil erosion assessment / calculation
- Mathematical / empirical models (rockfall, debris flows…)
- Risk assessment
- Remote sensing
- Chemical methods to prove pesticides, metals…
- Decision supporting systems (dss), such as GIS, excel programming etc…

The following sediment observations are again divided in torrent, river and lake observation.

4. 1. Torrents

Sediment observations	Supplements
Bed load Bed load potential Transportcapacity, (maximum bed load discharge) Bed load discharge during floods Bed load discharge graph Grain size distribution at flood events Bed load discharge of floods of different size (recurrence intervals) Suspended sediment Suspended sediment concentration Relation between water discharge and suspended sediment concentration Suspended sediment discharge Sediment features Grain size distribution Grain shape and petrography Specific weight Bulk density of accumulations Composition of material of debris flows Wash load Transported wood volume per flood event	Cross sections Longitudinal profiles of torrents and their changes with time Flood traces Accumulation volumes in and out of river bed Volumes of landslides and bank erosion Volumes of erosion in torrents Waterquality Channel roughness

4. 2. Rivers

Sediment observations	Supplements
Bed load Bed load potential Transportcapacity, (maximum bed load discharge) Bed load discharge during floods Bed load discharge graph Grain size distribution at flood events Bed load discharge of floods of different size (recurrence intervals) Suspended sediment Suspended sediment concentration Relation between water discharge and suspended sediment concentration Suspended sediment discharge Sediment features Grain size distribution (as function of place, time and water discharge) of moving and laying bed load and suspended sediment Grain shape and petrography Specific weight Bulk density of accumulations Wash load Transported wood volume per flood event	River morphology River shape (outlines) Cross section Bed shape (banks, Thalweg, etc.) and the changes by time including the features derived (Slope, accumulation and erosion volumes etc.) River bed roughness Water quality

4. 3. Lakes

Sediment observations	Supplements
Sediment in- and output Sediment load (to be determined in in- and outflowing rivers) Bed load - Delta survey Suspended sediments Suspended sediment concentration (as function of time and space) Turbidity profiles Composition of suspended sediments (grain size distribution, organic / inorganic, chemkical / mineralogical, clastic) Features of adsorption Sediments Sedimentation rate Volume change by redeposition and diagenesis of sediments Grain shape and petrography Composition of suspended sediments (grain size distribution, organic / inorganic, chemkical / mineralogical, clastic) Wash load Transported wood volume per time	soil mechanic parameters origin of sediments: rivers bank erosion rockfall landslides avalanches dust fall artificial earth deposits and intakes chemical and biogenic production dredgings survey of extraordinary events bathymetric surveys, delta formation sediment budget of catchment area water quality turbidity measurements flow measurements

In the Netherlands there is no regular sediment observation program. Only the level of the (summer) riverbed is measured each year with a multibeam loding system.
Occasional we organize (large) research projects to understand the sediment phenomena better. For instance to understand the morphological behaviour of the bifurcations and the morphological respons of bedstabilisation works. A short description of the results of such research project could be valuable for a case study.

5. Available Sediment Data

5. 1. Switzerland

5. 1. 1. Historic background

For about hundred fifty years, sediment observations have been carried out in Switzerland. Different thematic weighting can be found with time:
Bathymetry and delta surveys were carried out in the 19th century. The purpose was to achieve basics for water economical question formulations (waterpower, transfer of cords). On the other hand there was a geological interest (denudation, watershed modifications). Homogeneous survey methods and descriptions of the applied procedures were not yet so important.
The first studies on suspended sediments in Switzerland were made at the end of the 19th century in the river Arve during one year. Later on, more such investigations were carried out, however with different methods and quality. 1904 the Rhone river at was examined for a year, with special regard to suspended sediments.
At the beginning of the 20th century, measurements directly in the catchment area were done. Besides sediment transport, discharge processes were in the foreground, too. The Federal Institute for experimental forestry introduced the investigation fields Sperbel- and Rappengraben
During and immediately after the first world war, the first studies and the publications about sediment observations resulted, for example suspended sediment observations (Rhone, Port du Scex, Massa, Drance, Trient) and about sediment accumulations (river Aare at Bern).
Between the two world wars, more investigations on suspended sediments and delta formation were carried out. In addition, cross-sectional profiles have been taken at different rivers. The experimental watershed of Melera was established, mainly for sediment deposit observations in the retention basin.
After the 2nd world war, the works carried out up to the time were extended and complemented. Many delta surveys were in particular carried out with more modern survey techniques.
In the 70s of the last century, a subgroup "Sediment observation" of the Group for Operational Hydrology (GHO) was founded under the chairmanship of the Hydrological Survey. The aim was to achieve more results from detailed sediment observation to provide basics and information for practical use. In 1979, the GHO transmitted to this subgroup the task to elaborate a concept for future activities on the field of sediment observation in Switzerland. On account of this task, different studies and other activities resulted.

5. 1. 2. Sediment observations today

Since 1987, the Federal Hydrological Survey, the Federal Institute for Forest, Snow and Landscape and interested cantons have registered sediment deposits in retention basins. Goal of this program is the long-term and low-cost recording of the sediment output from small Swiss catchment areas.
Moreover, university institutes and private institutions carried out observations within the framework of studies and investigations in order to find solutions for particular problems concerning hydraulic engineering, and also to receive basics for model calibration or verification (table 7.
Today's sediment observations in Switzerland are concentrated on three levels:

a Surveys within the frame of a network, like the ones mentioned above (suspended sediment concentration (fig.24 sediment deposits in retention basins fig. 25. This survey is executed by the federal authorities (Hydrological survey, in the case of sediment deposits with the aid of many cantons).

The suspended sediment observation network consists at the moment of:
13 stations with each two samples per week
15 stations with periodic sampling (special campaigns))
2 stations with continuous sampling (several times per day).

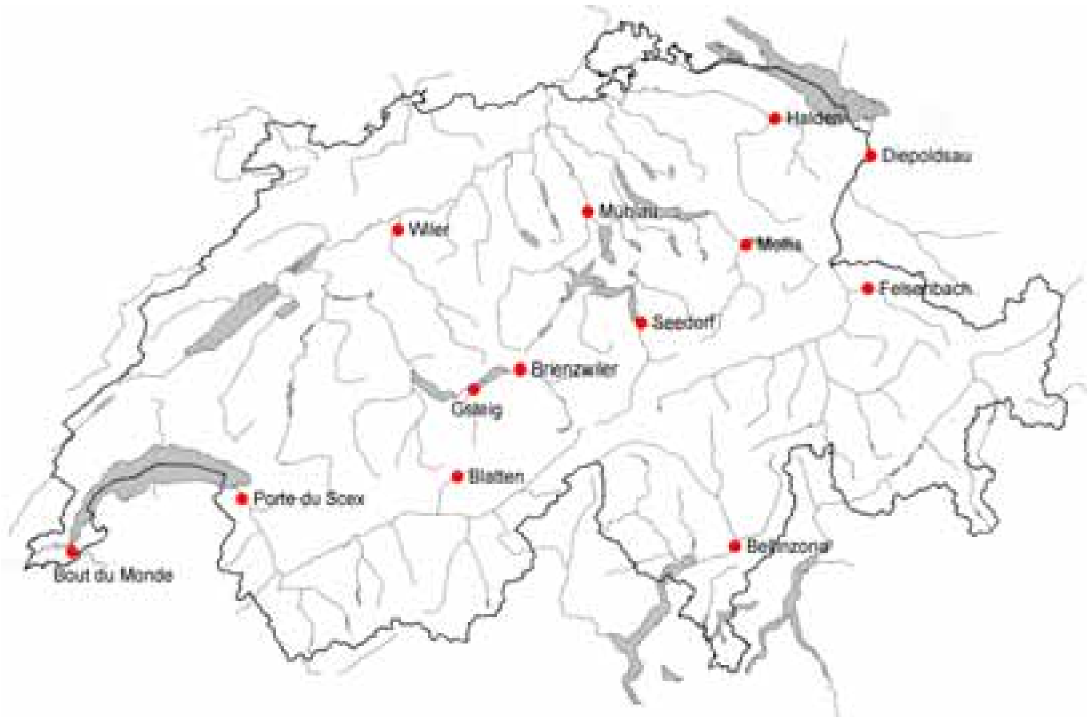

Fig. 24 Map of suspended sediment observation network

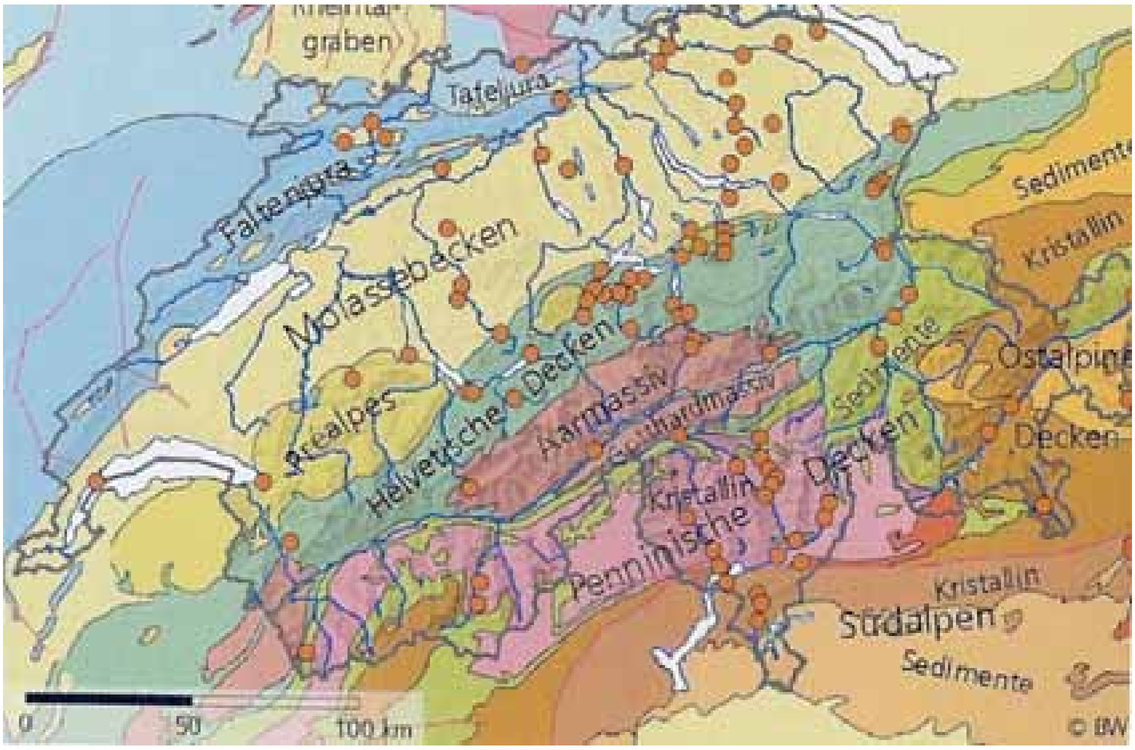

Fig. 25 bservation of sediment deposits in retention basins

b. Special surveys (on request or periodically), mainly executed by federal institutions (Federal Office for Water and Geology), also by universities and, to a small extent, by cantons.

This category contains mainly the already mentioned delta surveys, which recently have become rather rare due to financial problems and river bed surveys (longitudinal profiles and cross sections).
Further on, debris flow observation by the Federal Institute for Forest, Snow and Landscape is done at several sites.

c. Investigations carried through by private enterprises in the frame of special projects. Since recent times, federal and cantonal authorities ask comprehensive basic investigations for hydraulic and environmental projects. These special investigations include in many cases sediment transport assessment and calculations. The same has to be done by danger zone mapping.

Table 7 Overview of sediment observations carried though up to day in Switzerland

Sediment	Torrents	Rivers	Lakes
Bed load	Annual load estimations, sistematically in test sites only and within the GHO network Catastrophic events: Estimation of accumulation volumes or deposits in retention basins. Estimation of sediment transport of future events with aid of GHO (1996) “Hydrograph” of sediment (in test sites only)	Bed load discharge: Sporadic measurements Total load discharge: Only together with suspended sediments or or At scattered places	—
Suspended load	Suspended sediment load and discharge Systematically in test sites only	Suspended sediment concentration At many measuring stations Suspended sediment load Systematically in a few river stretches Suspended sediment discharge (at measuring stations)	Mean discharge of sediments for several years Sporadically in lake delta and retention basins Sedimentation rates By special inverstigations Properties o sediment By special inverstigations Suspended sediment budgets By special inverstigations
Special features	Grain size distributions, bulk density For special investigations	Grain size distributions sporadic investigations	Grain size distributions sporadic investigations
Wash load	Discharge of wash load Estimation at special events	Discharge of wash load Sporadically after flood events Ice discharge Sporadic estimations	Discharge of wash load estimations after flood events
Supplement observations	Erosion potential Sediment budget special method for its estimation	Cross sections and longitudinal profiles Every 10 years in many river stretches River morphology In single cases	Bathymetric surveys poradically Turbidity measurements At spezial cases

5. 2. Germany

Available Sediment data can be divided in:

Sedimentological and geological data of the river bed ,
bedload data, and
suspended load data

River bed:
Grain-size and petrographic composition of bed sediments, longitudinal section of grain-size composition, sedimentological description of bed surface (e.g. armouring, bedforms), structure of subsurface, depth of bedrock surface, geology of valley fill

Bedload:
Grain-size composition of bedload, transport rates, transport-discharge functions, monthly and annual bedload, longitudinal section of annual bedload, resulting bed elevation changes, comparison between water-level change, bed elevation change derived from bedload measurements and bed elevation changes derived from bed surveys (echo sounding)

Suspended load:
Concentration of suspended sediment, daily, monthly, and annual suspended sediment loads, suspended sediment yields, longitudinal section of suspended sediment loads, grain-size composition of suspended sediment (especially portion of sand), mineralogic composition, and organic portion of suspended sediment, vertical and lateral distribution

Data are collected, evaluated , and stored by the Federal Institute of Hydrology (BfG). Suspended load data are partly published in the German Hydrological Yearbook

5. 3. Netherlands

a. Bed levels

Every year since 1930 of all the Rhine branches, except the tidal area. In the tidal area the river bed is loded every ten year.
Since 2002 the riverbed is loded with a multibeam system. Before 2002 a single beam system was used.

b. Available sediment data:

The morphological behaviour of the bifurcations (see annex 2)
Bedload measurements during floods and mean discharge with the Helley Smith at the Bifurcations:
Pannerdensche Kop
Ijsselkop
Bifurcation of the Merwedes in the lower parts of the river.
High resolution multibeam in the three bifurcation, in the same period as the bedload measurements. This to indicate the translation of the sanddunes and to calculate the bedload in the individual branches of the bifurcations and compare it with the bedload measurements.
Suspended load measurements. In the same period as the measurements mentioned above. The system used is described in the report of the joint (DI, SU, NL) sediment measurement in 1998 (Feststoffmessungen zum Vergleich von messgeráte und Messmethoden im Rhein).

Occasional survey from the subsoil of the dutch Rhine branches in 1976, 1984 and 1995. See example figure 26

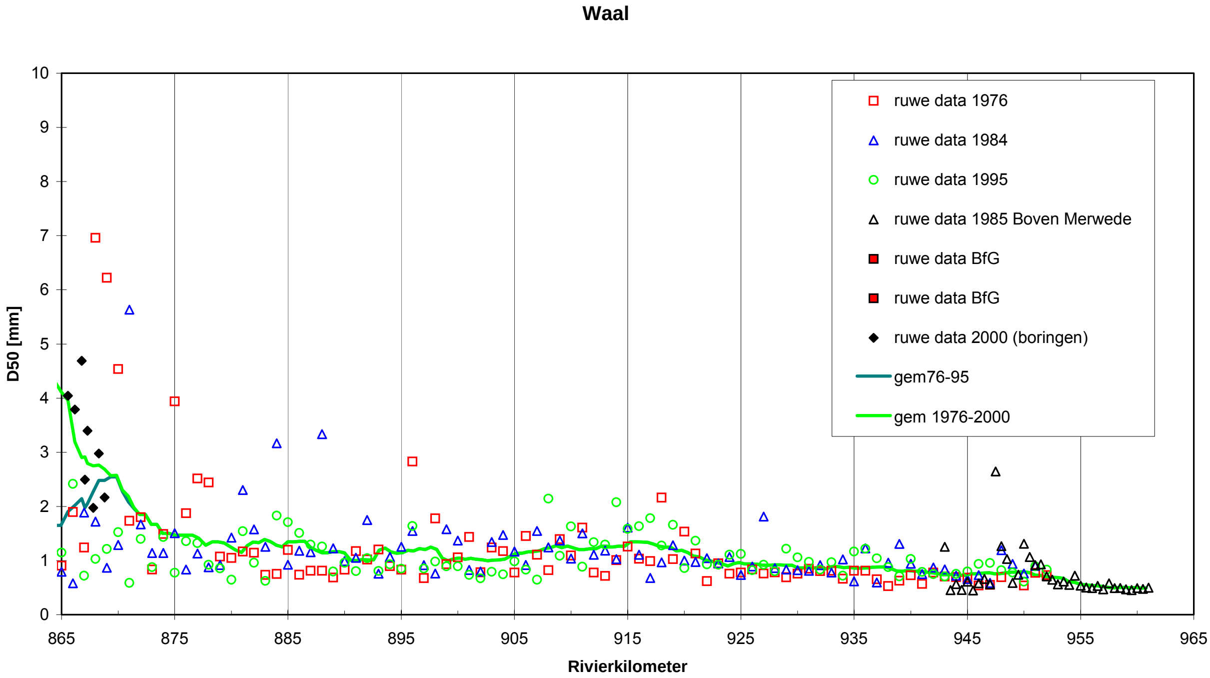

Figure 26: Survey of the D50 of the subsoil of the Waal

6. Monitoring Equipments and Methods

6. 1. Switzerland

6. 1. 1. Bed load

Hydrophones
The direct measurement of the bed load in torrents is limited today to few test sites. There are three measuring stations with hydrophones in operation in the Swiss Rhine basin.
Installations with underwater microphones allow a continuous recording of the bed load discharge.
The sensor is positioned at the bottom of a steel slab that is installed in a concrete check dam. The most important element of the sensor is a piezoelectric crystal. If stones roll over the steel slab, the strokes of the stones cause oscillations which are transmitted onto the piezoelectric crystal. The oscillations make a tension in the crystal which is amplified and measured. From the size of the tension can be concluded to the strength of the stroke. An impulse is registered each time the tension exceeds a minimum value (boundary value). The number of impulses measured per unit time is a measure for the intensity of the bed load transport (fig. 27).

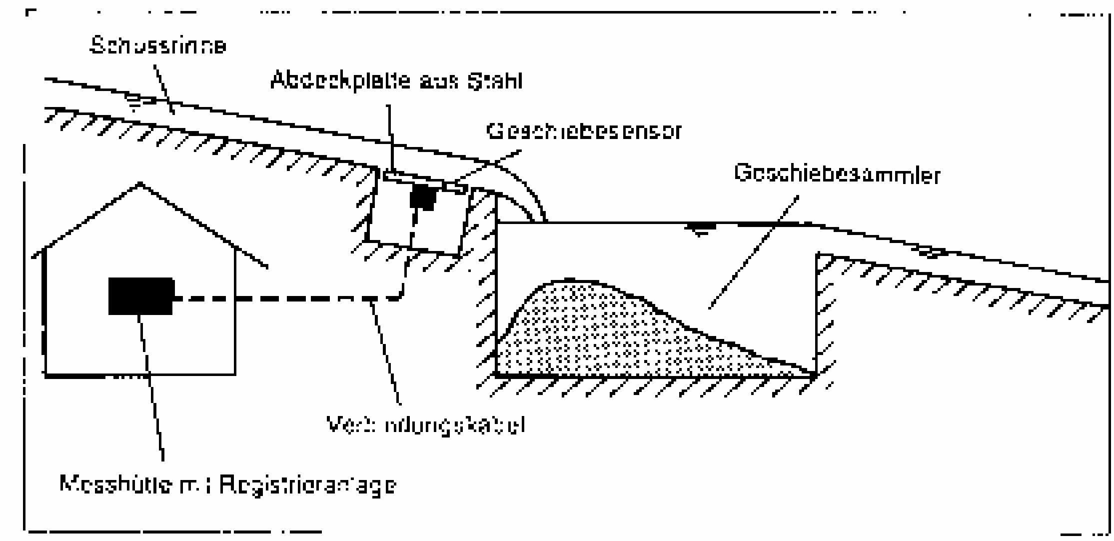

Fig. 27 Schematic sketch of a hydrophone installation

Sediment retention basins
The relevant possibilities of volume determination in sediment retention basins are measurements of cross sections and determination of volumes of the transported material by trucks during clearance.

6. 1. 2. Suspended Sediment

Suspended sediment concentration can be determined by direct measurements. The measurements with manual withdrawal devices provide in a specific point of the measuring section a quasi current concentration value. Further punctual samples have to be taken in order to determine the concentration values for a mean concentration at the cross section. This means a large expenditure to time and personnel.

[Examples]

6. 2. Germany

6. 2. 1. River bed

Echo sounding (single beam and multi beam), seismic survey, drilling and sounding, direct investigation of the river bed by using a diving bell craft, grab sampling

6. 2. 2. Bedload

Network of stations , bedload sampler (Koblenz-Arnhem), sampling 4-5 times per year at the individual stations, establishing of transport-discharge functions and connecting those with the hydrograph, video controlling of bedload transport, vessel based measurements, combination with suspended load measurements

6. 2. 3. Suspended load

Network of monitoring stations with daily bucket sampling (5l), Filtration and gravimetric determination of suspended sediment concentration

Additionally pump sampling of suspended sediment and simultaneous velocity measurements in different depths and at several points in the cross section during bedload measurements (4- times per year at the bedload measuring sites), separation of sand fraction

Turbidity meters are used for continuous monitoring and for special investigations.

[Examples]

6. 3. Netherlands

See report Feststoffmessungen zum Vergleich von Messgeräte und Messmethoden (1998) and Feststoffbeobachtung im Rhein (Beschreibung der Messgeräte und Messmethoden) (1996)

[Examples]

7. Estimation Techniques

7. 1. Switzerland

7. 1. Recommendation for the Assessment of Sediment Yield in Mountain Streams

The following recommendation for the assessment of sediment yield in mountain streams can be considered as a contribution to the understanding of mountain stream processes and describes a method for the assessment of a future mountain stream event. The method was developed by the the Geographical Institute of the University of Berne in association with the Swiss National Hydrological and Geological Survey and the Swiss Federal Office for Water Economy. For the recommendation, it has been attempted to collect the current information into a practical guide for specialists who are familiar with hydrological, geological, geomorphological and hydraulic engineering issues and have specific problems to solve in the area of mountain stream processes.
The recommendation consists of two volumes. Volume 1 contains a description of the method and volume 2 discusses the basic technical background knowledge. The calculations can be done with the aid of a computer program.

With this method the sediment yield of an event can be assessed in the following manner (figure 28):

Preparations

The main part of the preparation work can be done in the office and involves the following:

- a preliminary examination of the transport process which involves an ascertainment of the mountain stream's capability for debris flow, using available documentation, descriptions of past events, maps and aerial photographs.
- a preselection of the most important sediment sources that can be determined using maps and aerial photographs.
- for „no debris flow mountain streams" and in the case that no measurements are availible: construction of a simplified hydrograph to calculate the sediment transport capacity of the channel.

Field Work

In the field the following has to be undertaken:

- assessment of the channel's capability for debris flow, in case that this is not known.
- division of the mountain stream into channel sections. In each channel section the following has to be undertaken:
    - estimation of the sediment potential of the main sediment sources.
    - estimation of possible deposits
    - mapping-out of cross sections with slope, bed width and d_{90} d_{50} d_{30} of bed material for „no debris flow mountain streams". These parameters are used in the calculation of the transport capacity.

The significance of a sediment source can be judged using the following two criteria:

- Material composition

  Sediment sources consisting of loose material are important. Those originating from bedrock are less important, unless the rock is easily erodible and slaty, as the sediment discharge in the channel (e.g. from a rock slide) is not directly related to a flood event in the mountain stream.

- Location of the sediment source and transport path of the material in the channel

  Sediment sources of loose material lying near the channel will be eroded during an event and are to be considered of great importance. Mountain streams with large sediment sources in the channel area tend to be especially active. As a rule large sediment volumes are to be expected.

The transport path for sediment sources outside of the channel area is important. Large sediment sources such as talus cones, open erosion scars, etc. are meaningful when their material is able to directly reach the mountain stream via side channels or gullies.

For sediment sources that do not have a direct path of connection to the channel, the slope gradient plays an important role. If the gradient of the slope is less than 30°, then the material tends to come to rest on the slope from where it can be eroded at a later time.

Analysis

Back in the office an analysis of the data can be carried out that involves a detailled calculation of the sediment yield and a check of the field investigation (plausibility check).
For each channel section the following is calculated:
the sediment potential
the sediment transport capacity using the hydrograph (not applicable for „no debris flow mountain streams")
the volume of possible deposits
and for each cross section moving downstream the difference between the sediment potential and the transport capacity taking into consideration the deposits. These differences are then summed together to create a sediment budget (Figure 29). At the last cross section the volume of the sediment yield at the cone is found.
In the case of debris flow mountain streams these calculations cannot be done in as much detail as there is no way of calculating the transport capacity of debris flows. The sediment and deposit potential in each channel section is recorded so that the sediment budget can be constructed on a channel section basis.

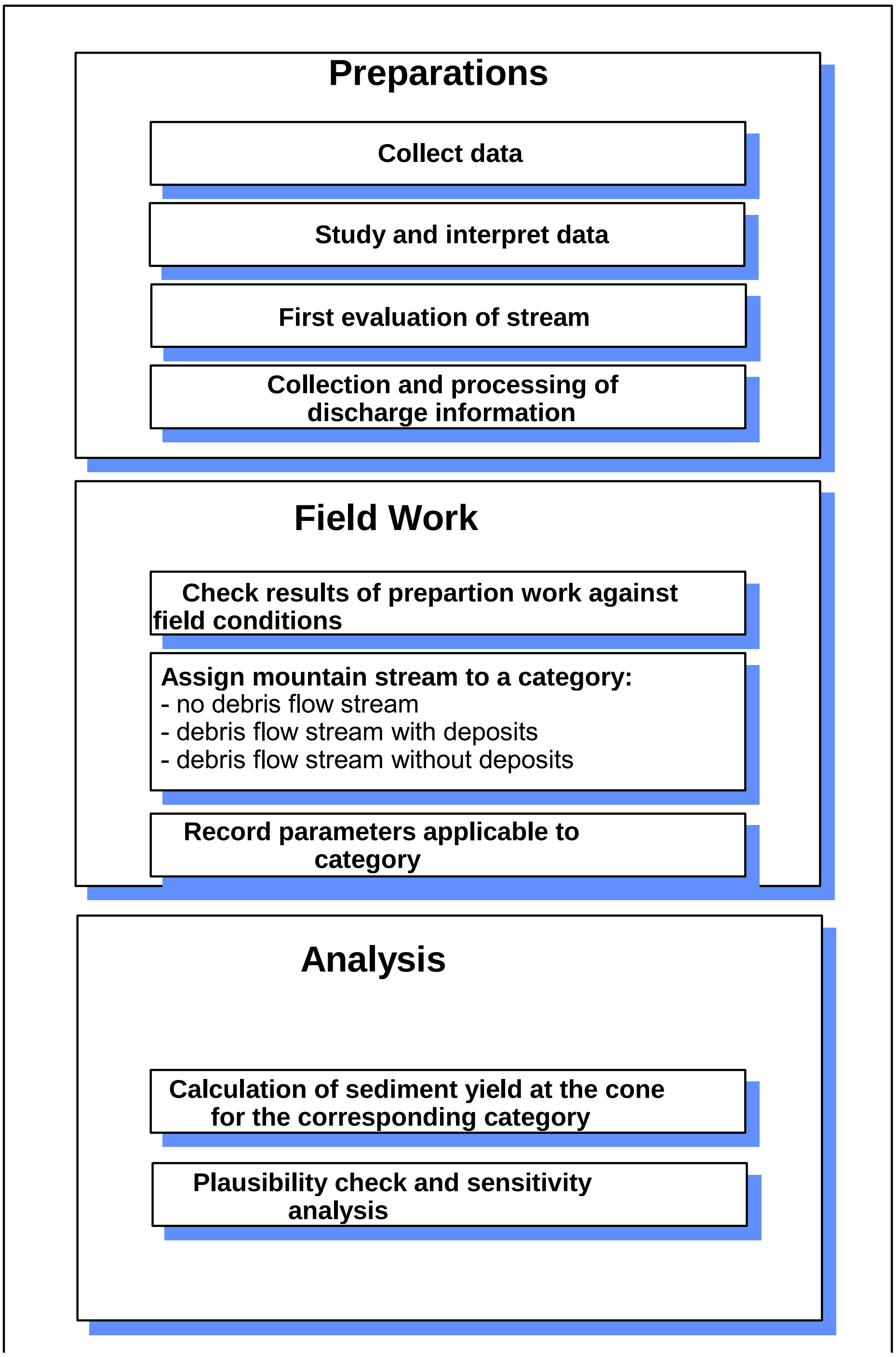

Figure 28 Overview of the Steps required for the Assessment of Sediment Yield

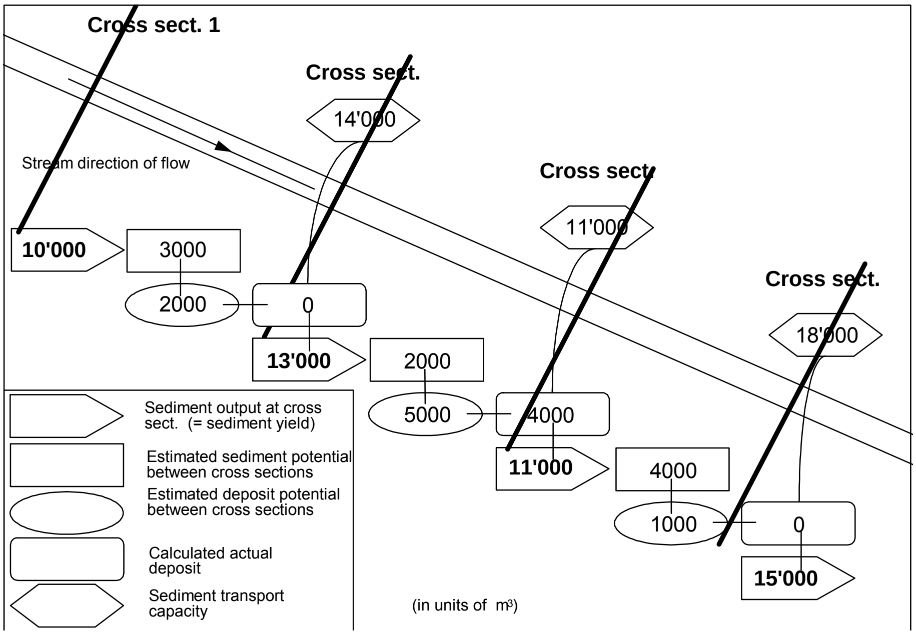

Figure 29: Determining the Sediment Yield in Mountain Streams

Results from the Calculations

Figure 30 is an example representation of the result of calculations which were done for the Guppenruns in the canton of Glarus. The flow of the stream from cross section no. 21 (gorge) down to mouth at the Linth (no. 1) is plotted in the diagram. The larger natural deposit points (to be observed at cross sections 19, 18, 13, as well as 8 and 7) are not sufficient to reduce the sediment input in the Linth so that the danger of damming can be ignored.

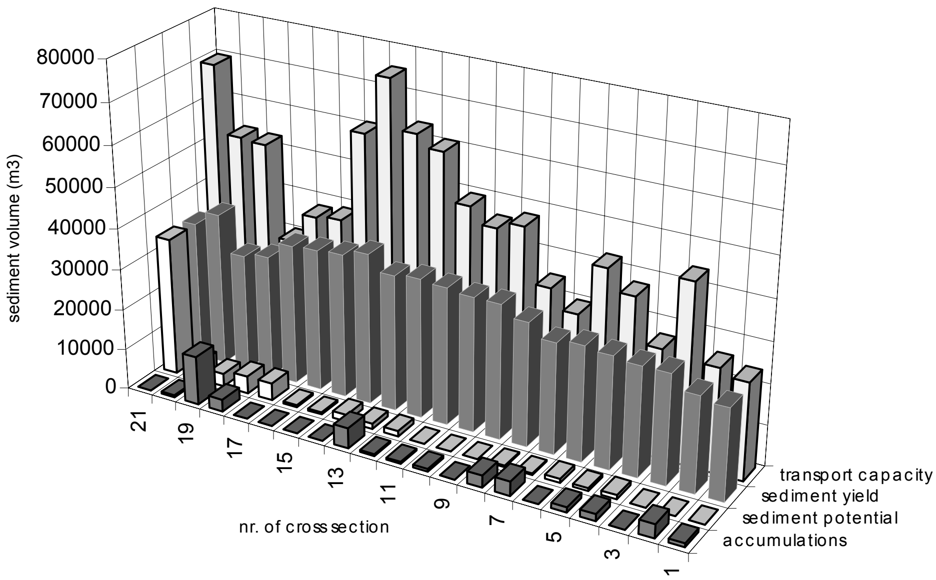

Figure 30: Sediment transport during a large event in the Guppenruns, canton of Glarus

So it is possible that much material could be deposited at the fan (cross sections 2 and 1) and cause damage there. It was shown that planning a bed load deposit area near cross sections 8 and 7 together with further retaining measures (near cross sections 14 - 12) can drastically reduce the sediment yield of a large event which would practically prevent a possible damming of the Linth.

7.2. Germany

To derive bed elevation changes from the deficits and surplusses of the sediment budget it is necessary to incorporate the morphologically active portion of suspended sand into the bedload budget. This portion is estimated to be one third of the entire suspended sand.

[Examples]

7. 3. Netherlands

There are several techniques that are used in morphological river studies:

One dimensional Models (graded and not graded). There is a 1D morph. model for the whole Rhine in the Netherlands.

Two dimensional morph. models : for some study areas there is a two dimensional morphological model available. On this moment an ongoing study looks for the possibility to build a two dimensional (graded) morphological model for the Dutch Rhinebranches.

Analytical models to understand phenomena as the propagation of large scale bedforms.

Sediment balance studies for the extrapolation of the bedlevel developments etc.

[Examples]

8. Legal, administrative and organizational aspects

8. 1. Laws

8. 1. 1. Switzerland

The federal constitution of 1874 (FC) proves that it has been recognized how important the protection of the living space before floods was already at that time. In article 24, the federation was assigned the superintendence over hydraulic and forest police. The same time, the possibility to financially support water correction works was imposed.
In 1877 with the Water Surveyor's law, the first federal law in the field water resources management was created.
Some Swiss laws in historical order are lined out in table 8.

Table 8: Laws and resolutions in Switzerland, in favor of the protection of human and nature

Year	Law / resolution
1804	Resolution of the “Tagsatzung” about the Linth correction
1848	Art. 21 of FC about public works
1874	Art. 24 hydraulic and forest police
1877	First federal water surveyor’s law, use of waters
1908	Art. 24bis of FC use of waterpower
1916	Second federal law (water law)
1919	Art. 24ter of FC navigation; protection of waters
1953	Art.24quater of FC water conservation
1955	Third federal law water conservation law
1975	New article for water economy in FC: as base for: (also retrospectively):
1971	Federal law about water conservation (qualitative protection of waters)
1992	Law of 1971 revised, (for example for a minimum residual water discharge)
1991	New law on hydraulic works.

Besides the federal laws, there are the cantonal laws, which might vary in details from federal law, but without being contradictive.

8. 1. 2. Germany

There are several Federal laws for the protection of water resources, soil, and other environmental issues, but due to the Federal system in Germany the executive competence for water resources management belongs mainly to the individual states.
In this context responsibility for sediment management in Germany is split regionally in waterway reaches (large rivers and canals) and remaining streams. Responsible for the latter are the water boards of the individual states, whereas the Federal Ministry of Transport, Building and Housing and its subordinate authorities like the Waterway and Navigation Administration operate at the waterways.
The relevant national laws concerning water and sediment are the Water Management Act (WHG) and the Federal Waterways Act (WaStrG), but for certain management activities the Environmental Impact AssessmentAct (UVPG), the Federal Soil Protection Act (BSchG), and the Closed Substance Cycle and Waste Management Act (KrW-/AbfG) have to be considered.
Since 2002 the European Water Framework Directive has come into force. In consequence the Water Management Act has already been adapted to the new European directions. Adaption or modification of other national regulations to European law will follow.

8. 1. 3. Netherlands

[still to describe]

8. 2. Regulations

8. 2. 1. Switzerland

The regulation about hydraulic engineering of 1994 (Wasserbauverordnung WBV) regulates financial support and priorities for the construction of protective works. The evaluation of basic data is also regulated, as by federal authorities as well as by cantons.
The regulation about water conservation (Gewässerschutzverordnung, GSchV) protects all waters from negative impacts and enables their sustainable use.
The forest regulation (Waldverordnung, WaV) of 1992 regulates the use of forests in the country. As forests have also a protective function against natural hazards (erosion, landslides etc.) the forest regulation confers the elaboration of basics in the field of risk assessment (mapping etc.)

8. 2. 2. Germany

Concerning dredging and disposal of contaminated sediments there is an internal regulation of the Ministry of Transport „Handlungsanweisung für den Umgang mit Baggergut im Binnenland(HABAB-WSV). The deposition of dredged sediment on land is subject to the Federal Soil Protection and Contaminated Site Ordinance (BbodSchV) or the EU-Dump Directive. Some states in Germany have established individual regulation for handling dredged sediments.

8. 3. Bilateral an multilateral agreements and treaties

17th of March 1992, the riparian states of the Rhine basin ratified the basic agreement about the protection and the use of international rivers and lakes. This basic agreement obligates the riparian states

- to avoid, control and reduce water pollution
- to use transnational waters in an environmentally compatible way and protect water resources
- to use transnational waters in a reasonable and fair way
- to secure the protection and at all events the restoration of ecosystems.

8. 4. Cooperation in international River basin committees

Because of the significance of the Rhine River basin various international commissions have been active for some time already. A survey on these Commissions and the scopes of their work is given in table 9.

Table 9 International organizations in the Rhine River basin

Name	Task	Activity
KHR International Commission for the Hydrology of Rhine basin	Support of co-operation of the scientific hydrological institutes and hydrological services in the Rhine basin Promotion of data and information exchange in the Rhine basin Standardization of data in the Rhine Basin countries	Comparison of hydrological models and instruments Forecasting of floodwaves Flood analysls Investigations on sediment transport Geographical Information System Rhine Influence of climate change on runoff in the Rhine
IKSR International Commission for the Protection of the Rhine	Investigations on sources, transport and sinks of pollutants Recommendations for the govemments of the Rhine basin countries Drafting contracts for the protection of the Rhine Realization of govemmental Agreements Plan of action related to floods	Investigations on pollutants in the water, flora and fauna of the Rhine Biological and chemical monitoring Research on ecomorphology Investigation on point and non point sources of pollutants Alarm modelling Surveillance of emissions
IKSMS International Commission for the Protection of the Mosel and Saar	Investigations on pollution of the rivers Mosel and Saar Recommendations for the Governments of the riparian countries States Realization of governmental agreements	Research on ecosystems Planning of measures against pollutant inputs Standardization of measuring systems Inventory of main pollutants and their reduction Alarm modeling
IAWR International Association of Water Treatment Plants in the Rhine Basis	Monitoring of water quality Standardization of water analysis concerning drinking water supply Improvement of water quality	Comparison of techniques used in water treatment plants Comparing and standardizing of analytical procedures Investigation on techniques for the improvement of the quality of drinking water
IGKB International Commission for the Protection of Lake Constance	Monitoring of the water quality of Lake Constance Recommendations for the riparian countries Advice concerning future antipollution measures in the basin	Promoting research on water quality and limnology Continuous evaluation of water quality Planning of further use of water (drinking water supply, recreation)
ZKR Central Commission for Navigation on the Rhine River	Cooperation of the riparian countrics with regard to Navigation , maintenance of on the waterways standardization of technical/policy guidelines	Individual working groups draft proposals and supervise navigation on international waterways within the Rhine basin

8. 5. Organizations, responsible for monitoring

8. 5. 1. Switzerland

Sediment monitoring is executed by the Federal Office for Water and Geology…..

8. 5. 2. Germany

Sediment monitoring at waterways is controlled by the Federal Institute of Hydrology (BfG), at the remaining streams by the State Agencies for Environment. These Institutions also operate the data bases for water and sediment. Sampling and measuring are done by the Water and Navigation offices and the offices for Water Management of of the states respectively.

8. 5. 3. Netherlands

The national government departments involved in integrated river management are the Ministry of Transport, Public Works and Water Management (Dutch initials: V&W), the Ministry of Housing, Spatial Planning and the Environment (VROM), the Ministry of Agriculture, Nature Management and Fisheries (LNV) and the Ministry of Internal Affairs (BiZa). BiZa's involvement is in the field of crisis management. At the regional and local levels there are of course the provinces and municipalities and the water authorities and water purification boards. Various nongovernmental organizations (NGOs) have important roles as well, generally representing the interests of particular groups. Yet another aspect is the involvement of the business community in the implementation of policy.
Across the river basins, international policy is coordinated through organizations such as the International Commission for the Protection of the Rhine (IRC), the International Commission for the Protection of the Meuse (ICBM)

and the Scheldt against pollution, the International Working Group for Flood Protection on the Meuse (WHM) and, in the field of shipping, the Central Rhine Navigation Committee (CCR). Various bilateral working agreements also exist at national, regional and local level.
The highest level of collaboration is through the European Union (EU). Legislation from Brussels, such as the framework directive Water, will in the future become increasingly important.

9. Examples

9. 1. Switzerland

In recent years, there was a number of sediment related studies executed in the Rhine basin in Switzerland (refer to chapter 5). The following examples serve as a selection and are not a comprehensive recital.
Each of the three examples shown below represents a special category of investigation:

- Numerical simulation of sediment transport (Alpenrhein)
- Comprehensive study of sediment budget (Emme river, Canton of Bern)
- Assessment study of sediment yield in a small alpine watershed (Lütschine, Bernese Oberland)

1. The Alpenrhein investigation

The first comprehensive investigation on the bed load transport of the Alpine Rhine carried out in the thirties and forties at the Laboratory for Hydraulic Research and Soil Mechanics at the Swiss Federal Institute of Technology, Zurich.
Until 1970 all construction measures undertaken on, and gravel withdrawal from this mountain river aimed at lowering the river bed or at least preventing further gravel deposition. An increase in discharge capacity was desired for flood protection reasons. With time the initially desired, but unfortunately further continued lowering of the river bed took on such an extent that the stability of bank protection measures, dams or bridges were endangered. Because of these artificial measures along different sections of the Alpine Rhine a transition took place:
Reaches with sediment deposition turned into reaches with erosion.
Until 1988 all gravel withdrawal except for at three locations, in the Alpine Rhine was stopped to prevent or at least to slow down the undesired erosion. Gravel withdrawal at the confluence of the Upper and Lower Rhine Rivers and at the mouth of the tributaries Plessur and Landquart still take place. Additionally several boulder ramps were built to stabilize the river bed, for instance at Felsberg, at Chur, at the Ellhom and at Buchs (fig. 29).
The stakeholders in the Alpine Rhine have various interests. The Rhine serves for example as a source of gravel for construction material and hydroelectrical power.
To serve these two interests the bed load budget of the Alpine Rhine between Domat/Ems and the mouth into Lake Constance was investigated with the numerical model MORMO (figure 31). The numerical model first had to be calibrated with effective discharges and with the river bed alterations observed. The period between 1-1-1974 and 31-12-1988 was chosen for the calibration. With this calibration procedure a range for the characteristic grain diameters of the bed load and a corresponding range for the bed load inputs into the Alpine Rhine for the calibration period could be determined. The resulting mean annual bed load inputs were: up to 15'000 m^3 at Domat/Ems, 35'000 to 65'000 m^3 from the tributary Plessur, 60'000 to 80'000 m^3 from the tributary Landquart and 20'000 to 30'000 m^3 from the tributary Ill. Additional calculations in the area of the confluence of the Vorder- and Hinterrhein and the tributaries mentioned above confirmed the magnitudes of these bed load inputs.

Furthermore, it showed clearly the importance of the downstream bed load fining. The mass reduction of bed load due to fluvial abrasion must be significantly less than previously assumed. In a special research project focusing on this topic, it was shown that the reduction value due to fluvial abrasion is dependent on the transport distance, and that for the Alpine Rhine a medium value of magnitude 0.01 km-l would be more accurate than the traditional value of 0.046 km-l.

Former investigations showed that mean annual bed load transport volumes between the mouths of the tributaries Landquart and Ill were 1.3 Mio. m^3 to 0.25 Mio. m^3. The new study however showed that the effective bed load transport during the calibration period was significantly lower. At km 44.5 (bridge Sevelen-Vaduz) a maximum transport volume of 75'000 m^3 per year occurs for the calibration period. The reason for the difference arises from different methods of calculation. An analysis of the calculations of Meyer-Peter shows that for the strip method, the assumption of an equilibrium longitudinal profile between Ellhorn and the mouth of the tributary Ill and a reduction value due to fluvial abrasion of 0.046 km-l result in too large values for the bed load transport.

Predictions for a period of 45 years show, compared to the calibration period and assuming bed load inputs remain the same, processes will not significantly change. However, degradation and aggradation processes will slowly decrease with time. A large proportion of the erosion takes place at flood discharges exceeding 1000 m^3/s. Erosion will still take place even with high bed load inputs along the reach of the Canton Grisons. Between the boulder ramp at Buchs and Lake Constance extensive deposition has to be expected except for the scenario without bed load input. The bed load input from the Alpine Rhine into the international reach below the mouth of the tributary Ill is independent of the bed load transport at the boulder ramp at Ellhorn. This is because the local bed load transport capacity in the deposition reach upstream of the mouth of the tributary Ill acts as a control.

The diagnosis of the bed load budget and the prediction of the development of the river bed is an important basis for the planning of future river training measures. Planned measures can be optimized and their effects analyzed with the help of the numerical model of the Alpine Rhine.

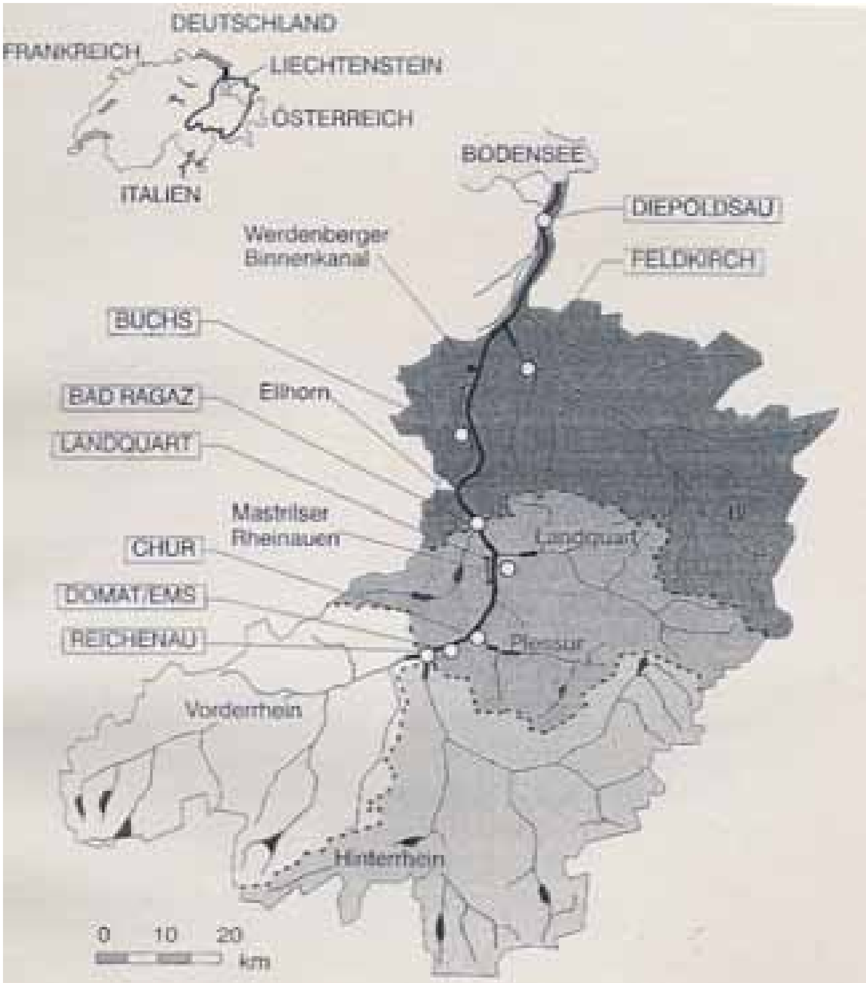

Figure 31 Investigation site of the Alpenrhein basin

2. Emme 2050

The concept study "Emme 2050" was carried out by the Laboratory of Hydraulics, Hydrology and Glaciology at the Swiss Federal Institute of Technology, Zurich (VAW) and the Geographical Institute of the University Bern (GIUB). The Emme had itself eroded the river bed in the last decades, what endangered embankments and check dams. Besides, the bed erosion effect caused a lowering of the groundwater level. As a result, danger existed that the ground-water supplies will decrease in the future and therefore also effect the quality of agricultural land.

In order to settle the river bed of the Emme, various propositions for measurements were submitted, which surpass traditional defense strategies and allowed a more natural river bed at appropriate locations along the river.

The investigation included a reconstruction of the principal causes of e bed erosion since 1880 and tried to extrapolate river bed development until the year of 2050. Besides, most important influences on discharge and sediment budget in the Emme basin were lined out (table 10) and quantified and an assessment about their influence until 2050 was made.

Some results of the investigations are presented below.

Table 10 Some results of Emme investigation

Results of the investigation	Effect on sediment budget regarding river bed erosion
Increase of forest areas	Positive
Increase of “sealed” surfaces	Negative, but not significant
Reduction of sediment input by lateral tributaries	Negative
No significant change in precipitation	Neutral
No significant change in discharge	Neutral

As for sediment inputs by lateral tributaries to the main river, the development was as follows (figure 32)

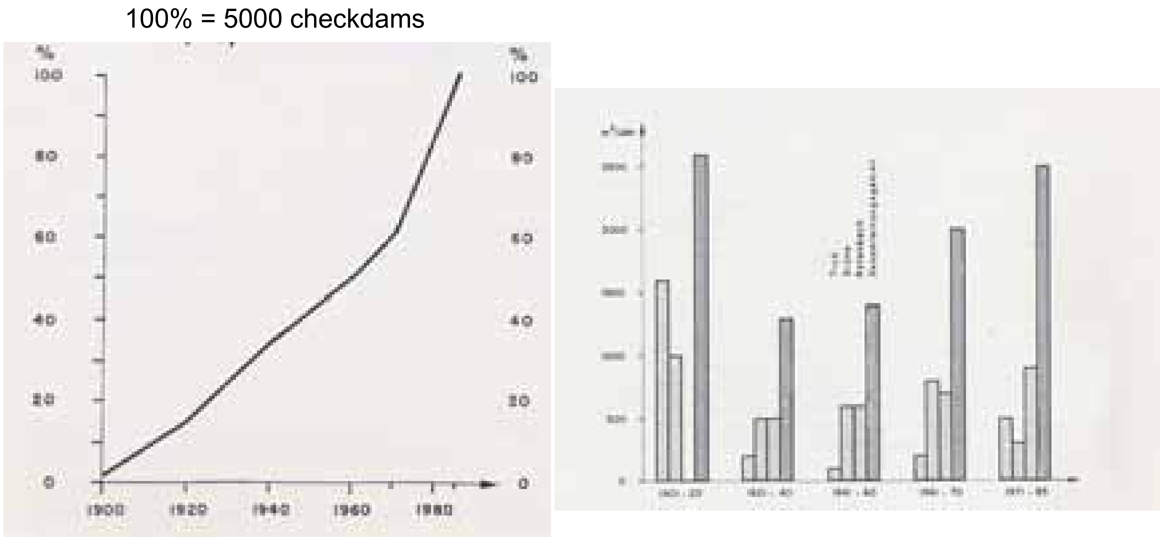

Figure 32 Construction of check dams in tributaries between 1900 and 1985 and mean annual sediment retention by new check dam construction in 4 main tributaries of the Emme river

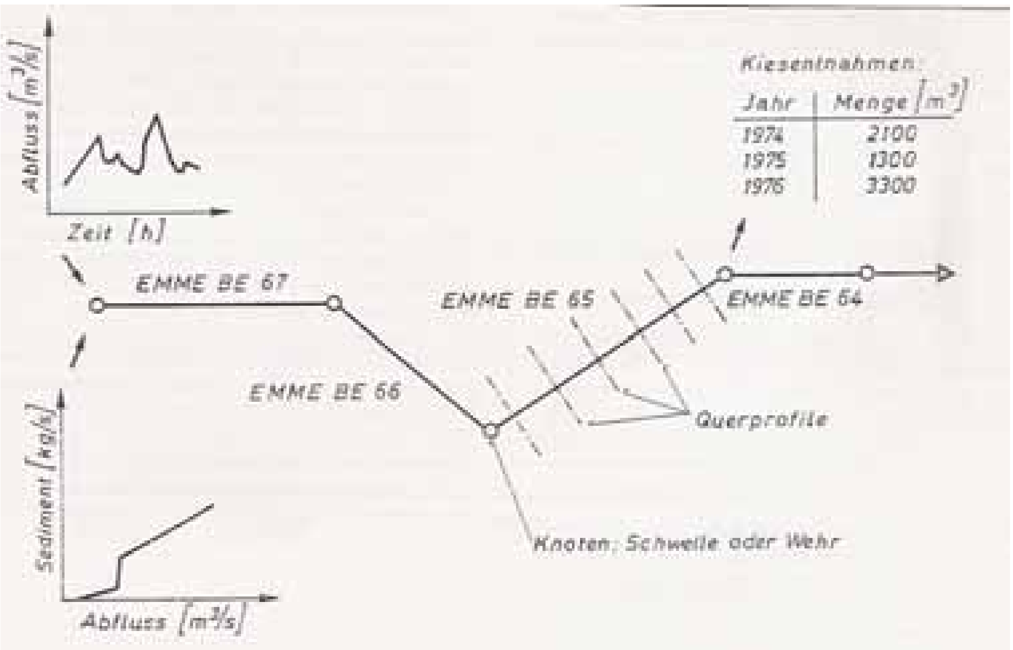

Fig. 33 MORMO-modeling scheme of the Emme River

Fig. 34 Prediction of river bed changes until 2013 and 2043 respectively

With laboratory investigations, various possible results for the settlement of river behavior were achieved (fig. 33, 34). Among them, local widening of the river bed seemed most promising.
One of the most important measures undertaken in the following years was the first local widening in Switzerland, stabilizing the river bed for several 100 meters (fig 35) instead of constructing 3 or 4 additional check dams.

Fig. 35 Local widening of Emme River

3. Assessment of Sediment Yield in the Weisse Lütschine, Canton of Bern

Assessment studies are mainly carried out in small watersheds for the following reasons:

- design of protective works
- sediment yield into receiving waters
- delineation of danger zones.

The assessment study Lütschine mainly served for the two first reasons.

In October 2000, a large flood event transported some 20’000 m^3 of material to the reaches of the small village of Stechelberg. Before undertaking some countermeasures, a study should investigate sediment yield in each of the tributaries and sediment transport of large flood events in the Lütschine river (fig. 36). The main question was to know if an event like the one of October 2000 could easily be repeated and what could be river behavior in the future, especially regarding climate change.

Fig. 36 Investigation site of the Lütschine study

The sediment yield into the Weisse Lütschine is primarily caused by the torrents south of Stechelberg, depending on the distribution of local storms. A scenario which causes flood discharge at rare recurrence intervals in all torrents simultaneously into the Weisse Lütschine is rather unrealistic on account of the findings made in the study.
The greatest sediment load occurs when the two largest tributaries simultaneously transport material into the Weisse Lütschine.
Therefore, one must count for the future that large sediment transport comparable to the one of the fall 2000 event will occur again, but not every 10 to 20 years. A recurrence interval from available data is difficult to derive, especially considering effects of climate change. But events of a recurrence interval of about 50 to 100 years depending on scenario will probably transport 20 - 30'000 m^3 of material or even more. On account of glacier withdrawals (uncovered debris cones), the frequency of the corresponding events would however increase in the future.
On account of the small transport capacity of the Weisse Luetschine, a high sediment load induces deposits by force. These deposits occur in different places along the Lütschine. Bed elevations caused by the deposits provoke flooding of neighboring settlements and cultivated land (fig. 37). Besides retention areas, which alone are not sufficient as protection measures, it was planned to support some natural deposit places in the river by application of technical measures, such as a reinforced local river widening, serving as a periodic sediment retention place.

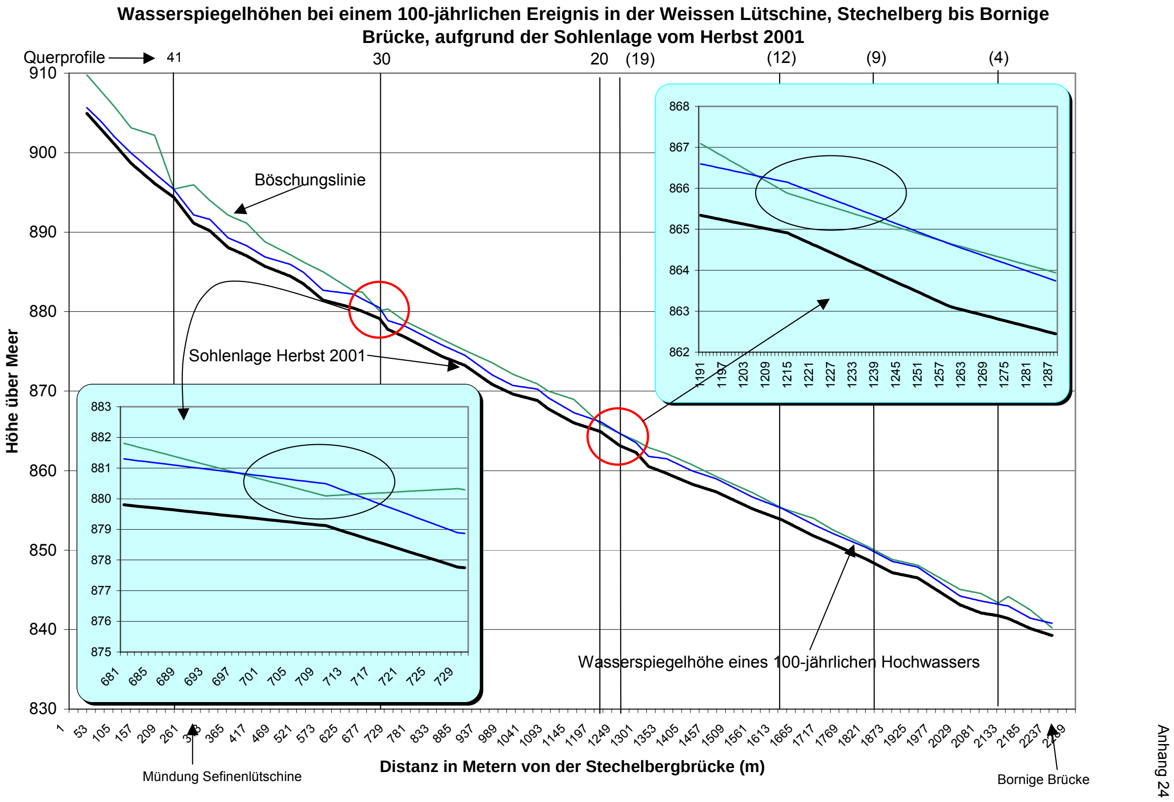

Figure 37 Bed- and water level in the case of an event of 100 year recurrence interval indicating potential places of river outbursts

9. 2. Germany

Two comprehensive studies on sediment transport and sediment management in the German Rhine were carried out on behalf of the Federal Ministry of Transport:

BMV (1987): Discharge and bedload conditions of the Rhine river
BMV (1997): Bed equilibrium at the Rhine river

A Dutch/German study is

RIZA&BfG (2001): Bed level changes and sediment budget of the Rhine near the German-Dutch border

[Examples]

10. Policy recommendations concerning sediment management

[still to work out]

11. Literature

[Annexes]