Reservoir Sedimentation and Sediment Management

ISI International Training Workshop on Integrated Sediment Management in River Basin

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Lecture Note by

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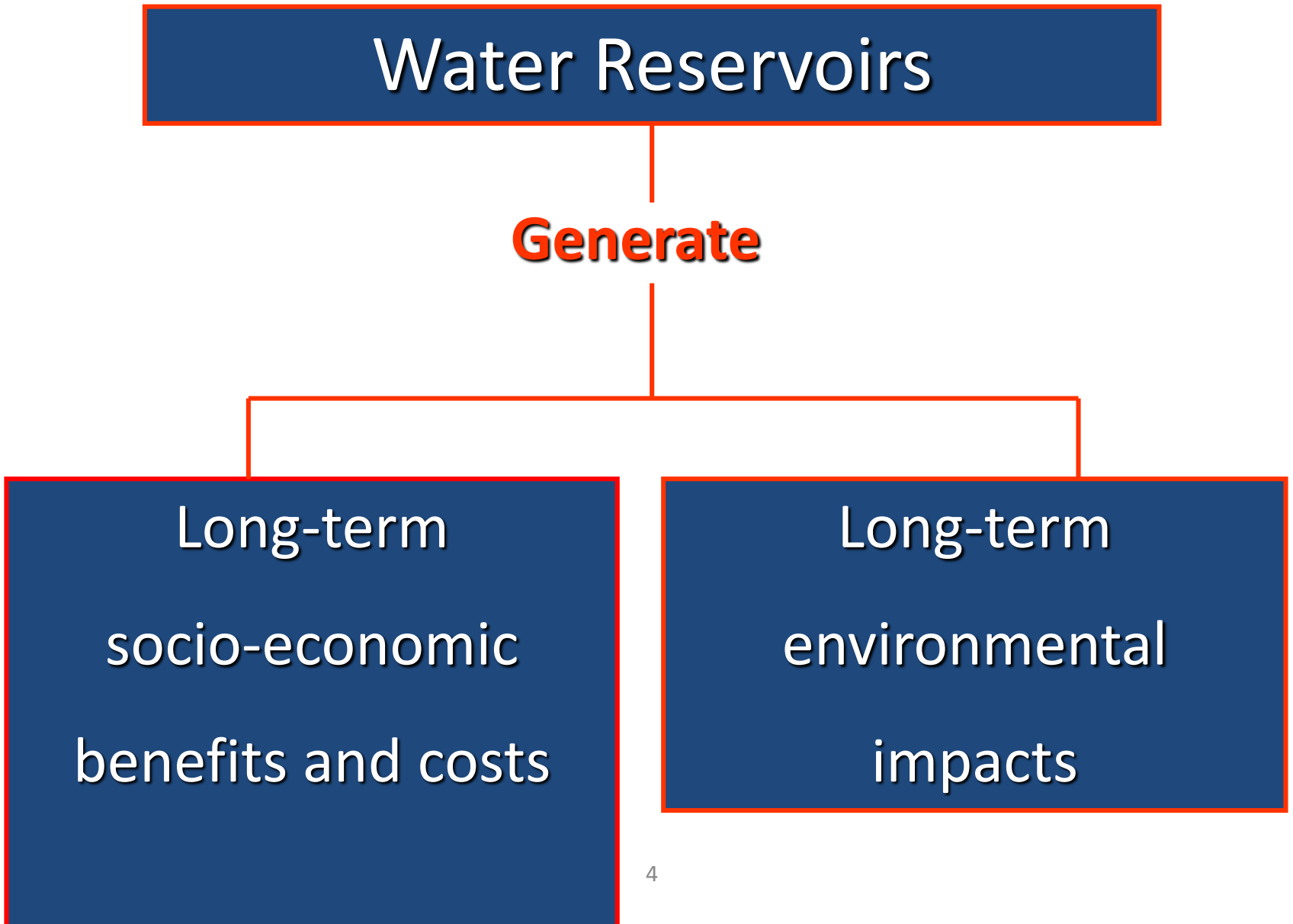
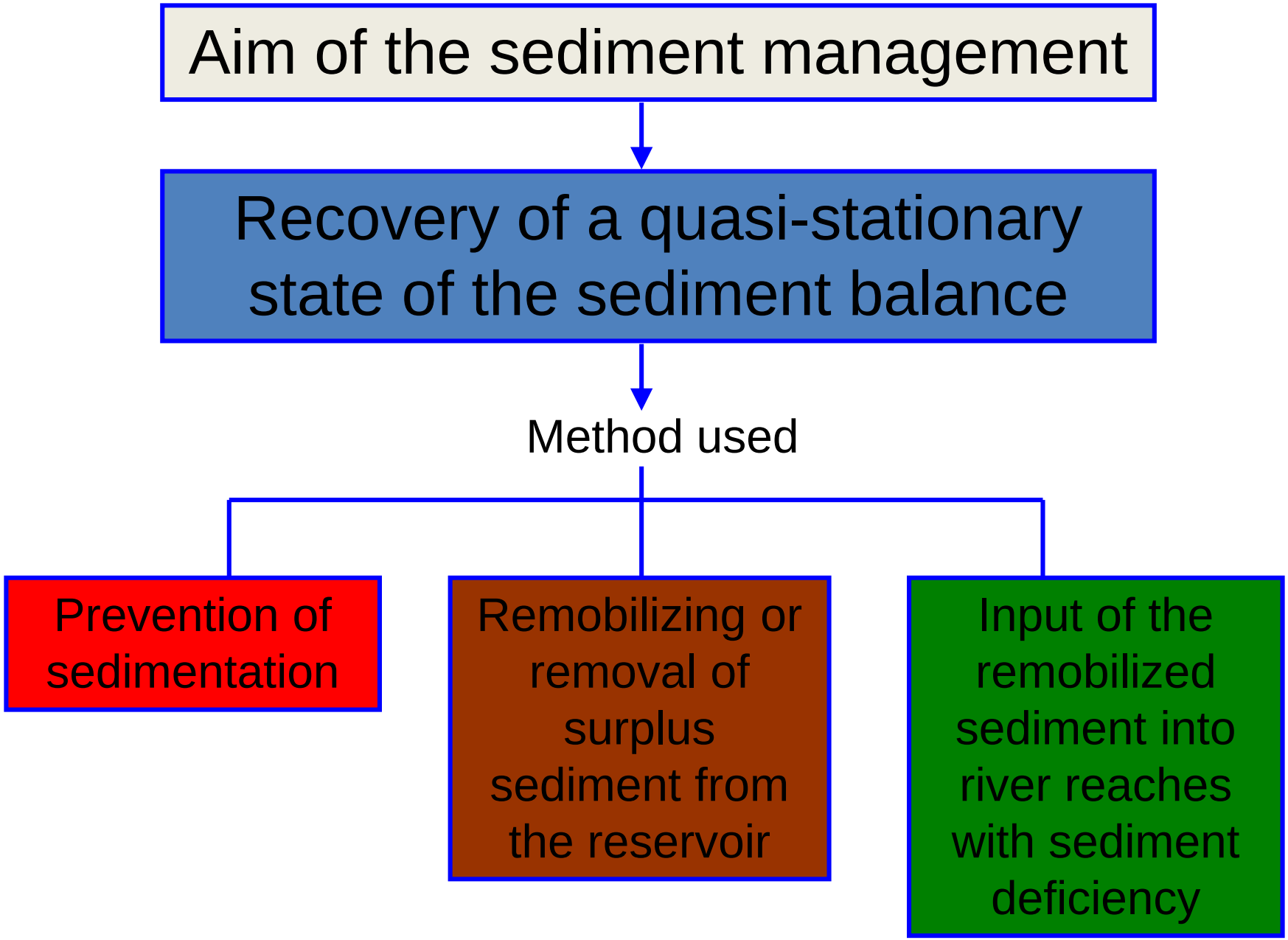
Content

1. **Brief overview of environmental impacts and problems of reservoirs in the context of erosion and sedimentation**
2. **Determination/estimation of necessary information and basic sediment data**
3. **Possibilities and effects of measures for the reduction of sediment input into the reservoir**
4. **Reservoir sedimentation**
5. **Procedures of the removal of sediment from reservoirs and impacts on the ecology**
6. **Modification of the hydrological regime and changes in erosion and sediment downstream of reservoirs**
7. **Difficulties by the determination of the impacts of reservoirs on downstream areas (Example Grimsel reservoirs)**

1. Brief overview of environmental impacts and problems of reservoirs in the context of erosion and sedimentation


Water Reservoirs
Generate
Long-term socio-economic benefits and costs
Long-term environmental impacts

Interrelation between sediment management and other players in sustainability


Aim of the sediment management
Recovery of a quasi-stationary state of the sediment balance
Method used
Prevention of sedimentation
Remobilizing or removal of surplus sediment from the reservoir
Input of the remobilized sediment into river reaches with sediment deficiency

Basic sediment control strategies for reservoir sedimentation

- Reduce sediment inflow
- Route sediments
- Sediment removal
- Provide large storage volume
- Sediment placement

Actions to achieve sustainable use

Sedimentation assessment

Evaluation of sedimentation impacts

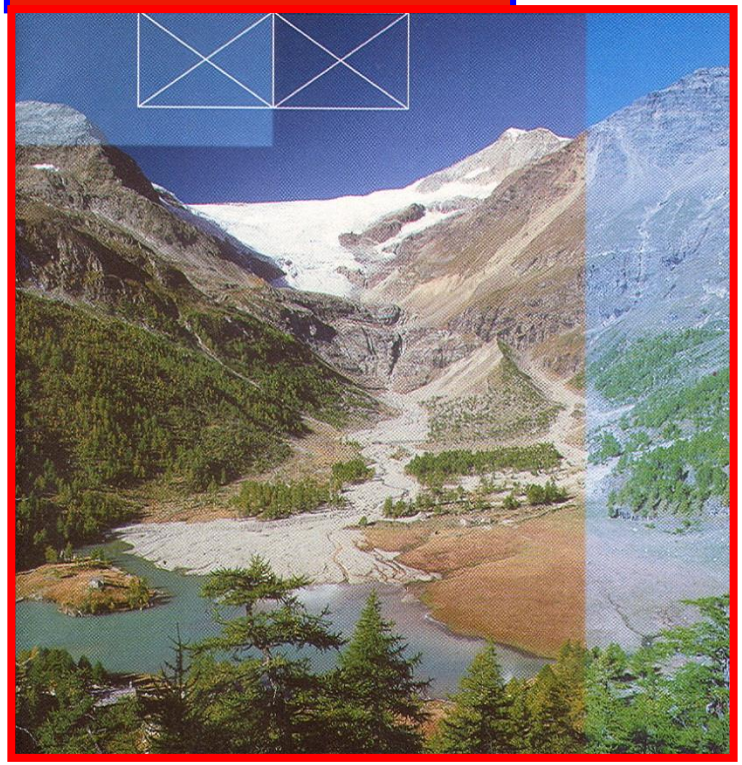
Identification of priority sites

Screening of sediment management alternatives

Design, implementation, monitoring

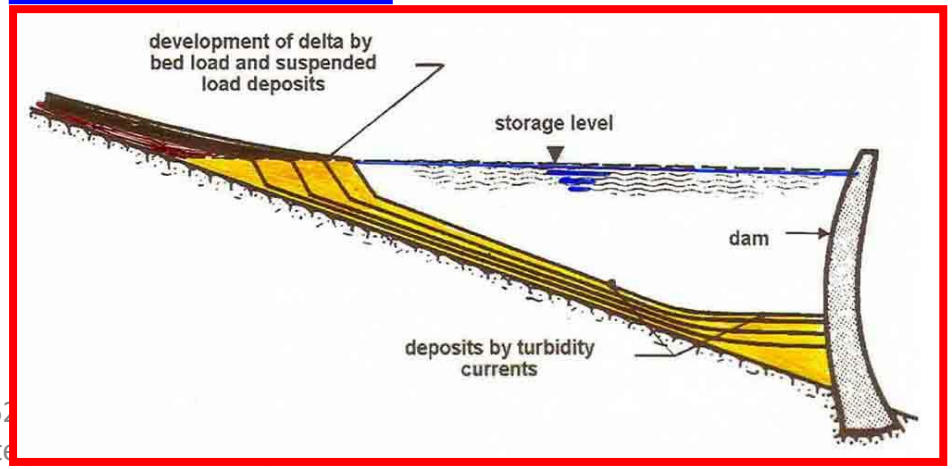
Environmental issues related to sediment and its management

Upstream of the reservoir



Downstream of the reservoir

Within the reservoir



Environmental issues upstream of the reservoir

- Reduction of river slope due to the prolongation of the river length by the deposits in the delta area.
  - Reduction in discharge and transport capacity
  - Disturbance of the surface/groundwater interaction

Environmental issues within the reservoir

- Loss of storage capacity due to sedimentation resulting in reduced water availability for water supply, hydropower and flood control.
- Water quality can be negatively influenced by the storage of contaminated sediments contributed from upstream or primary produ-cers in the reservoir. The bottom water can get anaerobic due to the oxygen demand.
- Sediment removal can mobilize contaminated sediment.

- Turbidity can reduce the clarity of the water and makes the reservoir aesthetically unpleasant for recreation. Turbid water reduces depth of photic zone resulting in a decrease of primary productivity.
- Loss of houses and infrastructure in the flooded area by the reservoir
- Loss of agricultural land occupied by the reservoir
- Impact on health
- Effects on fauna
- Salinisation and water logging in newly irrigated areas

Environmental issues downstream of the reservoir

- Modification of the hydrological regime
  - Reduction of peak discharge
  - Change of the seasonal flow variability
  - Creation of pulsed flows
  - Reduction of discharge and transport capacity (Lateral sediment input, vegetative encroachment)
- Modification of the river hydraulic
  - Changes in slope and width
  - Change of the sediment balance
  - Bridges, river training works can be undermined
  - Riverbed will coarsen and may become unsuitable for spawning.

- Reduction of fine sediment load
  - Loss of sediment-dependent wetlands
  - Reduced nutrient and sediment inputs to floodplains
  - Decrease of delta area downstreams
  - Higher recreation value due to clear water
  - Reduced sedimentation and dredging in navigational channels.
- Increased suspended sediment due to flushing can impact downstream aquatic system

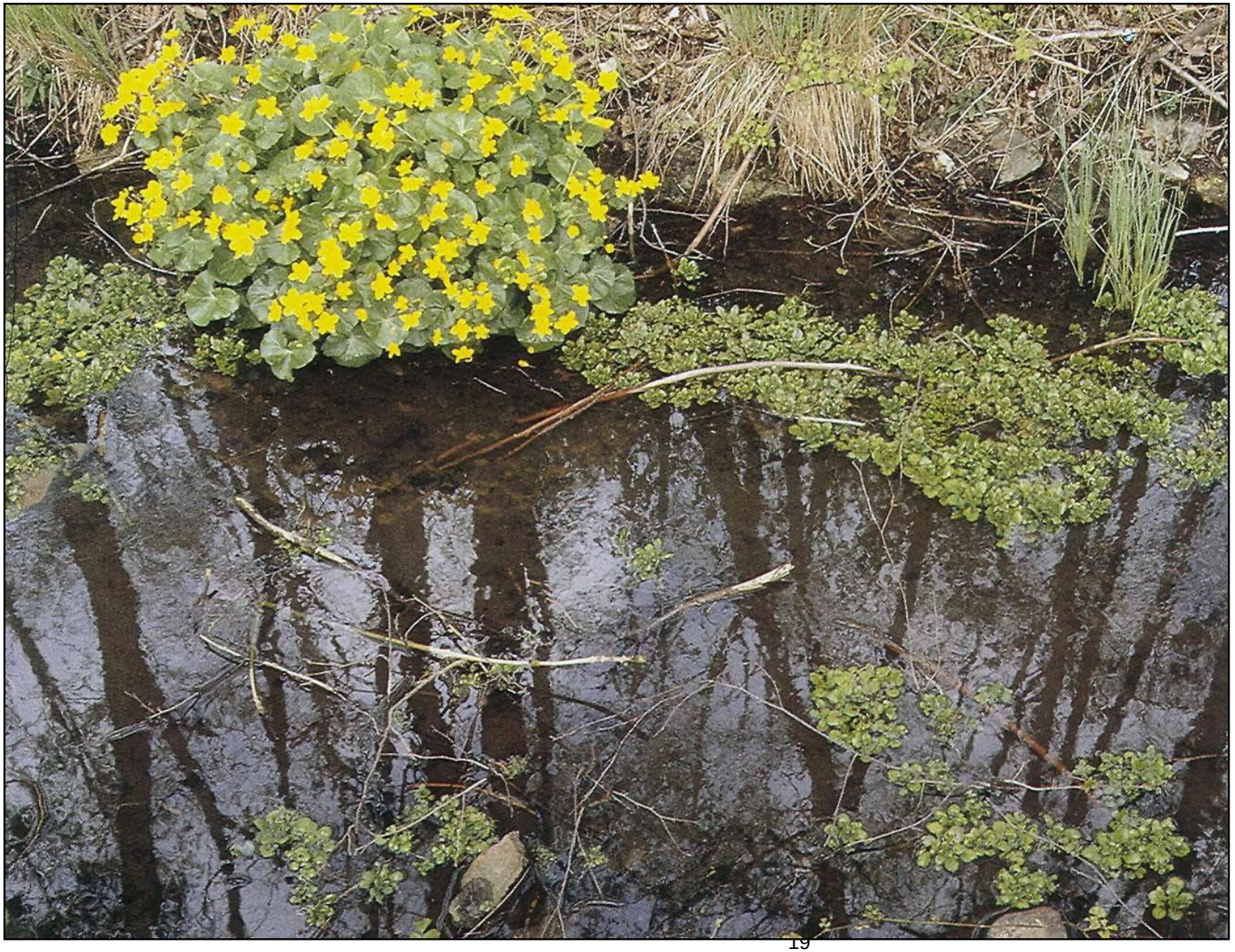
- Significant benefits to flora and fauna can arise if sediment areas become wetlands.
  Fine sediment deposition can reduce resting habitat for fish.

Sediment islands
Dry low water zones during winter time

Old bed of the Alpine river near to the mouth

Habitat of the old Alpine river

Example of vegetation after rehabilitation



Problems caused by reservoir sedimentation

Technical problems

- Blocking of water outlets
- Abrasion of turbines
- Static problems of the dam construction
- Reduction of sediment transport in downstream areas resulting in river bed erosion

  a. s. on

Economic problems

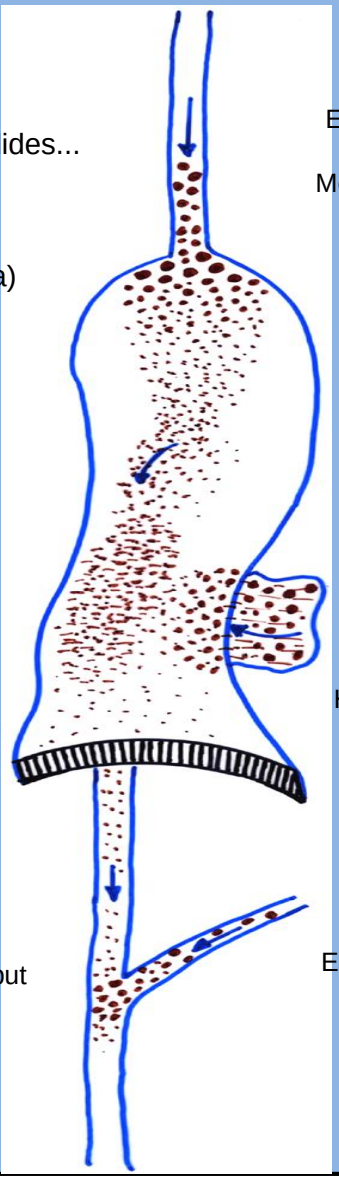
- Water losses due to spilling of sediment out of the reservoir
- Interruption of power production during flushing

Ecologic problems

- Modification of hydrological regime
- Change in sediment balance, deficiency and surplus of sediments
- Effects on the habitats typical of the benthic community
- Lowering of ground water tables
- Water pollution by contaminated sediments

Processes and actions related to reservoir sedimentation

Process	Action
Sediment input by rivers, landslides...	Monitoring Estimation of sediment potential Reduction of input Measures for reduction of erosion
Sediment accumulation (delta)	Delta survey
Turbidity streams	Monitoring Modeling Artificial change of flow direction
Formation of sediment by biological processes	Monitoring
Sediment accumulation disturbing outlet	Hydraulic model investigations
Reduced sediment transport capacity	Operation rules for flushing
Deposits of lateral sediment input	Estimation of sediment transport
Sediment deficiency	Hydraulic constructions



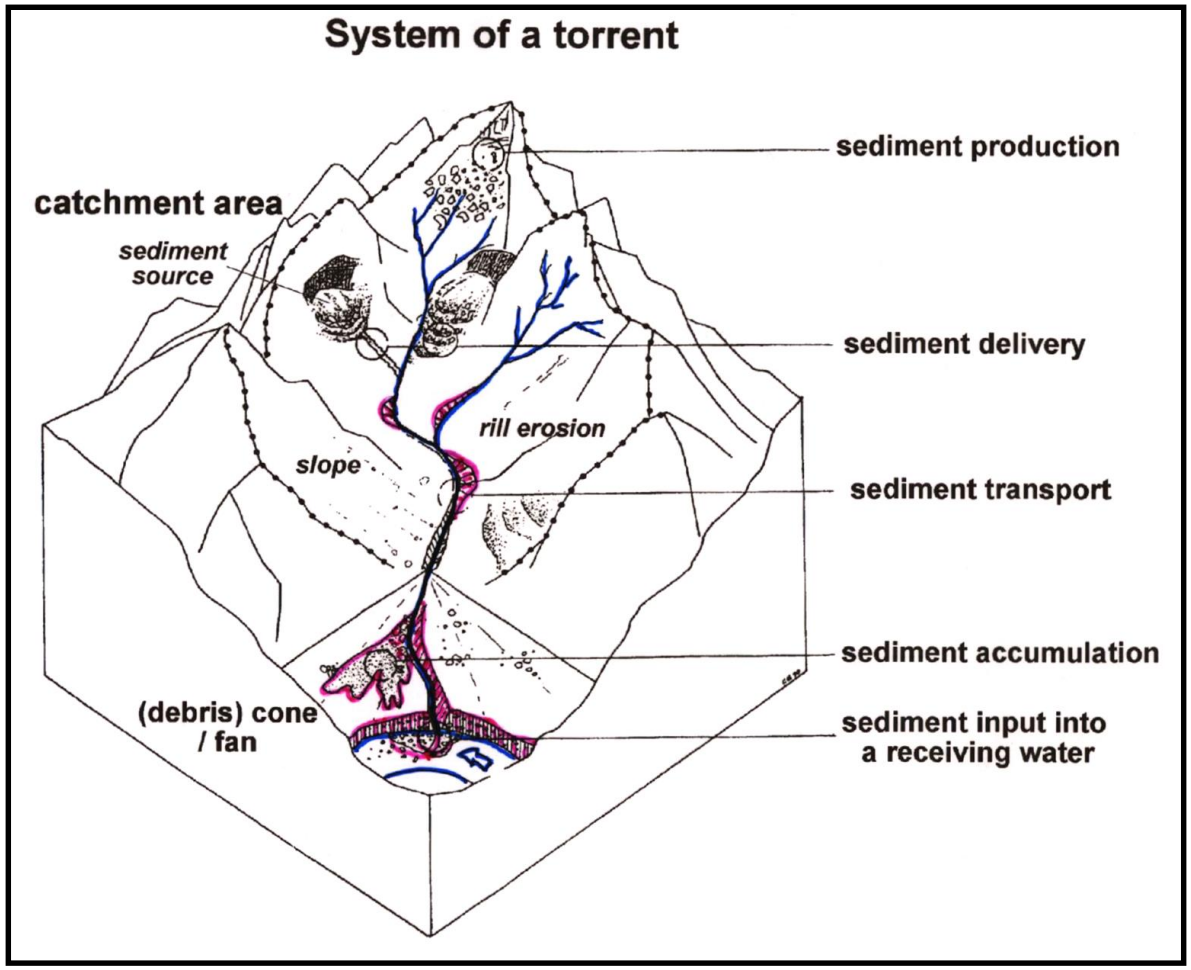
2. Determination/estimation of necessary information and basic sediment data

A. Detailled description of the basin
B. Description of the process
C. Determination of sediment transport in mountain streams
   E.g. Erlenbach CH, «benthley» of information gathering
D. Estimation of sediment transport by sediment retention reservoirs and problems of interpretation/accuracy of such an estimation procedure
E. Measurement of sediment
F. Problems of interpretation/accuracy of measured sediment data
G. Estimation procedures for sediment transport in small mountain streams
H. Estimation of amount of soil erosion
I. Sediment budget and balance in rivers

A. Detailled description of the catchment

1. General overview
2. History
3. Morphometry
4. Geology
5. Soil, soil cover, land use
6. Hydrology/ Meteorology
7. Geomorphology
8. Estimation of sediment potential
9. Sediment retention basin
10. Basic information

B. Description of the processes



C. Determination of sediment transport in the research catchment Erlenbach

Monitoring systems

In operation since 1982

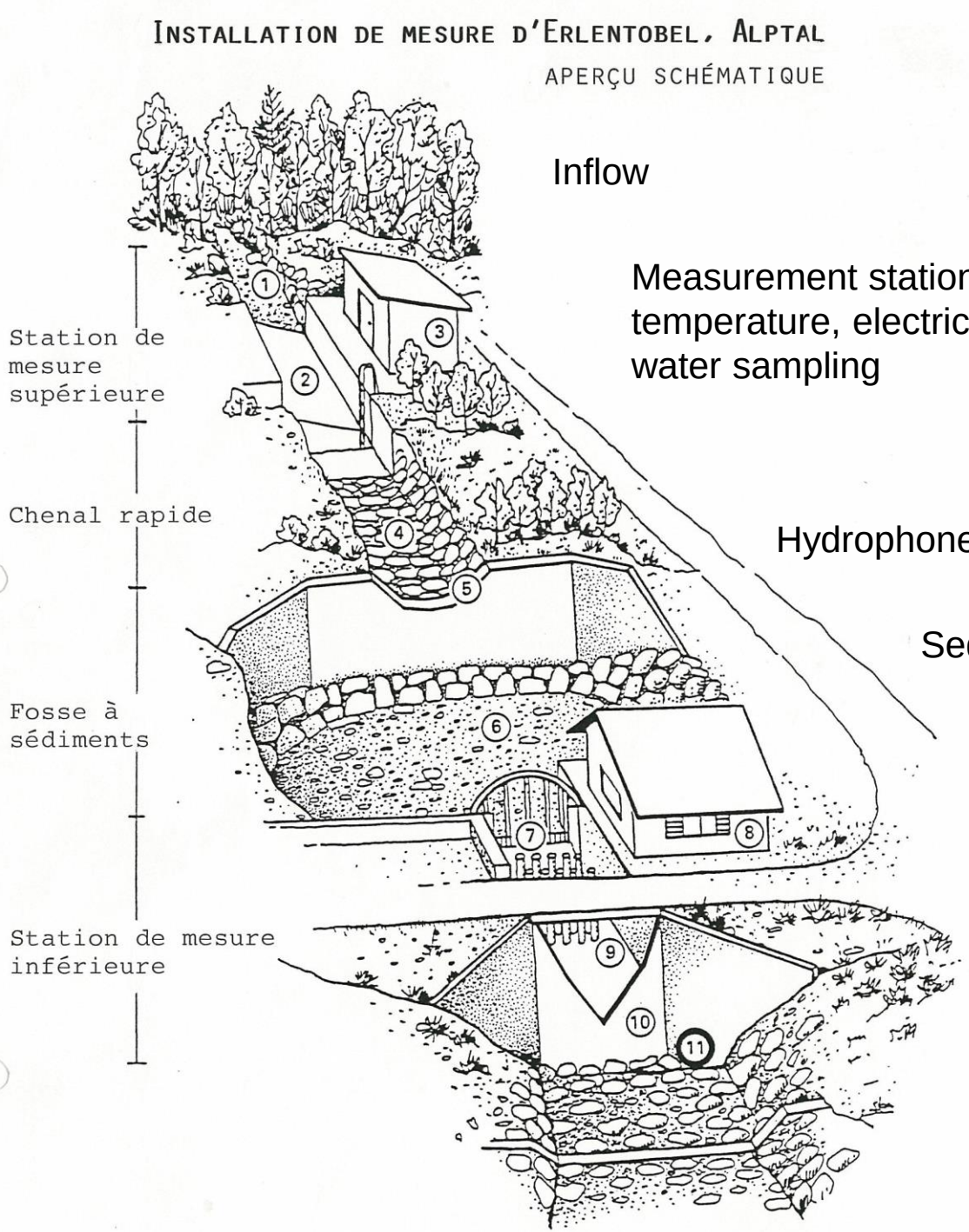
Area 0.74 Km^2

60 % meadows, 40 % forest

Altitude: 1110 - 1655 m asl

Precipitation: 2300 mm

Geology: Flysch



Inflow

Measurement station for water level temperature, electrical conductivity, water sampling

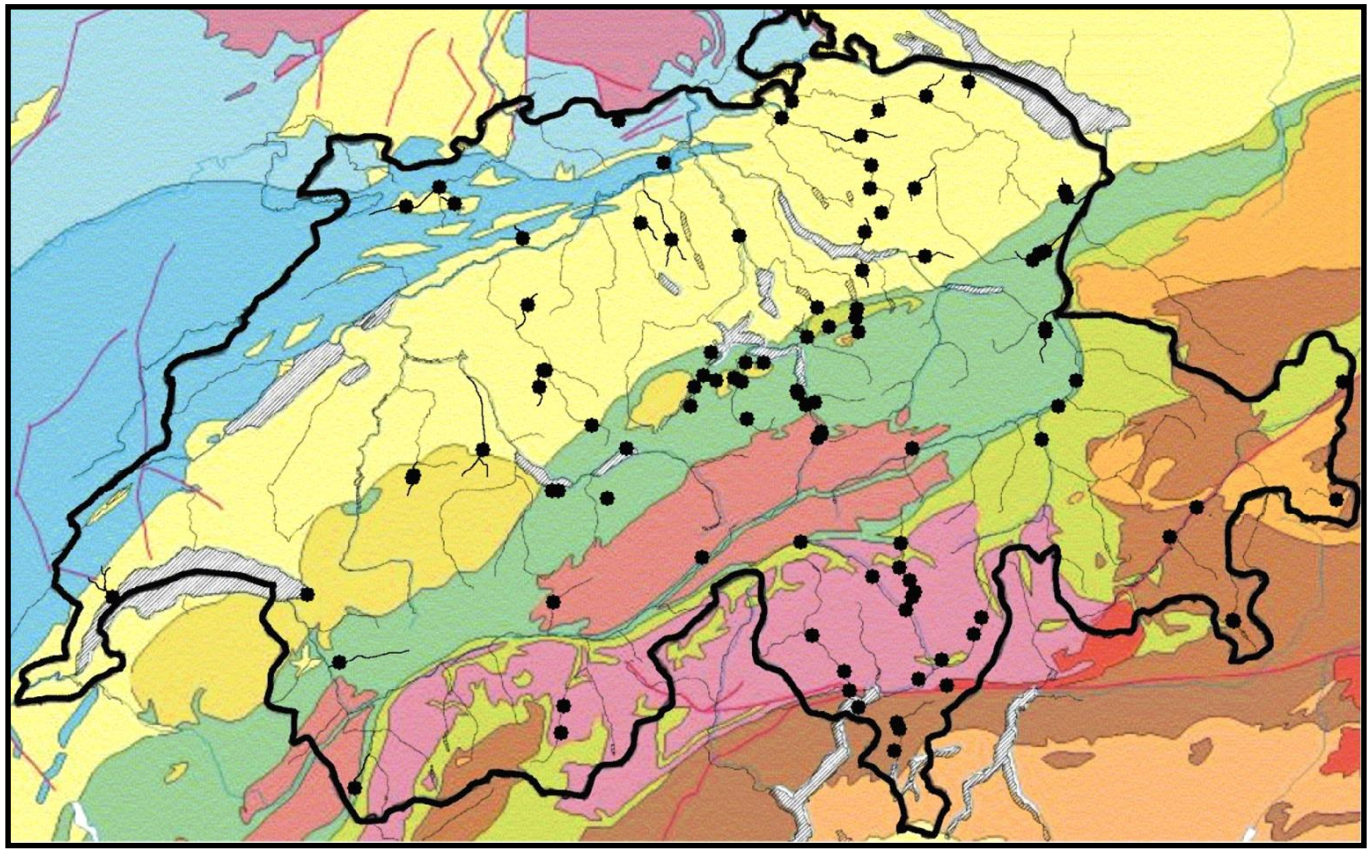
Hydrophone installation

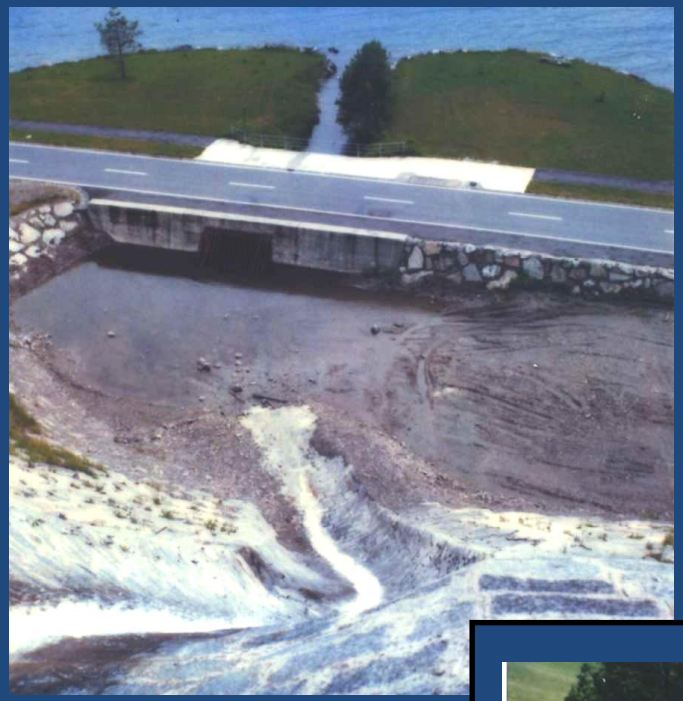
Sediment retention basin

Measurement station for water level, hydrophone signal

Outflow

D. Estimation of sediment transport by sediment retention basins and problems of interpretation/accuracy of such an estimation procedure



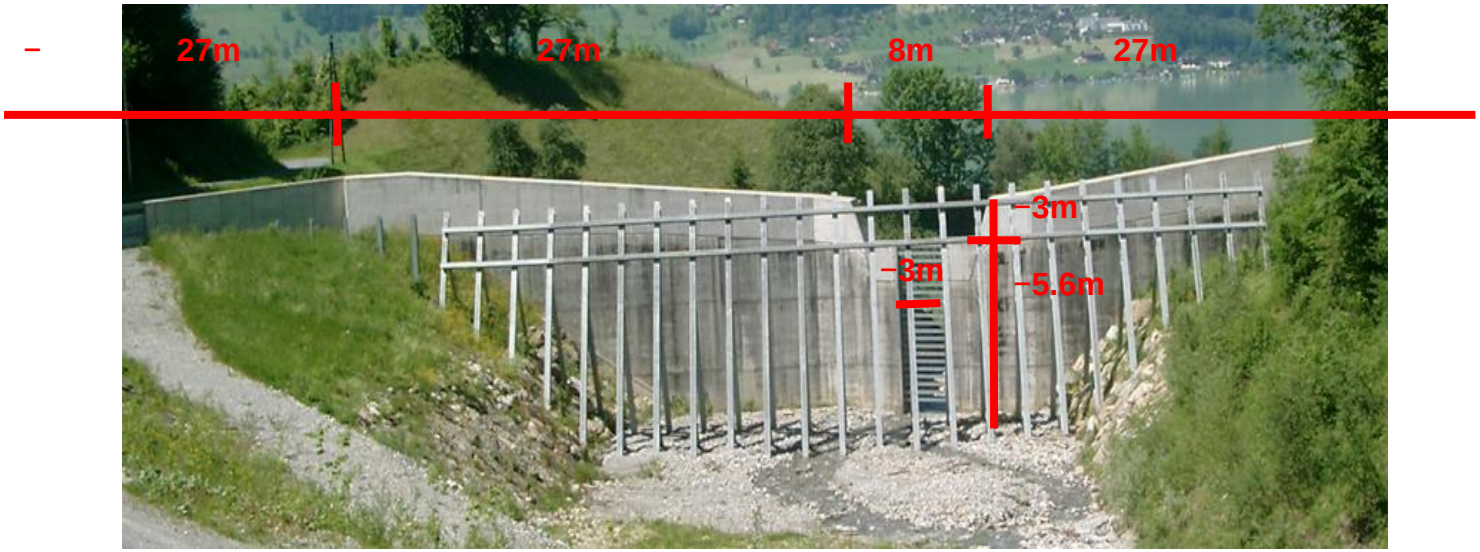


Fischlauwi Seedorf

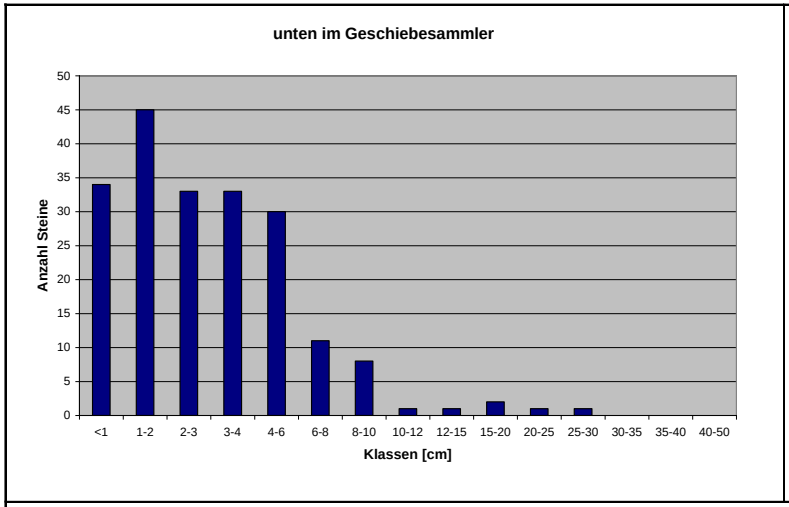
Berschnerbach Berschnis

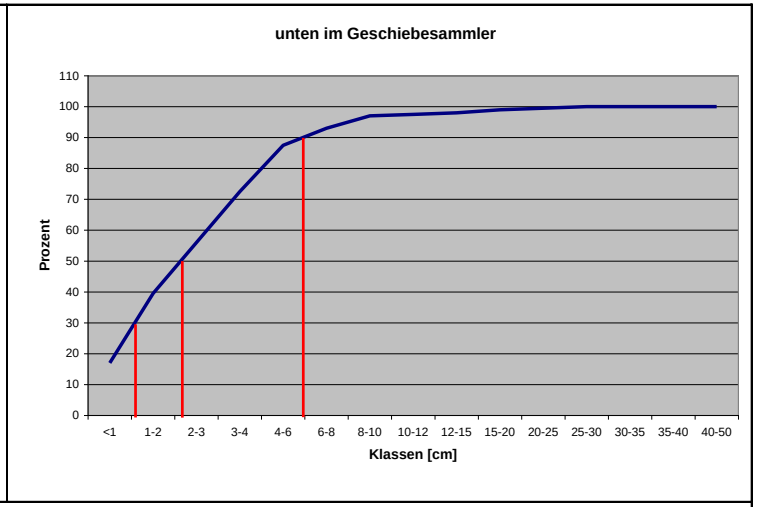
Filderenbach Hochybrig

Sediment retention basin with wood retention



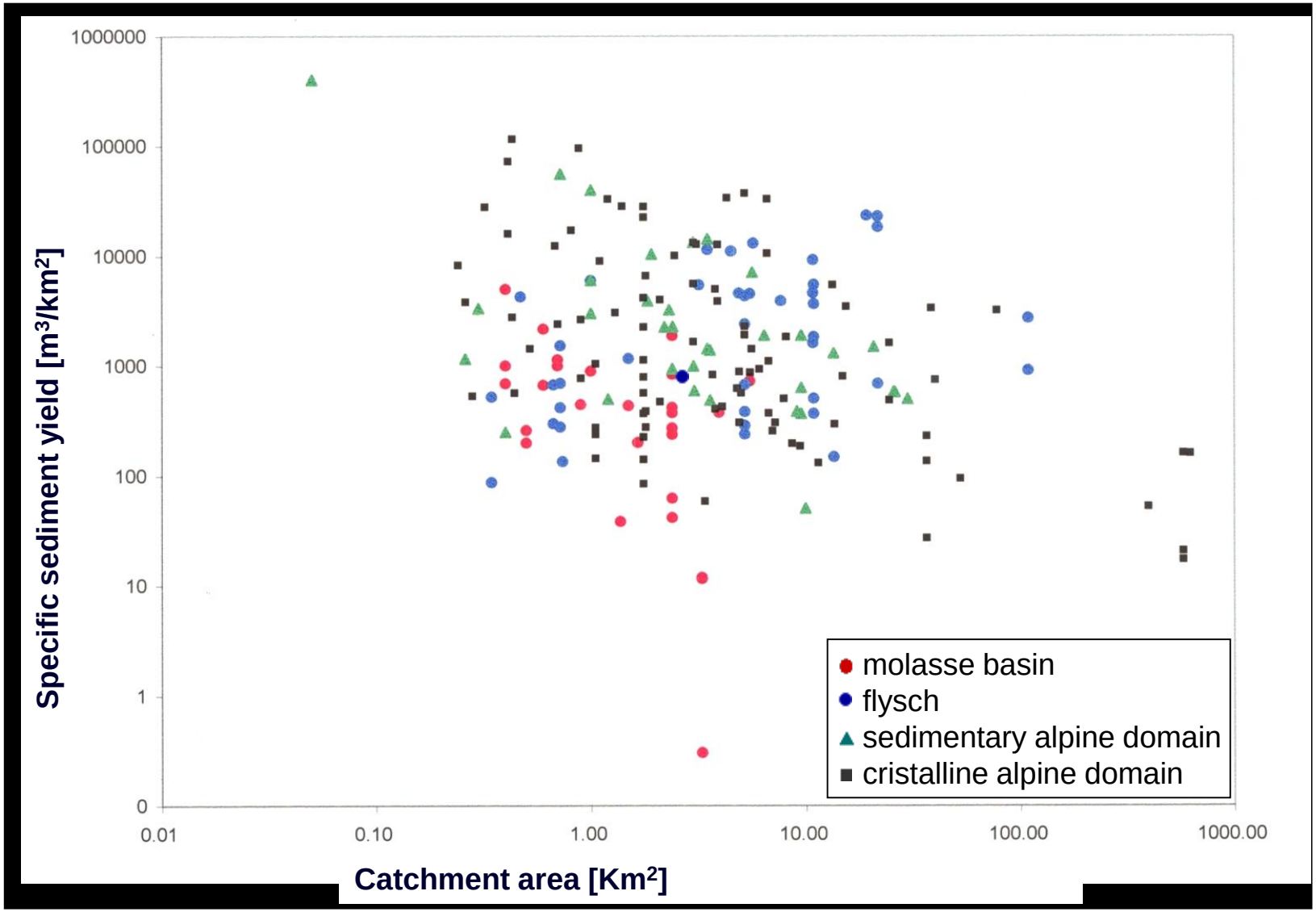
Grain size distribution in the reservoir



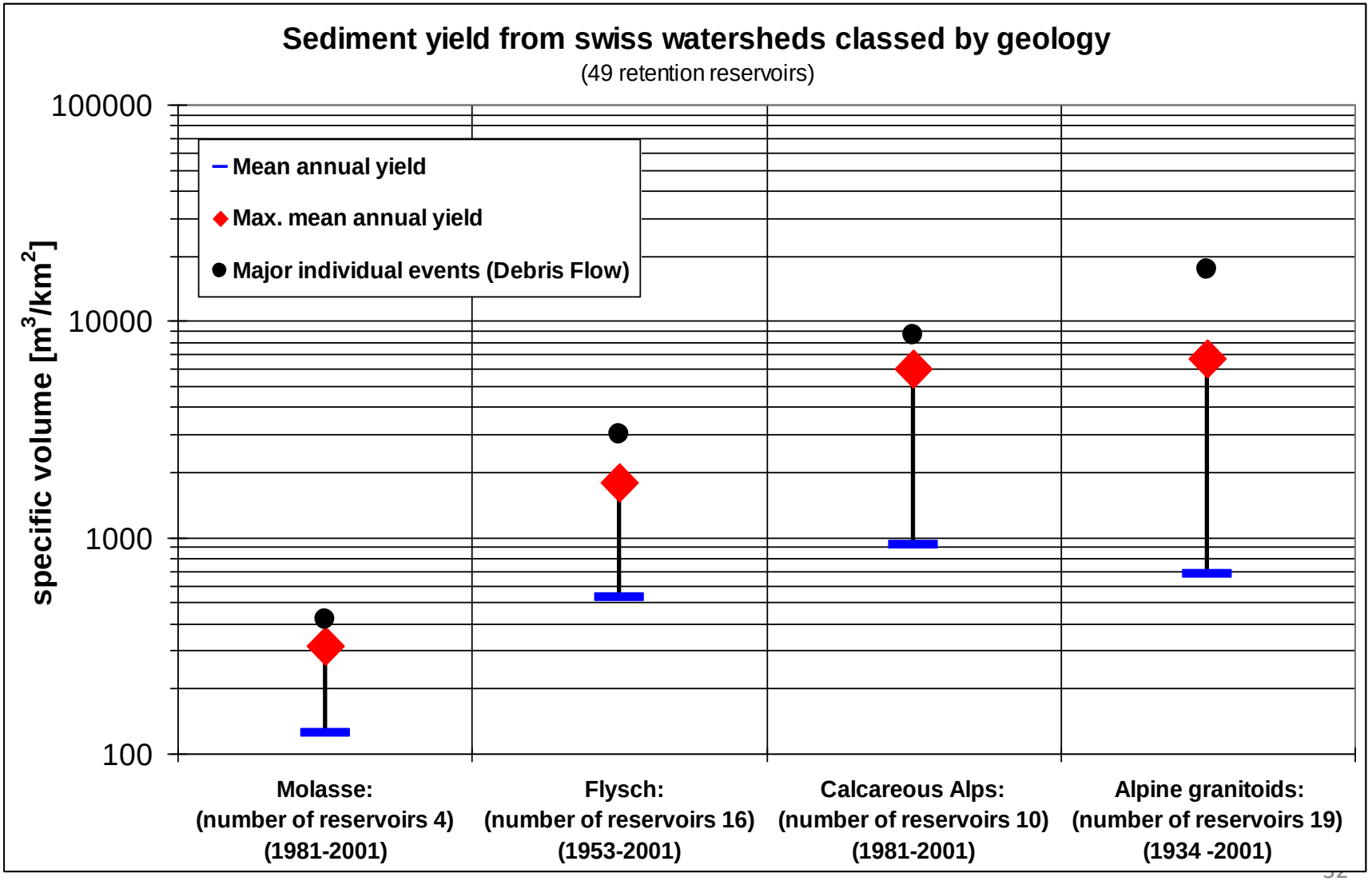


d_{30} = 1 cm; d_{50} = 2 cm; d_{90} = 6 cm; n=200; Länge der Probe 5.7 m; Feinmaterialanteil 10.5 %

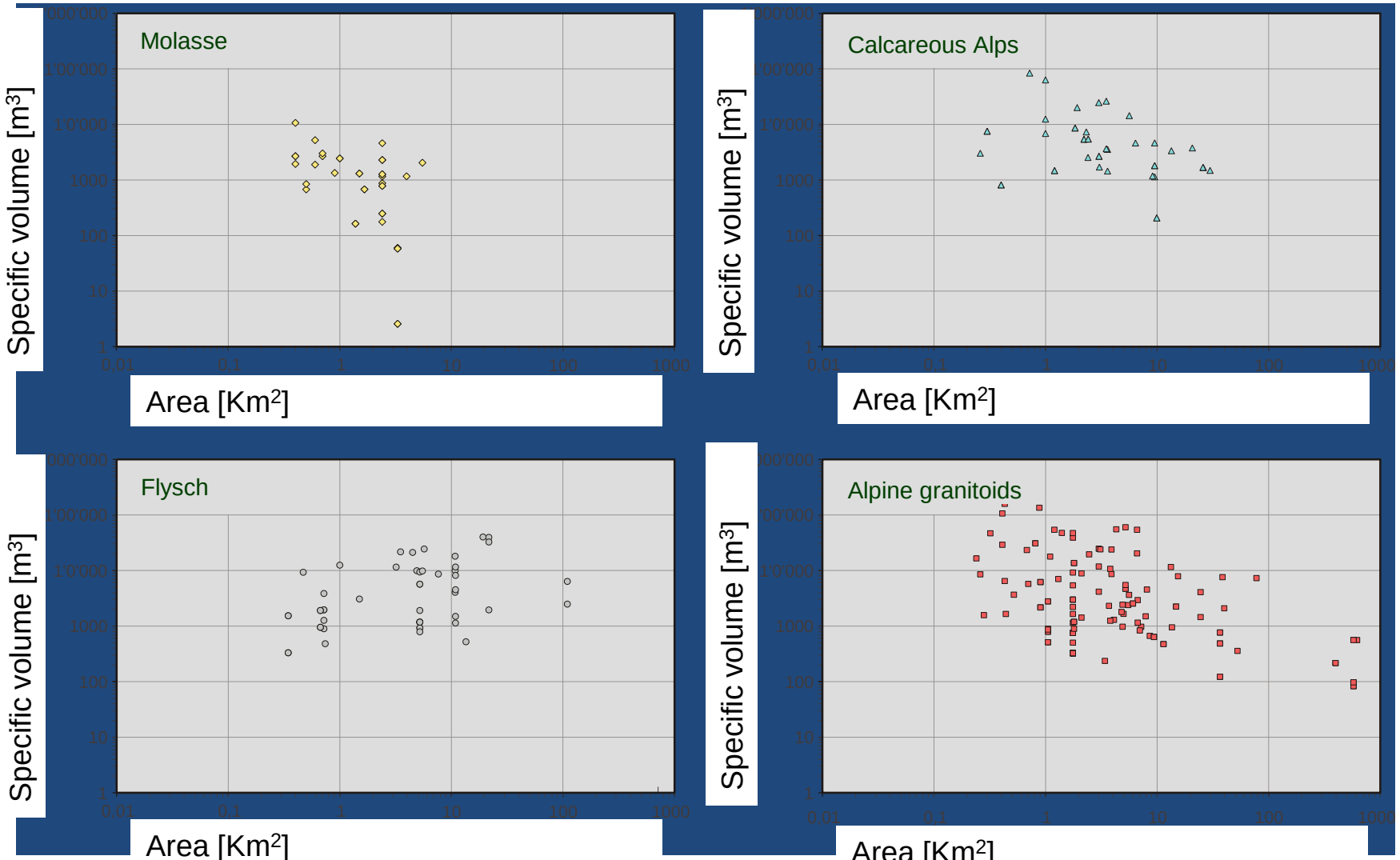
Specific sediment yield of floods and debris flows in Swiss mountain streams



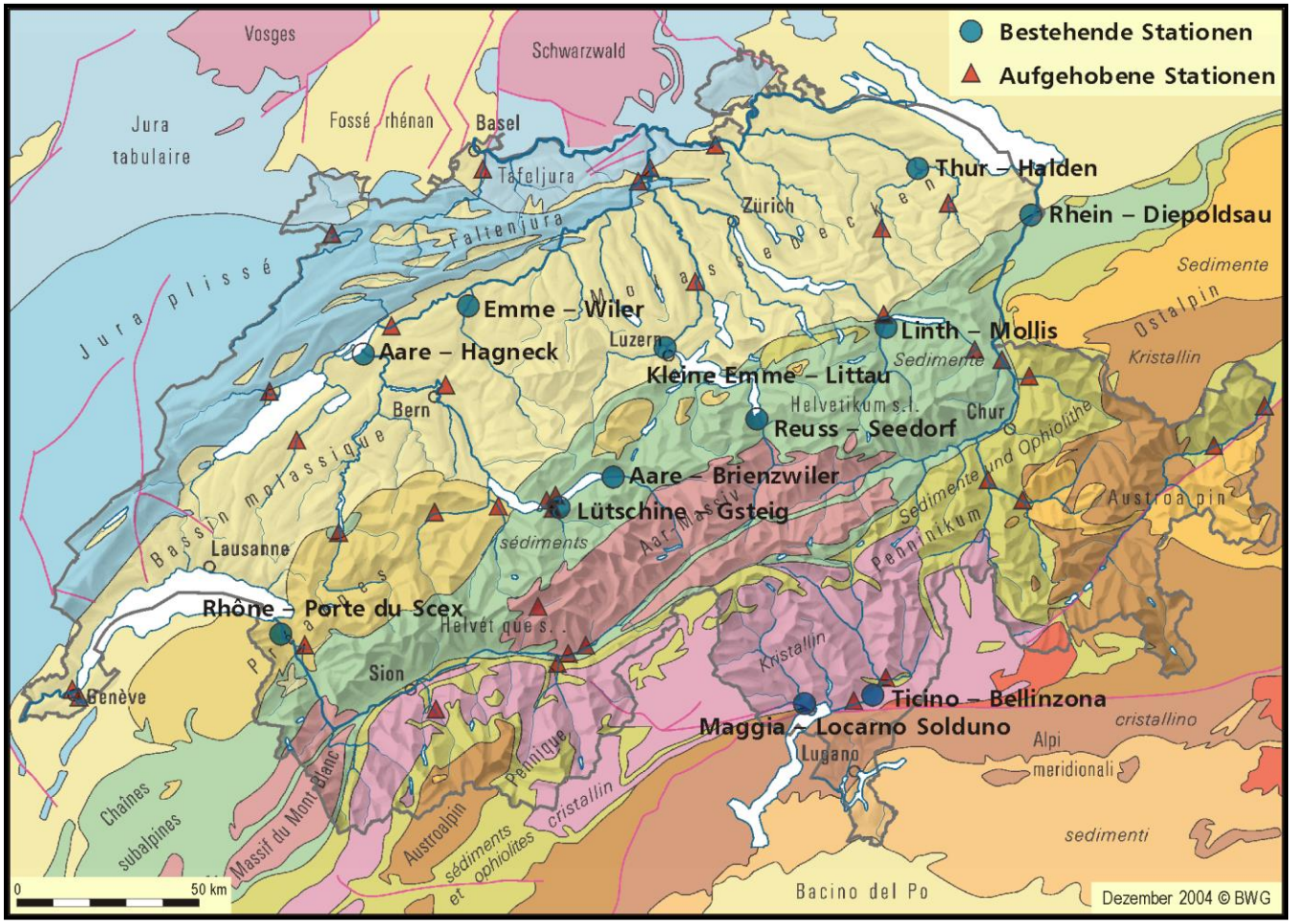
Sediment yield from Swiss watersheds classed by geology



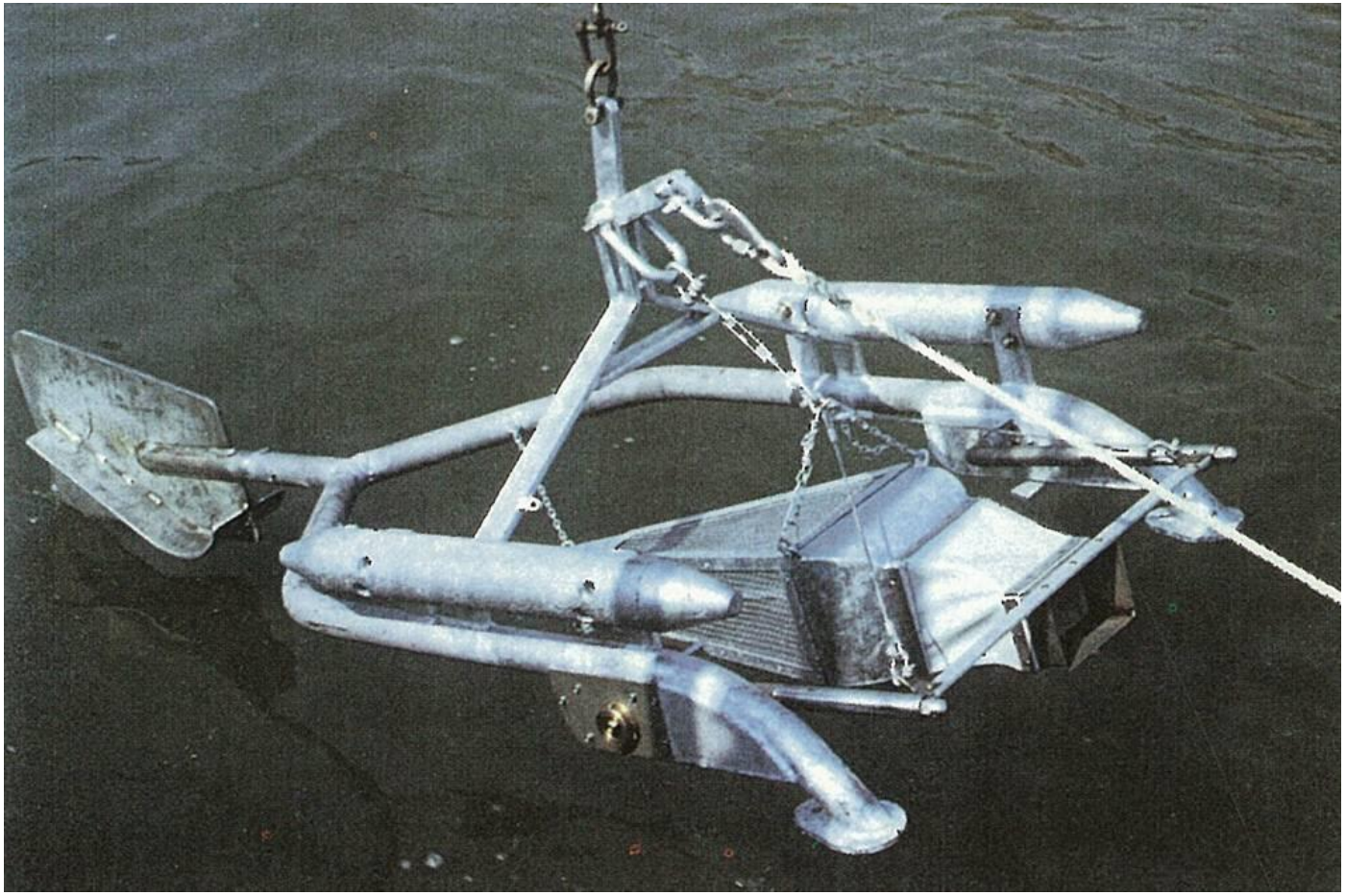
Specific sediment volumes of flood events related to catchment area and geological formations



E. Measurement of sedmiment



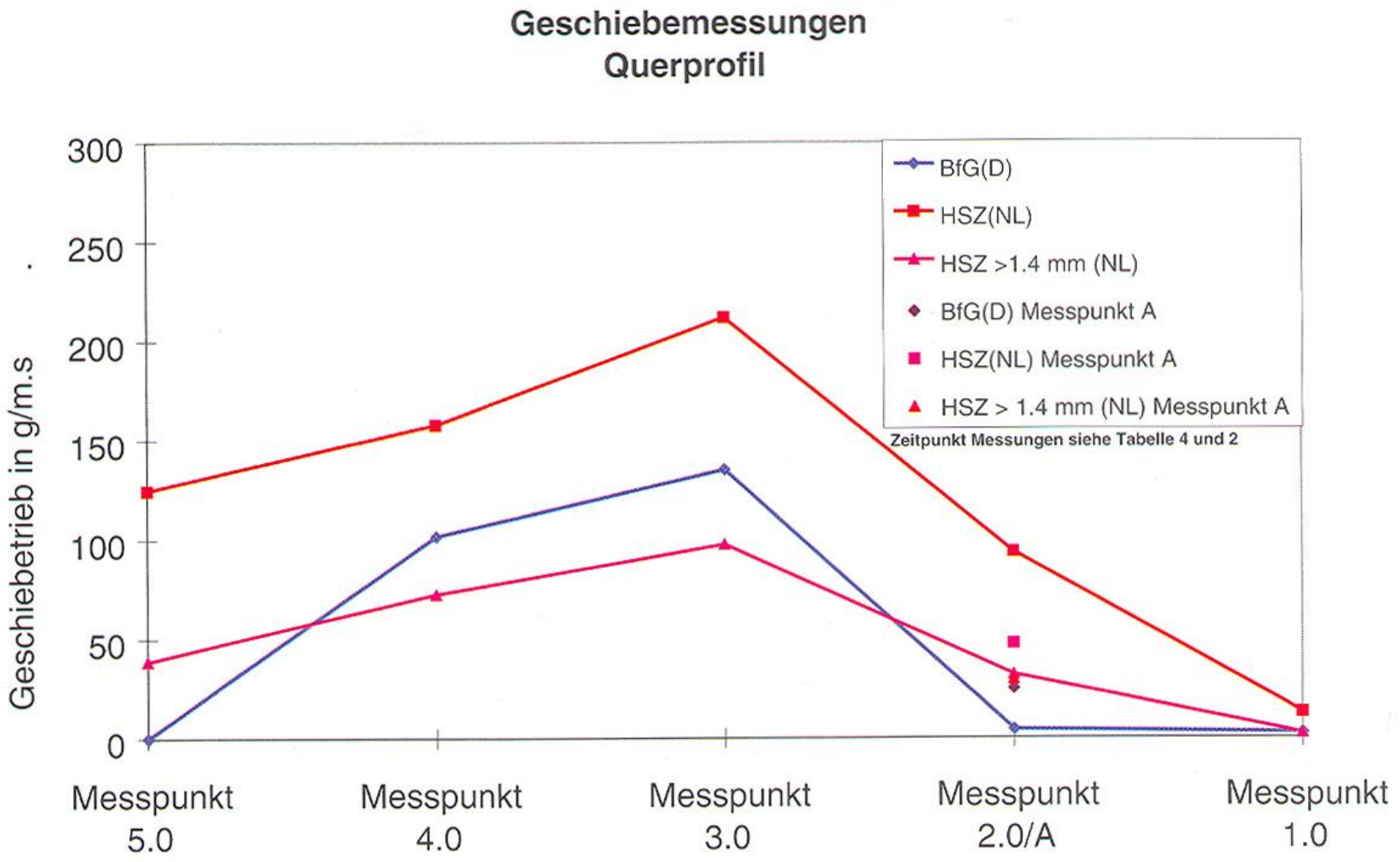
Measurement of bed load in rivers



BfG bed load sampler, 1.5 mm

Measurement of bed load with the Helley-Smith sampler

Comparaison of bed load samplers in the Rhine river



River bottom investigation

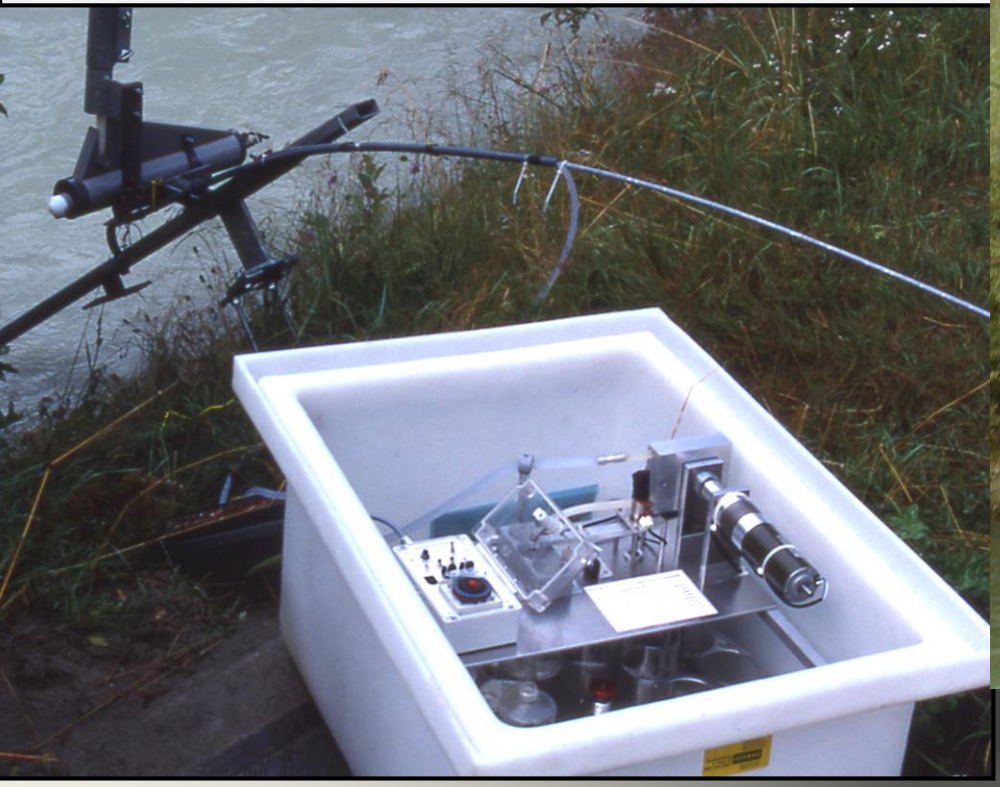
Special boat for bottom sediment sampling

Measurement of suspended sediment

Manual
suspended
sediment sampling

Equipment for integrated
sampling of suspended sediment

Monitoring devices for automatic suspended sediment sampling



Suspended sediment measurement devices

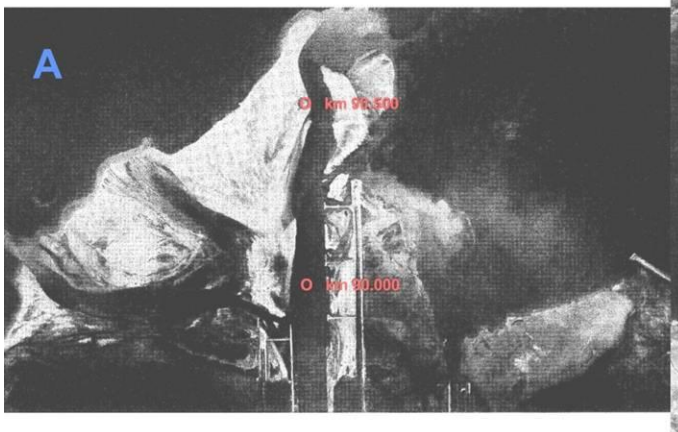
Turbidity meter

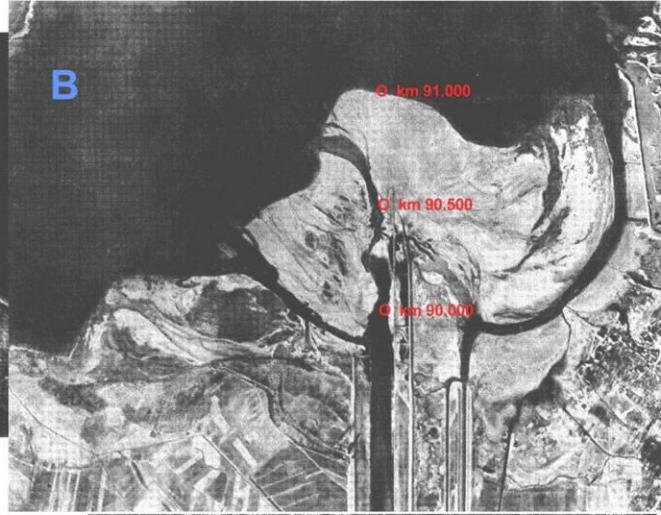
Measurement of wood debris/driftwood

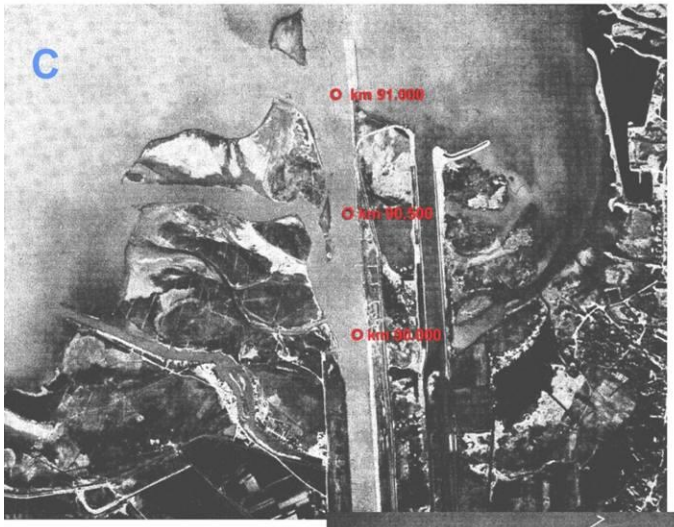
Blocked water intake of the water power station Massaboden

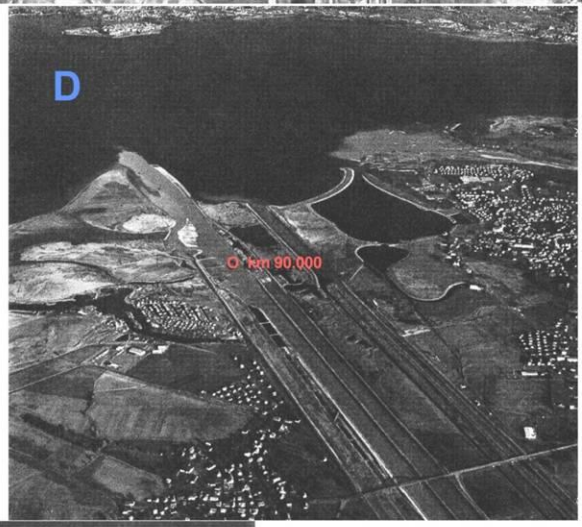
Driftwood in the city of Brig

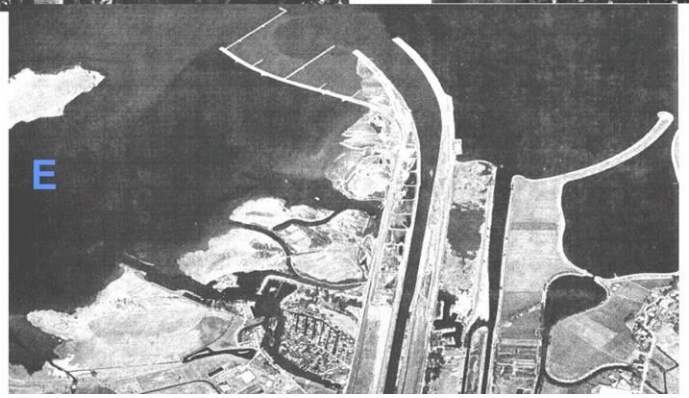
Evolution of the Rhine river delta





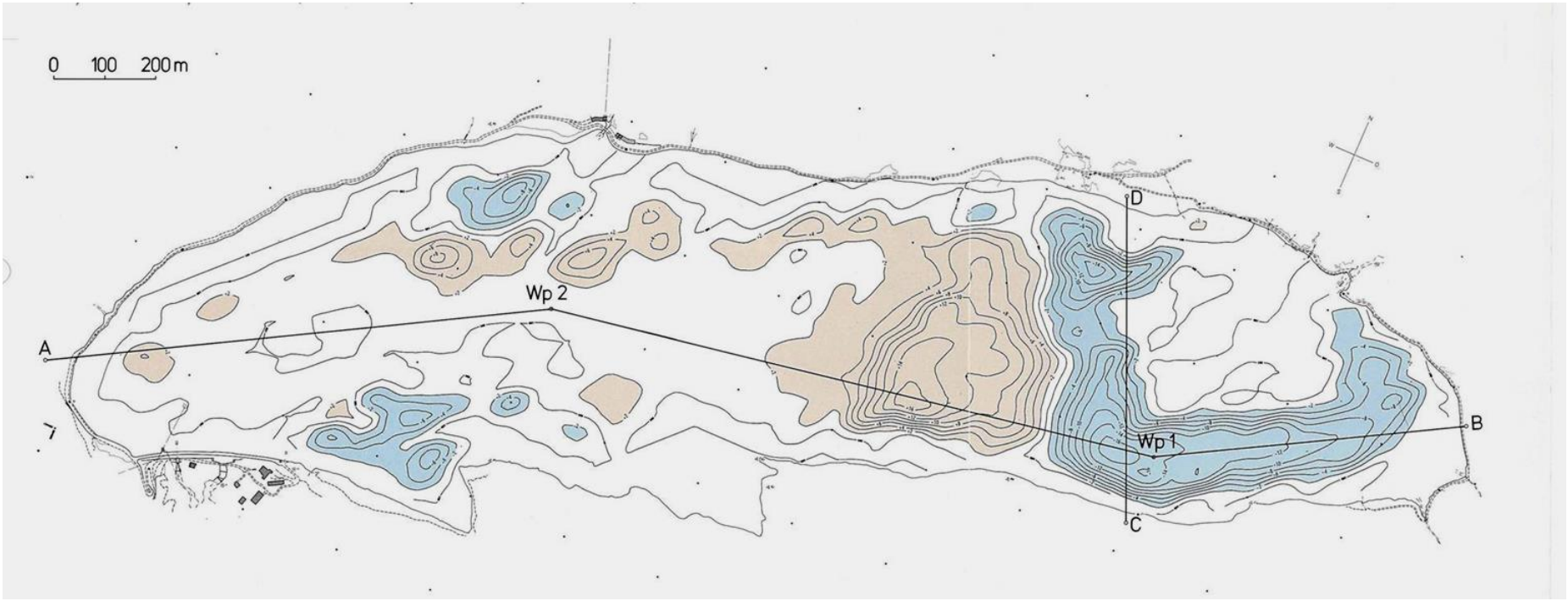




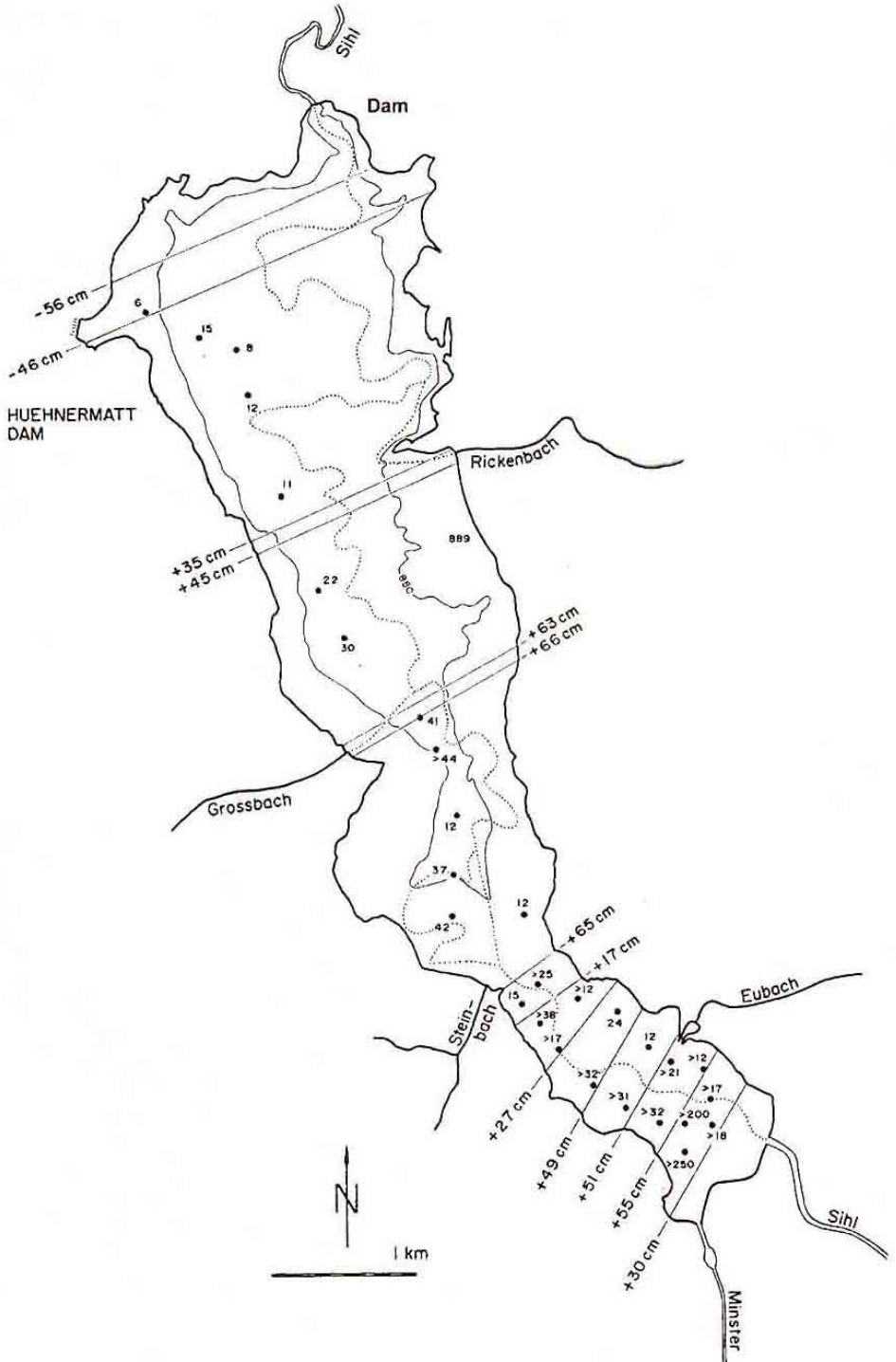


Bathymetric survey of artifical reservoirs

Ritom Reservoir



LAKE DEPOSITS AT SIHL RESERVOIR, 1937 - 1979

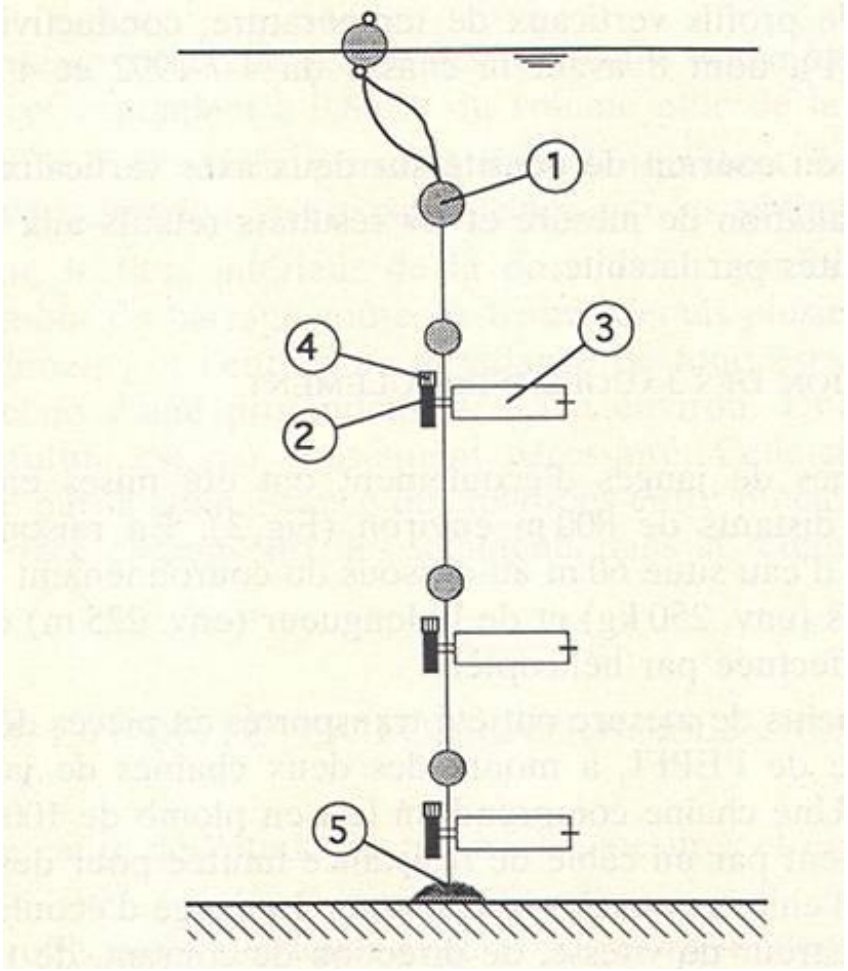


Legend

— - 56 cm Erosion at cross section
— + 35 cm Accumulation at cross section

37 Point measurement
>44 Point measurement, but ground not reached

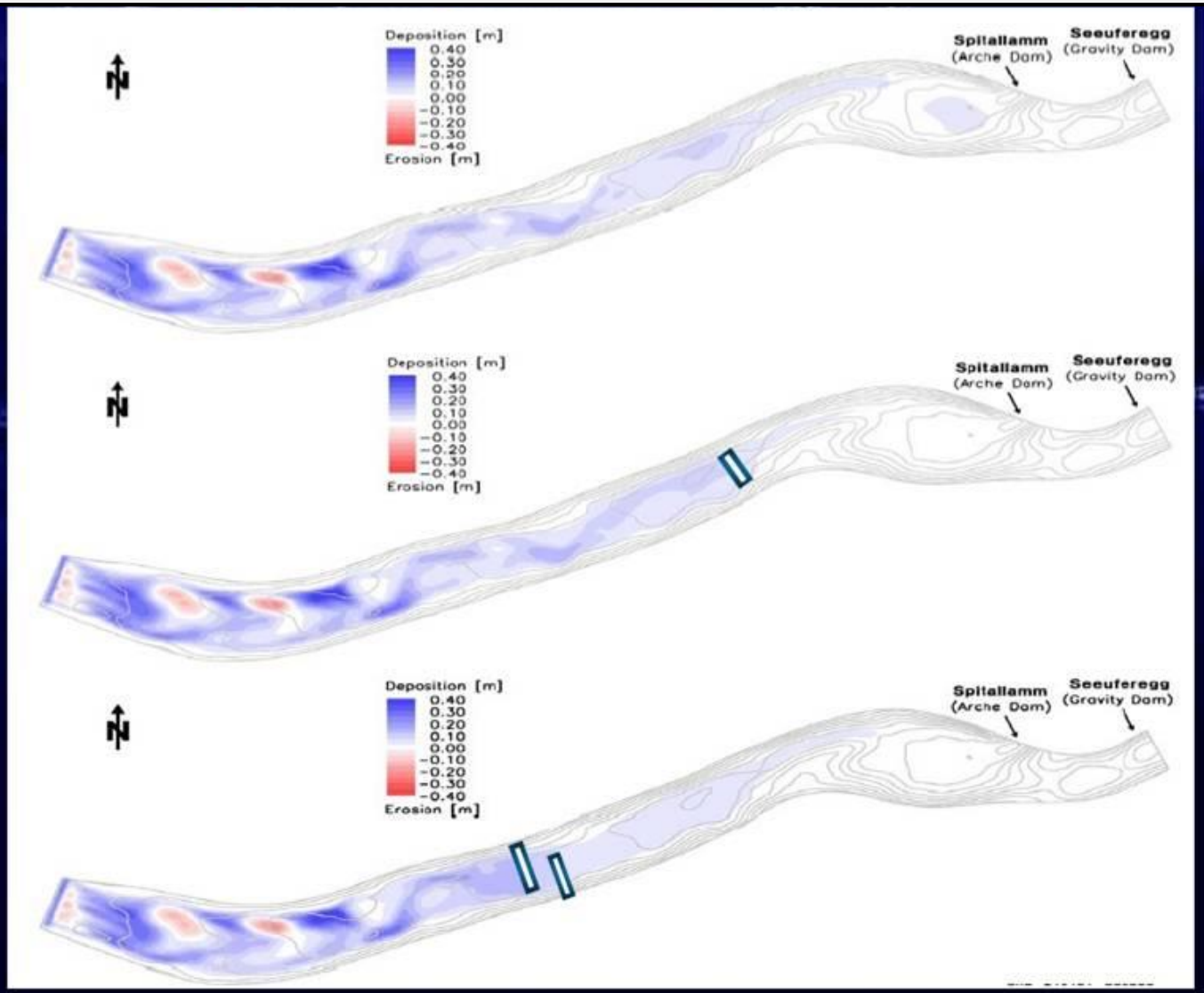
Measurement of turbidity flow



Measurement chain with three current meters

(1) Sub-surface buoy
(2) Recording unit
(3) Flow direction device
(4) Current meter
(5) Ballast

Example Grimsel lake



Ablagerungen und Erosionen eines im Grimselstausees simulierten Trübestroms (Hochwasser vom Oktober 2000)

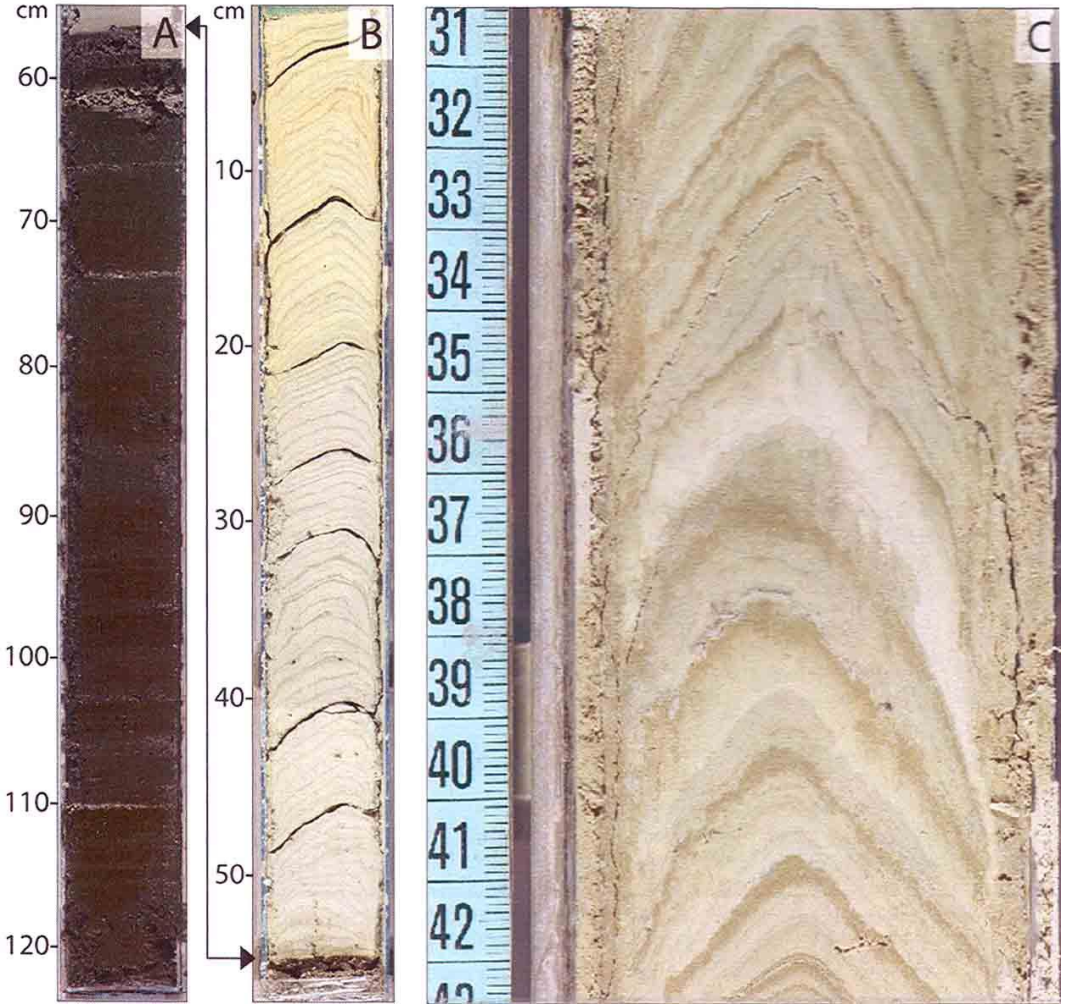
(Schleiss, 2007)

Sediment cores from reservoirs in the Aare basin

Photographs of sediment cores from reservoirs:

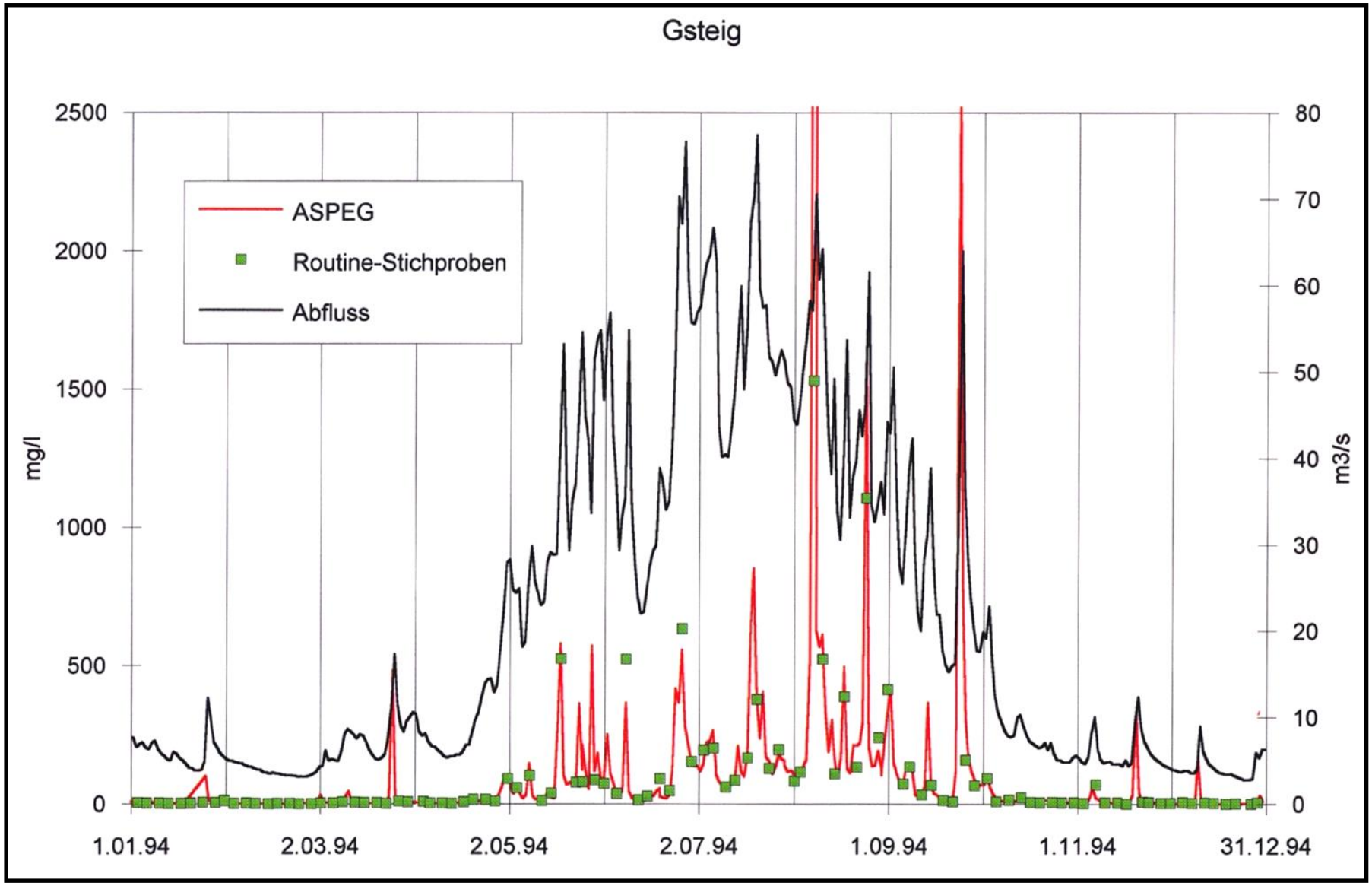
A,B: Core from Grimselsee: Sediment from former natural lakes location showing diatom-rich gyttja (dark brown, A) overlain by 71 proglacial varves (B) that were deposited after the first inundation of the Grimselsee in 1929.

C: Core from Oberaarsee showing details of proglacial varves. The darker layers represent fine-grained sediments that are deposited during winter in the frozen lake.

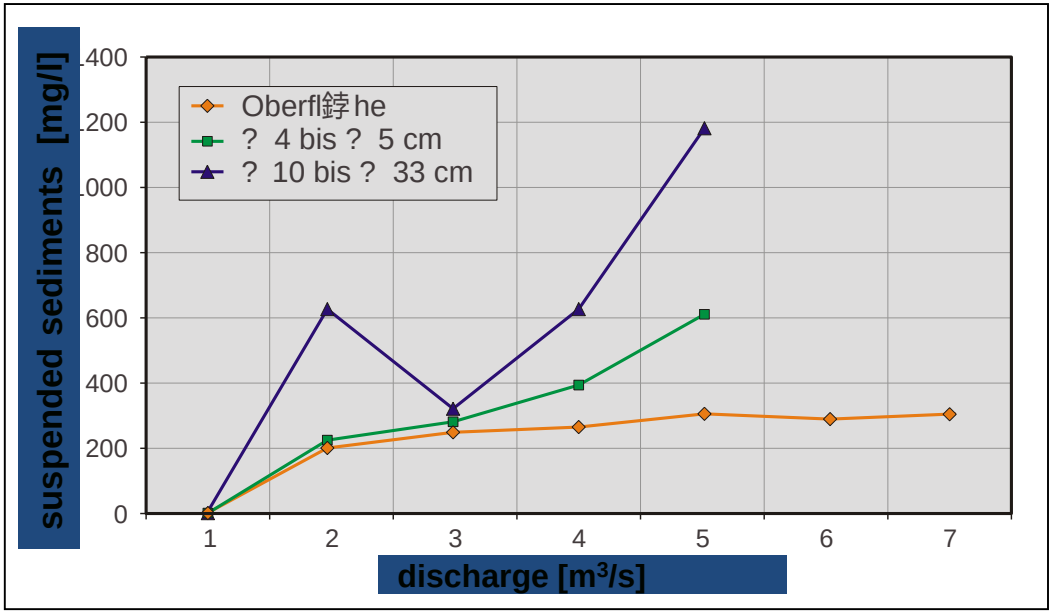


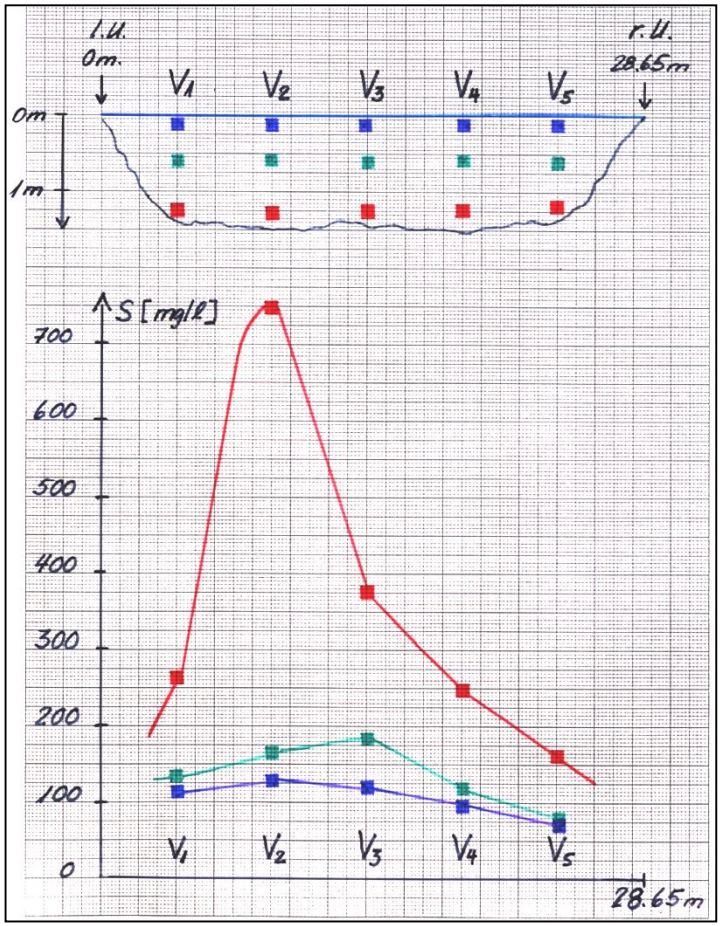
F. Problems of interpretation/accuracy of measured sediment data

Problem of representativity of random samples



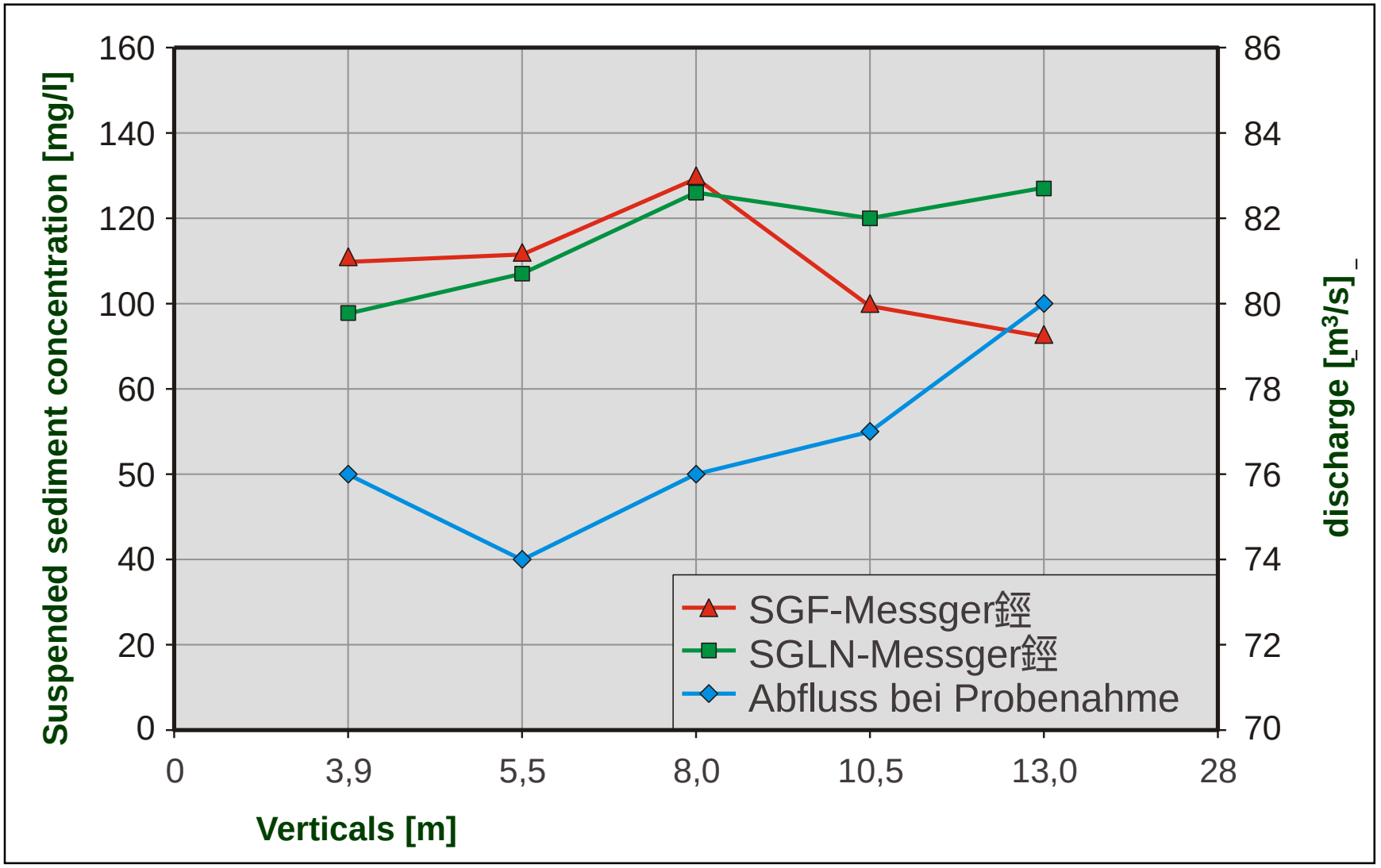
Observation in different water depth



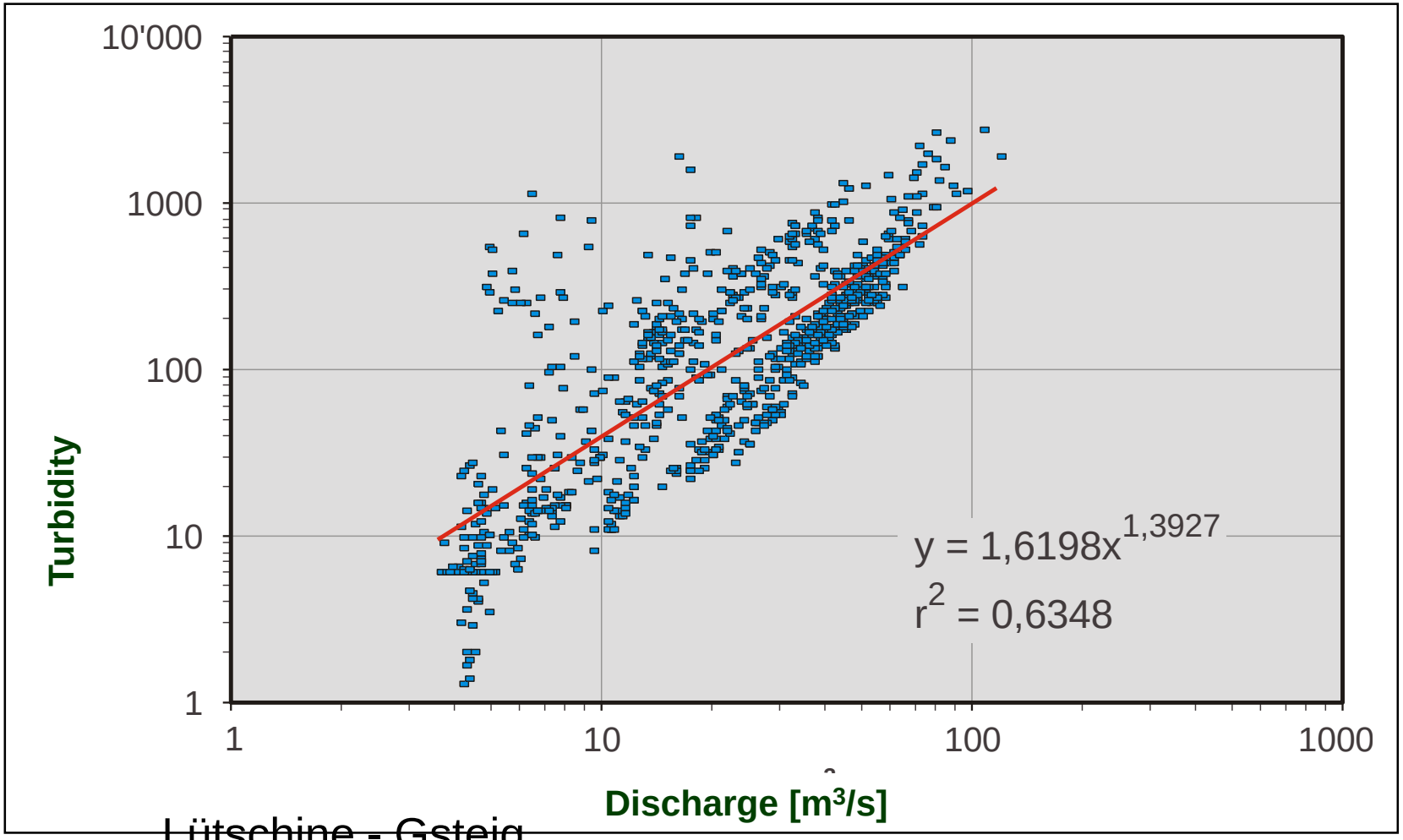


Increase of suspended sediment concentration from surface to bottom

Influence of the monitoring devices



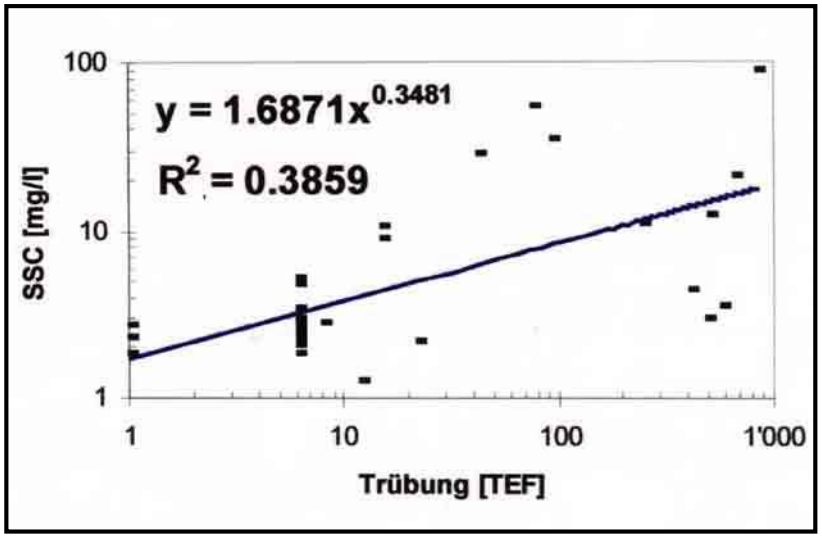
Correlation between turbidity and discharge

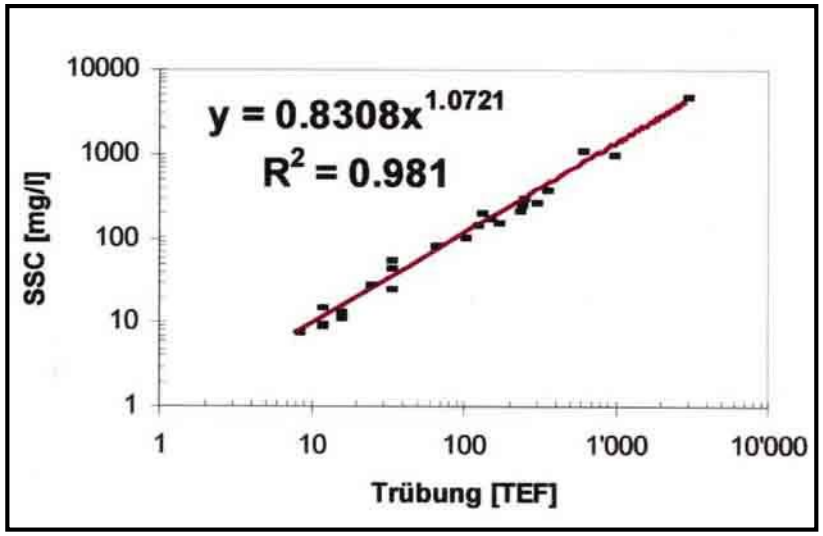


Lütschine - Gsteig

Accuracy problem

Relation turbidity - suspended sediment concentration





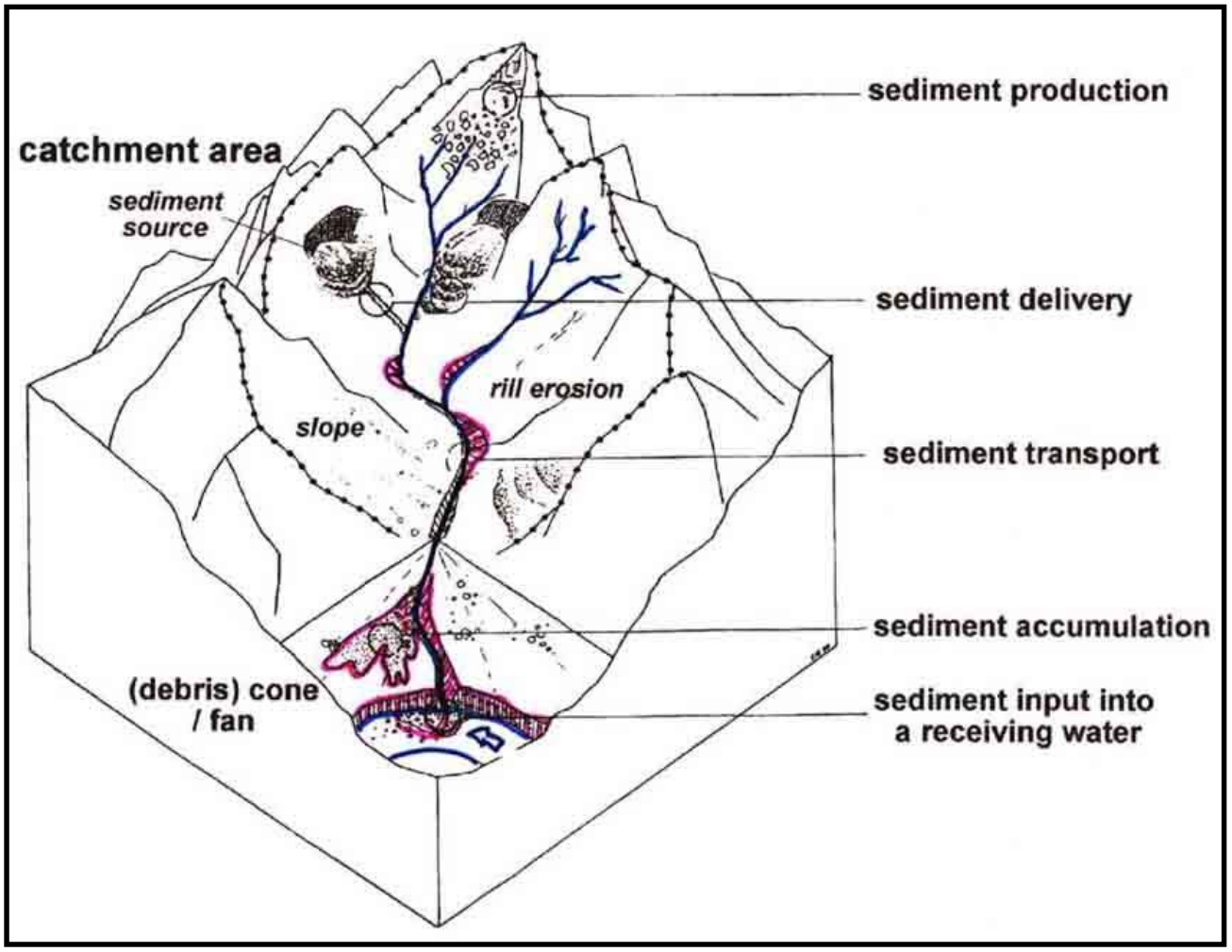
Lütschine - Gsteig

Governed by: - Snow and glacier melt
- Precipitation

(Binderheim, 1999

G. Estimation procedure for sediment transport in small mountain streams

System



(GHO, 1996)

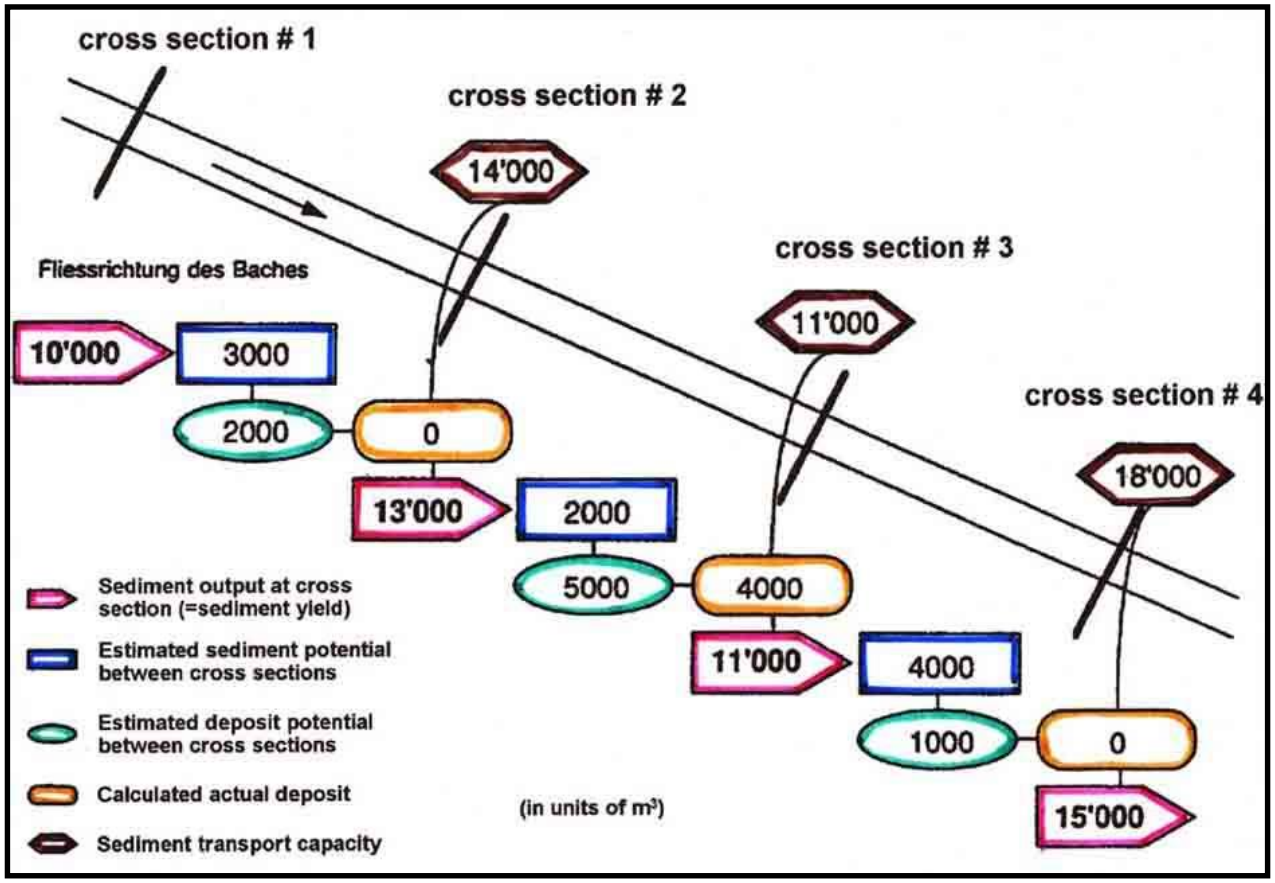
Method: LEHMA

Procedure:

– Estimation of sediment potential of specific reaches of the torrent

– Determination of transport process and calculations of transport

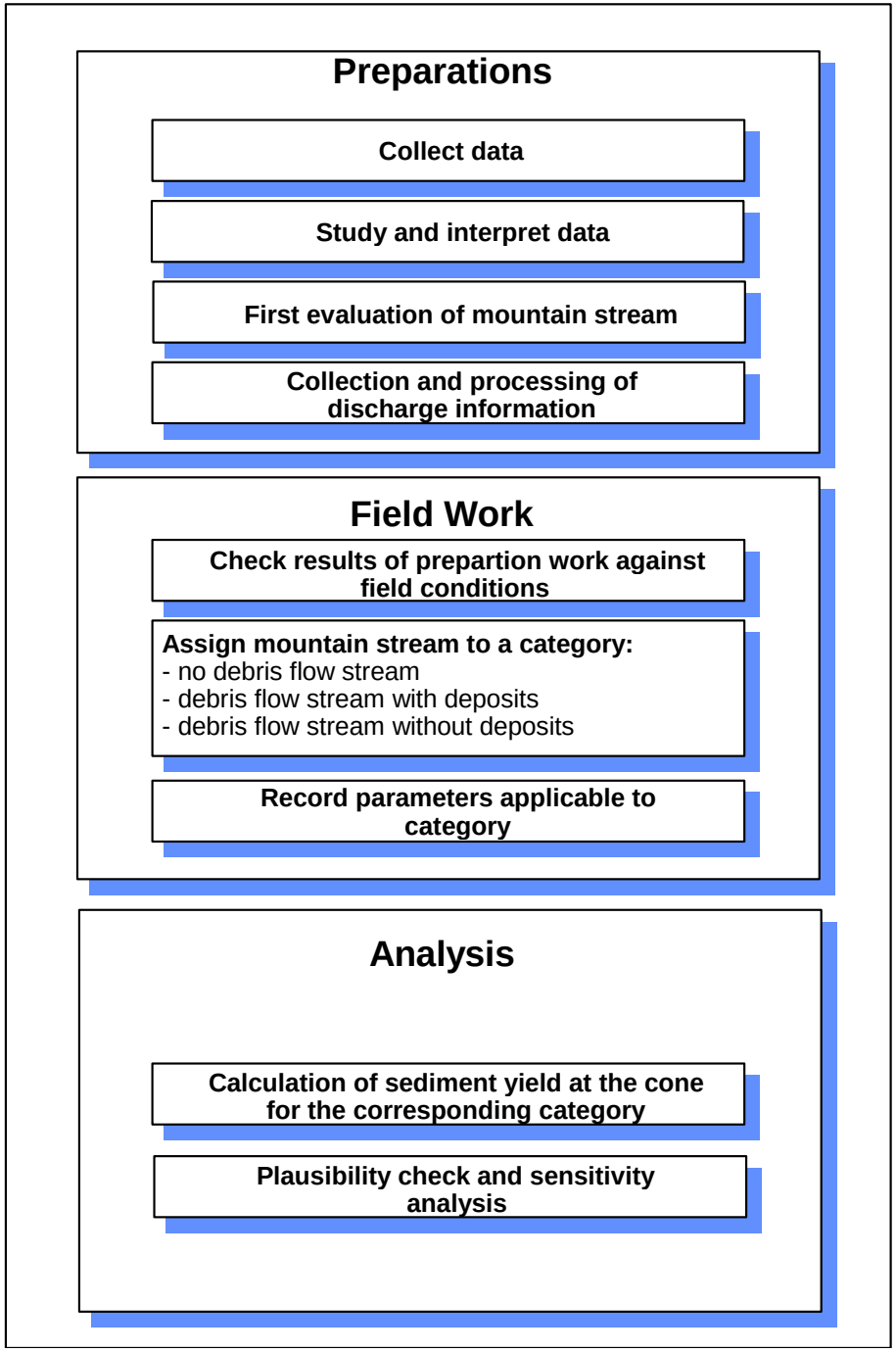
Assessment of sediment yield in mountain streams



Procedure:
Determination of sediment balance for each channel section

Level of operation:
- Handbook
- Theory book
- Computer program for calculation

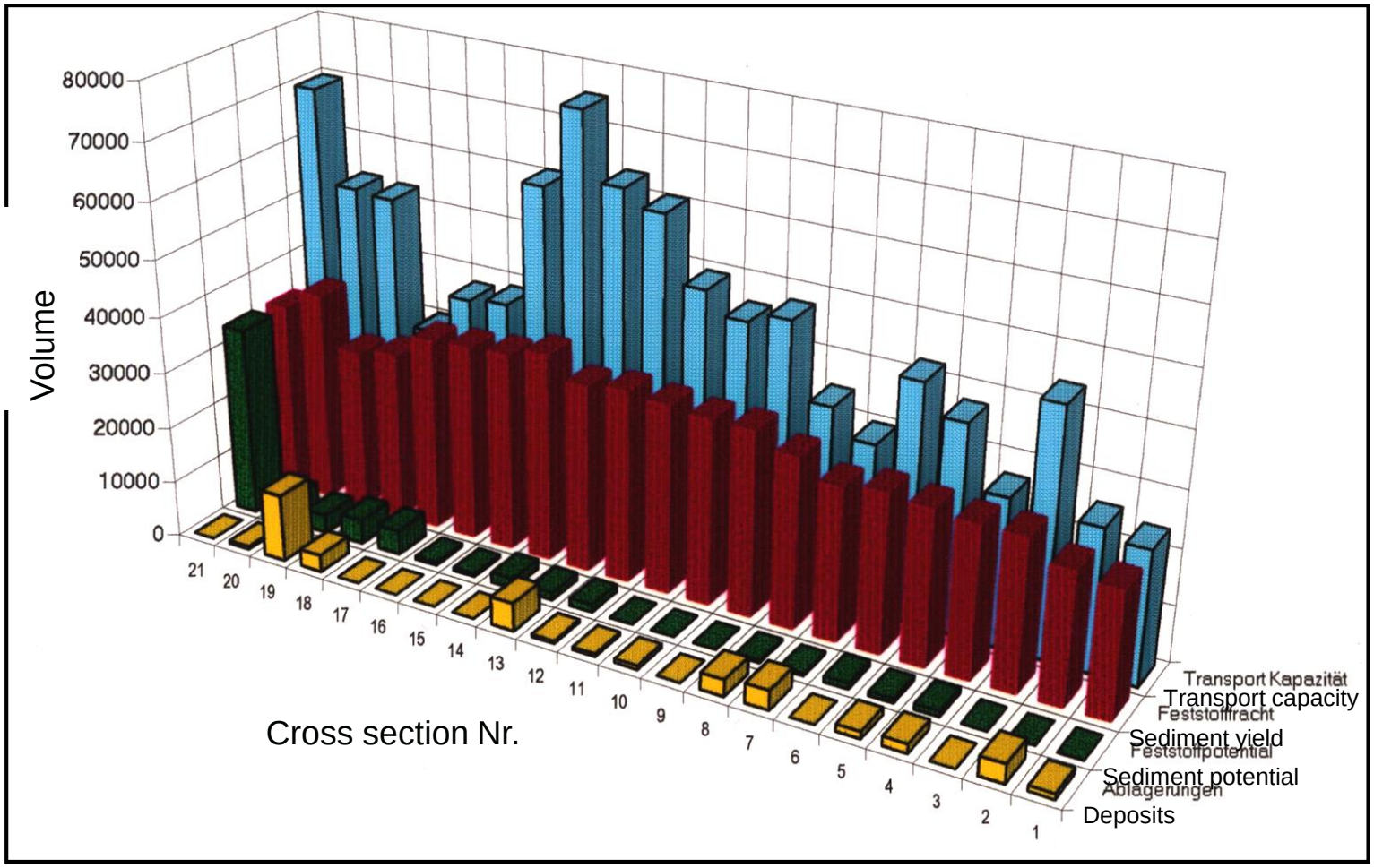
Procedure to assess sediment yield in mountain streams



(GHO, 1996)

Estimation of sediment transport in small mountain streams

Sediment transport during a 100-year flood in the Guppenruns



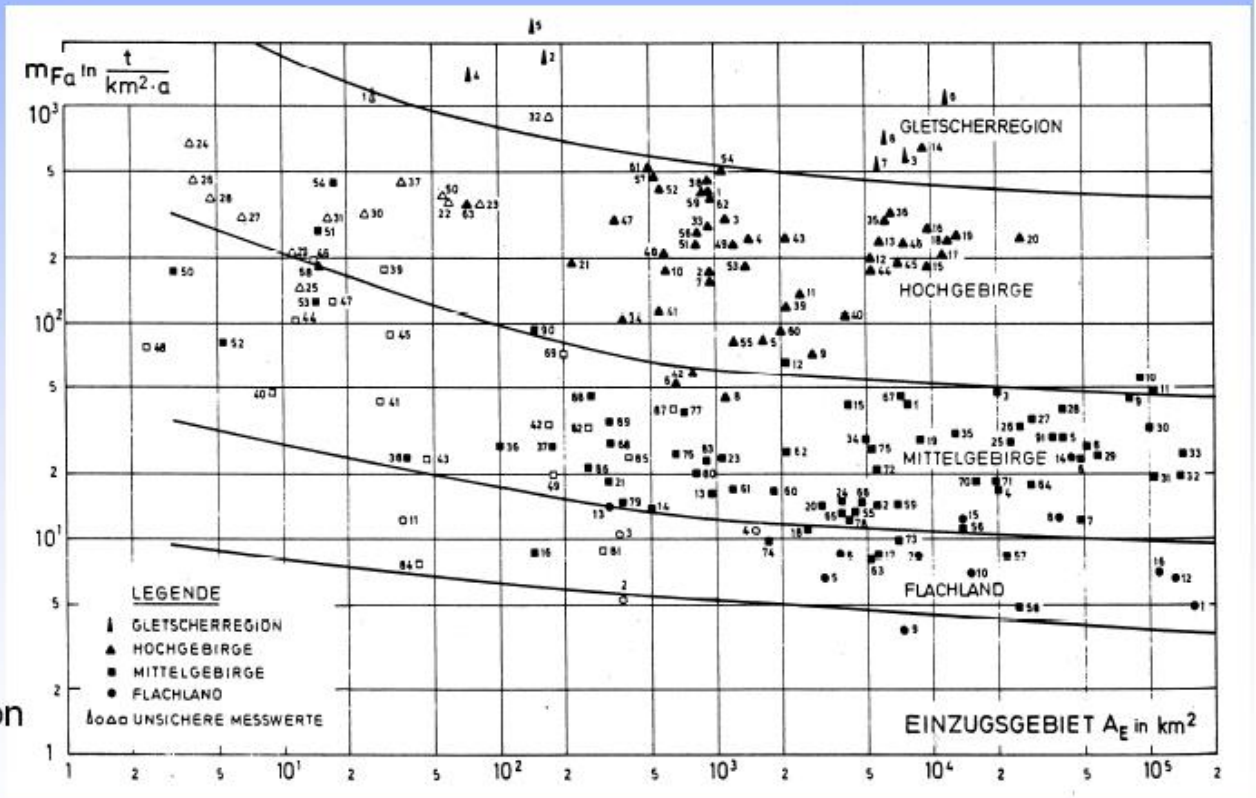
H. Estimation of amount of soil erosion

2.4 Denudation (Abtragungsrate) - Erosion / *Erosion rate*

Universal Soil Loss Equation

2.4.3 Sedimentaustrag / *Sediment yield*

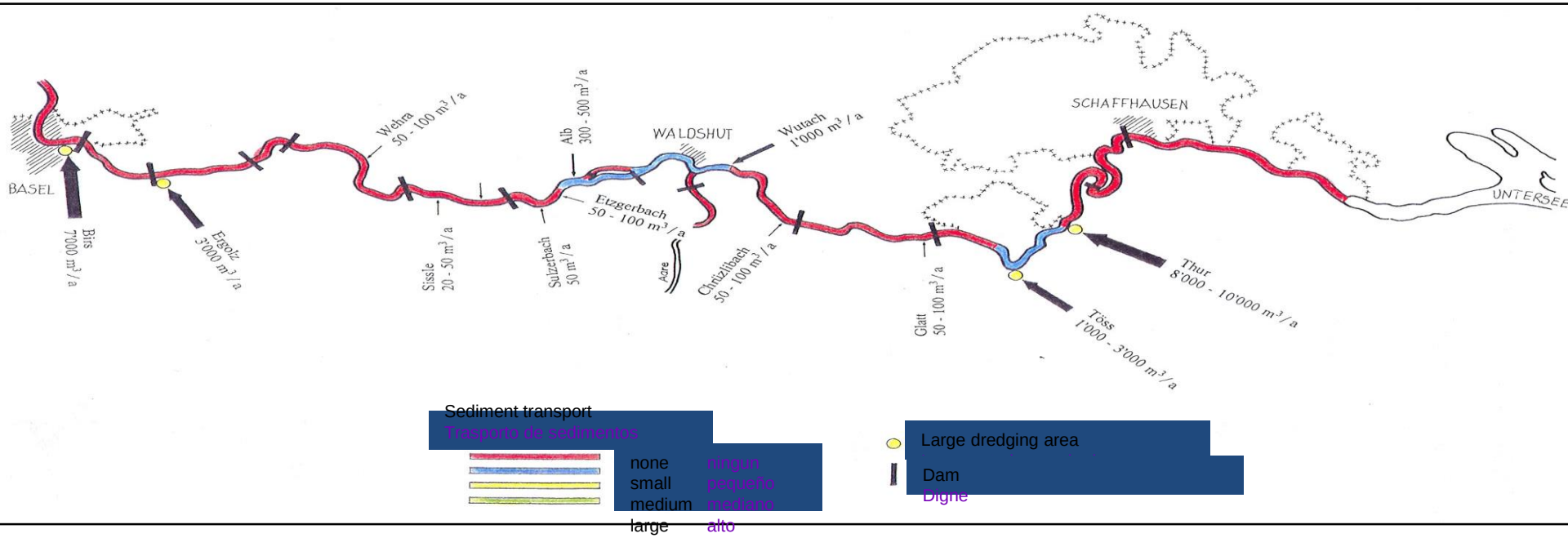
Sedimentlieferrate / *Sediment delivery ratio*



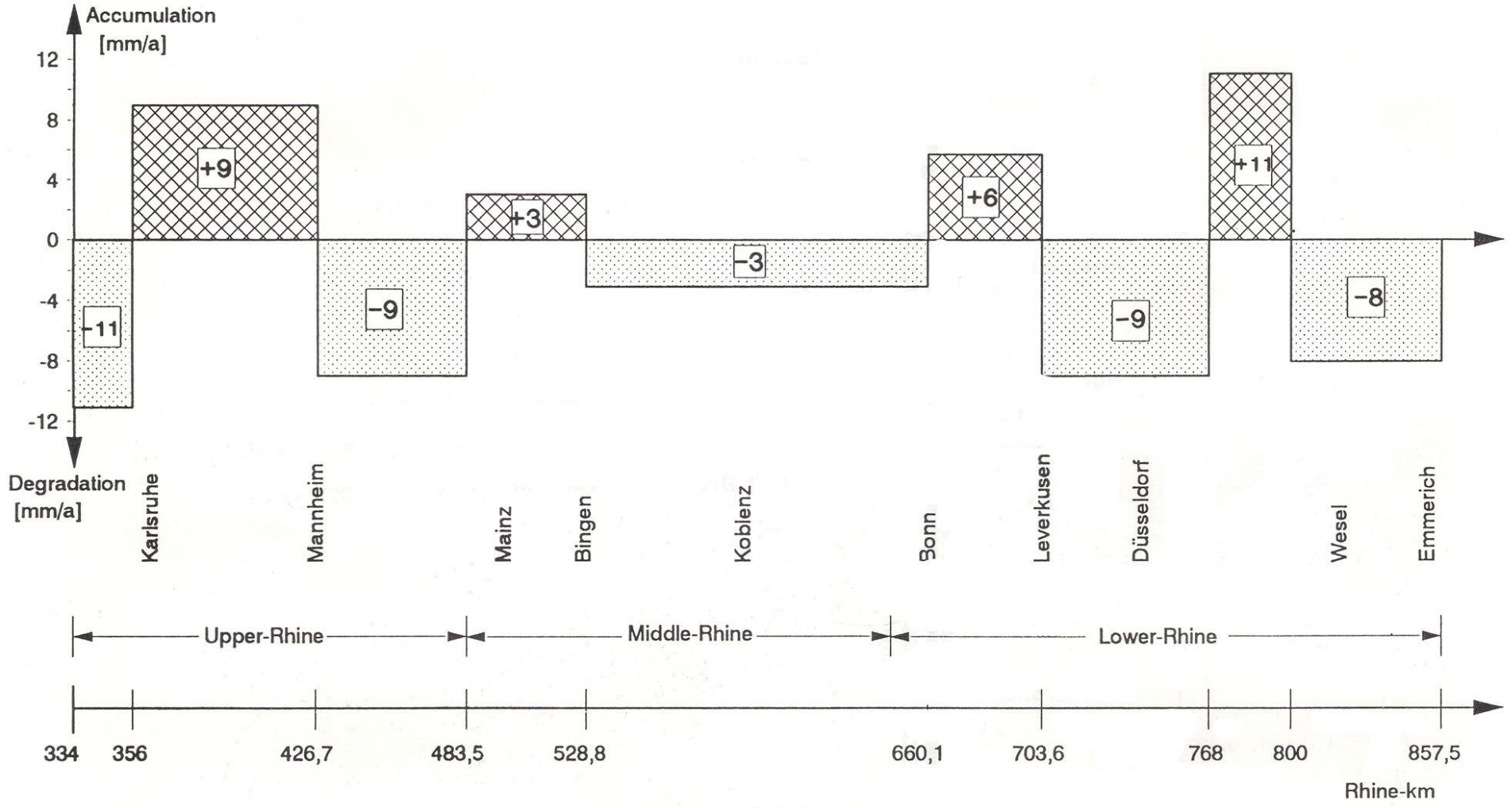
Jährlicher Feststoffabtrag in Abhängigkeit von der Größe des Einzugsgebietes A_E und der Region (Schröder et al., 1984)

I. Sediment budget and balance in rivers

Sediment inflow and sediment balance of the Rhine river between Lake of Constance and Basel

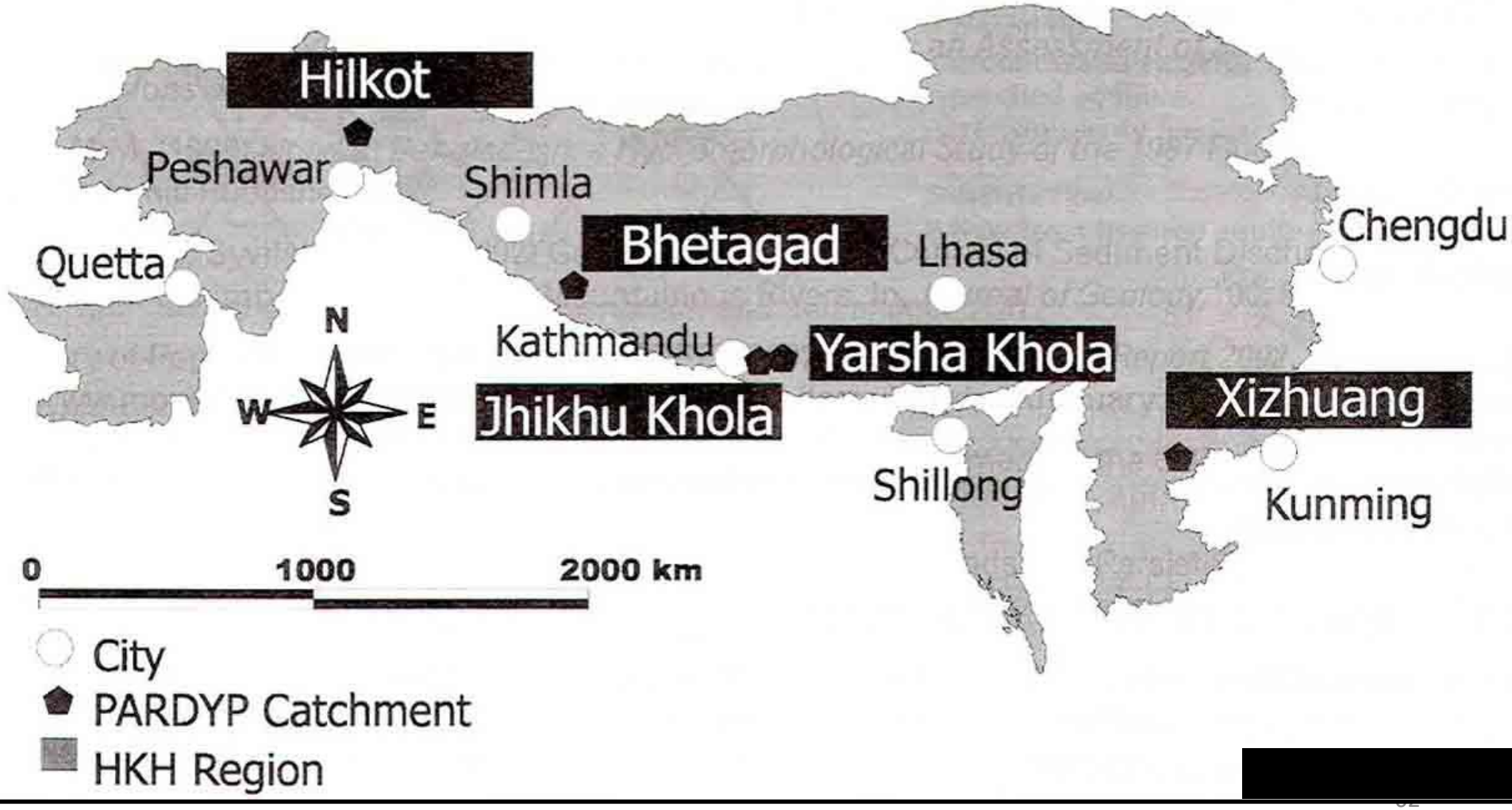


Mean annual change of the average bottom niveau and bed load balance between 1981 and 1990

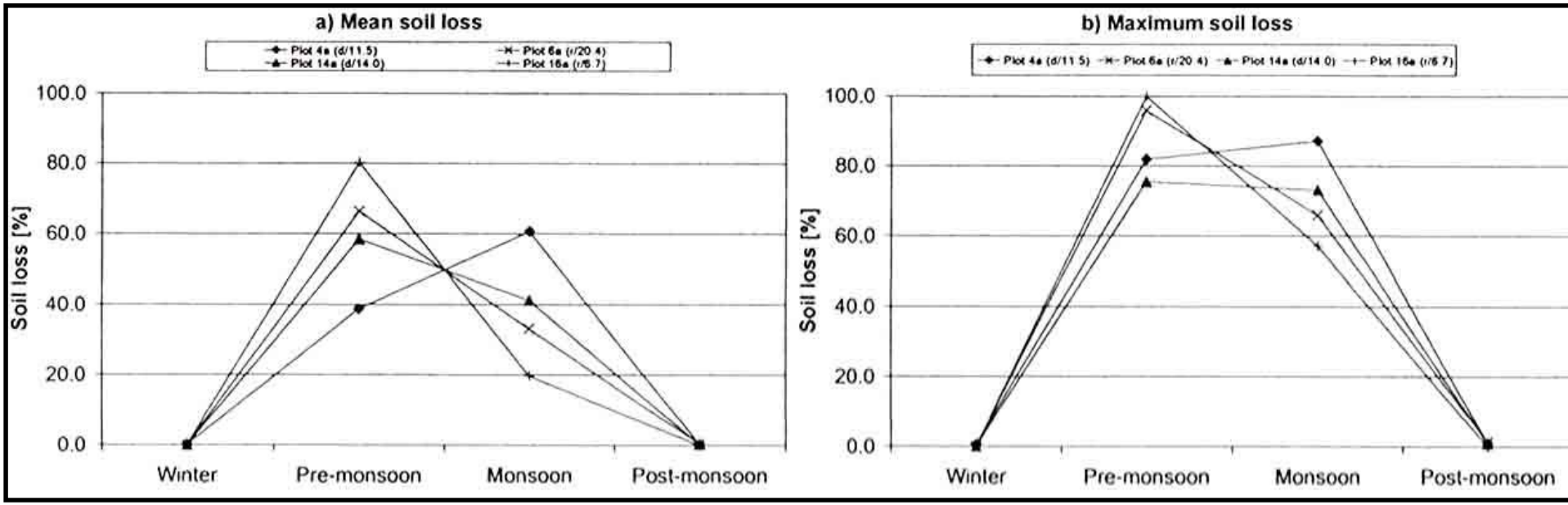


Sediment budgets in the Himalayas with special attention to Jhikhu Khola and Yarsha Khola

The PARDYP catchments, Jürg Merz

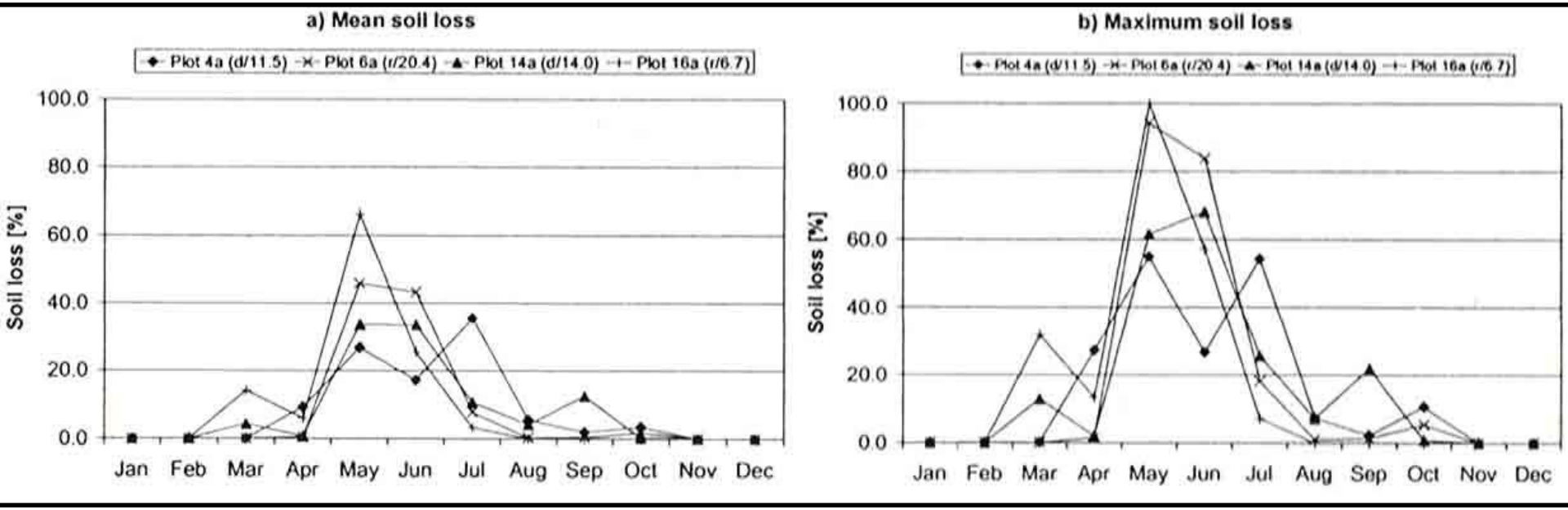


Seasonal soil loss Jhikhu Khola
1998 - 2000
(Plots monitoring)



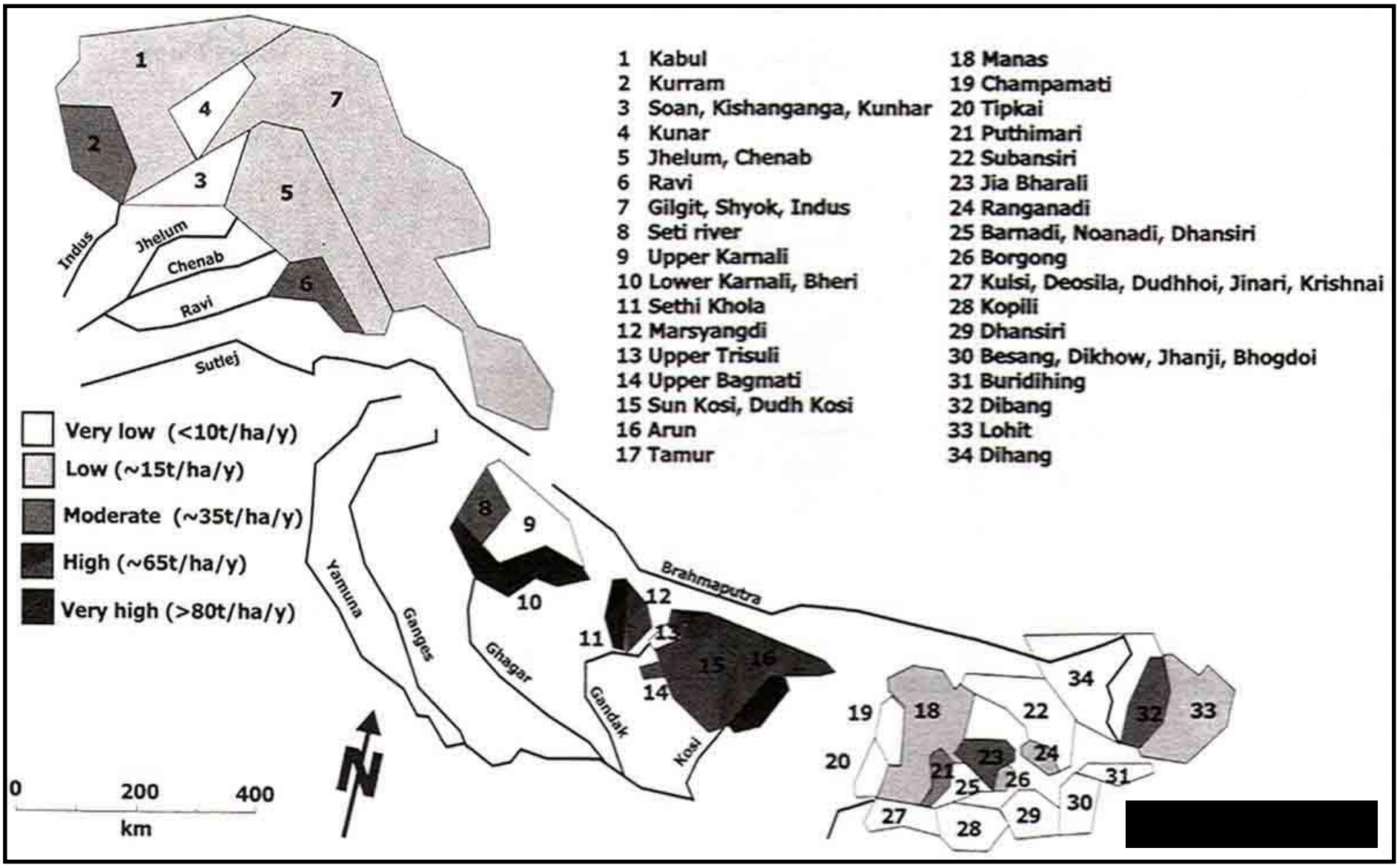
(Merz, 2003)

Monthly soil loss Jhikhu Khola



(Merz, 2003)

Suspended sediment delivery from some Himalayan rivers (Lauterburg 1993)

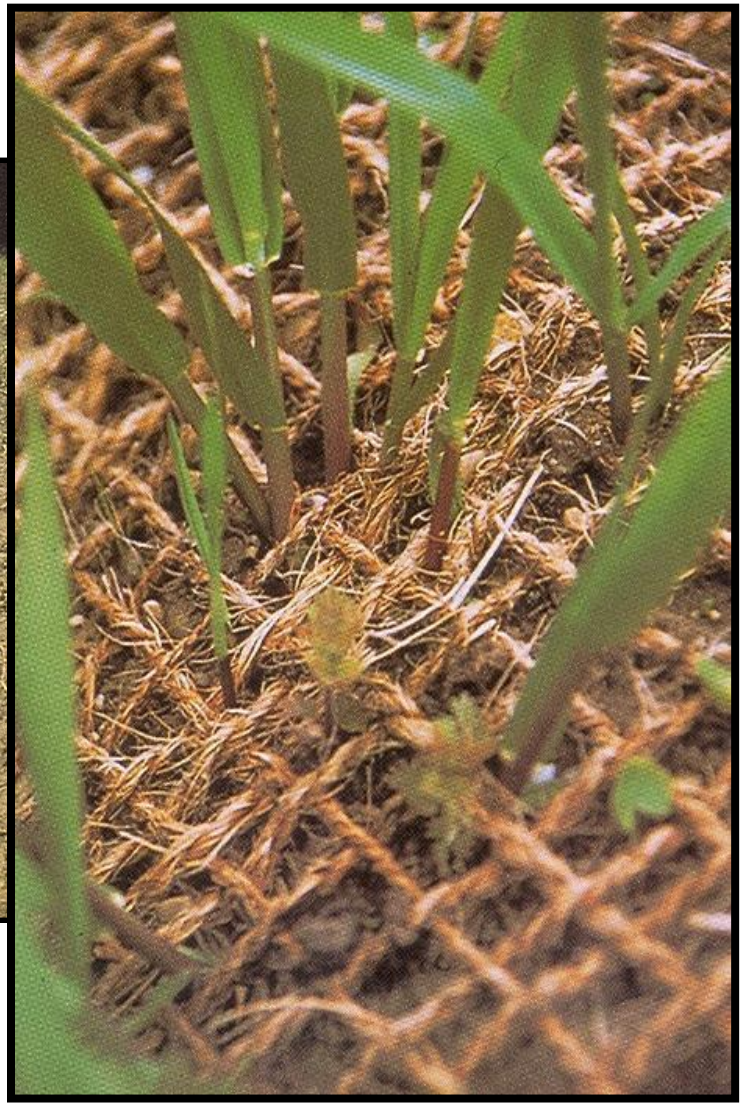


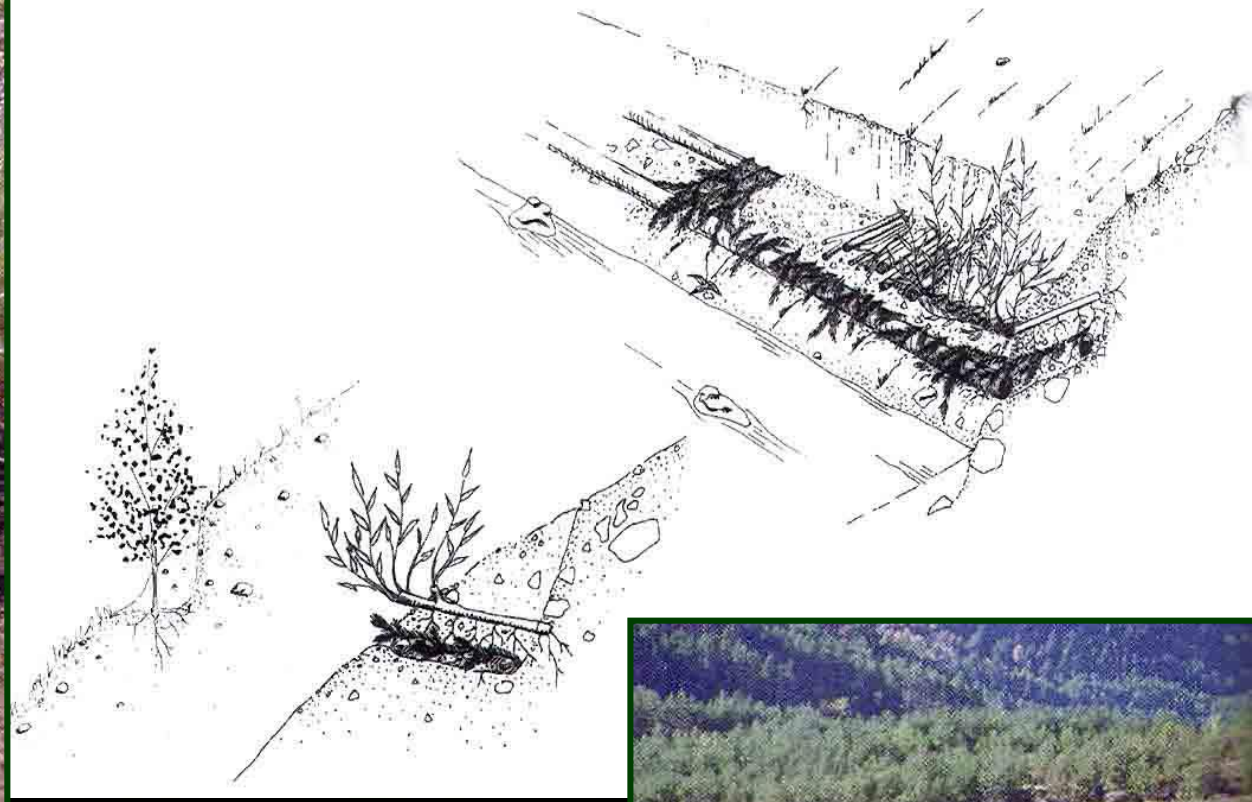
3. Possibilities and effects of measures for the reduction of sediment input into the reservoir

Reduction of erosion

- Conserving of soil vegetation
- Supporting of growth of pioneer vegetation
- Reforestation
- Stabilization measures

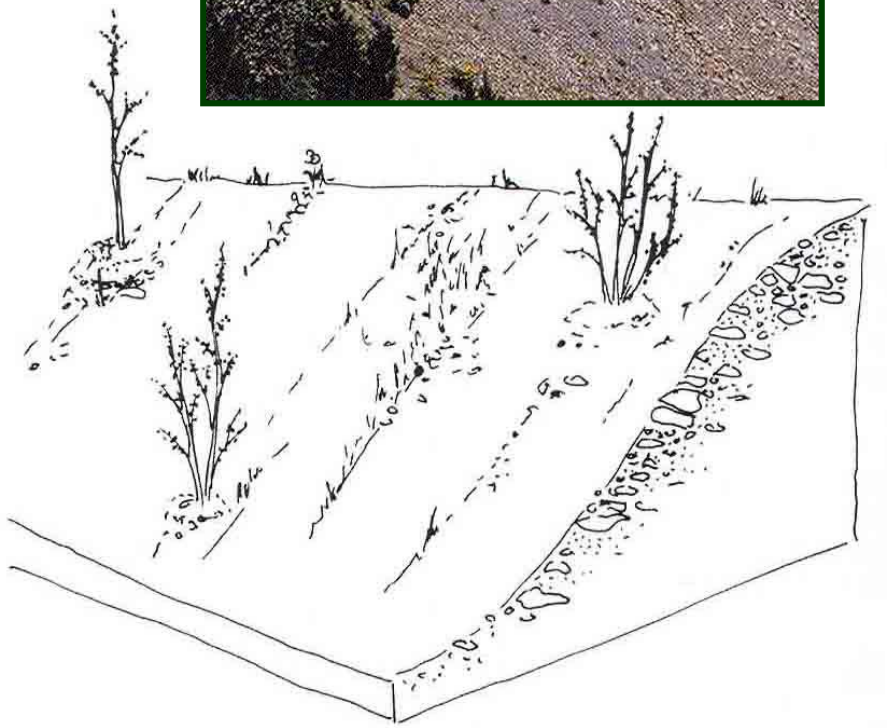
Supporting of growth of pioneer vegetation





Contour planting

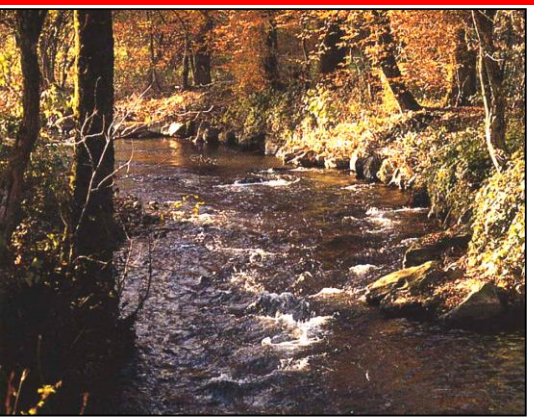
For reforestation of dry or snowy steep sites, the construction of terraces/Berms may be required in many cases.

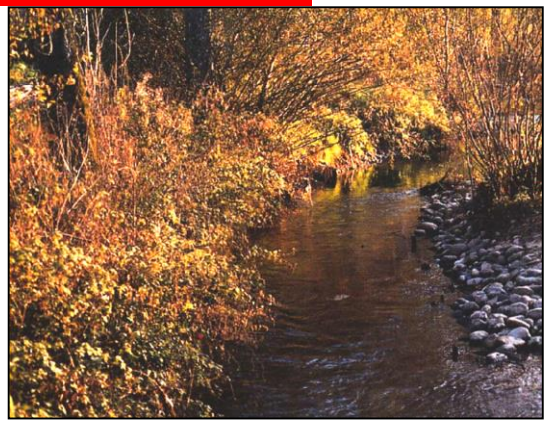


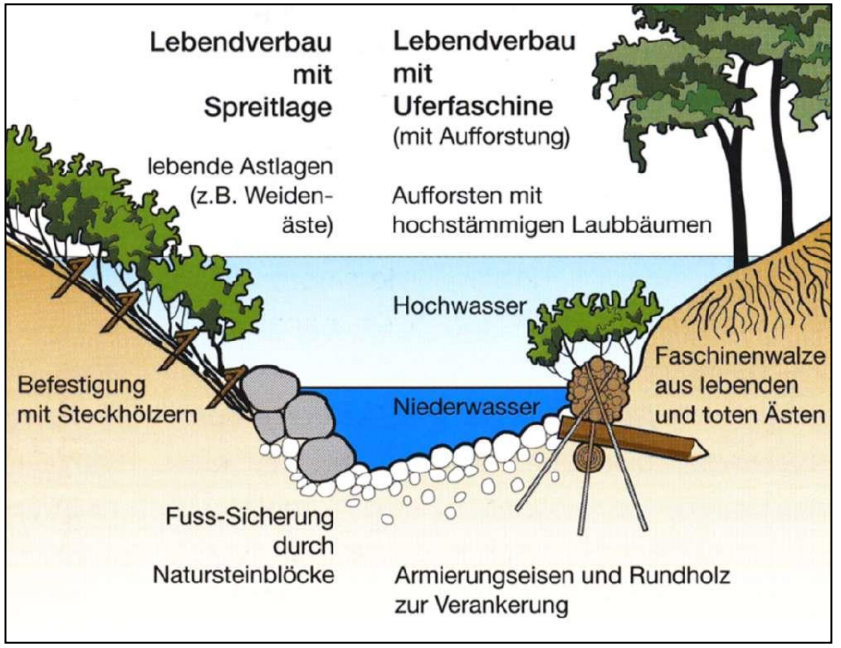
Afforestation with mixed planting

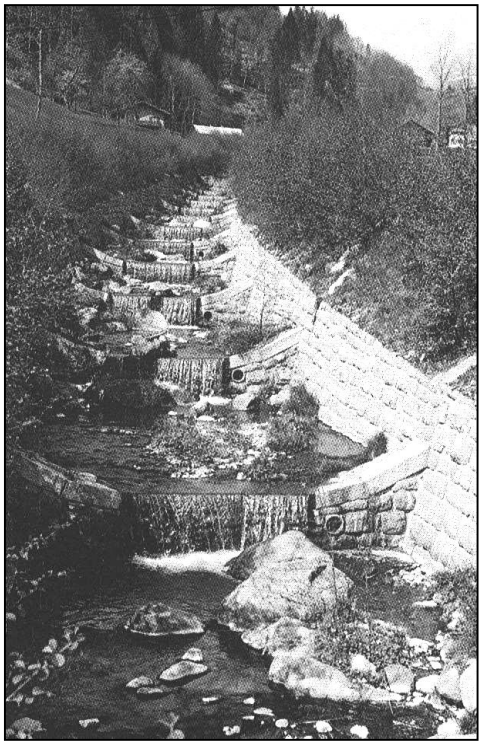
To accelerate forestation, woody species that are suited to the site are set out on barren areas at distances as required (1-3m) using various planting methods

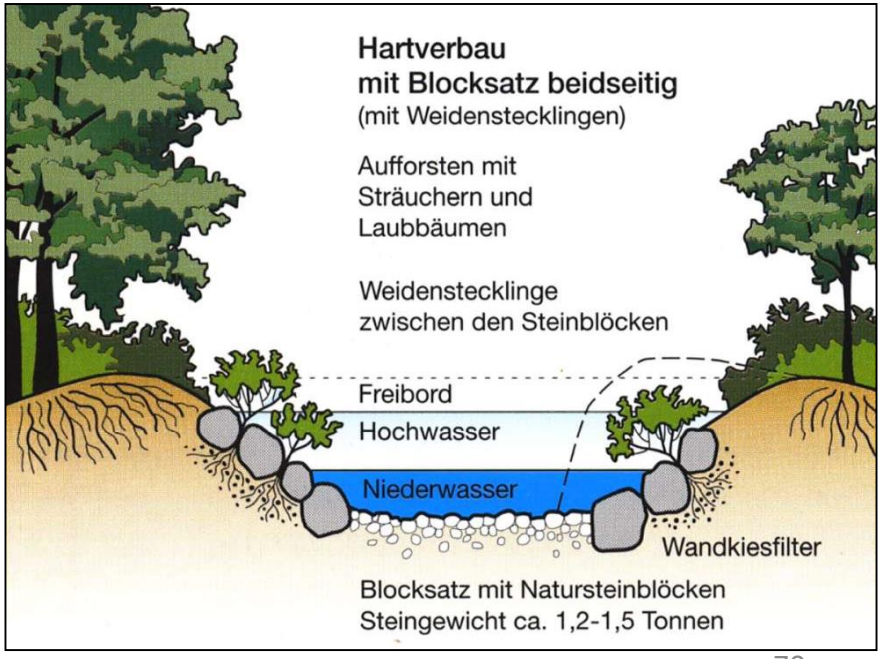
Stabilisation of rivers





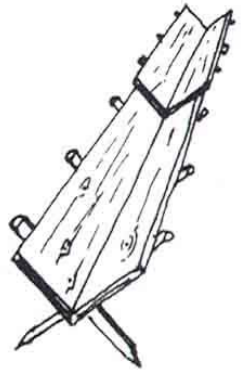


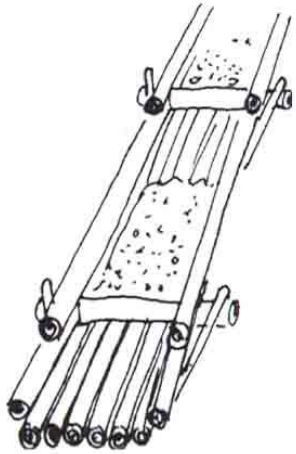


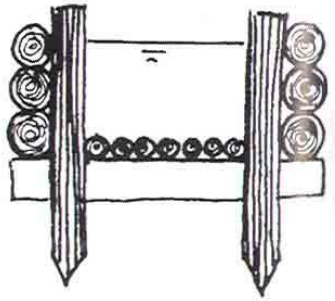


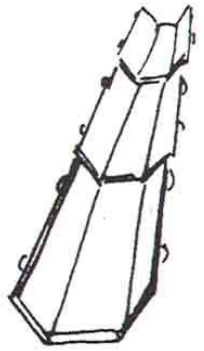
Open channels

Water that runs off the surface of a slope and cannot be taken up by vegetation alone and should not be allowed to seep into the ground either

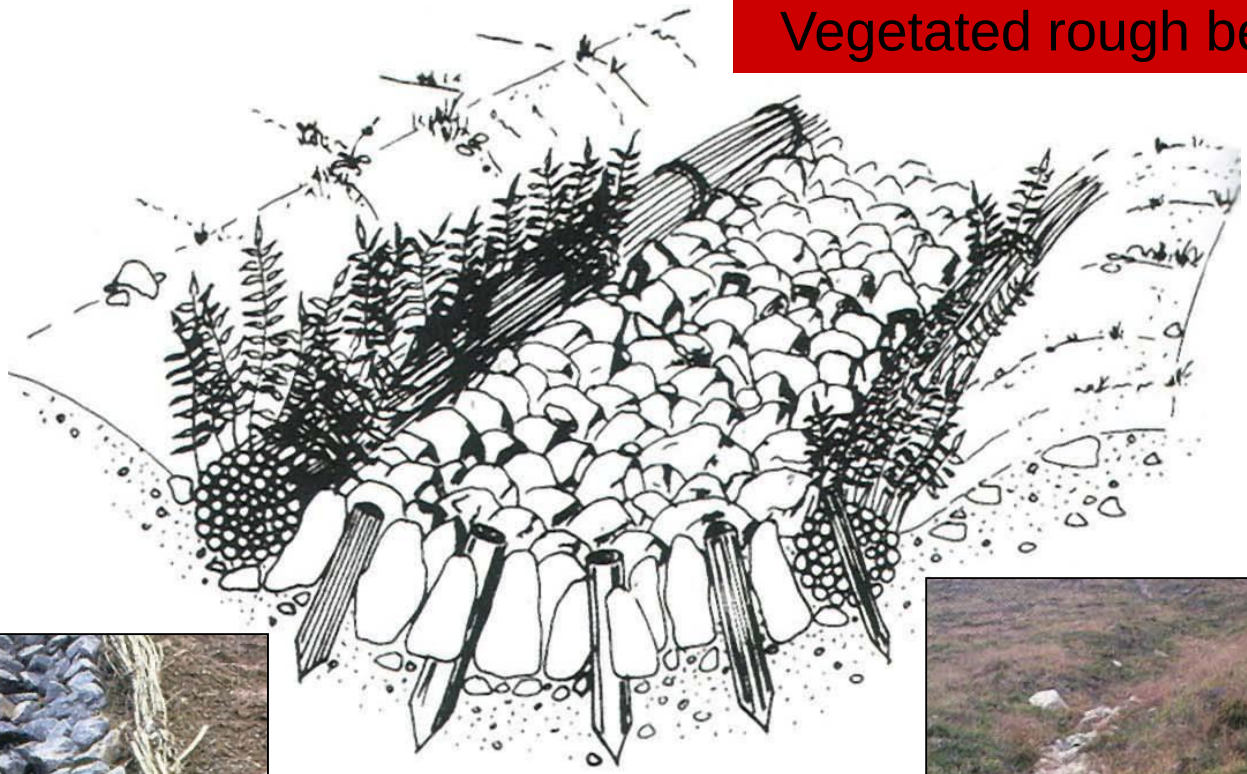


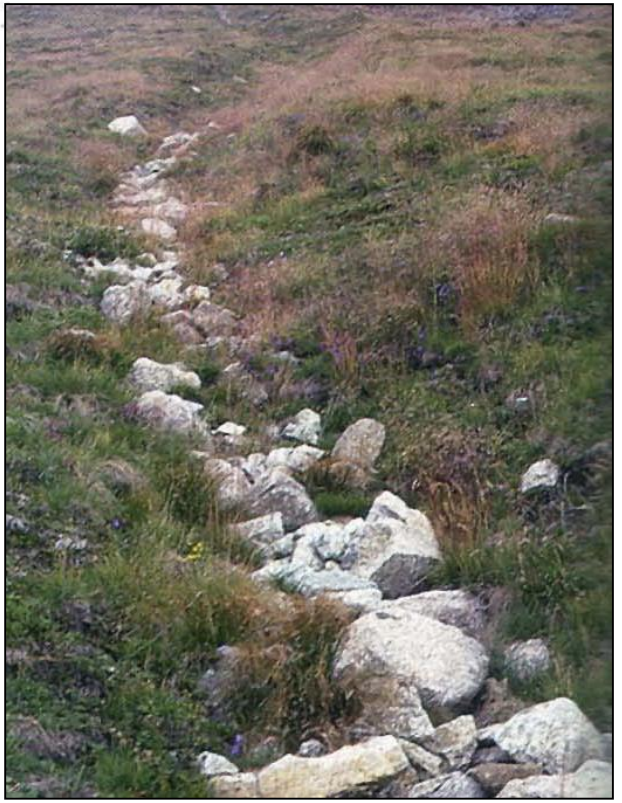




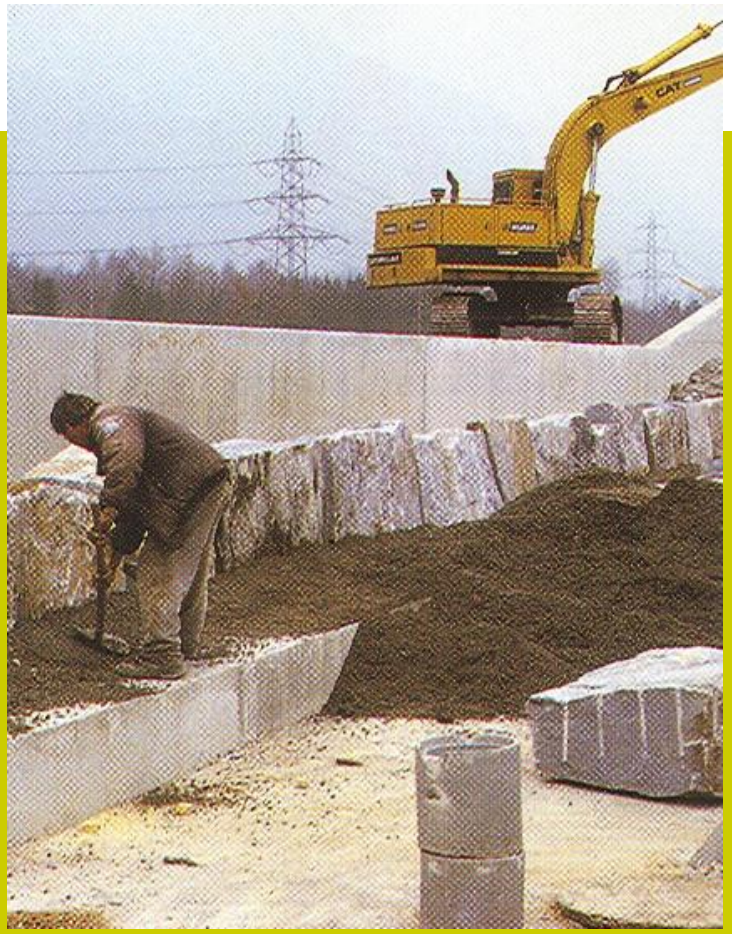


Vegetated rough bed channel

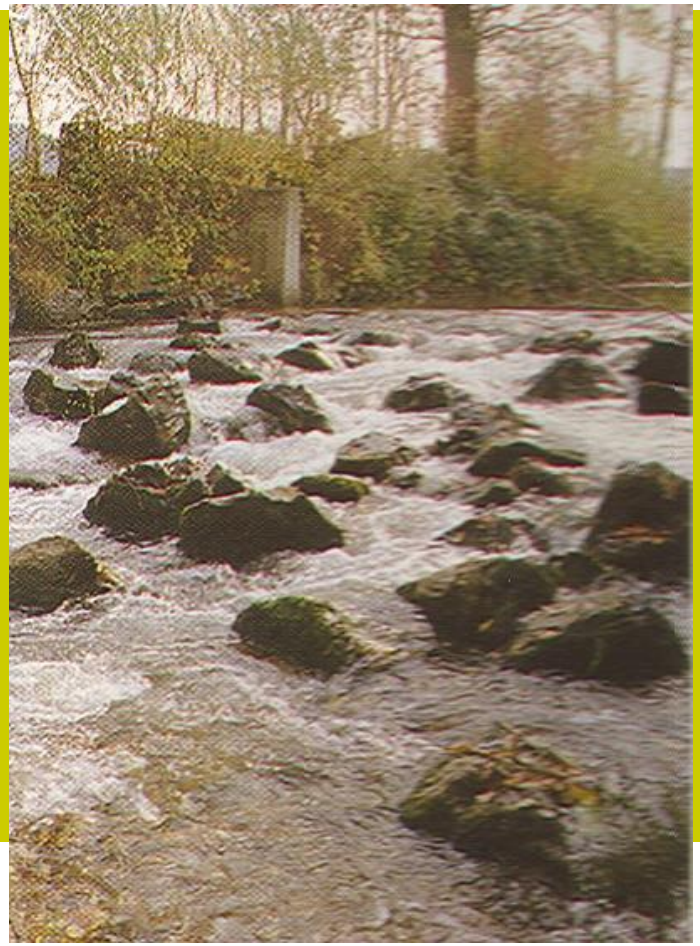




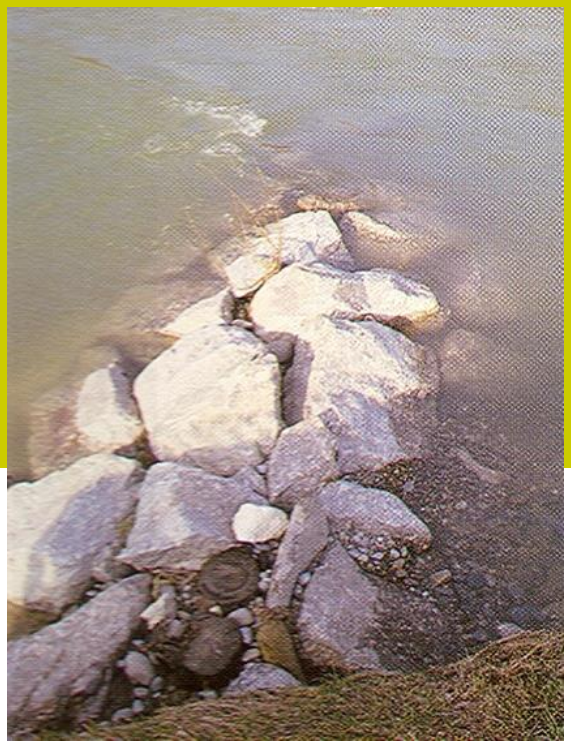
Dam construction, which allows overspill



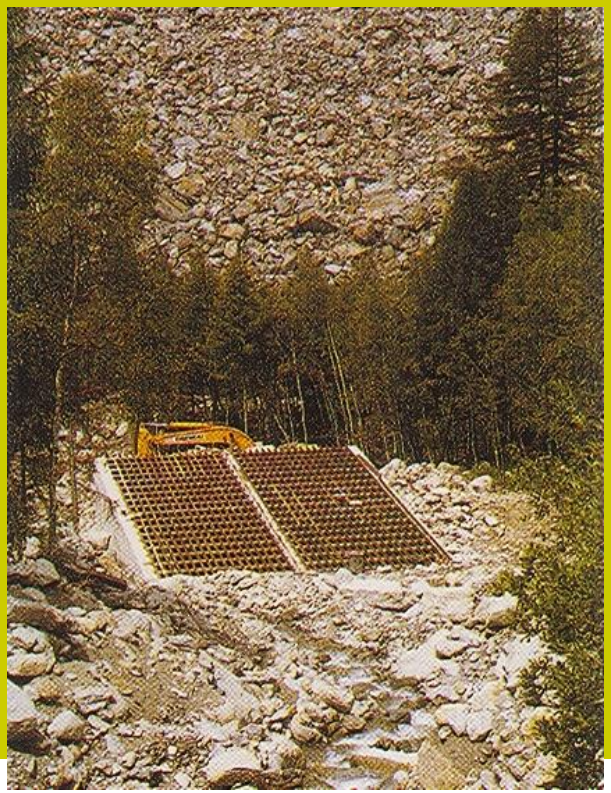
Block ramps



Opening of river bed

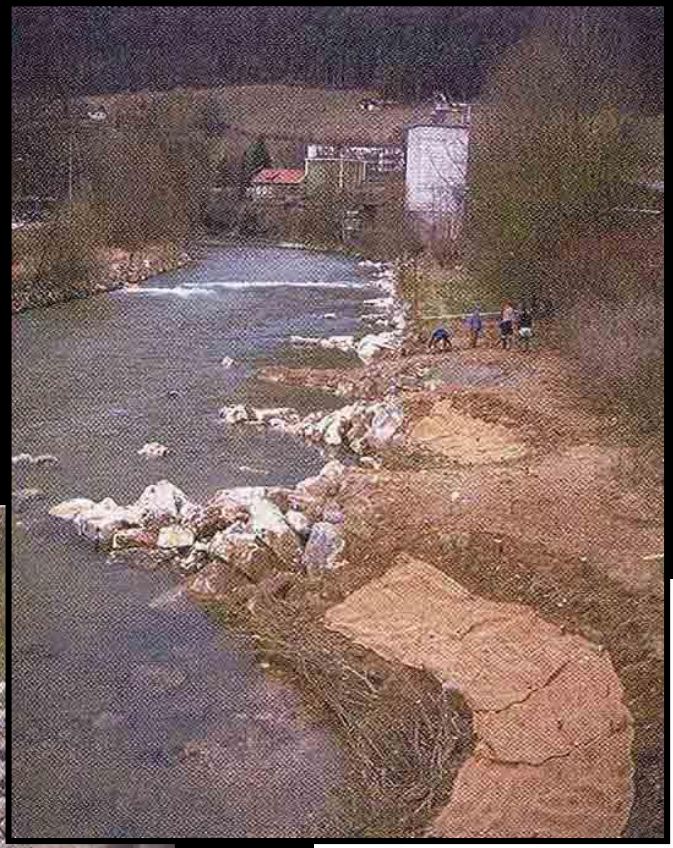


Rock groyne

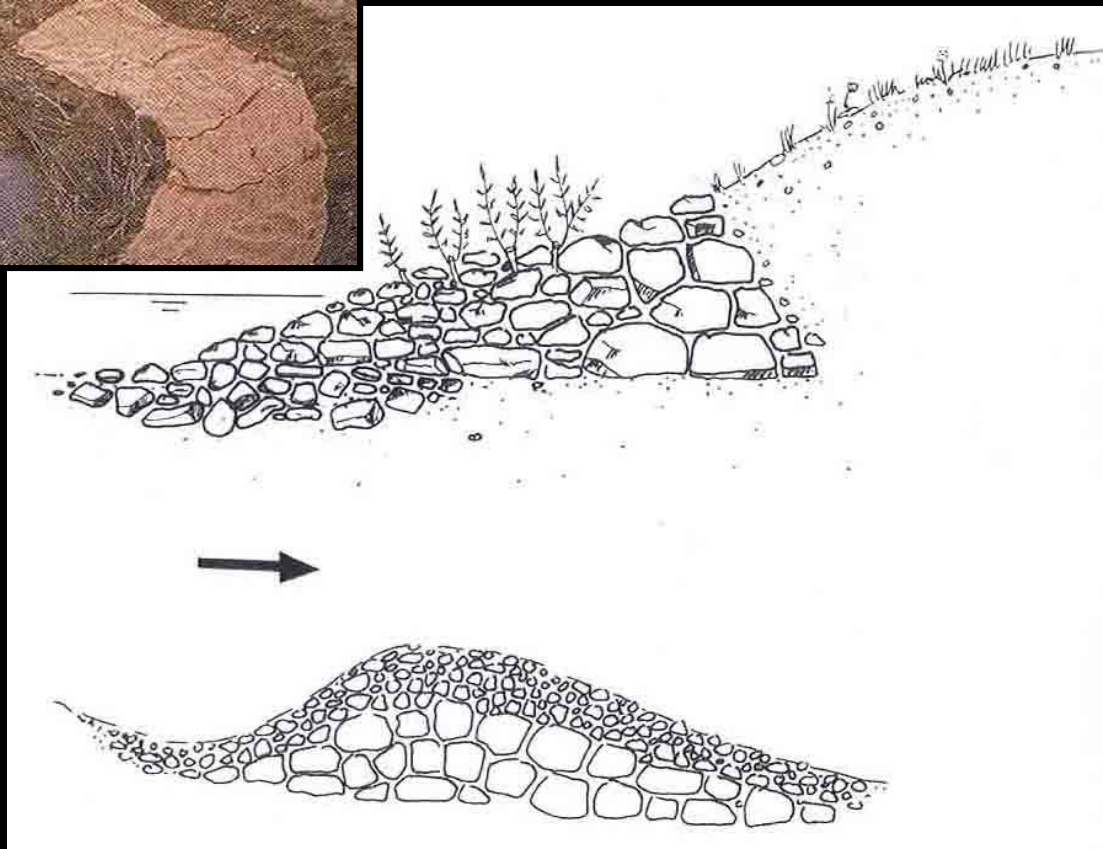


Debris flow breaker

Check dams



Rock groyne for bank protection. They guide the line of maximum velocity, generate scours and still water zones and protect the embarkment

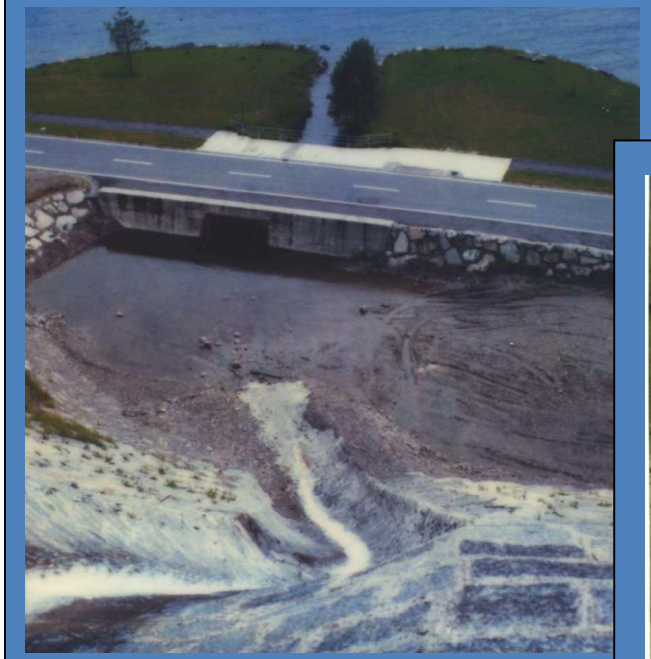


Reduction of sediment input into reservoirs

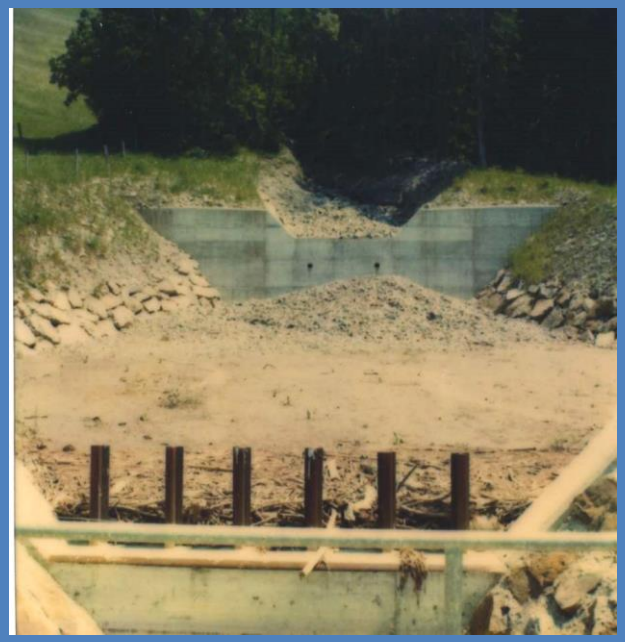
Retention of sediments upstream of the reservoir

- Retention of bed load
- Retention of suspended material or fine material
- Dredging in river beds

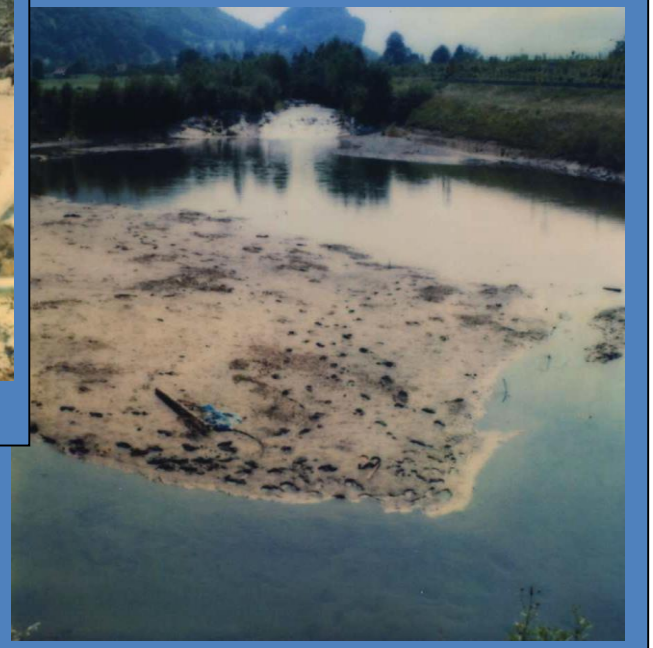
Sediment retention basins



Fischlauwi Seedorf

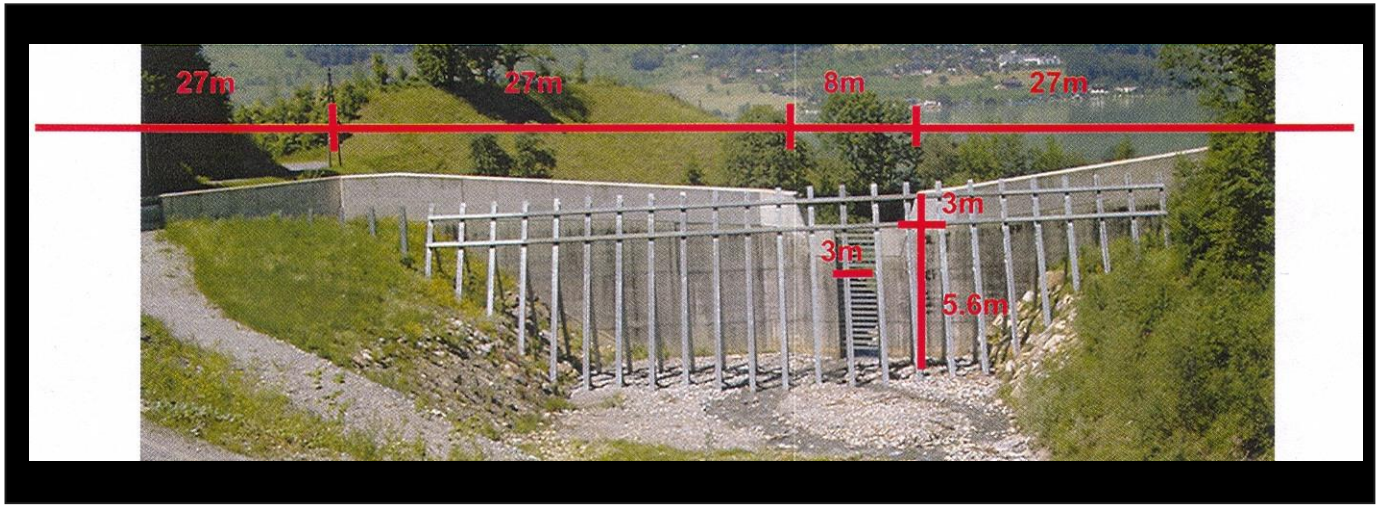


Filderenbach Hochybrig

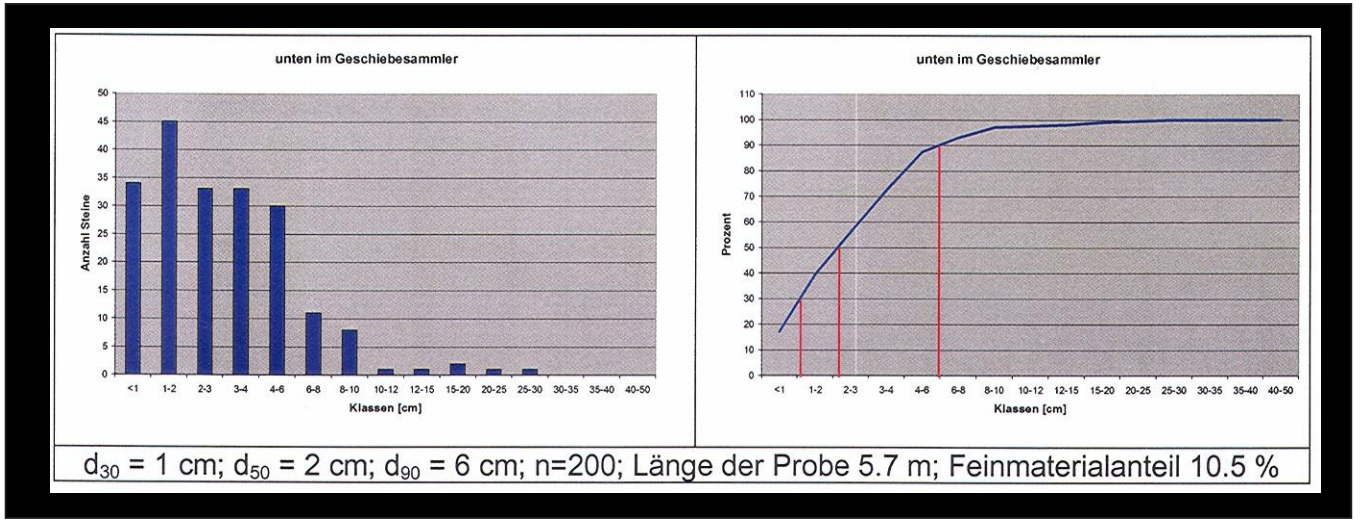


Berschnerbach Berschnis

Sediment retention basin with wood retention



Grain size distribution in the reservoir



WP8 Pilot Project Tourtemagne

Restoration and preservation of storage capacity in the small alpine reservoir Tourtemagne (CH)

Giovanni De Cesare

Laboratory of hydraulic constructions LCH, EPFL Lausanne, Switzerland

Pierre-Benoît Raboud

formerly Service des Forces Hydrauliques SFH - VS, Sion, Switzerland

Forces Motrices de la Gougra

Service des Forces Hydrauliques

Interreg IIIB ALPRESERV – Final Conference
March 6, 2007, Kloster Seeon, Germany

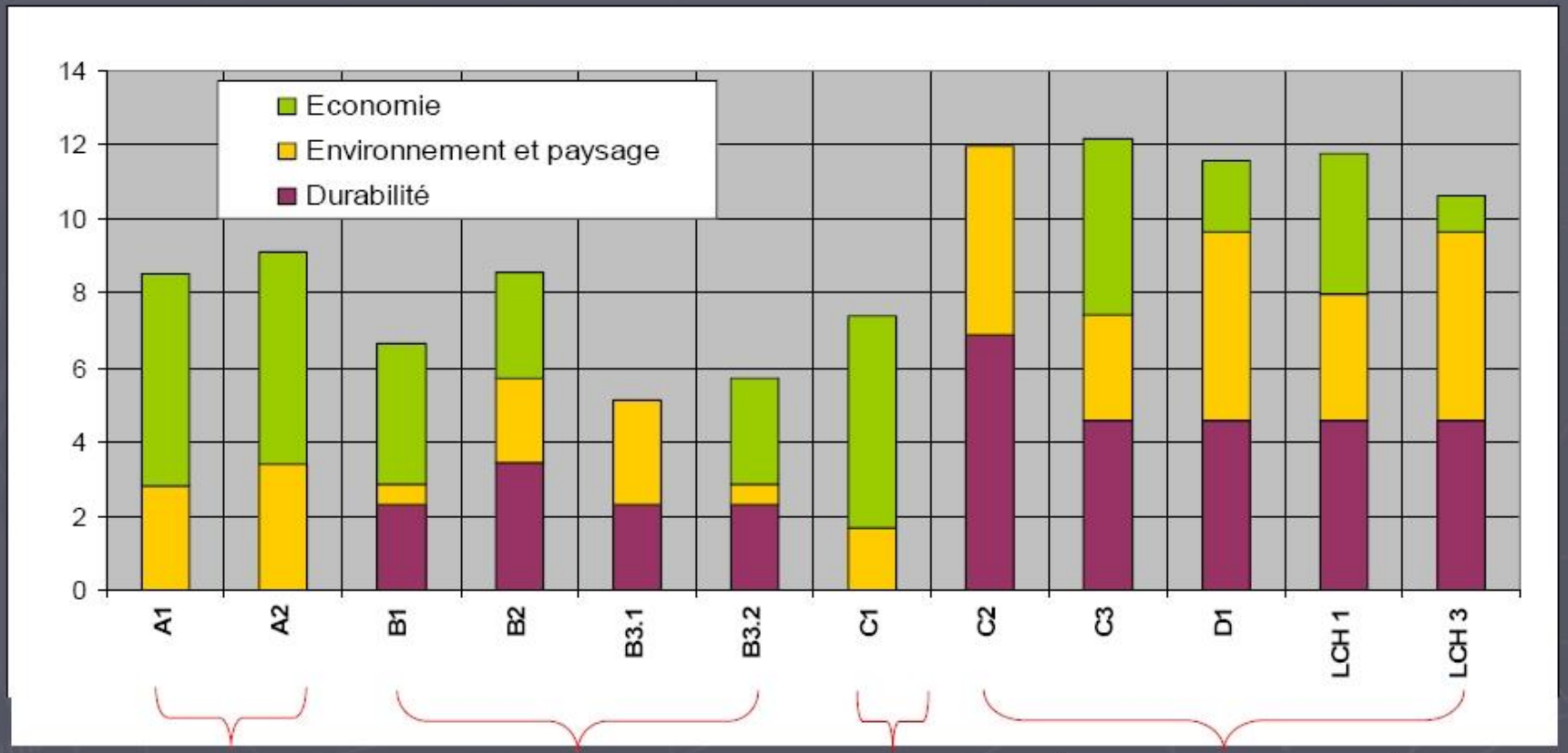
Auslass Rückhaltebecken

Rückhaltebecken und Speichersee

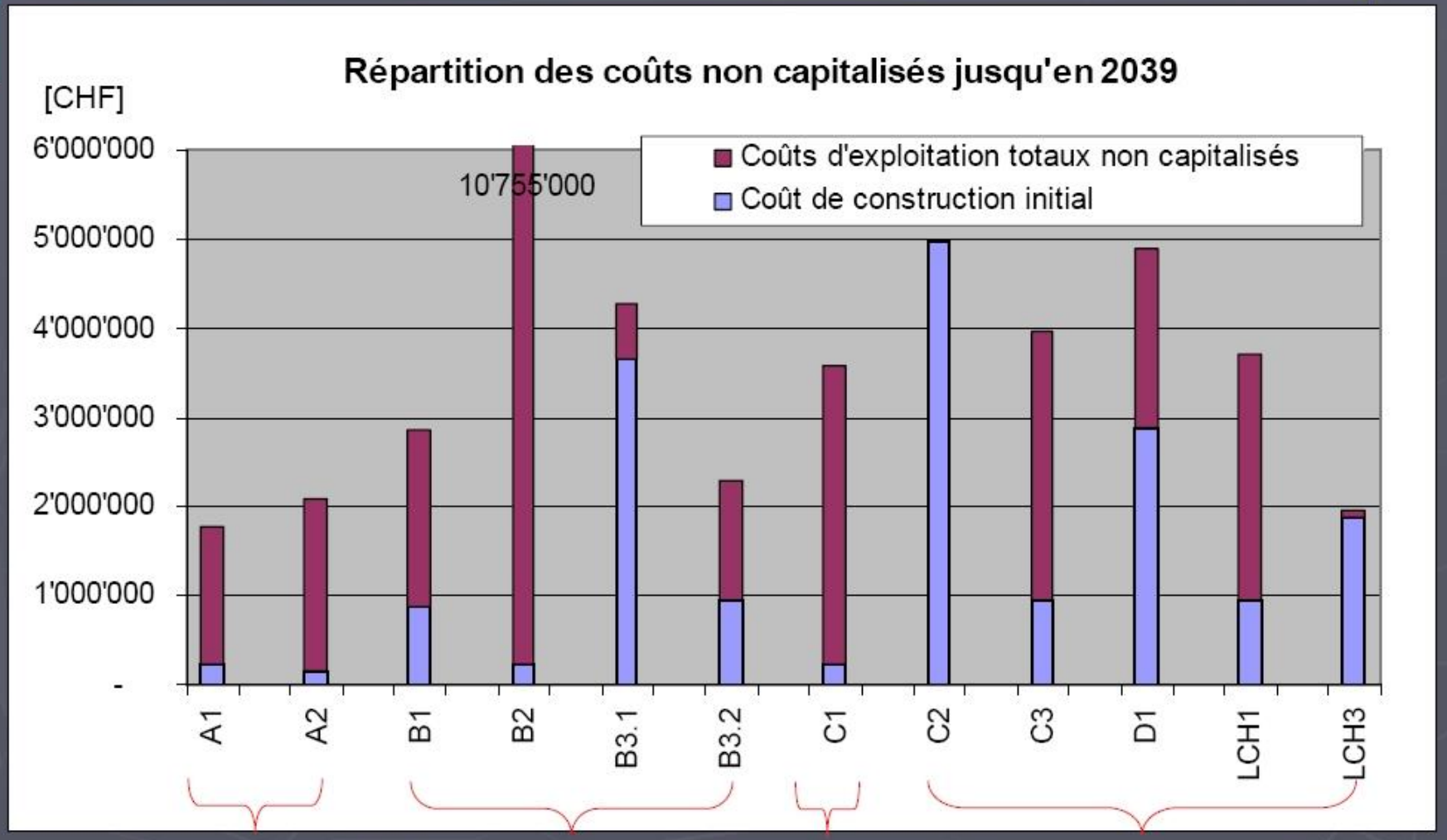
Contents: technical part (De Cesare)

1. Presentation of the Gougra HP scheme and Tourtemagne reservoir
2. Objectives of the study
3. Description of the various alternatives
4. Technical and economical analysis
5. Conclusions and perspectives

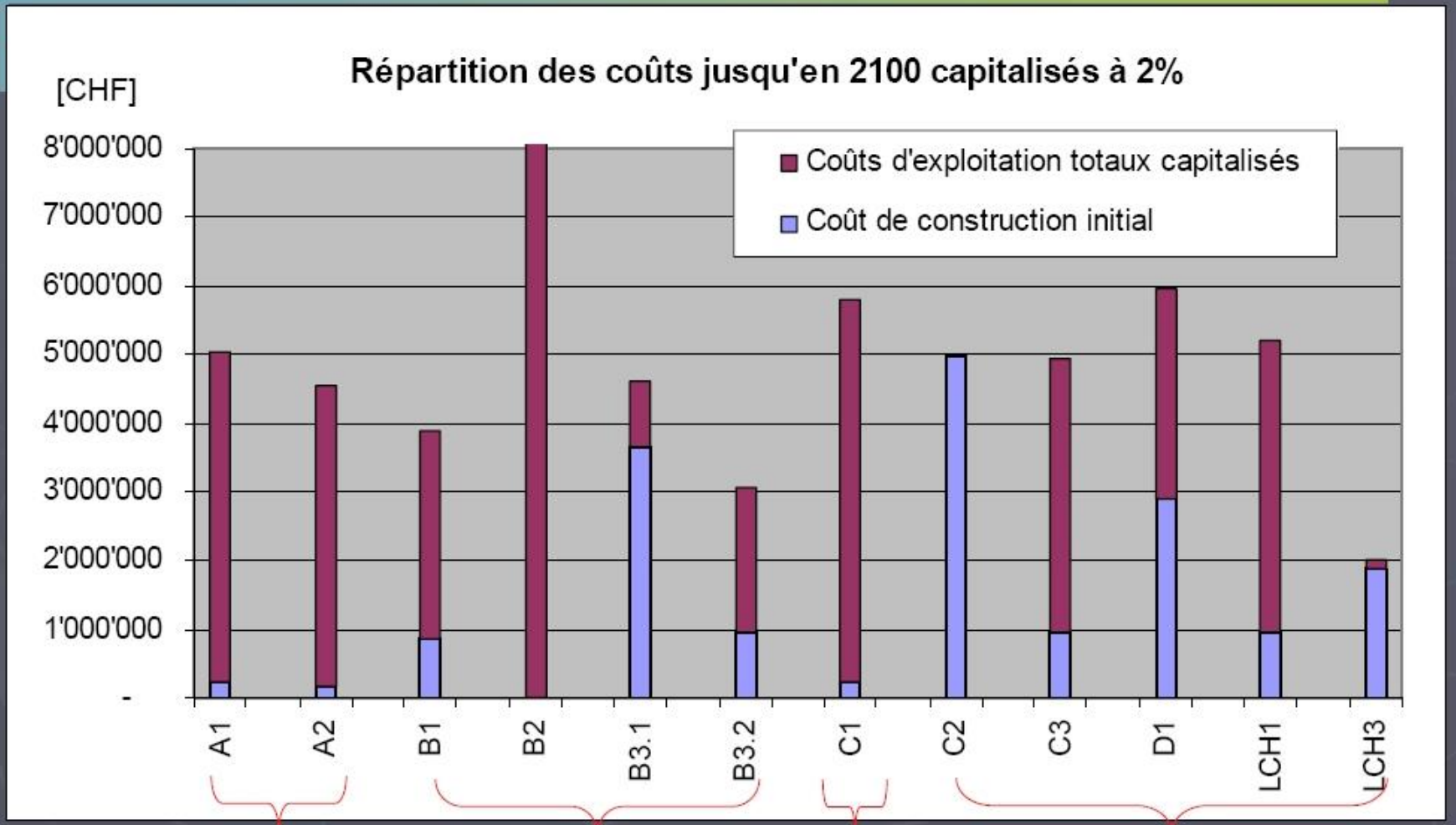
Overall analysis



Economical analysis

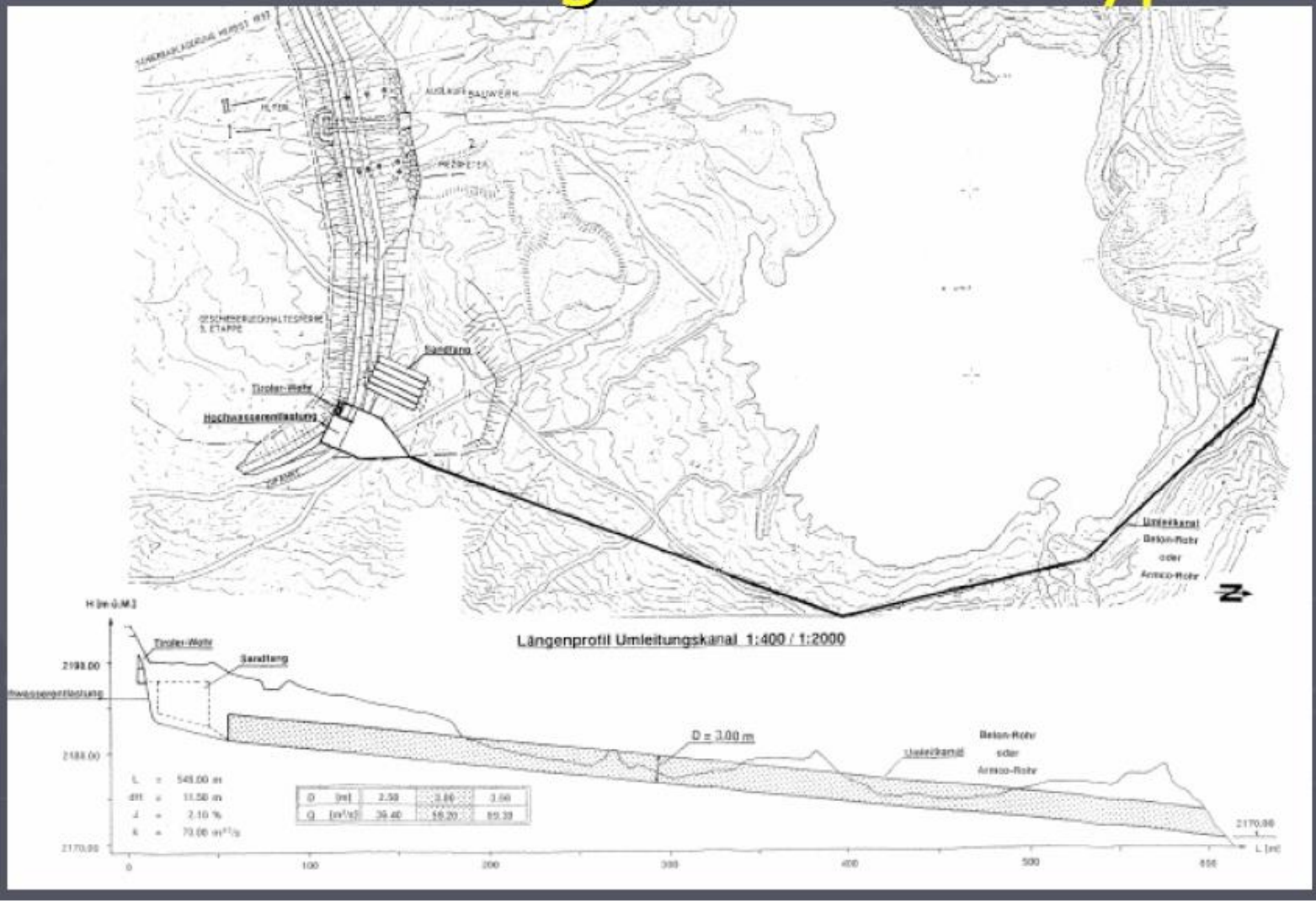


Economical analysis



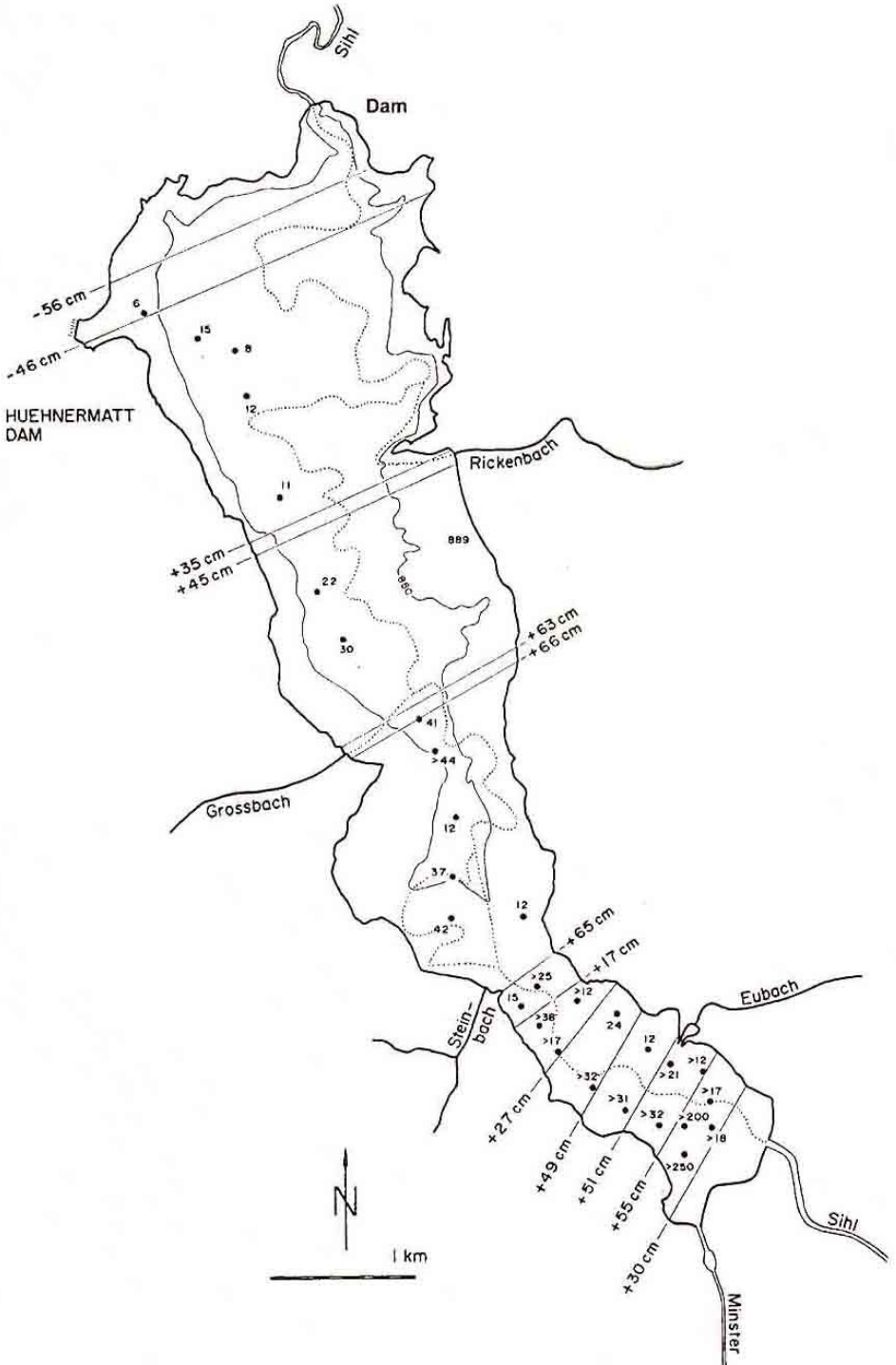
Final Project (under discussion) - overview

With desanding basins and bypass



4. Reservoir sedimentation

LAKE DEPOSITS AT SIHL RESERVOIR, 1937 - 1979

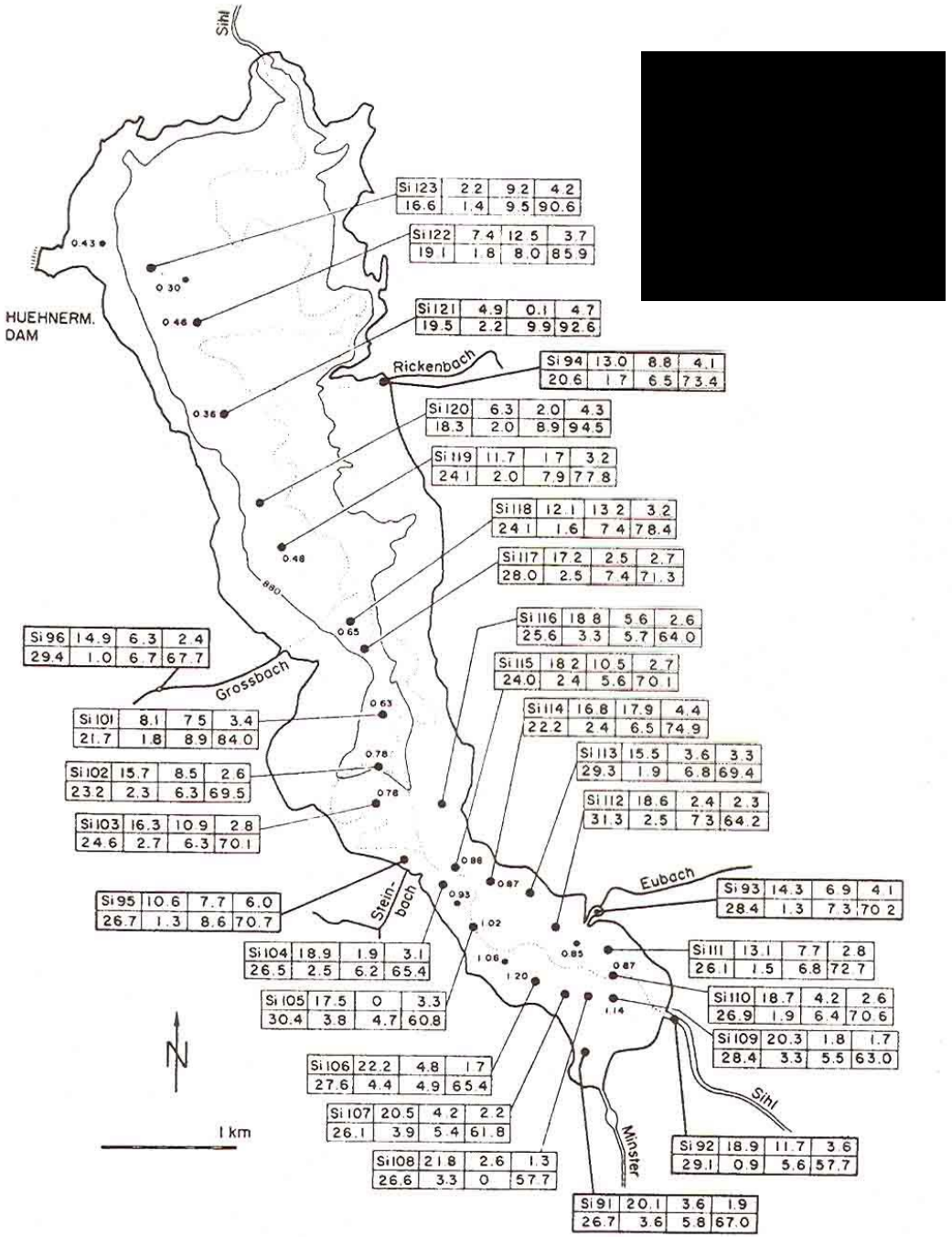


Legend

— - 56 cm Erosion at cross section
— + 35 cm Accumulation at cross section

37 Point measurement
>44 Point measurement, but ground not reached

PROPERTY OF LAKE DEPOSITS AT SIHL RESERVOIR



Legend

Sample	Calcite	Muscovite	Organic. mat
Quartz	Dolomite	Microlite	Ground mat.

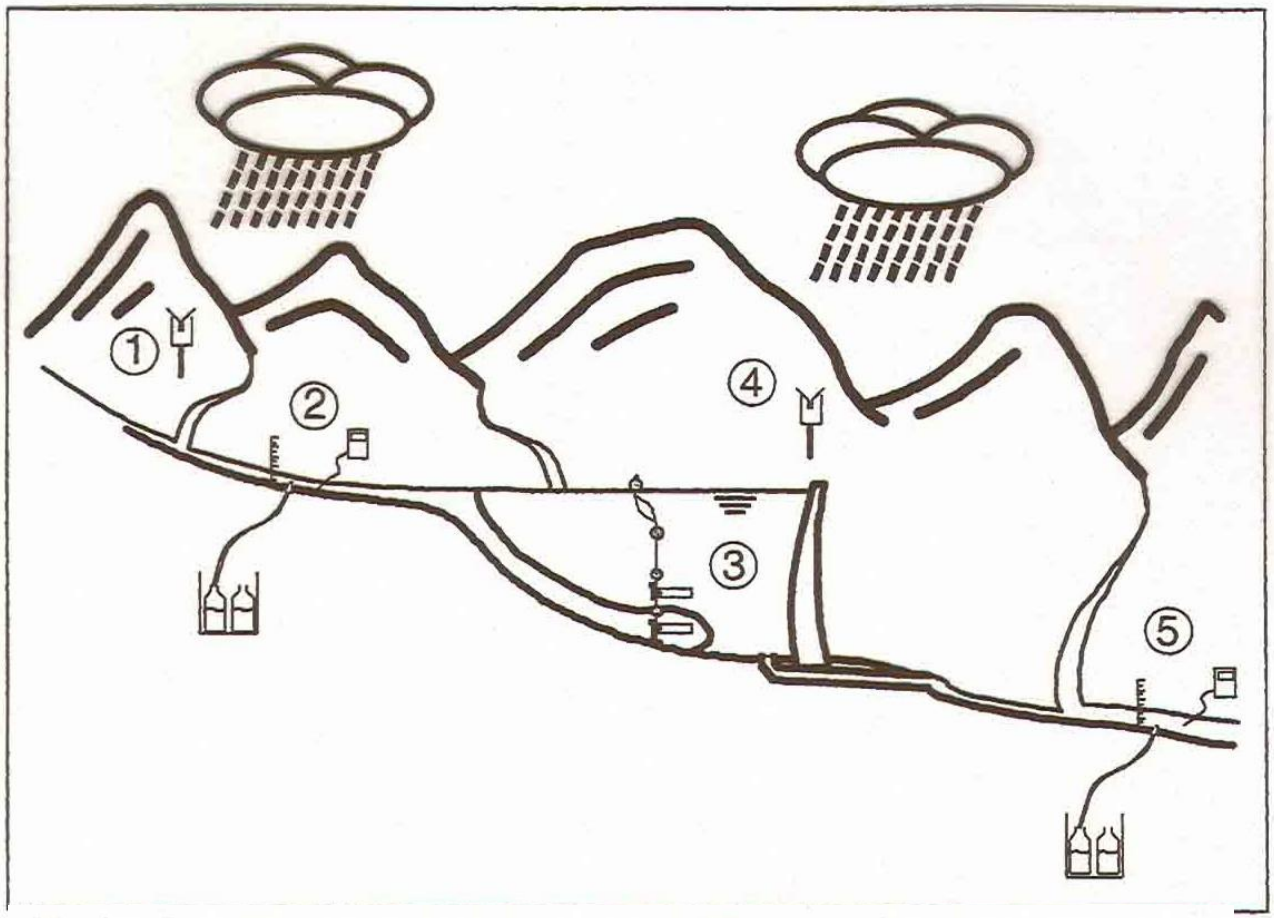
d_{50} = ~ca. 15 micrometer

Values in % of mass, relative value for ground material

Bulk density (g/cm3), values at point measurements

Governing the sediment deposition process by influencing the turbidity streams

NETWORK OF SEDIMENT OBSERVATION IN THE LUZZONE BASIN



Chain of turbidity meters at the ground of the retention basin.

Points A, B und C indicate the positions of the chains in the basin.

1) Subsurface buoy
2) Reader
3) Flow direction
4) Flow velocity
5) Weight

Numerical simulation of turbidity currents

- Transport equation for sediment concentration, c_{si} of fraction *i* with settling velocity, v_{ssi}:

$$\frac{\partial(\rho\, c_{si})}{\partial t}+\frac{\partial\left(\rho\,\left[U_i+\delta_{i3}v_{ssi}\right]c_{si}\right)}{\partial x_i}-\frac{\partial}{\partial x_i}\left(\Gamma_{eff}\frac{\partial c_{si}}{\partial x_i}\right)=S_E-S_D\big|_b$$

- Equilibrium Concentration [Van Rijn (1984)]

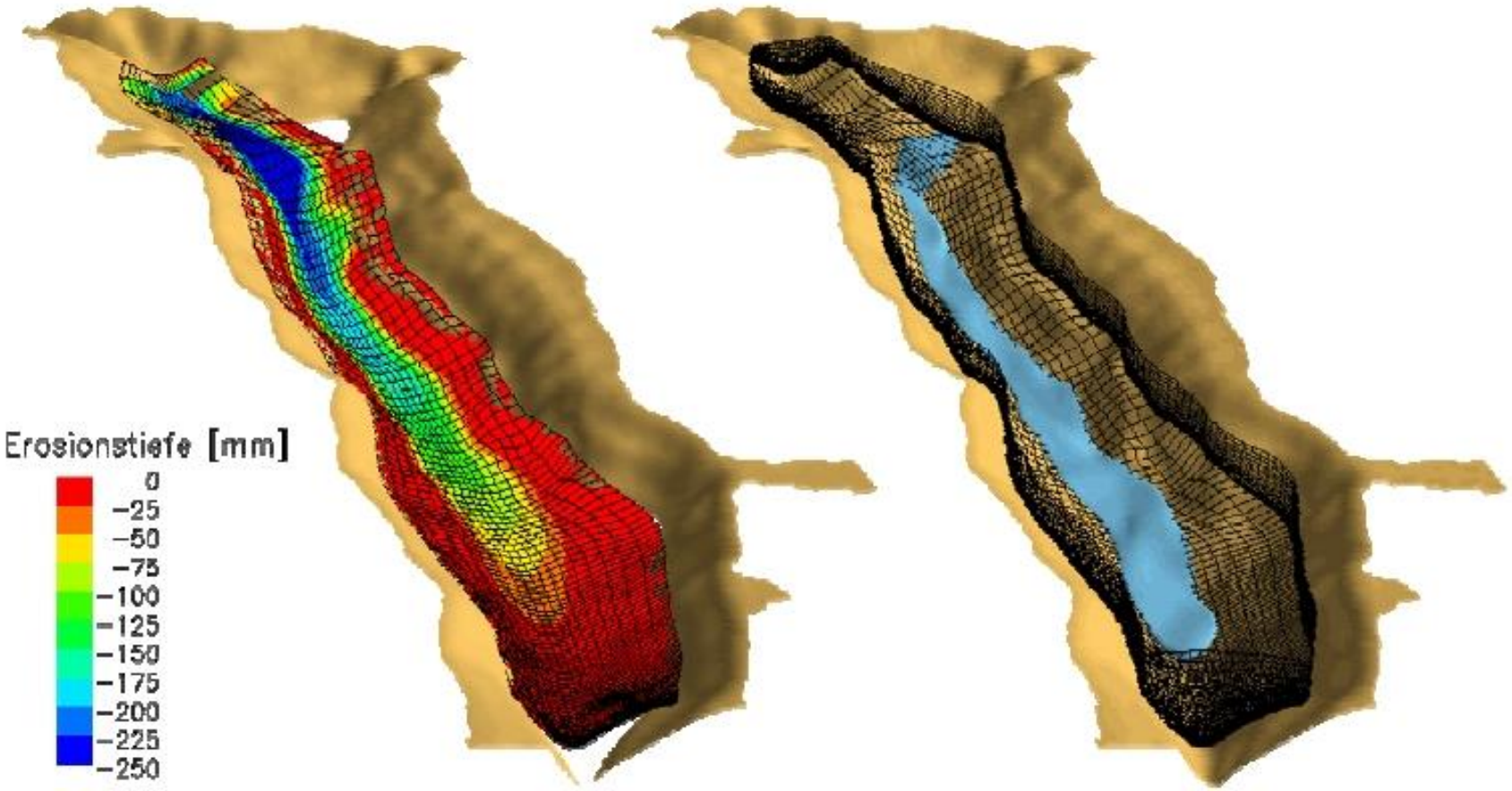
$$S_E-S_D\big|_b=v_{ss}\left(c_{sb*}-c_{sb}\right)$$

- Pick-up and Settling Rate [Garcia and Parker (1993)]

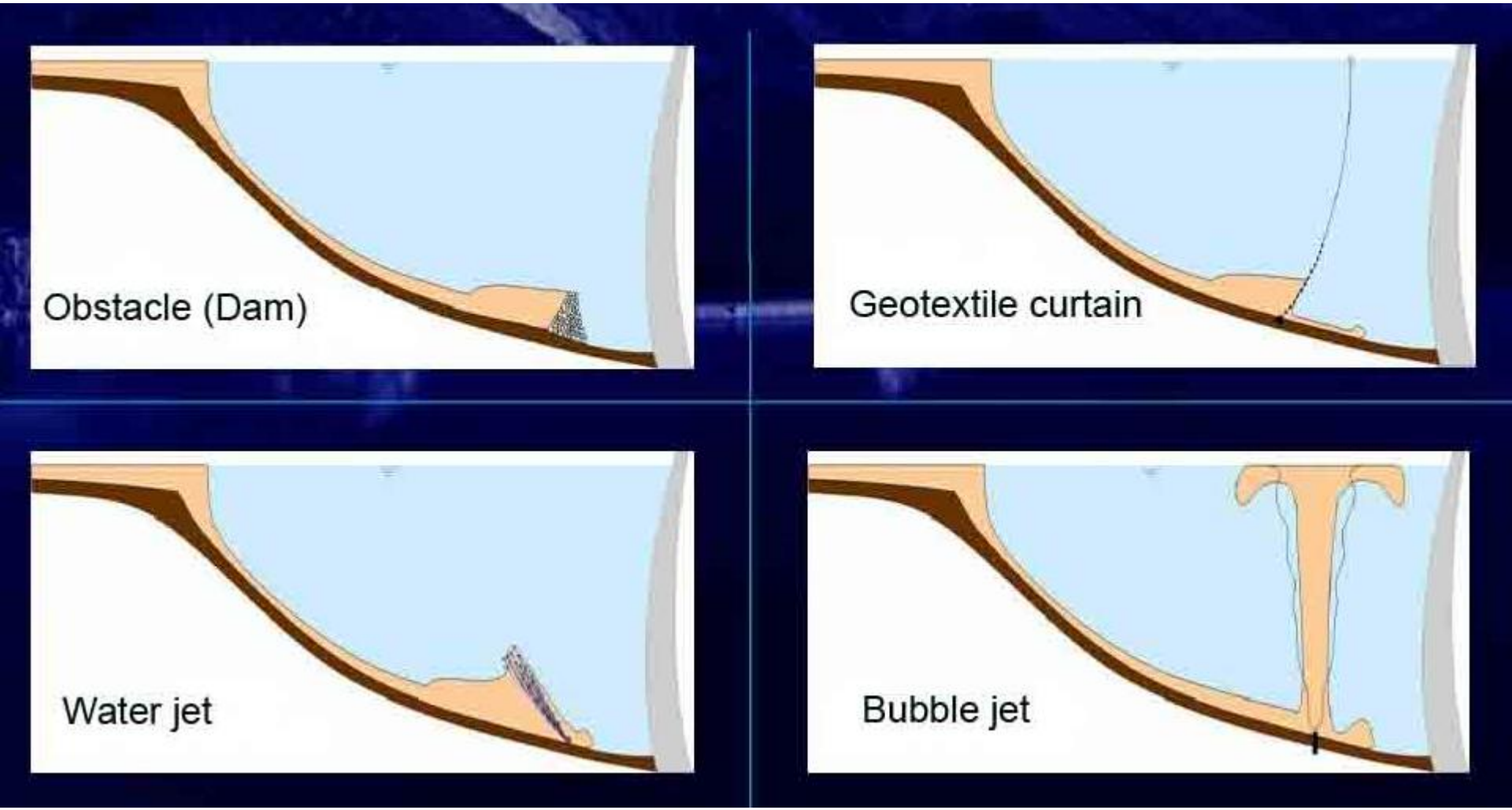
$$S_E-S_D\big|_b=v_{ss}\left(E_s-c_{sb}\right)$$

Turbidity currents

Main factor for the sediment transport in reservoirs



Management of turbidity currents



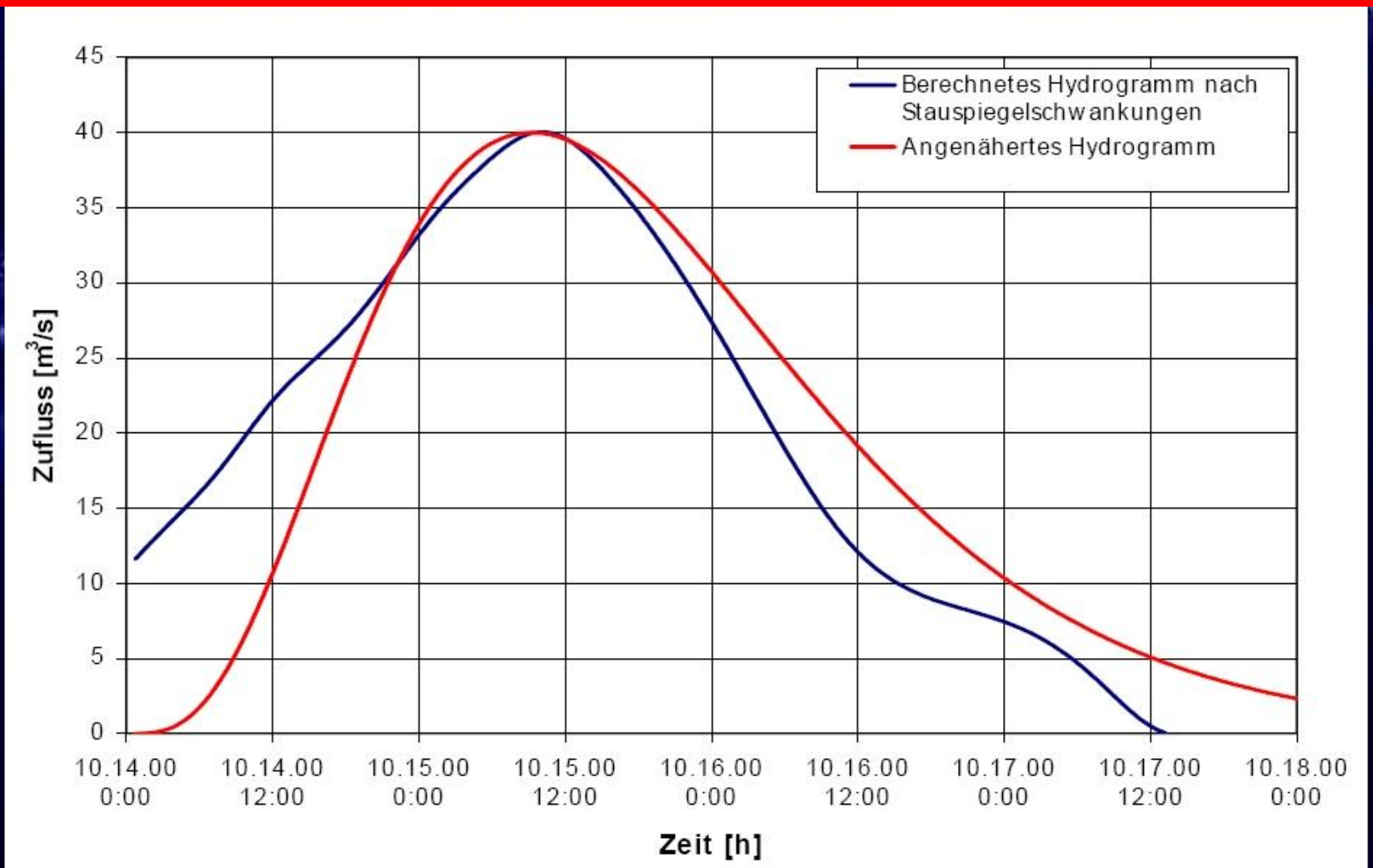
Case study Grimsel (dam heightening)

Ausbauprojekt Grimsel Plus:

3. Etappe:
Erhöhung der Staumauern um 23 m

Discretization of the reservoir

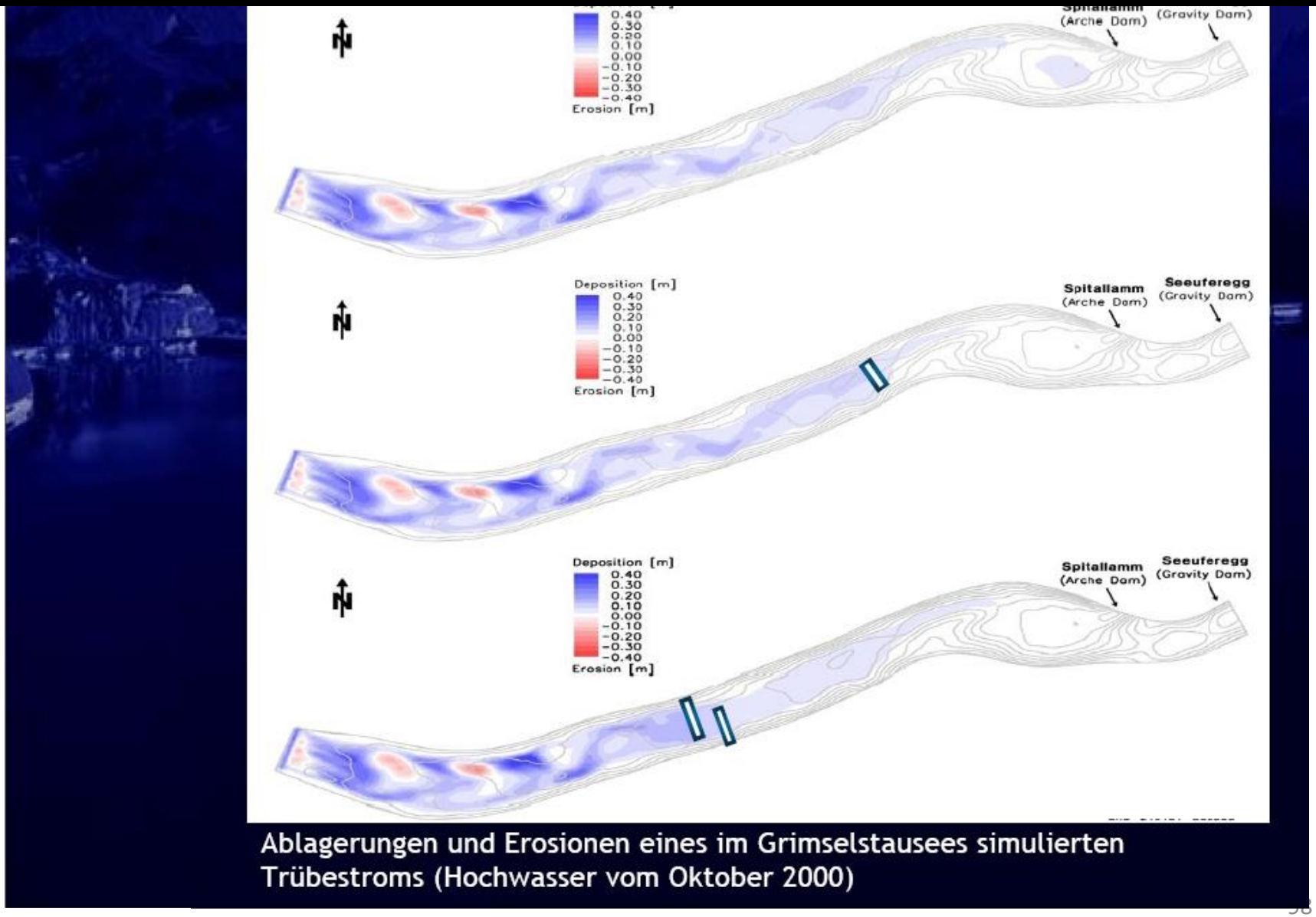
Flood hydrograph for simulation of turbidity flows



Case study Grimsel (dam heightening)

- Investigation of sites of obstacle installation for braking of turbidity flows

Example Grimsel lake

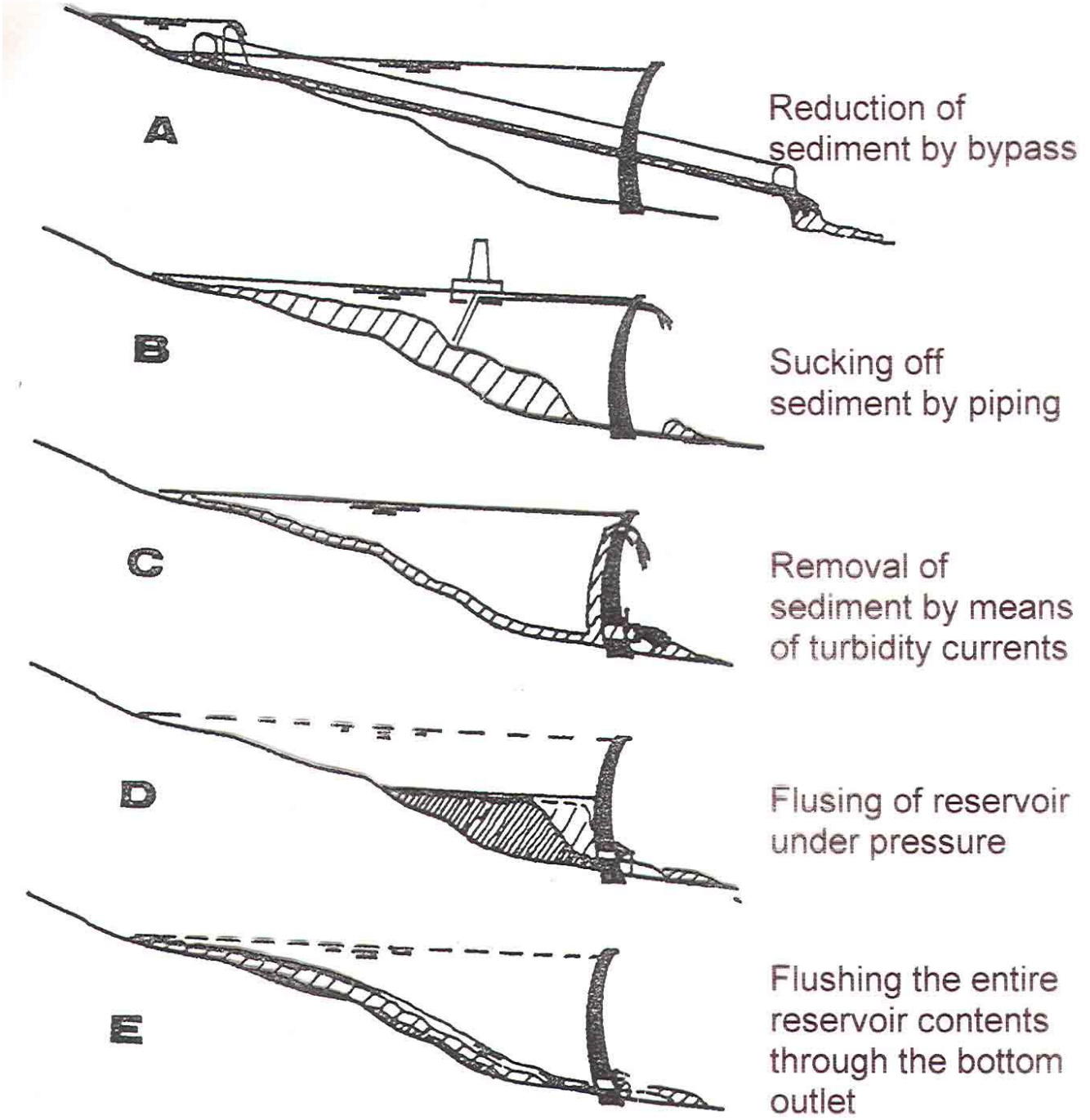


Ablagerungen und Erosionen eines im Grimselstausees simulierten Trübestroms (Hochwasser vom Oktober 2000)

(Schleiss, 2007)

5. Procedures for the removal of sediments from reservoirs and impacts on the ecology

Overview


A
Reduction of sediment by bypass
B
Sucking off sediment by piping
C
Removal of sediment by means of turbidity currents
D
Flusing of reservoir under pressure
E
Flushing the entire reservoir contents through the bottom outlet

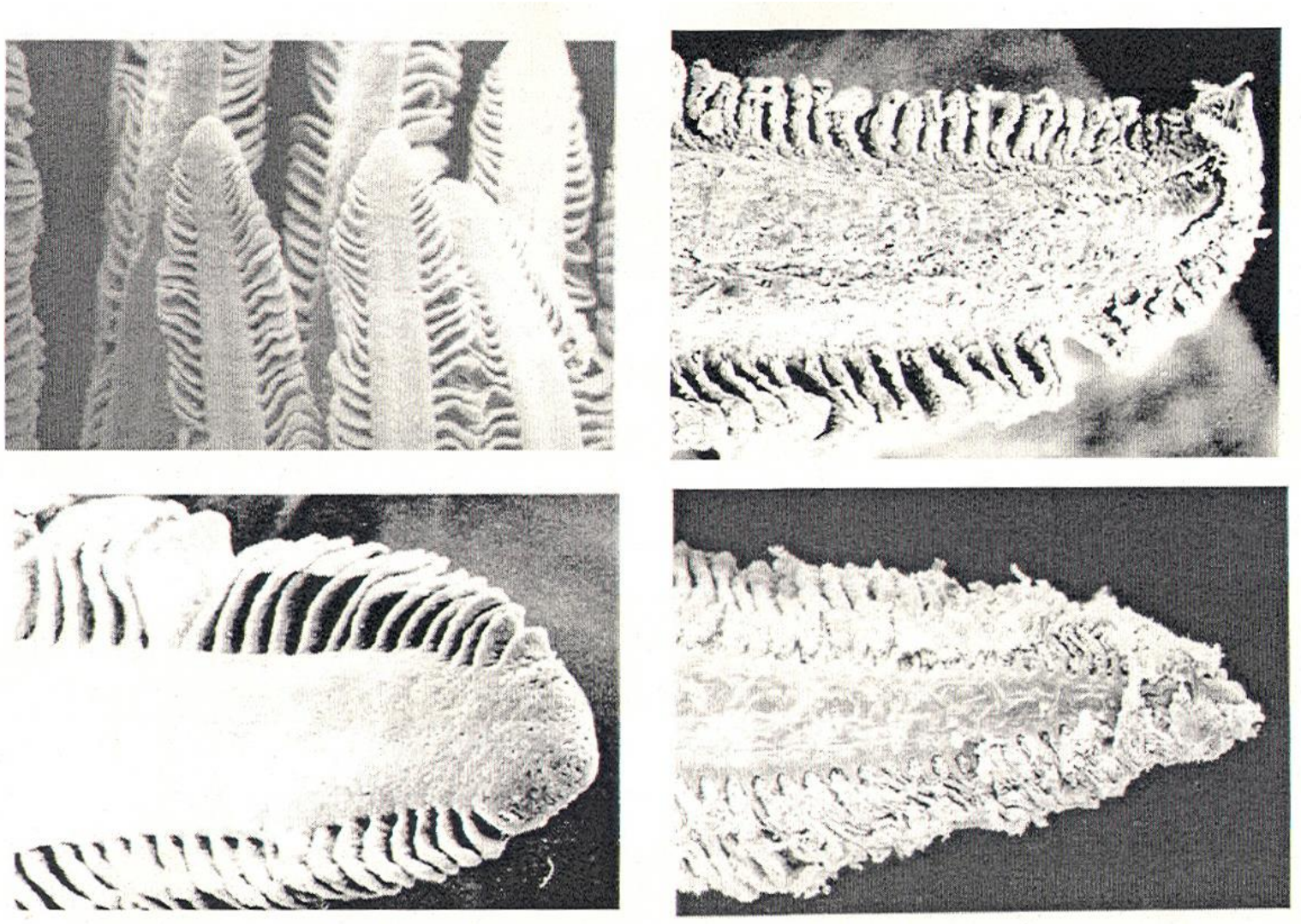
Effects of sediment flushing on fish and invertebrates in Swiss Alpine Rivers

Aquatic systems are especially sensitive to flushing

Most Swiss dams are located in alpine and prealpine regions, where, even under natural conditions, fish and macroinvertebrates are exposed to a harsh environment

Causes of oxygen depletion problems for fish

- Mechanical damage to the gills hinders oxygen transfer in the gills
- Oxygen concentration in the water is reduced because reducing substances are released from the flushed sediment
- Hydraulic stress increases the oxygen demand of the fish because of increased swimming activities



Scanning electron micrographs of rainbow trout gills (Oncorhynchus mykiss) in a laboratory experiment (Petz-Glechner et al. 1999): control (upper left), 50g/l suspended sediment for 2 h (upper right), 5 g/l for 24 h (lower left) and 10 g/l for 24 h (lower right).

Impacts of flushing to the invertebrates

- If flushing cause an abrupt increase of water flow, invertebrates do not have enough time to move into the interstitial spaces, and their abundance may be greatly reduced.
- Residual flow changes the composition of macroinvertebrates taxa.

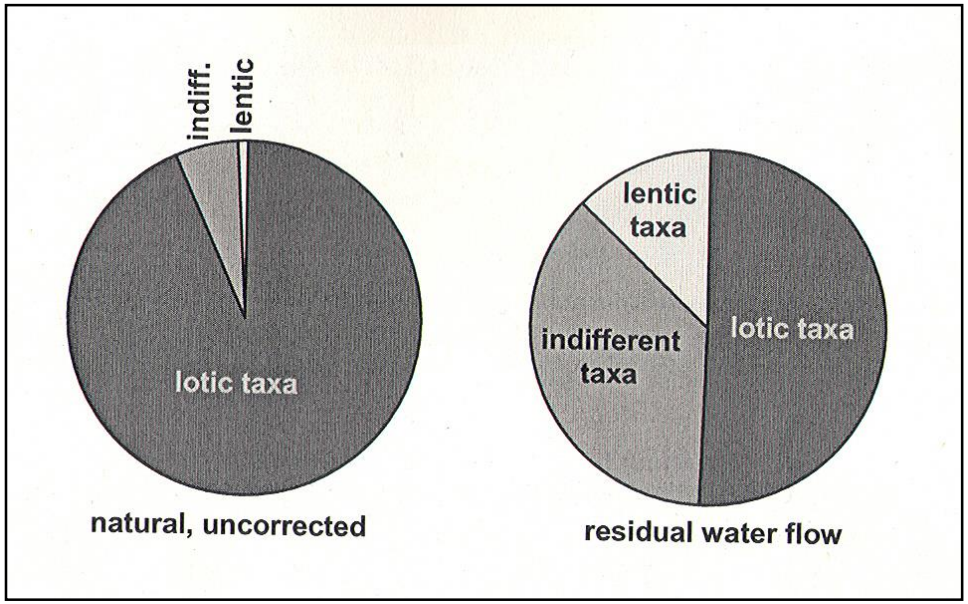


Figure 2: Percentage composition of macroinvertebrate taxa in three microhabitats (lentic, lotic, indifferent) in a prealpine brook without anthropogenic impact (left), and in a comparable brook under a regime of residual water flow (right). Data: Gerster&Rey (1994).

(Straub, 2000)

Recommendations

- A general threshold for harmless suspended sediment concentrations does not exist – however, 5-10 g/l is generally tolerable for fauna and flora.
- As unplanned events often occur during flushing operations and often provoke unacceptably high concentrations of suspended sediment, there must be a possibility of braking off and restart flushing.
- Frequent flushing operations with low impacts are tolerated better than rare operations with unacceptably high quantities of sediment.
- Increased post-flushing operations using clean water, and accompanying monitoring programmes are necessary.

Flushing procedure

Strategy

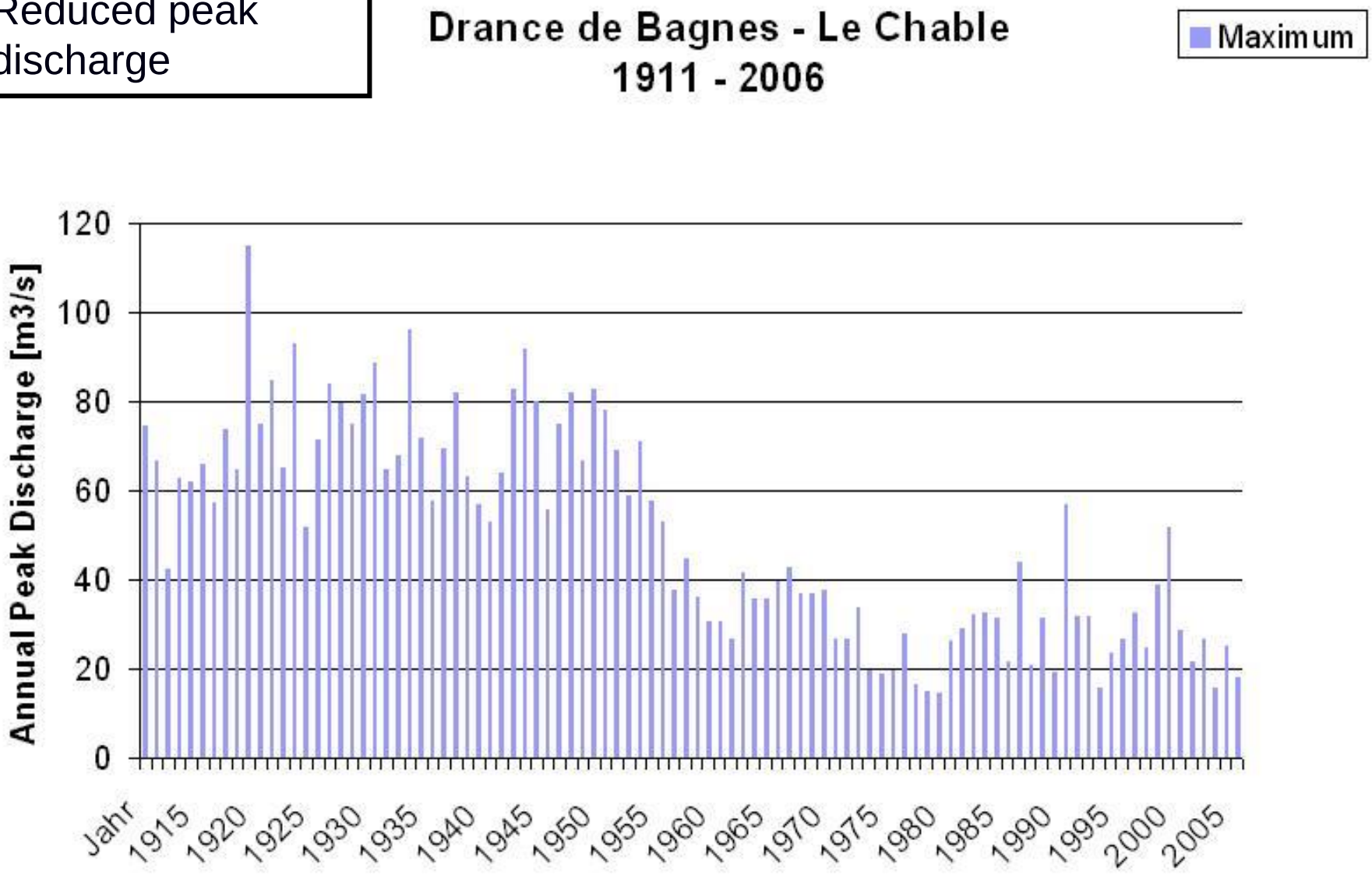
1. Flushing has to be executed during normal flood events
2. Boundary limits of sediment concentration may be
   10 ‰ as shorttime highest value
   5 ‰ for duration of less then 24 hrs
   2.5 ‰ 48 hrs
   1.25 ‰ of more than 48 hrsor instead of use boundary limits of sediment concentration, detailed specifications have to be done about
   - hydrobiologic conditions of the channel
   - flushing itself
   - observation program

3. The watertable of the sediment loaden reservoir has to sunk as low as possible.
4. The opening of the outlets shall be done slowly to simulate as much as possible a natural flood.
5. After flushing, rinse the channel bed with clear water to wash out the sediment surplus downstream.
6. Before and after the flushing, a comprehensive biological and sedimentological observation has to be executed.
7. The sediment concentration has to be checked before, while and after the flushing.
8. If anyhow technically possible, an addition of clear water near the dam has to be provided to reduce sediment concentration.

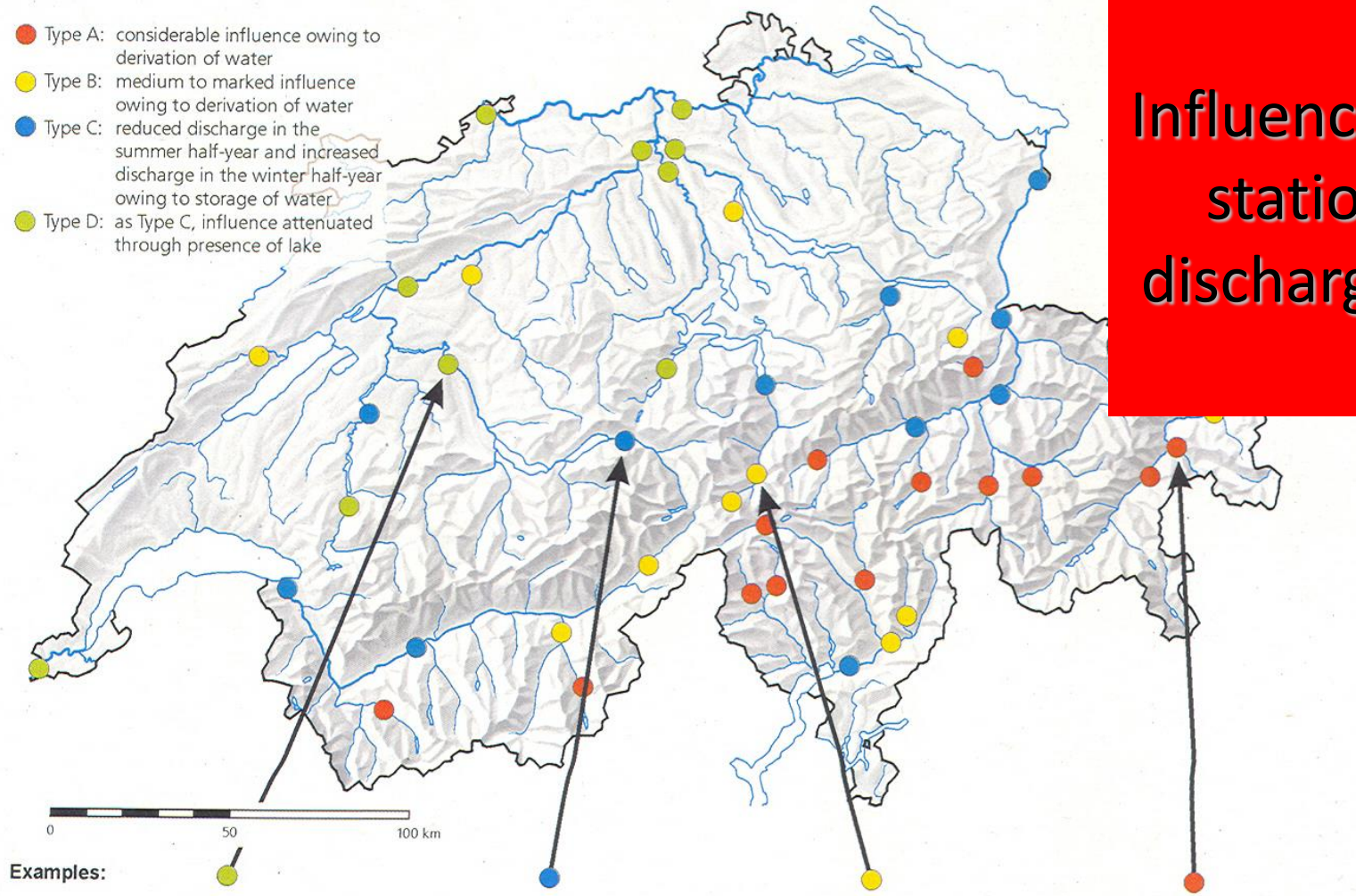
6. Modification of the hydrological regime and changes in erosion and sediment downstream of reservoirs

Modification of the hydrological regime downstream of the reservoir Mauvoisin

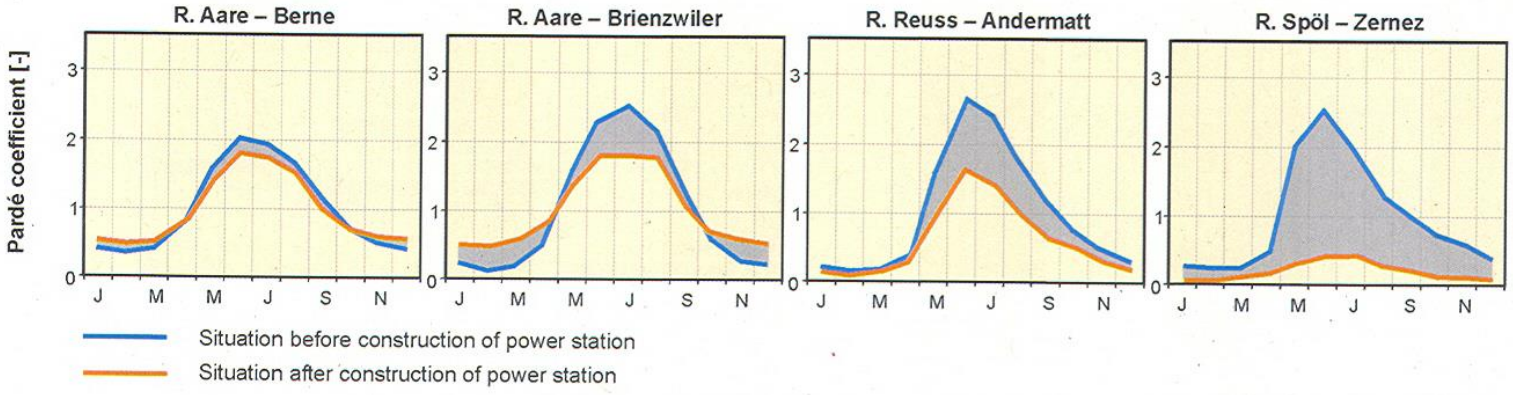
Reduced peak discharge



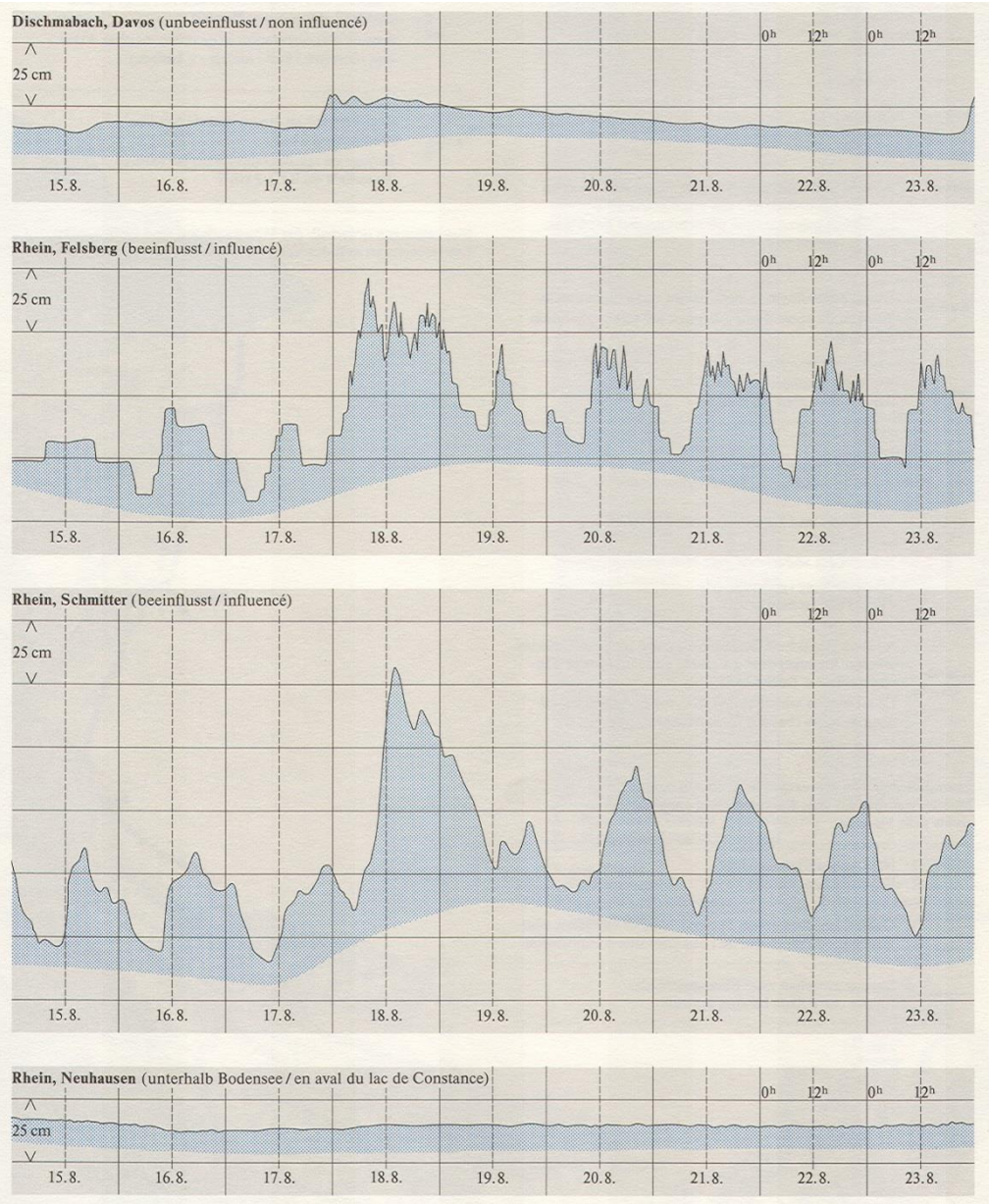
Influence of power stations on river discharge patterns



Examples:



Example Rhine



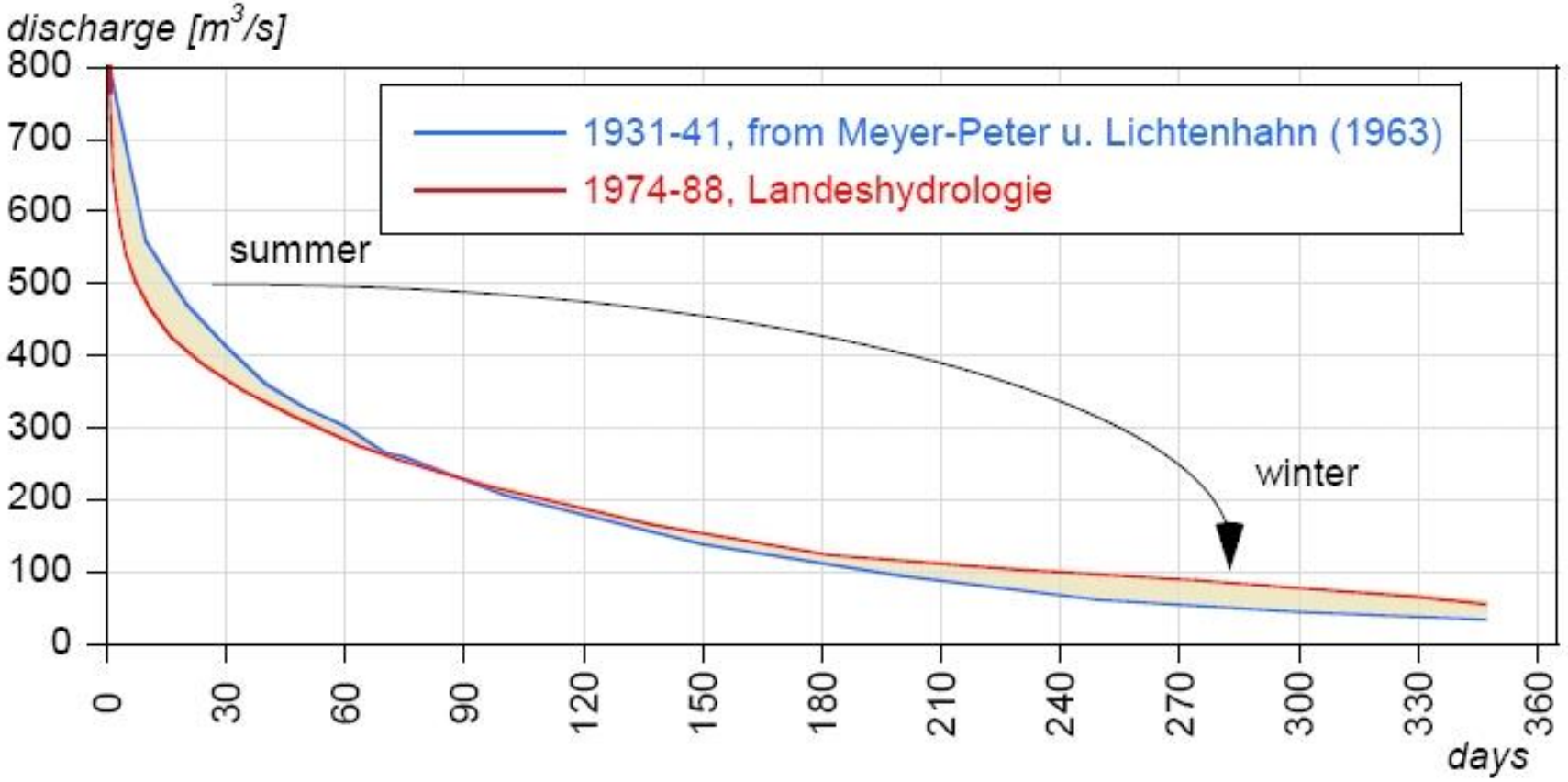
Influence of water power reservoirs and lake retention on discharge in the river Rhine

(HADES, 1999)

Discharge regime change in the Alpine Rhine

Displacement of summer runoff into winter due to water power plants

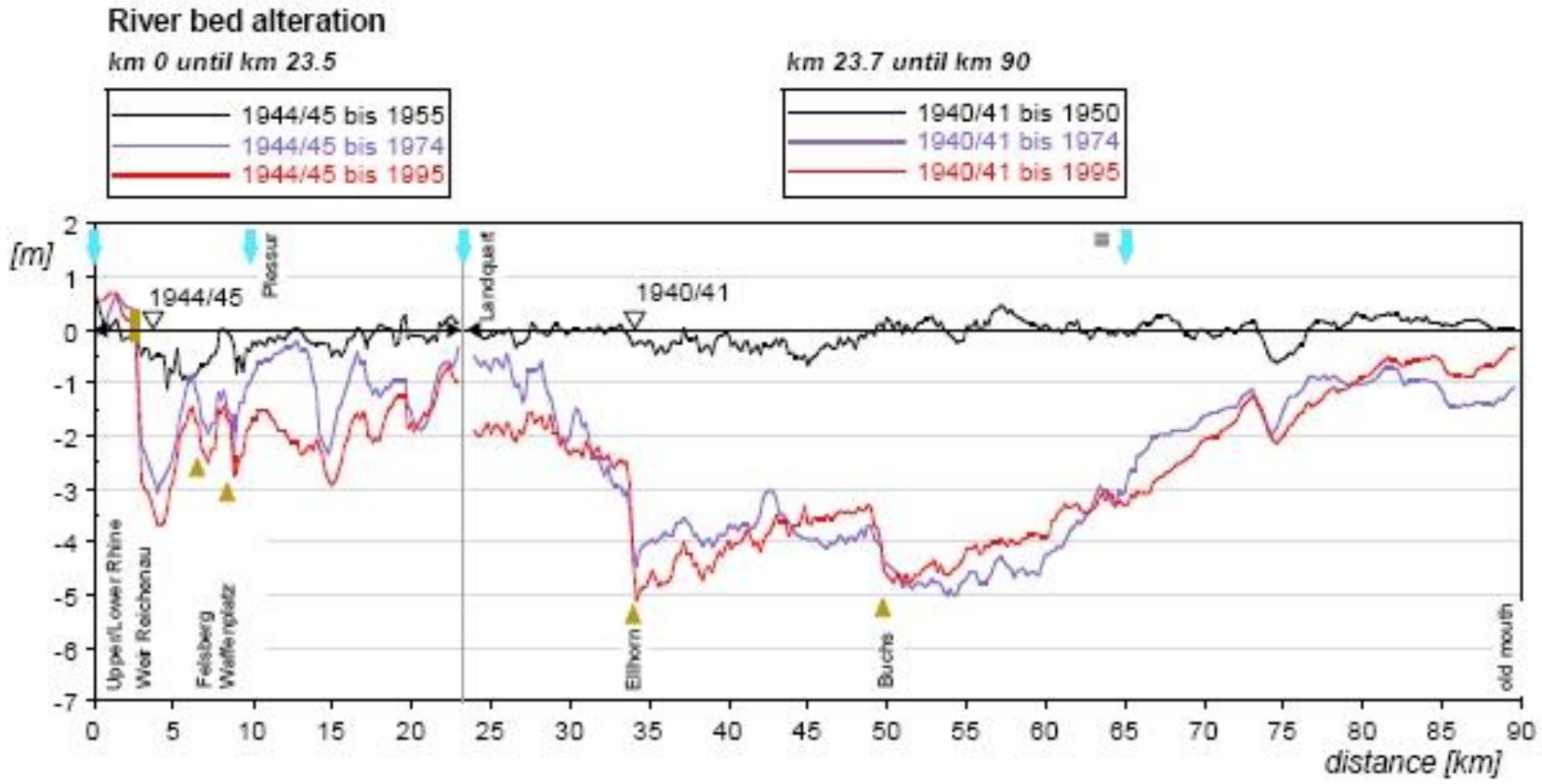
(Storage in reservoirs during summer time, energy production during winter time)



Alteration of the river bed since 1940 in the Rhine river

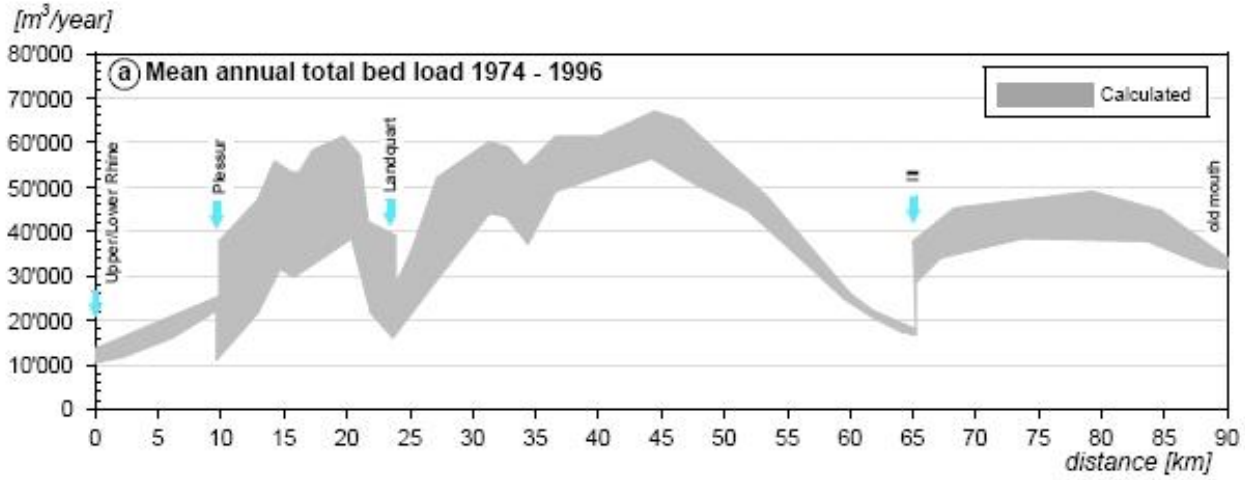
Deposited bed load caused reduced discharge capacity and flooding

→ Bed load excavation

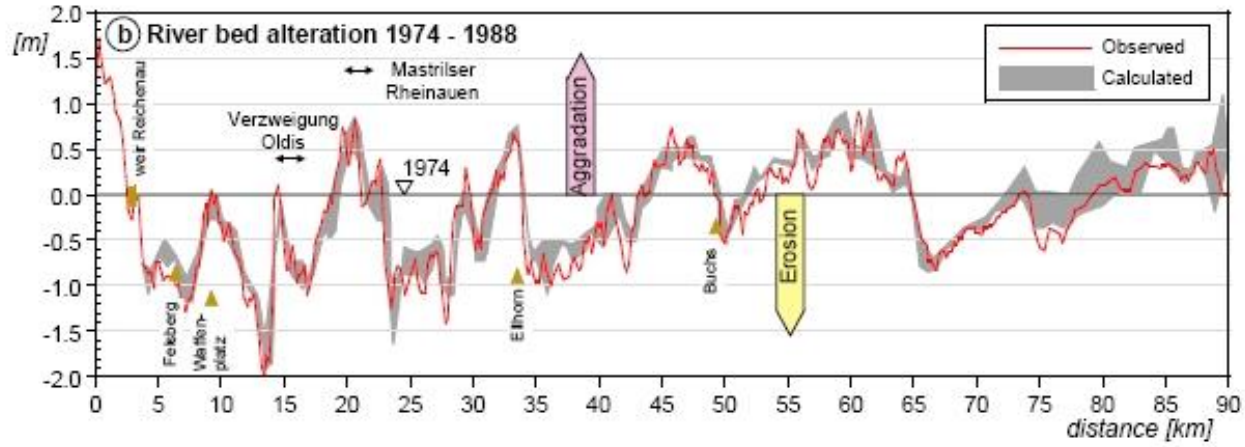


(Wälchli, 2005)

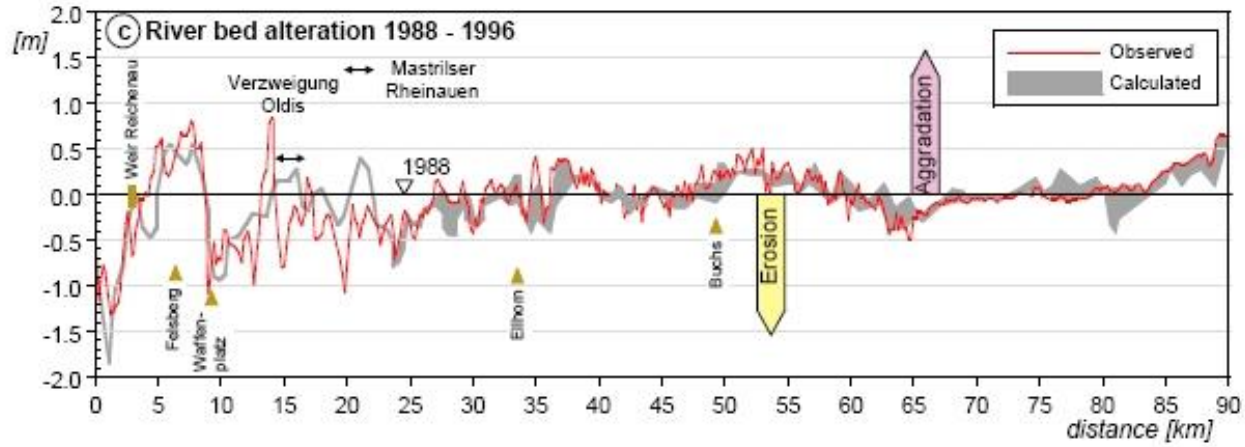
The bridge Buchs-Schaan collapsed in 1972 because of the erosion of the river bed. After the collapse numerous bed load excavation were stopped (Landesarchiv Vaduz).



Range of the mean annual total bed load which were transported in the Alpine Rhine between 1974 and 1995 (a),



and the river bed alteration in the period from 1974 to 1988
(b)



and from 1988 to 1996 (c).

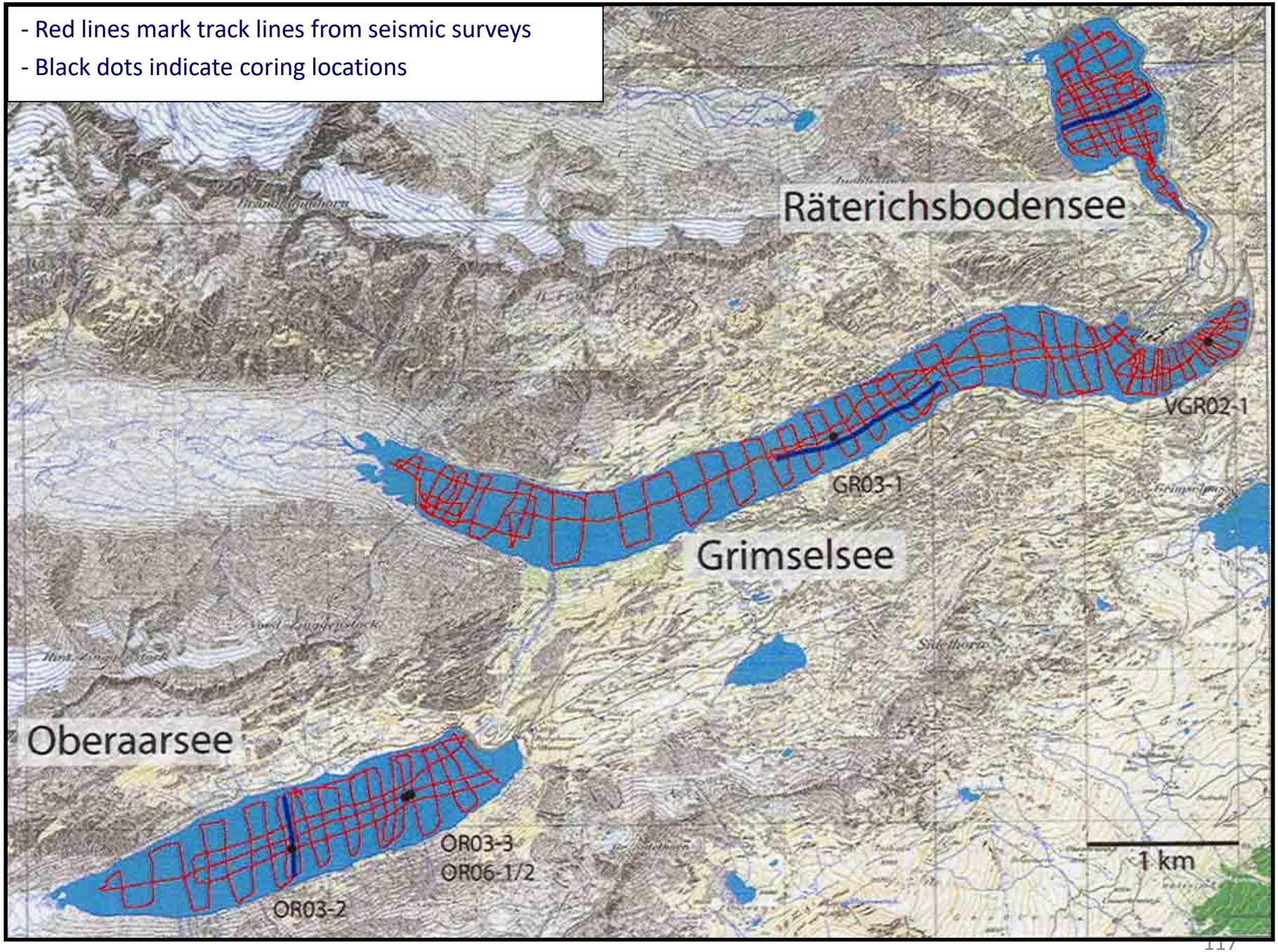
7. Difficulties by the determination of the impacts of reservoirs on downstream areas Example Grimsel reservoirs

EAWAG, SWISS FEDERAL INSTITUTE OF AQUATIC SCIENCE and TECHNOLOGY

GEOLOGICAL INSTITUTE, ETH-ZURICH

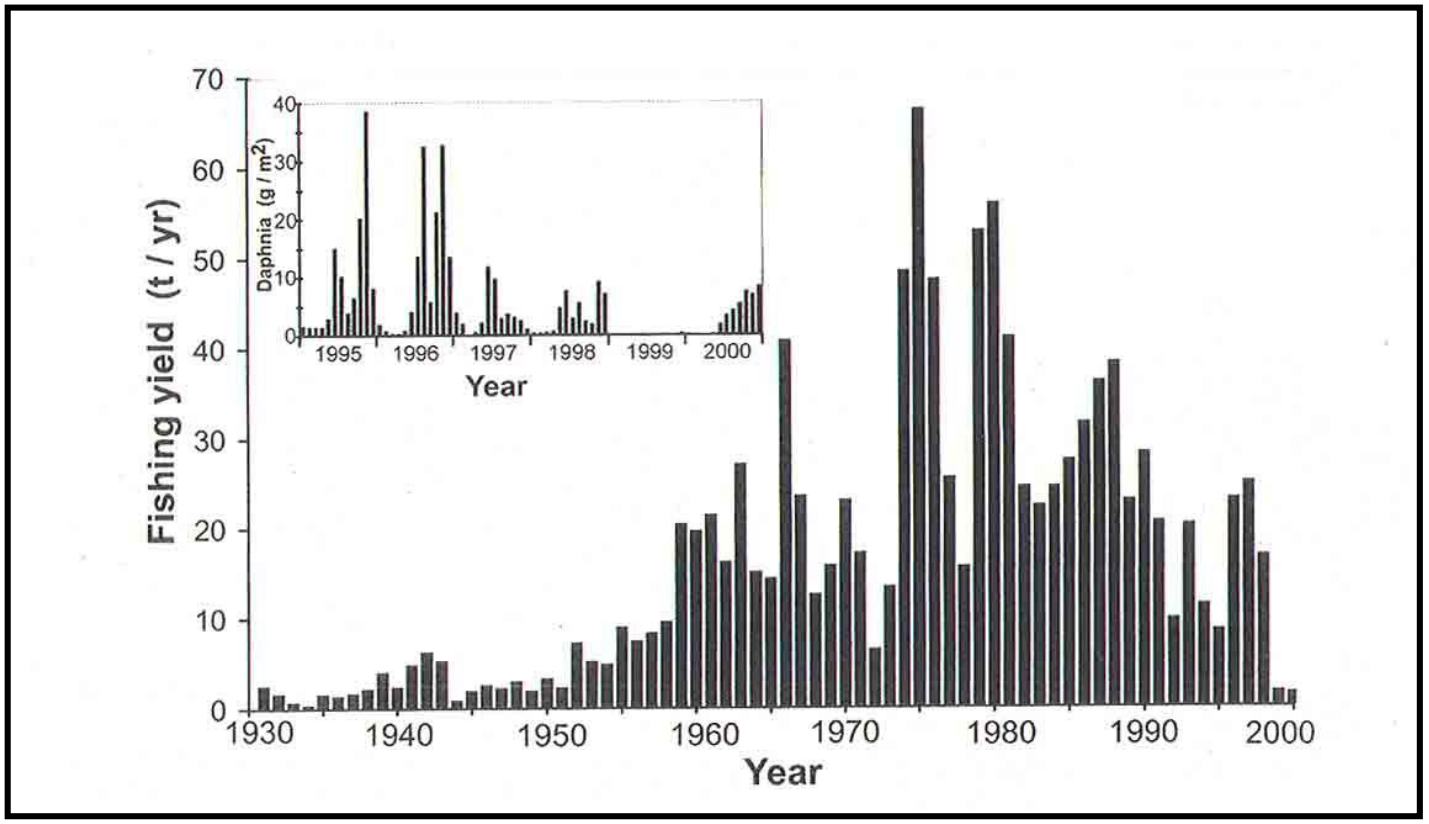
JÄCKLI AG, ZURICH

INSTITUTE OF INTEGRATIVE BIOLOGY

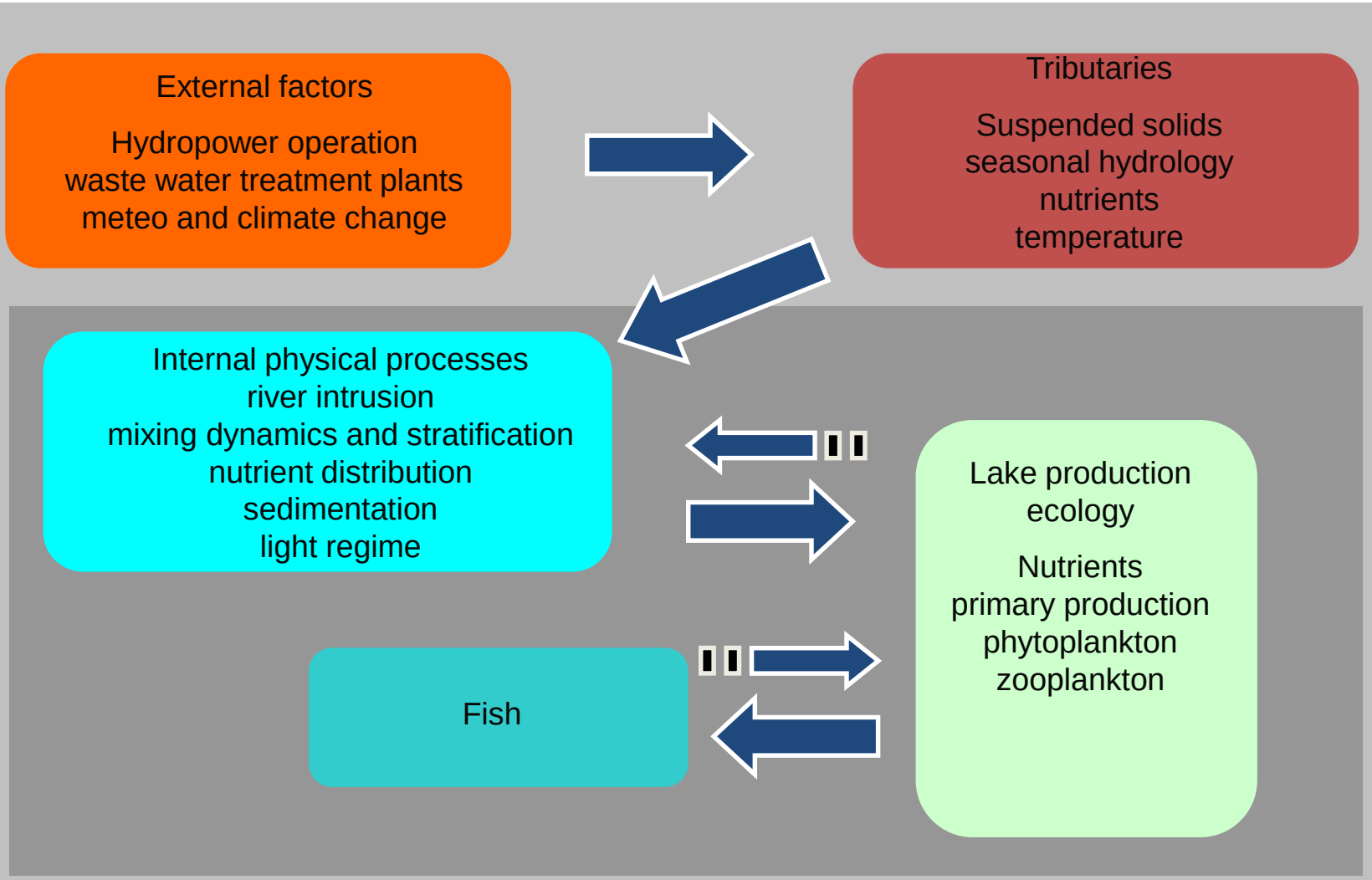

- Red lines mark track lines from seismic surveys
- Black dots indicate coring locations
Räterichsbodensee
VGR02-1
GR03-1
Grimselsee
Oberaarsee
OR03-3
OR06-1/2
OR03-2
1 km

Starting point

Rapid decline of whitefish (Coregonus sp.)

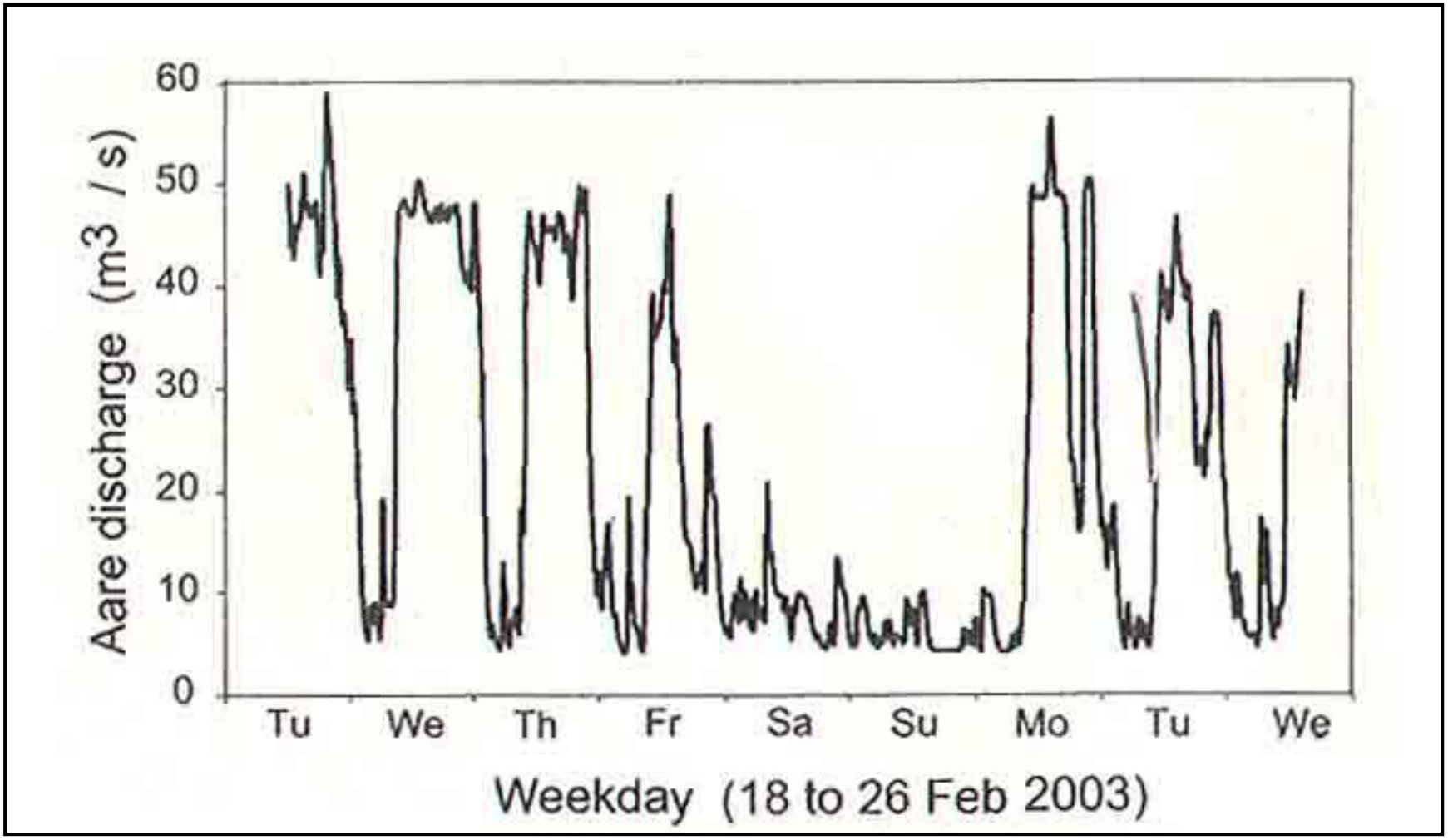


Annual whitefish (Corregonus sp.) catch in Lake Brienz (commercial fishery only) since 1931. The 90% drop in 1999 – was accompanied by a virtual disappearance of the Daphnia. Inset: Monthly wet biomass of Daphnia (g/m^2) integrated over the top 100 m water column at the center of the lake.



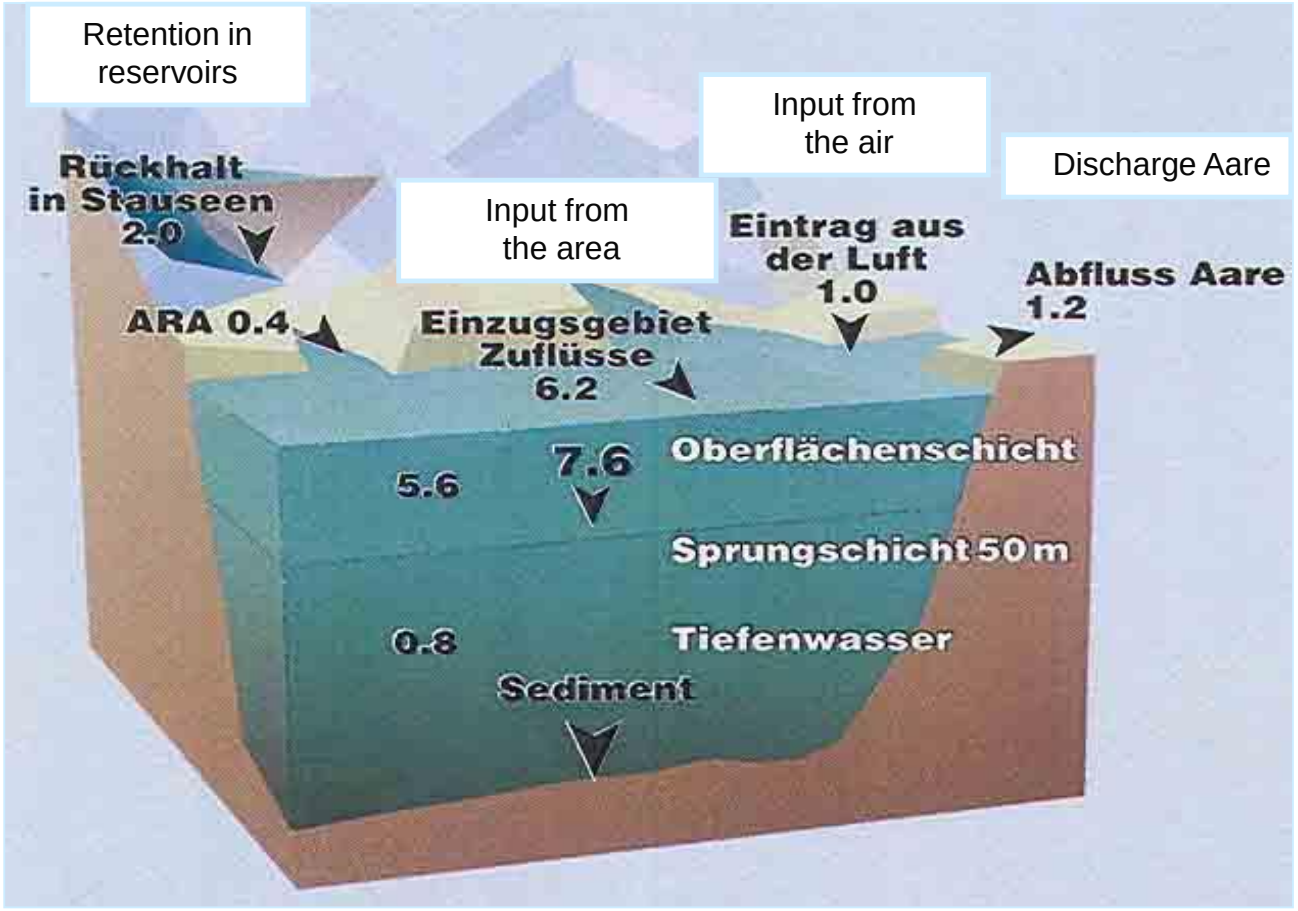
Conceptual model of the factors affecting Lake Brienz's ecosystem. Arrows point in the direction of the major effects.

Change of daily discharge due to electricity production



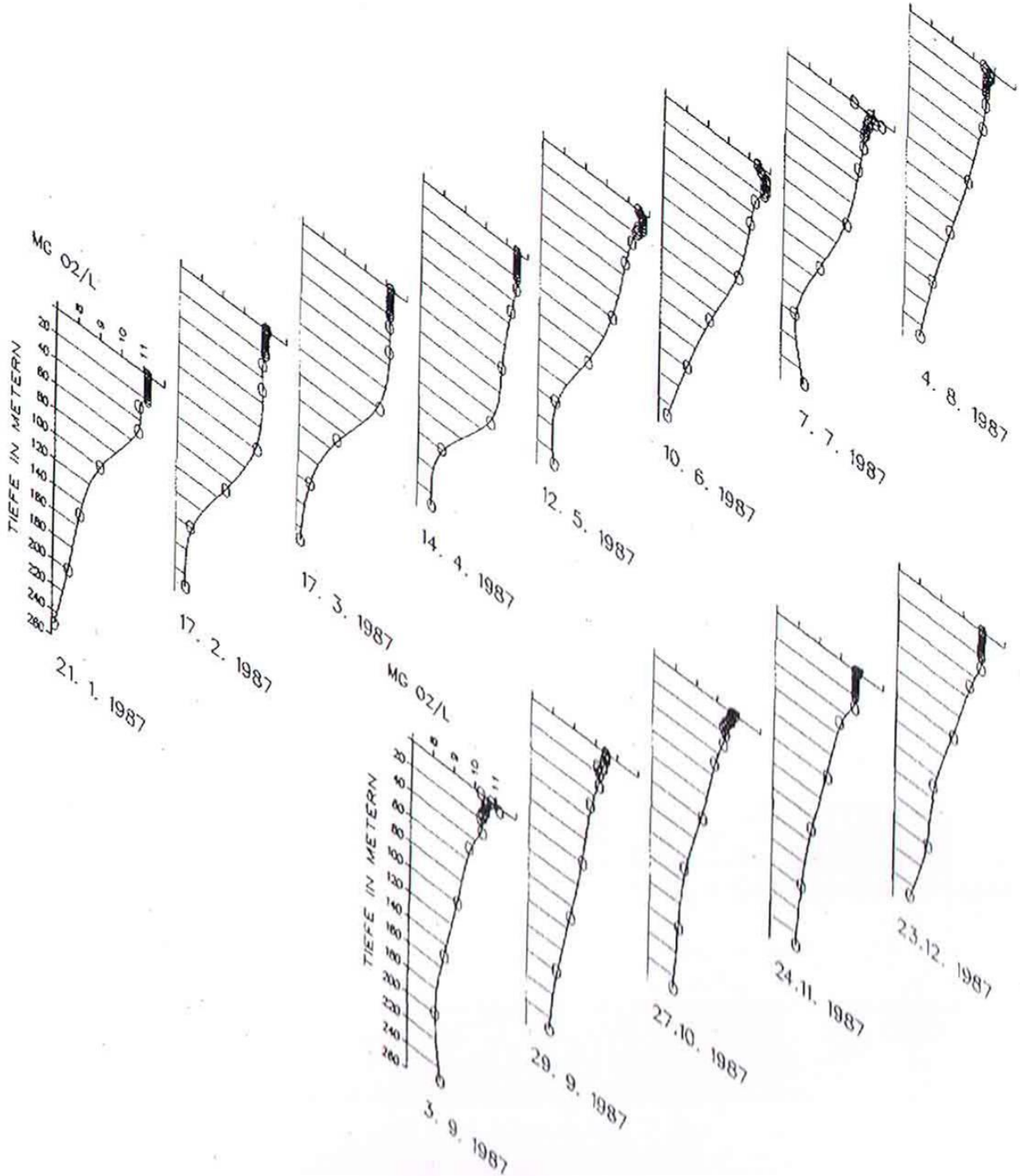
99% of the waste water is treated in waste water treatment plant

Annual balance of phoshorus input in Lake Brienz

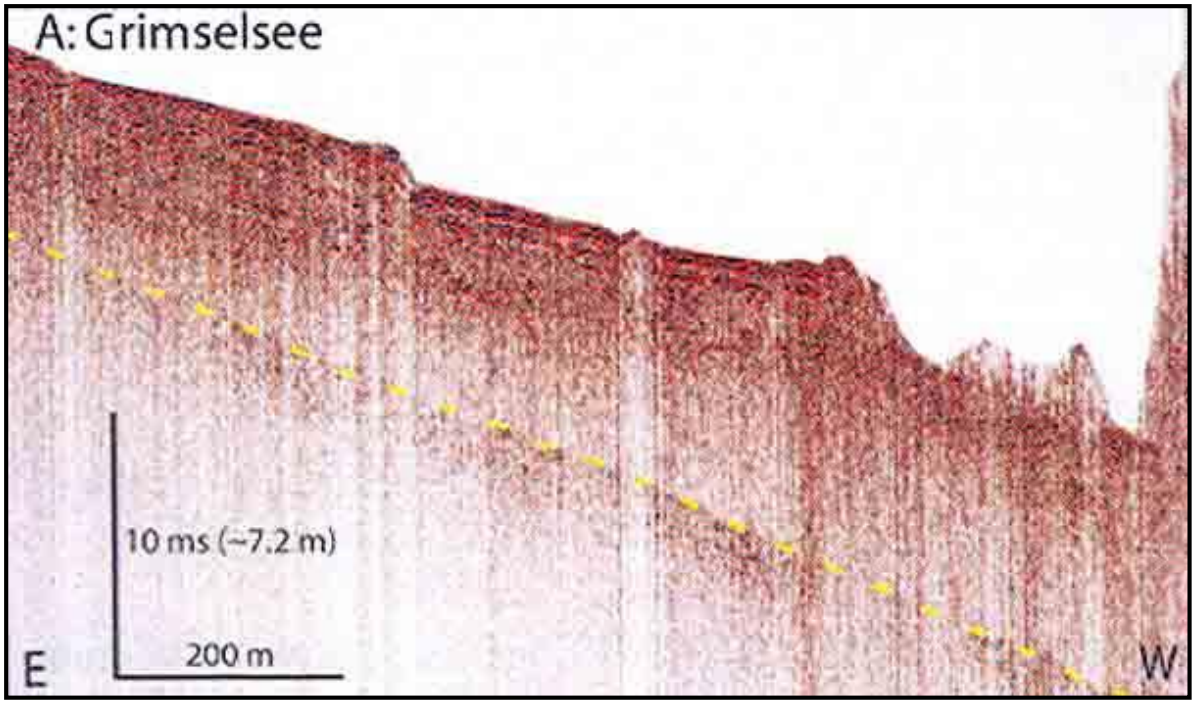


Storage of 2 tons of bio-activable phoshorus per year. 8 tons flow into the lake, deposited in the lake sediments after the death of the alges

Oxygen content of Lake Brienz



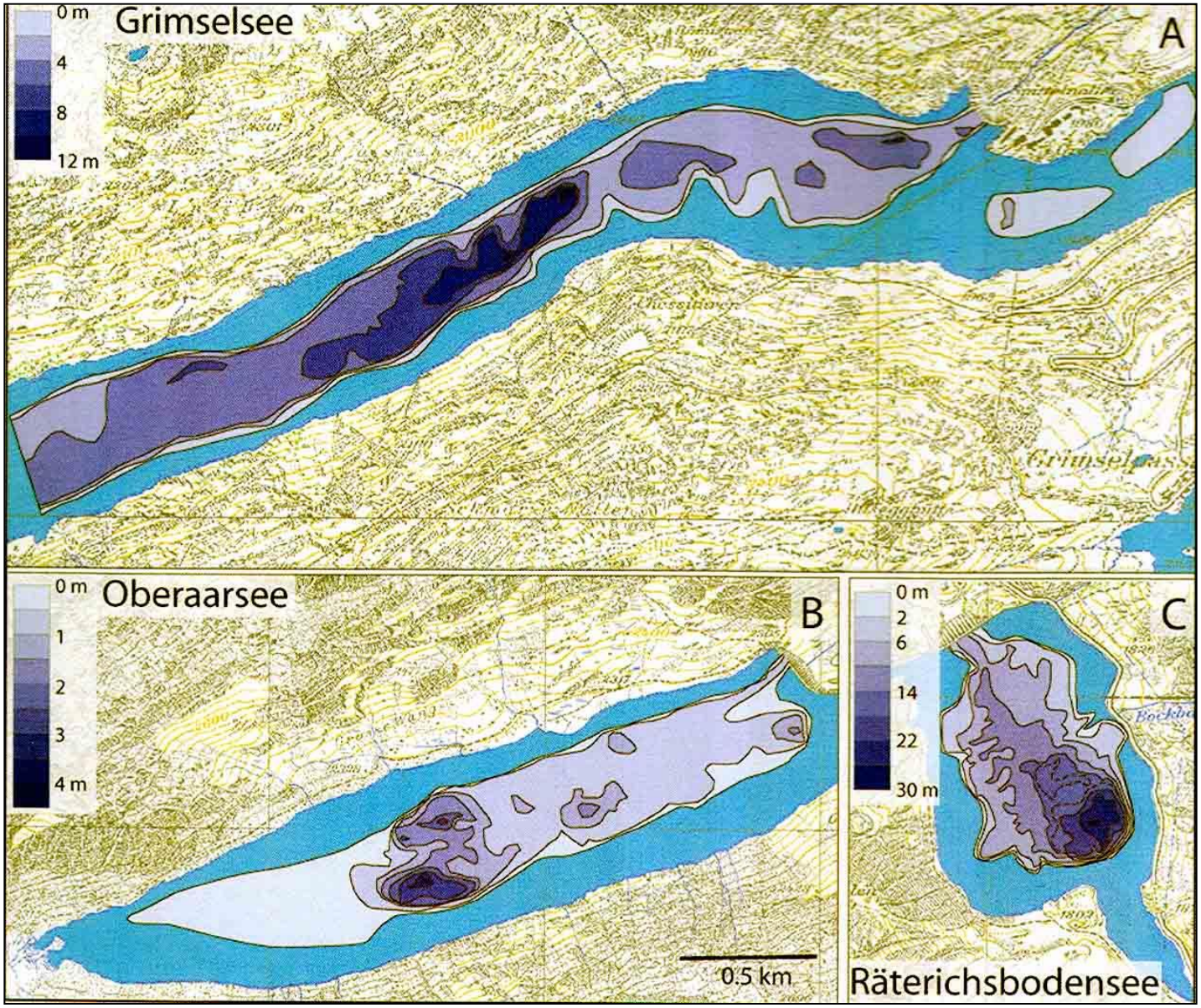
Seismic investigation in the upstream reservoirs



Erosion rate: 0.94 mm/y

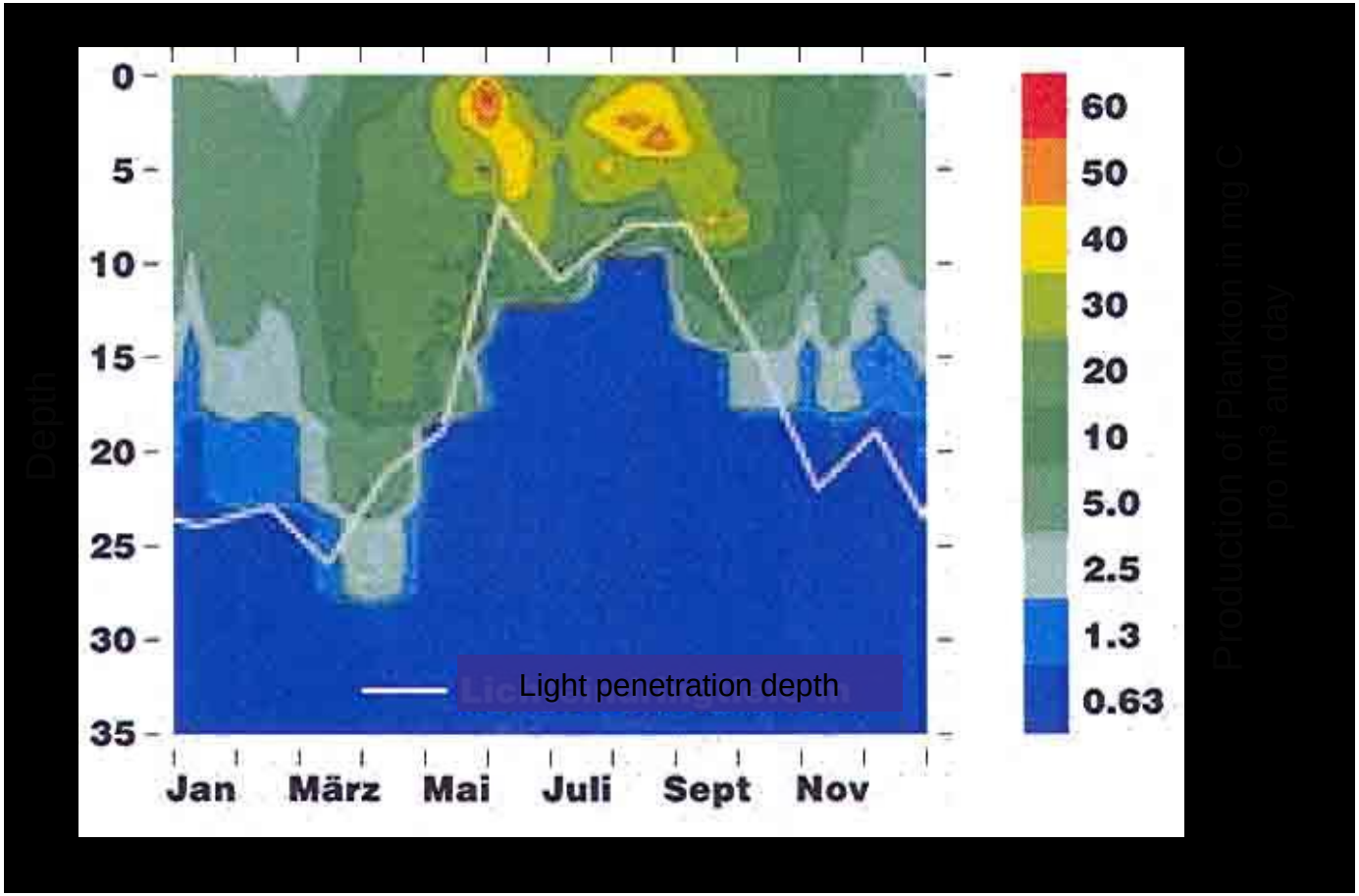
Sediment and erosion budgets of Grimsel area. Infilling times are calculated under the assumption of constant sedimentation

	Sediment volumes (10^3 m^3)	Infilling times (yr)	Eroded bedrock-volumes (10^3 m^3)	Solid particle mass (kt)
Oberaarsee (49 yr)	934	2990	607	1579
Grimselsee (71 yr)	5300	1270	3445	8957
Räterichsbodensee (50 yr)	3584	350	2294	5965
All three lakes (71 yr)	9818		6346	16,501
retained in reservoirs per year (71 yr)	138		89	232
Annual suspension in Aare			15	39
Total annual input from catchment			104	271



230 000 t/y of glacial till retained in the reservoirs. Only fine particles (<5 to 20µm) arrive in Lake Brienz

Dependency of plankton production to light



Summer: warm temperature and intensive sunshine result in a maximal production of algas (orange/yellow).

High discharges with a let of supended sediments raffle the water resulting in a limitation of plankton growth to the uppermost to meters.

Conclusions

- Daphnia population size has been decreasing in the 90ties as a result of phytoplankton density
- There was a collapse of Daphnia population in 1999 resulted from a combination of
  - flood-induced higher washout rate
  - lower temperatures
- It was found that due to climate variability already around 1955 we have had a period with similar productivity as today.
- As a result of Lack of Daphnia in 1999, the whitefish apparently starved and did not grow. They were to small and to slim to be caught by the gillnets used.
- The particle concentration in the lake did not have a negative effect on the fitness of Daphnia

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G.L. Morris, Jiahua Fan

McGraw-Hill

ISBN 0-07-043302-X

Methods for the Estimation of Erosion, Sediment Transport and Deposition in Steep Mountain Catchments

E. Gertsch, Chr. Lehmann, M.Spreafico

Report No II-21 of the International Commission of the Hydrology of the Rhine BasinISBN 978-90-70980-36-8

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