Stauraumver und –entlandung im Wandel der Zeit
Ein hochalpines Beispiel

Giovanni De Cesare

und viele weitere

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES


The Gries Glacier, Reservoir and Dam
(picture 2020: A. Baumer, OFIMA)

TAGUNG HYDRO+ 2024, 14.06.2024, Freie Univesität Bozen

Fangen wir mit der Reise an

Recent information … e.g. on BBC news

Climate change: Swiss glaciers disappearing at record speed

https://www.bbc.co.uk/news/av/science-environment-62727337

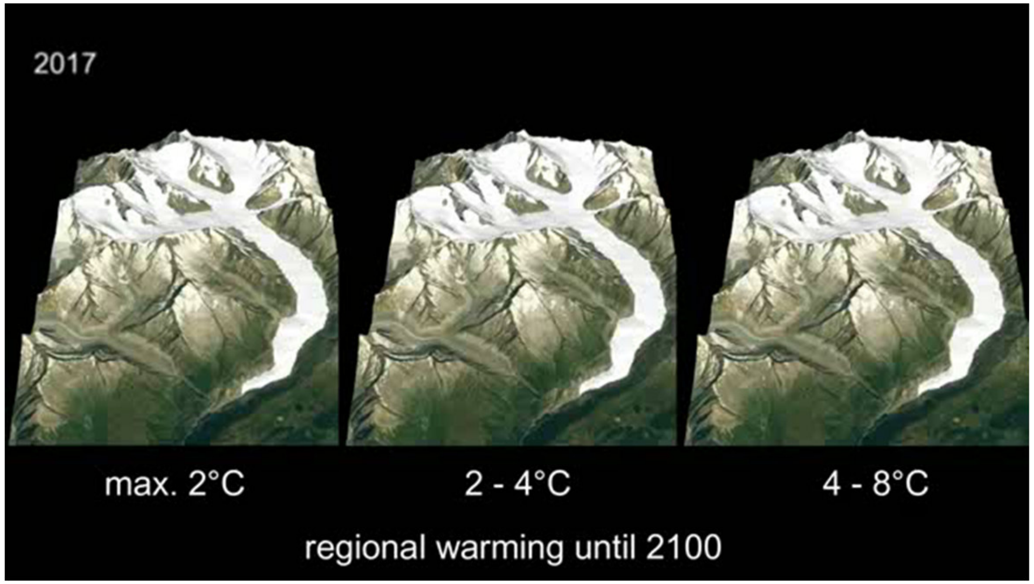
Reise - Beschleunigung

Current study shows that glaciers in Switzerland have lost more than **half of their volume** in less than 100 years. And it will go on

Source: https://ethz.ch/en/news-and-events/eth-news/news/2022/08/a-historical-perspective-on-glacial-retreat.html

Und wie geht es weiter – Gletscherrückgang

Whatever climate change scenario, most alpine glaciers will disappear by the end of the century, example of the Great Aletsch Glacier



ETHZ (2020) Future retreat Great Aletsch Glacier Simulation with three climate scenario, youtube W2o7glLGPZg

Kurze Quizfrage

find the chronologic order

Pictures by: Henry Pougatsch,
électrcité romande, Andrea Baumer

Kurze Quizfrage

find the chronologic order

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The Gries Reservoir, Dam, HPP Cascade, Watershed and Glacier

- Location
- Hydropower, main figures
- Watershed & Glacier, main figures
- Surveys and past evolution

Reservoir sedimentation

- General processes
- Effects, challenges

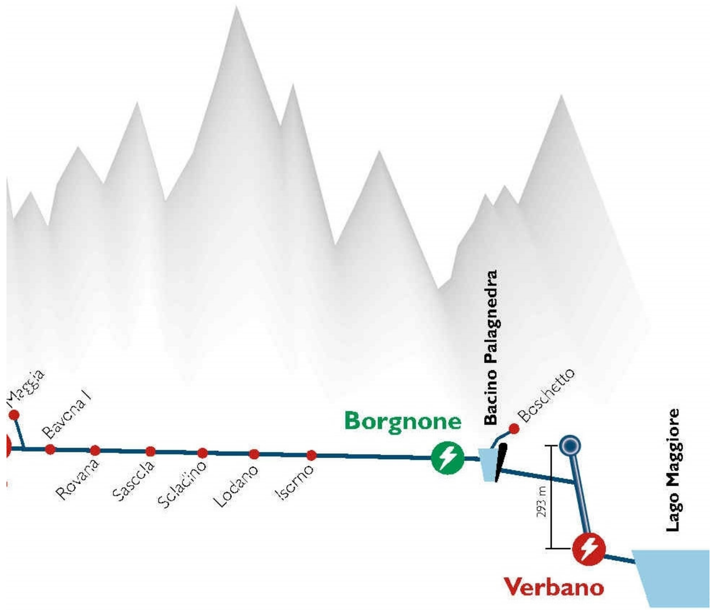
What's next, outlook

- Climate change scenarios
- Future evolution

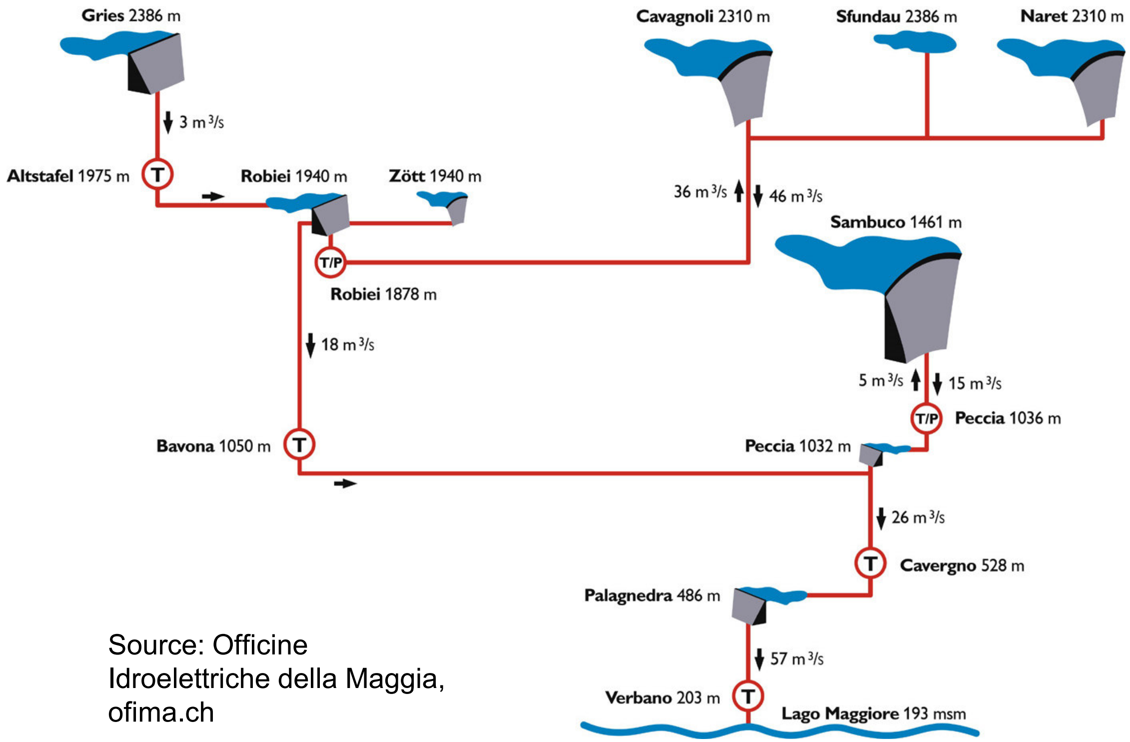
Anlage Gries, Einzugsgebiet und Gletscher

DosSanto (2020) Griesgletscher and Griessee - Part II, youtube eT2ppsgS2Ps

Source: Officine Idroelettriche della Maggia OFIMA SA, ofima.ch



Gries – Maggia Wasserkraftkaskade



Source: Officine Idroelettriche della Maggia, ofima.ch

* the highest potential energy of HPP storage water in Switzerland

- Gries located in Valais
- Altitude 2'386 m asl
- Water flows down to Lago Maggiore 193 m asl, Ticino
- Among the highest head alpine cascade, gross head some 2'190 m
- 6 Hydropower plants, from 9 to 150 MW and 8 artificial reservoirs
- Energy cont. 4.64 kWh/m^3 *

Gries – Maggia Wasserkraftkaskade

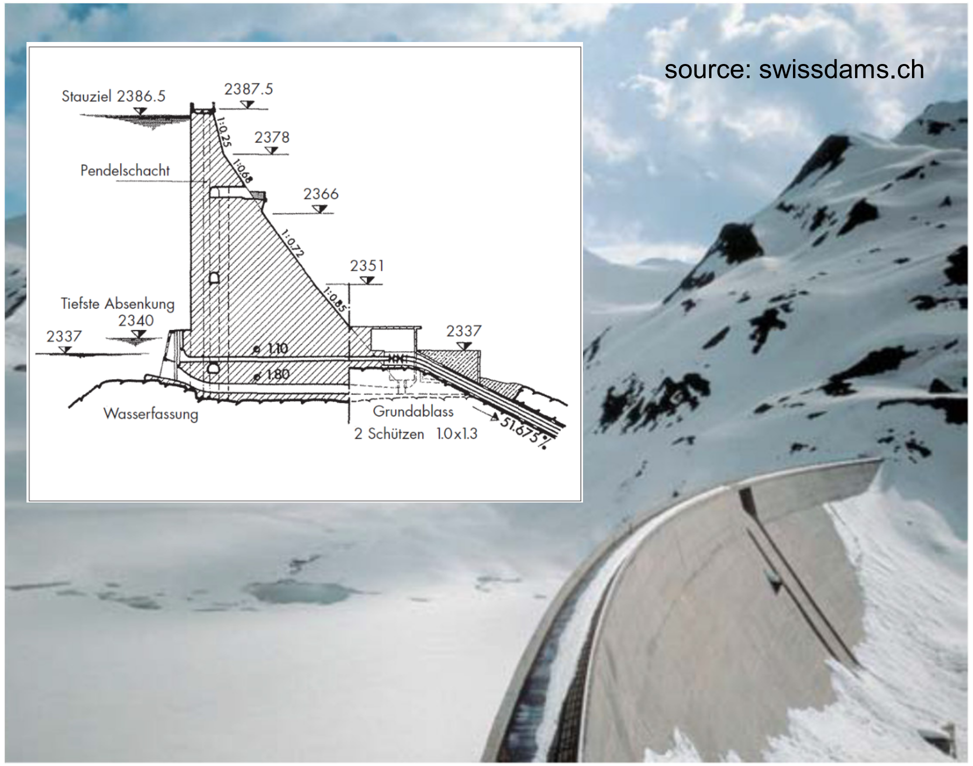
	Bacino imbrifero	Salto medio	Inverno	Estate	Anno	Inverno	Estate	Anno
Impianto	[km2]	[m]	acqua utilizzata [106 m3]			produzione [GWh]		
Alstafel	11	384	18	6	24	16	5	21
Robiei	14	338	69	57	126	58	48	106
Bavona	70	877	86	73	159	173	148	321
Peccia	57	381	67	27	94	62	25	87
Cavergno	212	489	170	163	333	195	189	384
Verbano	750	255	330	464	794	213	294	507
Produzione lorda impianti Ofima						717	709	1426
Perdite, restituzioni e compensi								-161
Produzione netta impianti Ofima								1265

- Large head and discharge variety
- 1.265 TWh total production
- ≈ 3% of Swiss HP production
- Importance of storage for winter production

Source: Officine Idroelettriche della Maggia OFIMA SA, ofima.ch

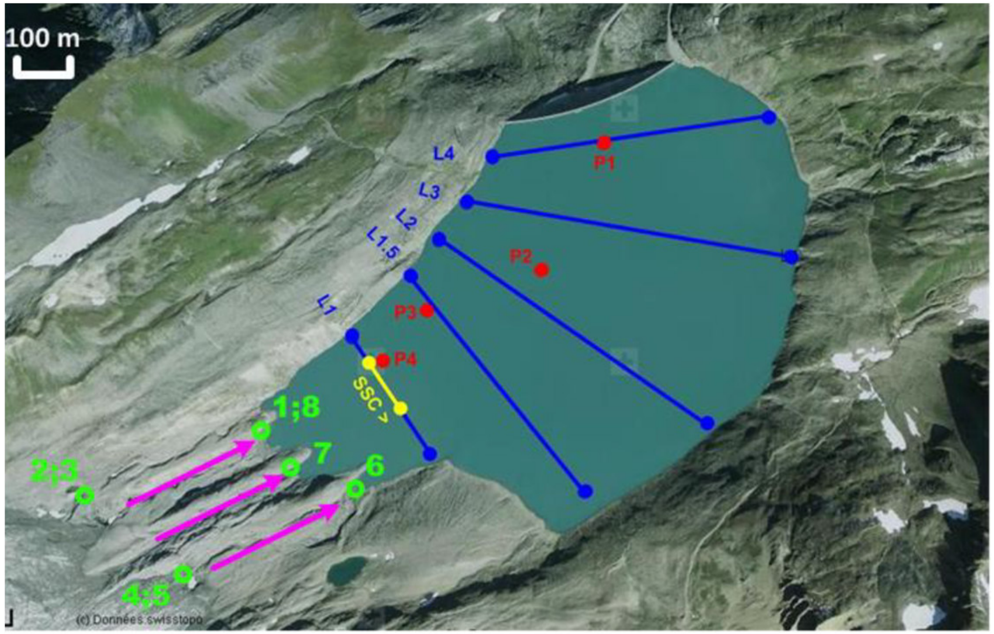
Gries Staudam und Speicher - Kennzahlen

- Slightly arched gravity dam
- Height 60 m
- Crest length 400 m
- Commissioned 1967
- Crest altitude 2’387.5 m asl
- Concrete volume 251’000 m^3
- Reservoir volume 18 Mio. m^3
- **August 2011, blocked waterway by sediment, start of awareness and subsequent studies**



Gries Staudam und Speicher - Monitoring

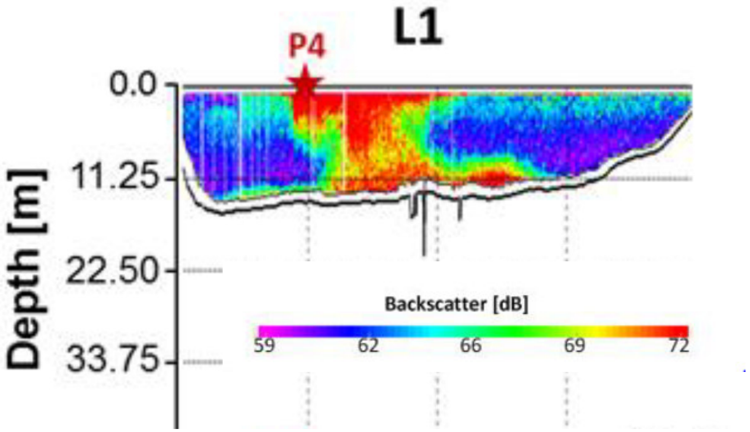
- 2012 first measurements and sampling campaign
- Bathymetry, sediment yield, summer dry weather conditions
- 3 main tributaries coming from the glacier (indigo arrows)
- 8 water and suspended sediment samplings (green circles)
- 5 ADCP profiles (blue lines)
- 4 SSC vertical profiles (red dots)



source: Bourban and Papilloud (2015). Gries: a global approach example for hydropower reservoir sedimentation management, Proc. Hydro 2015, Bordeau, France

Gries Staudam und Speicher - Monitoring

- Plunging turbidity current observed

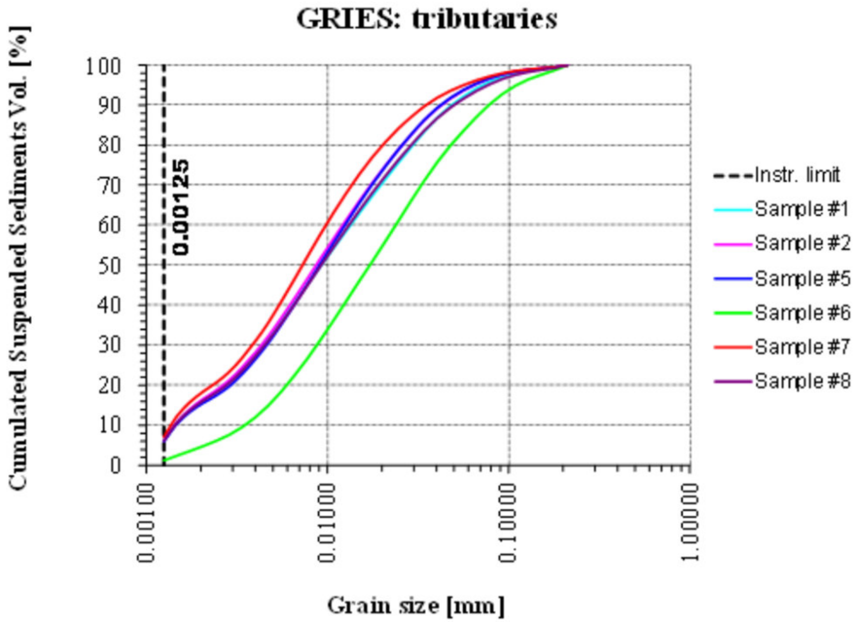


ADCP backscatter echo for profiles L1

source: Bourban and Papilloud (2015). Gries: a global approach example for hydropower reservoir sedimentation management, Proc. Hydro 2015, Bordeaux, France

Gries Staudam und Speicher - Monitoring

- Plunging turbidity current observed
- SSC Grain size distribution
  - ➢ $0.007 \le D_{50} \le 0.020$ mm



Tributaries suspended matter grain size analysis by laboratory Laser diffraction LISST-100X

source: Bourban and Papilloud (2015). Gries: a global approach example for hydropower reservoir sedimentation management, Proc. Hydro 2015, Bordeau, France

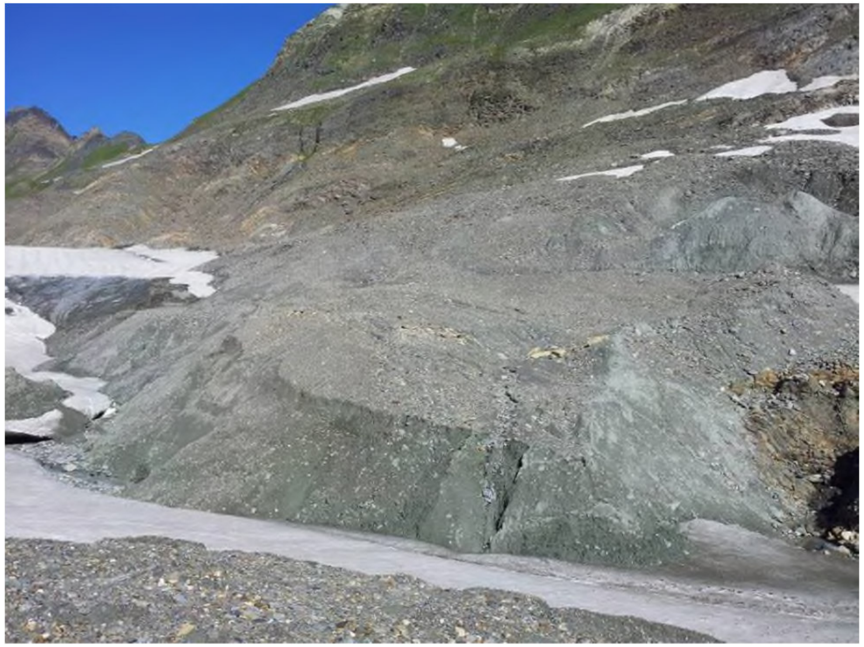
Gries Staudam und Speicher - Monitoring

- Plunging turbidity current observed
- SSC Grain size distribution
- During summer, SSC approximately independent from discharge
  - ≈ 1.5 ml/l

source: Hydroexploitation (2012). KWA Aegina AG, Stausee Gries / KW Altstafel, internal report

Gries Staudam und Speicher - Monitoring

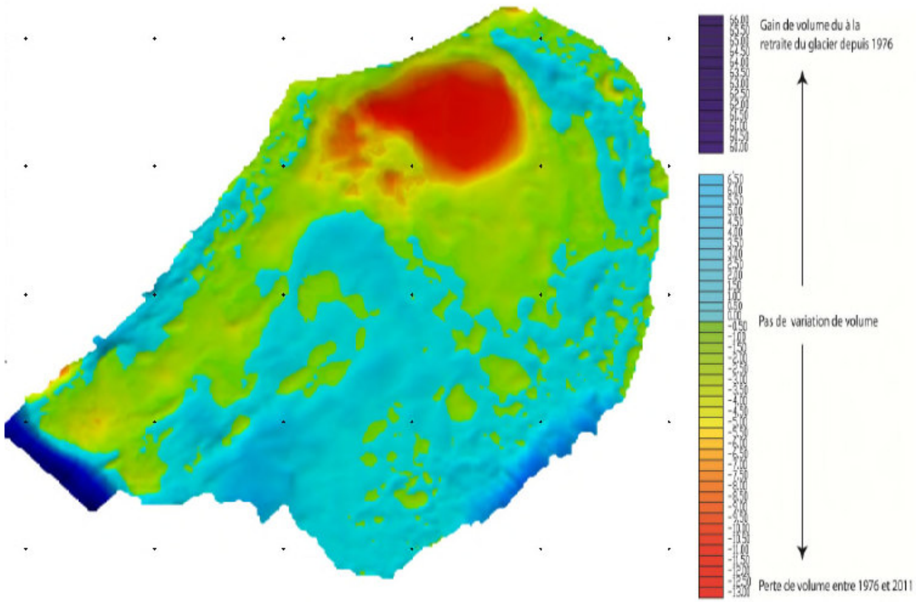
- Plunging turbidity current observed
- SSC Grain size distribution
- During summer, SSC approximately independent from discharge
  - ~ 1.5 ml/l
  - but large liberated coarser moraine material awaiting erosion



source: Hydroexploitation (2012). KWA Aegina AG, Stausee Gries / KW Altstafel, internal project report

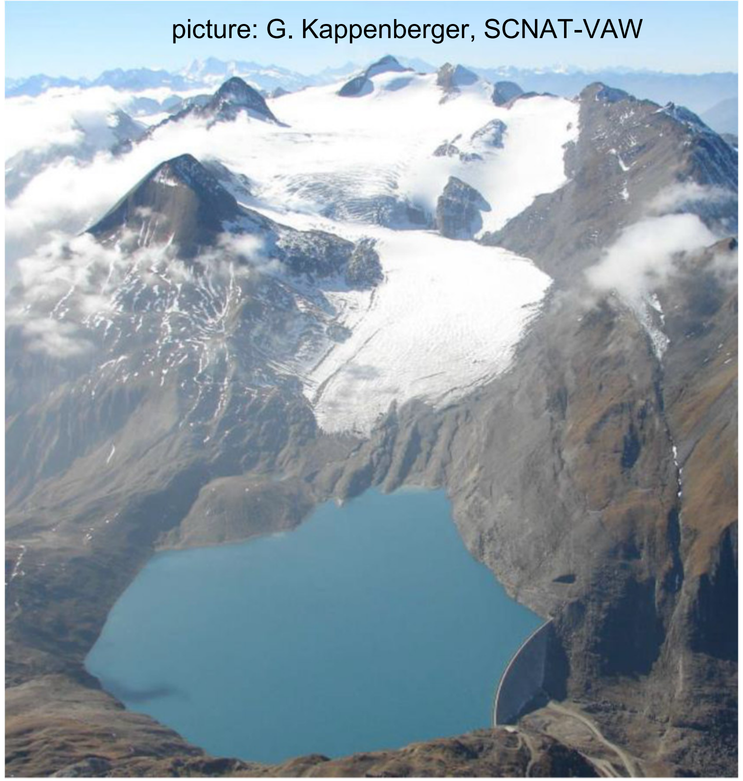
Gries Staudam und Speicher - Monitoring

- Plunging turbidity current observed
- SSC Grain size distribution
- During summer, SSC approximately independent from discharge
- Known daily inflow since 1970, total sediment yield from inflow
  - ~ 657’000 m^3 (~ 18’300 m^3/a)
- Total sediment accumulation from bathymetry, same period 1976-2011
  - ~ 620’000 m^3



source: Hydroexploitation (2012). KWA Aegina AG, Stausee Gries / KW Altstafel, Bathymetry by R.B.R Geophysics GmbH, internal project report

Einzugsgebiet und Gletscher - Kennzahlen



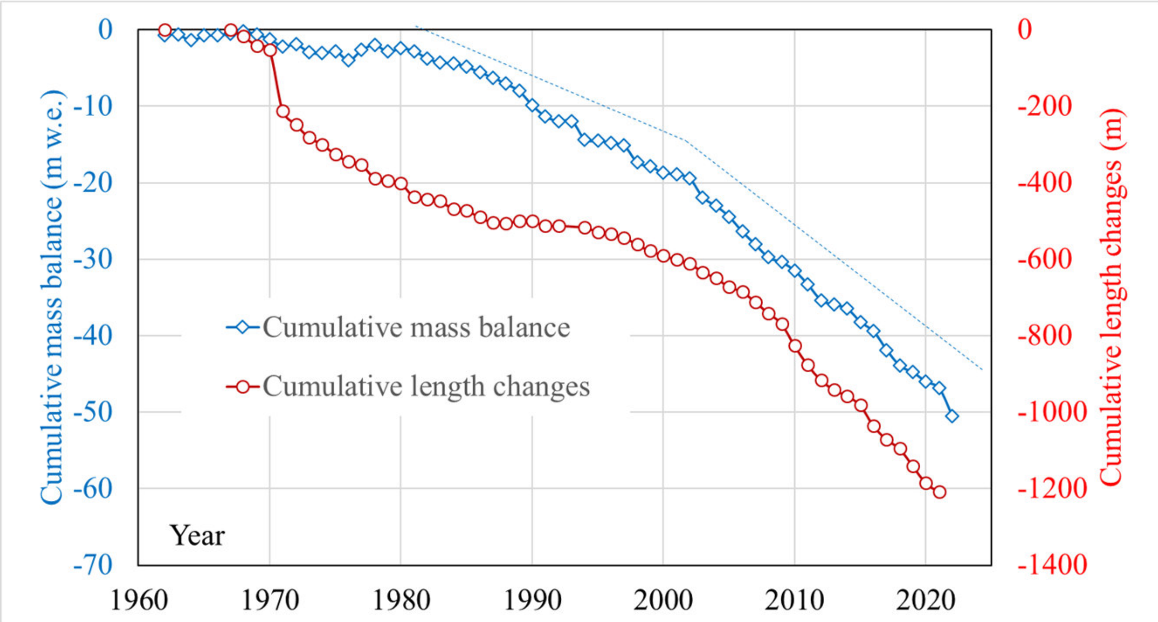
picture: G. Kappenberger, SCNAT-VAW

- Watershed 10.5 km^2
- Annual avg. inflow 24 Mio. m^3
- Water regime driven by glacier
- Low influence of precipitation
- Continuous monitoring since 1847
- Current ice thickness ~ 100 m
- Current shrinkage rate ~ 25 m/year,
- Current thickness loss rate ~ 2 – 3 m/year

Data:

- Delaney, I. (2019). Measuring and modeling sediment transport from glacierized catchments in the Swiss Alps. VAW-Mitteilungen 251, ETH Zurich
- Bourban and Papilloud (2015). Gries: a global approach example for hydropower reservoir sedimentation management, Proc. Hydro 2015, Bordeau, France

Einzugsgebiet und Gletscher - Kennzahlen



GLAMOS (2021). 1880-2021, The Swiss Glaciers 1880-22020/21, Glaciological Reports No 1-142, Yearbooks of the Cryospheric Commission of the Swiss Academy of Sciences

- Gries glacier cumulative mass balance in meter water equivalent (mwe) and length changes since 1961
- Declining trend (schematic dashed trend line for water mass balance) clearly visible
- especially after the hot 2003 summer

Stauseeverlandung - Definition

Reservoir sedimentation

Picture S. Soares-Frazão
Wushe Reservoir, Taiwan

Picture Forces Motrices de la Gougra SA
Tourtemagne Reservoir, Valais, Switzerland

Stauseeverlandung - Definition

Reservoir sedimentation

=

Filling of a water body with sediment from the catchment area

A priori, all lakes, reservoirs and accumulation basins are concerned

Stauseeverlandung - Definition

Reservoir sedimentation

=

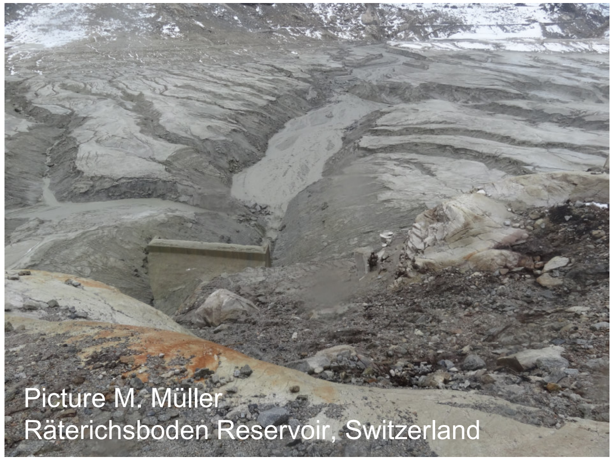
Filling of a water body with sediment from the catchment area

↓

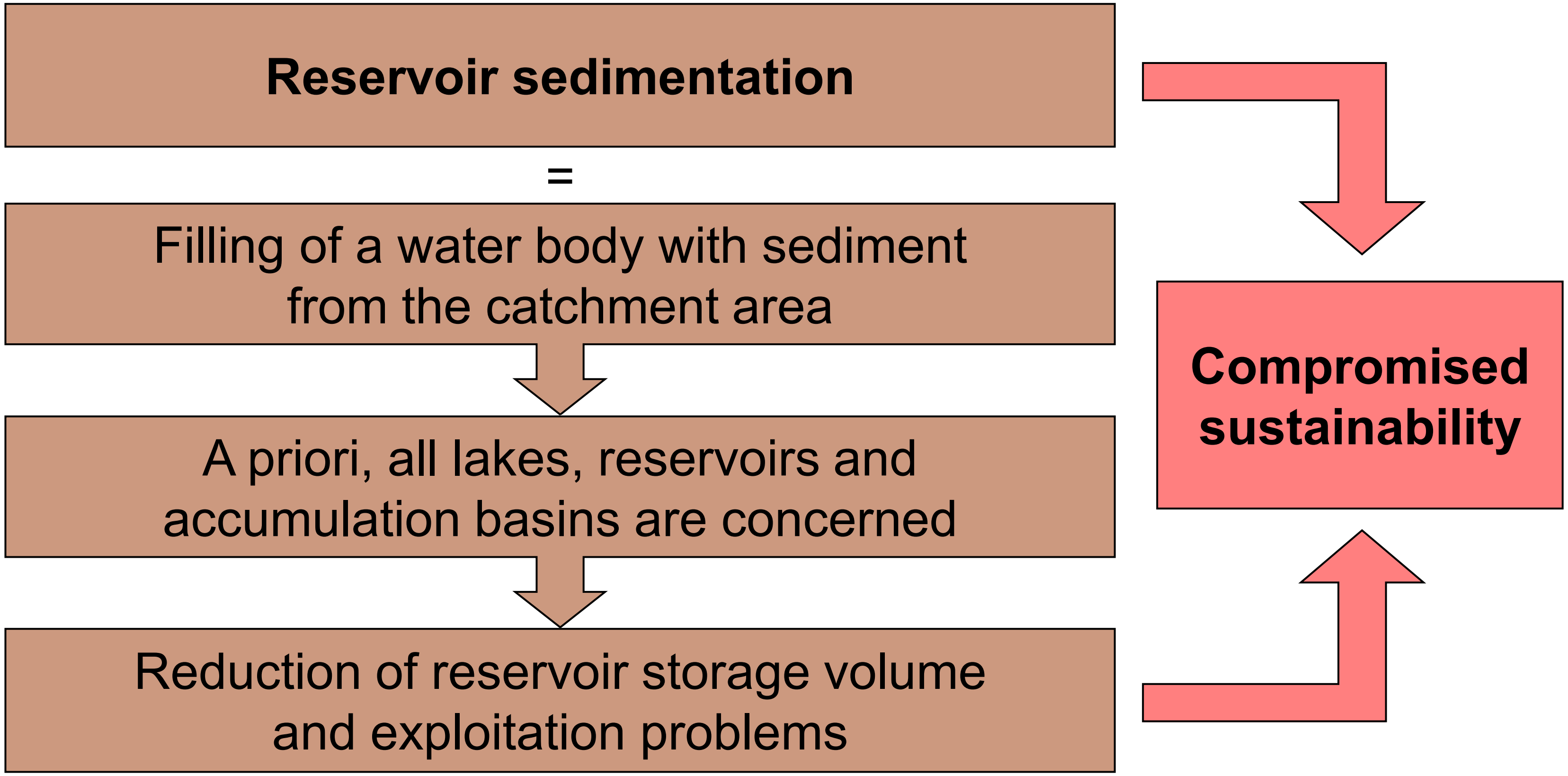
A priori, all lakes, reservoirs and accumulation basins are concerned

↓

Reduction of reservoir storage volume and exploitation problems



Stauseeverlandung - Nachhaltigkeit



Stauseeverlandung - Ursprung

Product of erosion and sediment transport originating in the watershed

Global sediment yield, essentially during flood events

Course material

Bedload transport

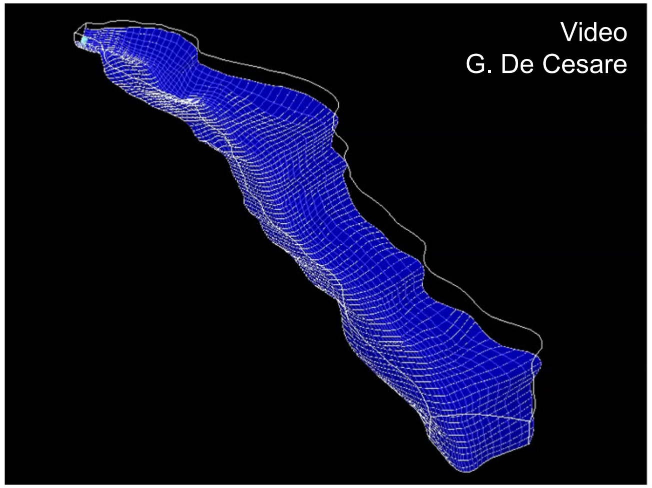
Delta deposits

Picture S. Stähly
Peyto Lake, Alberta, Canada

Stauseeverlandung - Ursprung

Product of erosion and sediment transport originating in the watershed

Global sediment yield, essentially during flood events



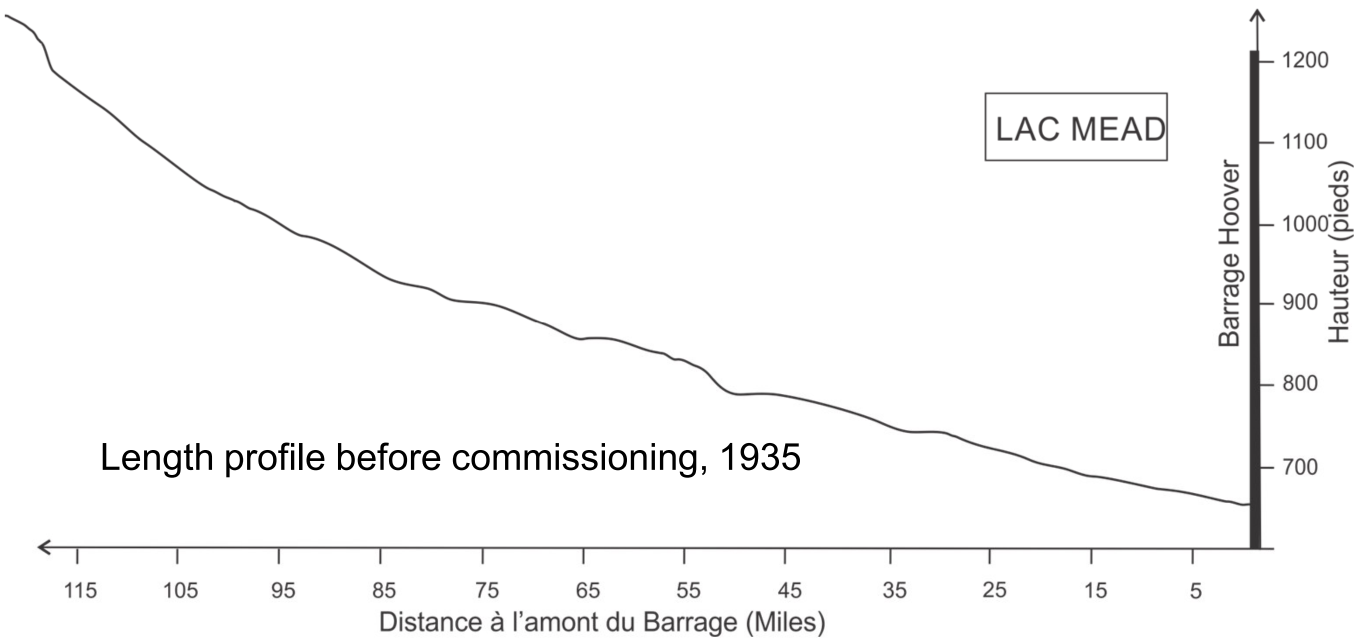
Particles in suspension

Transport by turbidity currents

Deposits on lake bottom

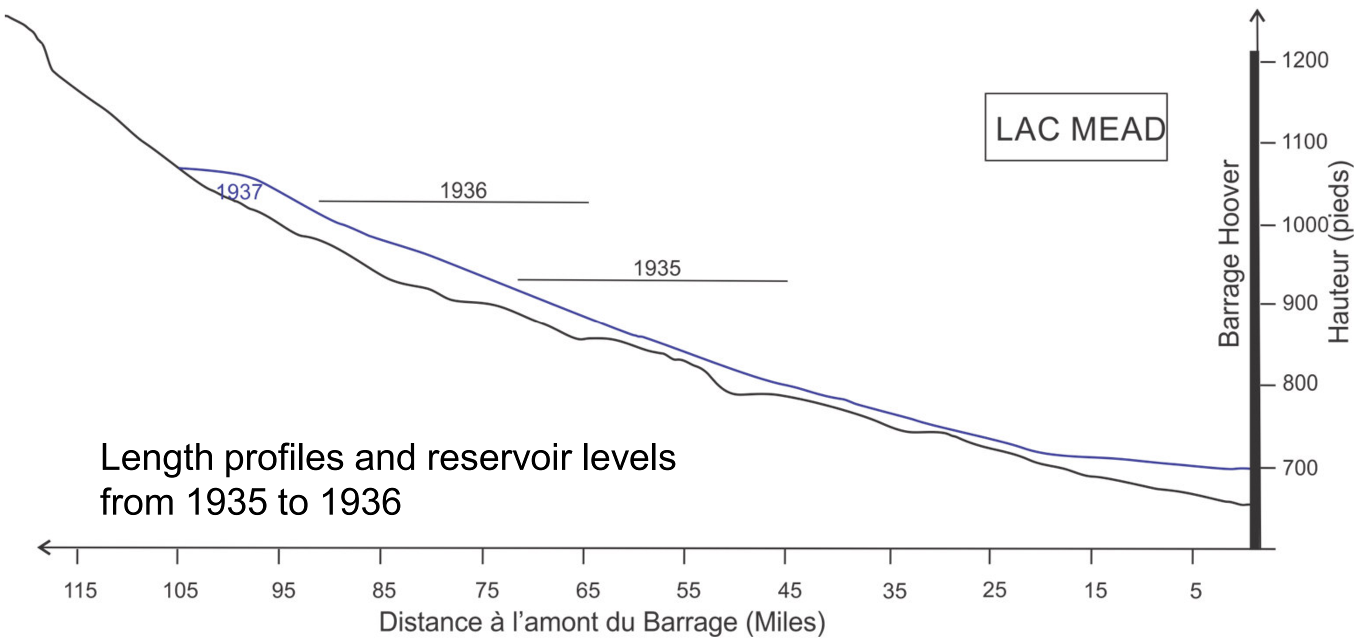
Stauseeverlandung - Prozesse

Time evolution of the deposits in Lake Mead (USA)



Stauseeverlandung - Prozesse

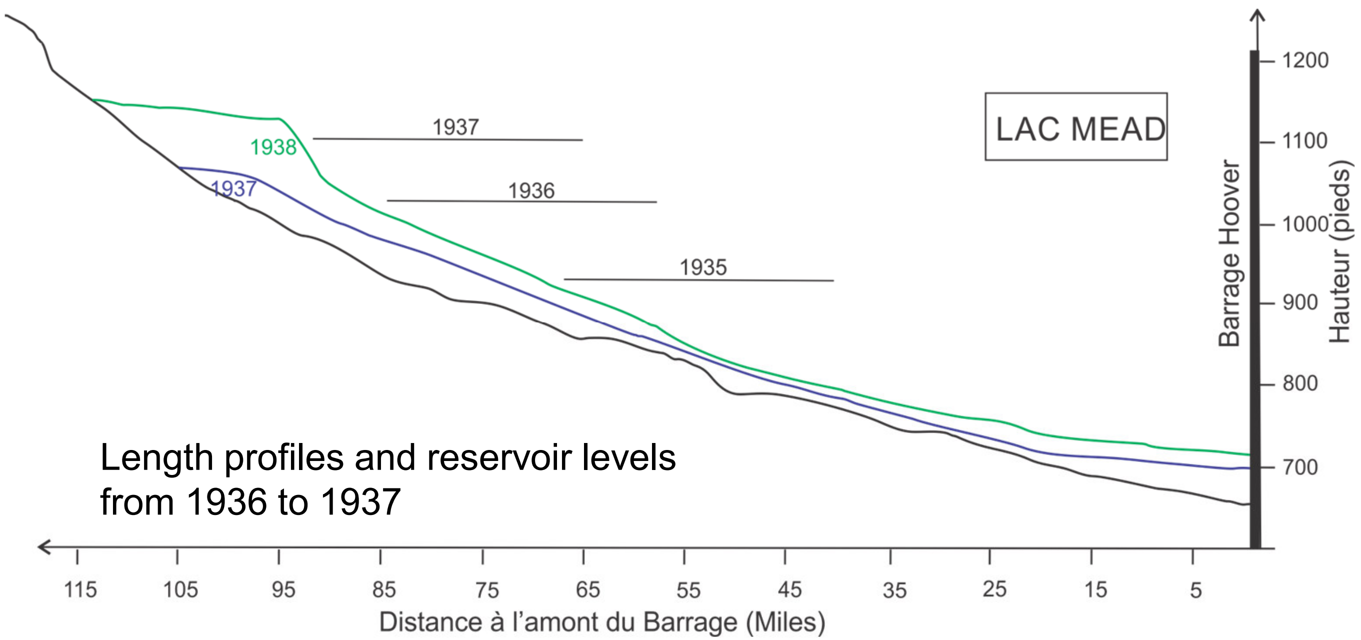
Time evolution of the deposits in Lake Mead (USA)



Length profiles and reservoir levels
from 1935 to 1936

Stauseeverlandung - Prozesse

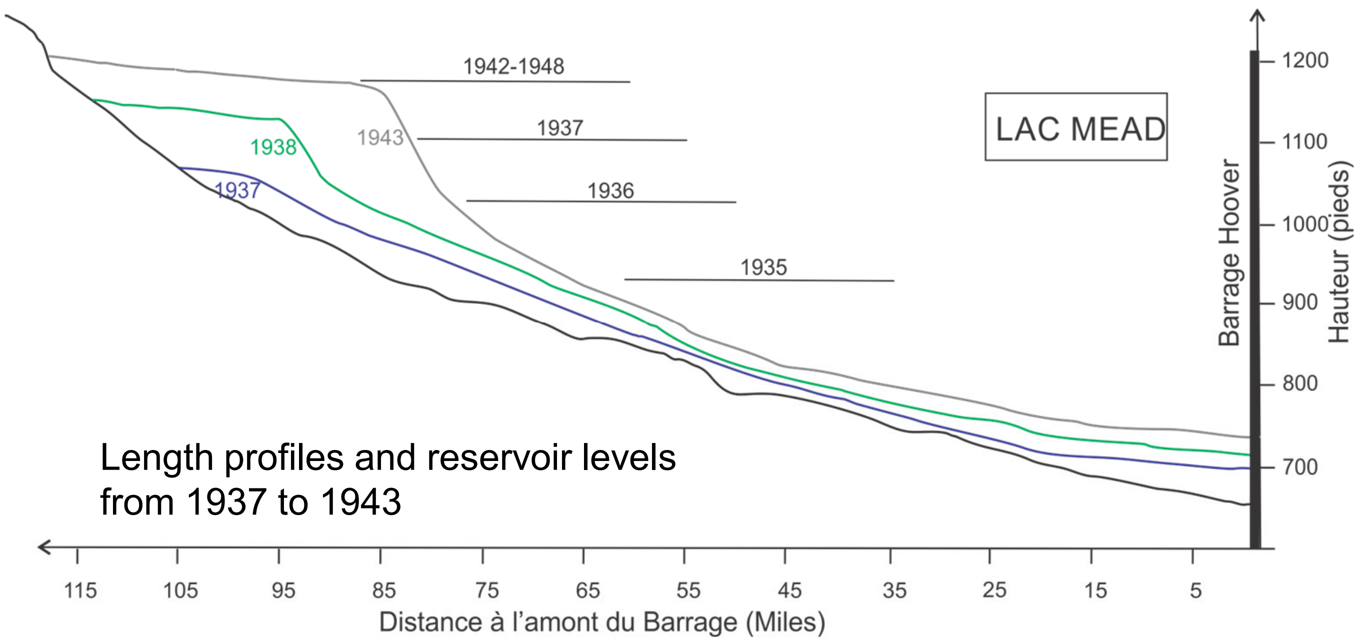
Time evolution of the deposits in Lake Mead (USA)



Length profiles and reservoir levels
from 1936 to 1937

Stauseeverlandung - Prozesse

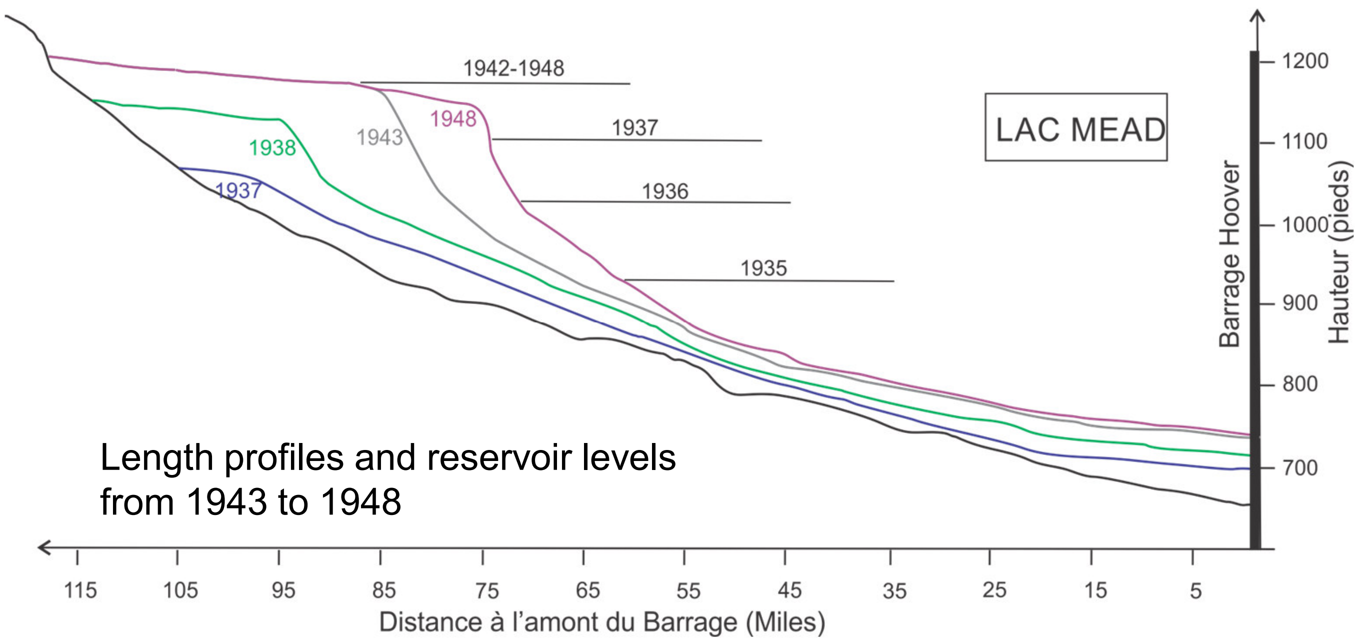
Time evolution of the deposits in Lake Mead (USA)



Length profiles and reservoir levels
from 1937 to 1943

Stauseeverlandung - Prozesse

Time evolution of the deposits in Lake Mead (USA)

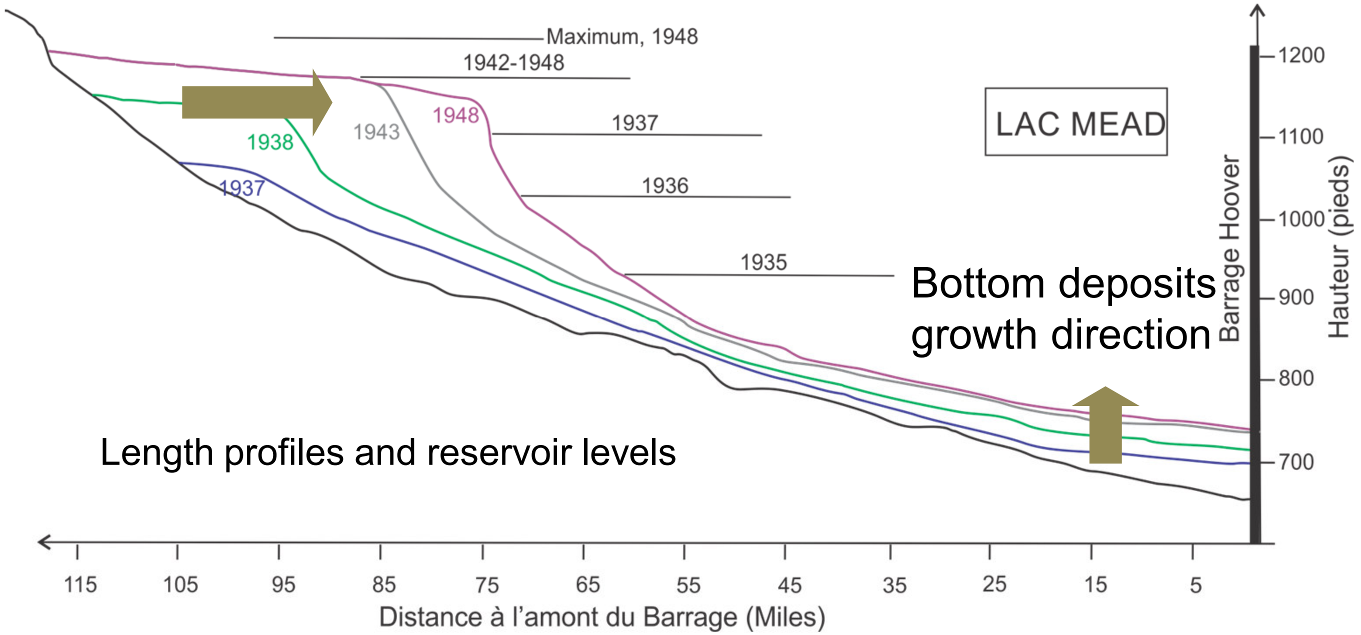


Length profiles and reservoir levels
from 1943 to 1948

Stauseeverlandung - Prozesse

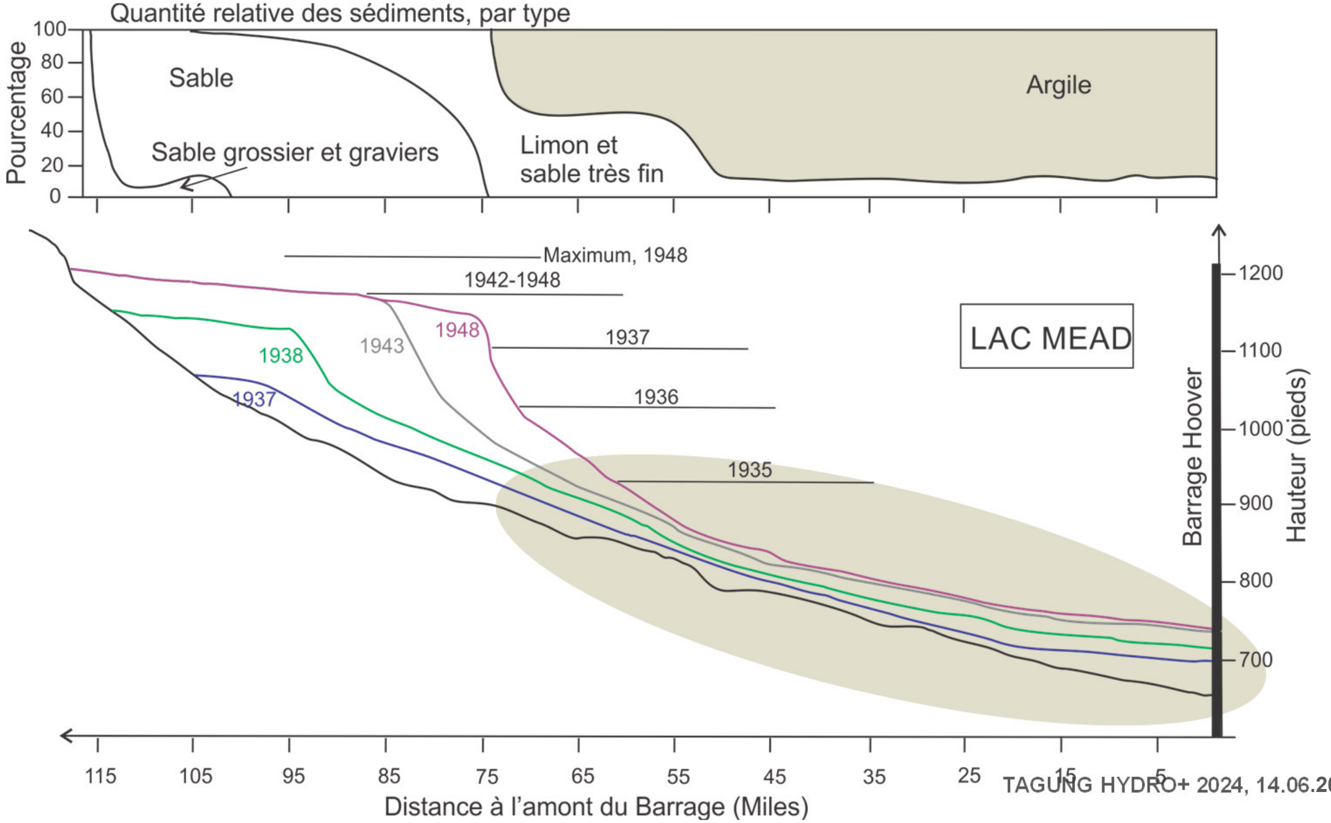
Time evolution of the deposits in Lake Mead (USA)

Delta growth direction, some 40 miles (ca. 65 km) in 13 years !



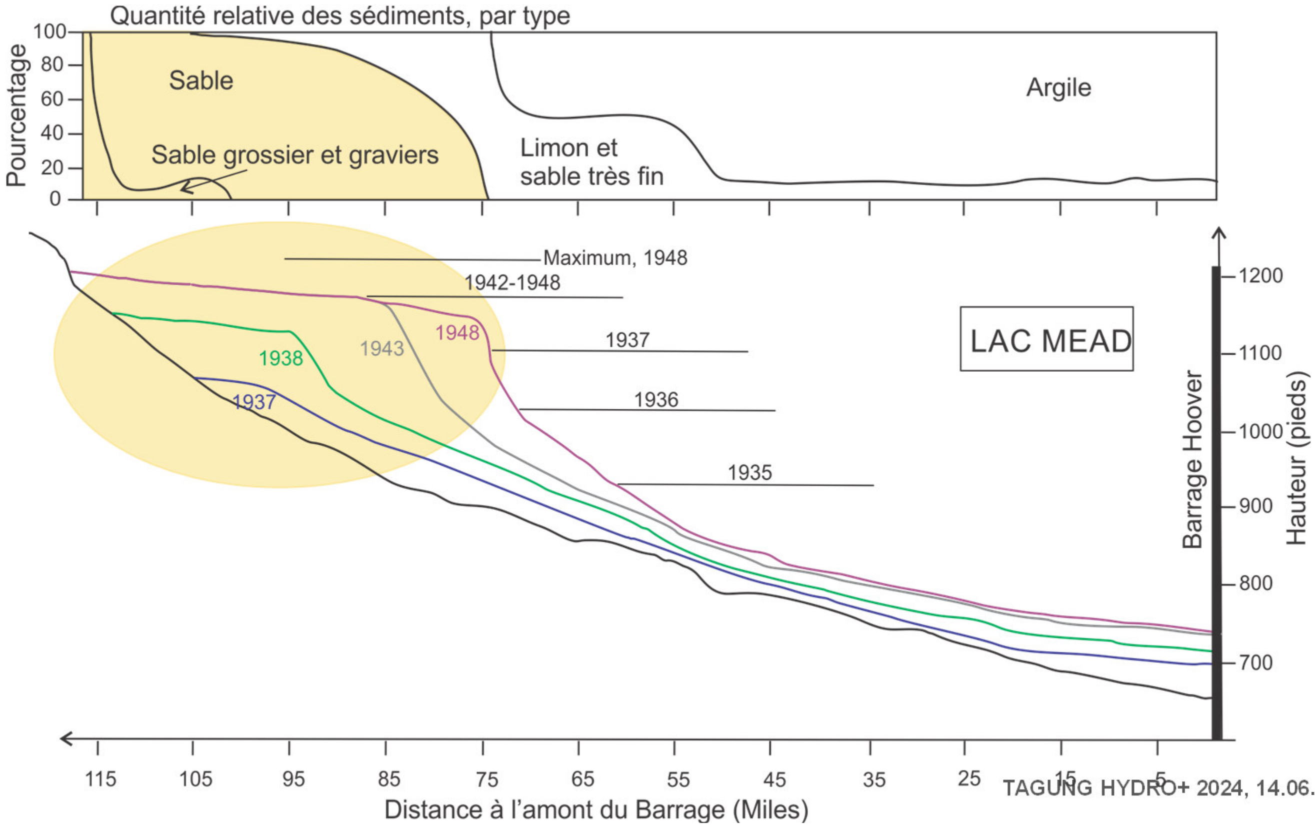
Stauseeverlandung - Prozesse

Grain size distribution of the deposits



Reservoir sedimentation - deposits

Grain size distribution of the deposits



Measures against reservoir sedimentation

Measures in the watershed

- Erosion protection, forest restoration, river training and bank stabilisation
- Bedload retention basins
- Filter check dams
- Sediment bypass tunnels
- Off stream storage

Measures inside the reservoir

- increasing dead storage
- Mechanical evacuation, dredging, hydro-suction, airlift, etc.
- Free surface flushing
- Sedimentation hindrance and resuspension
- Turbidity current control

Measures at the dam

- Dam heightening
- Heightening of power intake and bottom outlet
- Pressure flushing
- Sluicing (Lowering the water level during floods)
- Turbidity current venting
- Sediment evacuation through waterway and turbines

Was kommt auf uns zu – Gletscherschwund

Recent study* shows the extent of Switzerland's glacier ice loss in the 20th century through analysis of historical imagery:

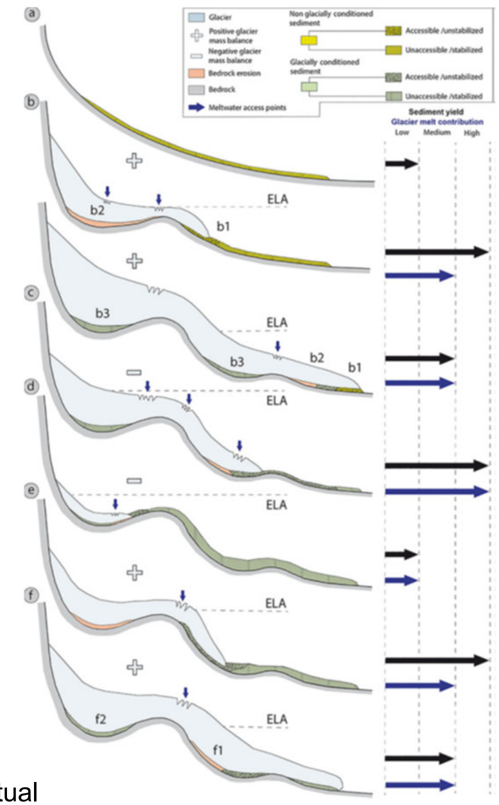
- the country's glaciers lost half of their volume between 1931 and 2016
- Lost volume corresponds to some 51.5 km^3
  - roughly 1.4 times the volume of Lago Maggiore or 58% of Lake Geneva
- and it's not ready to stop
- By way of comparison, while glaciers lost half their volume between 1931 and 2016, they lost a further 12 percent between 2016 and 2021 – i.e. in just six years
- not yet taking into account 2022-24

*Mannerfelt E. S. et al. (2022). Halving of Swiss glacier volume since 1931 observed from terrestrial image photogrammetry. The Cryosphere, 16, 3249–3268, doi:10.5194/tc-16-3249-2022

Was kommt auf uns zu – Gletscherschwund

e.g. Antoniazza & Lane (2021)* developed a glacier mass balance and sediment yield conceptual model during multiple glacial cycles:

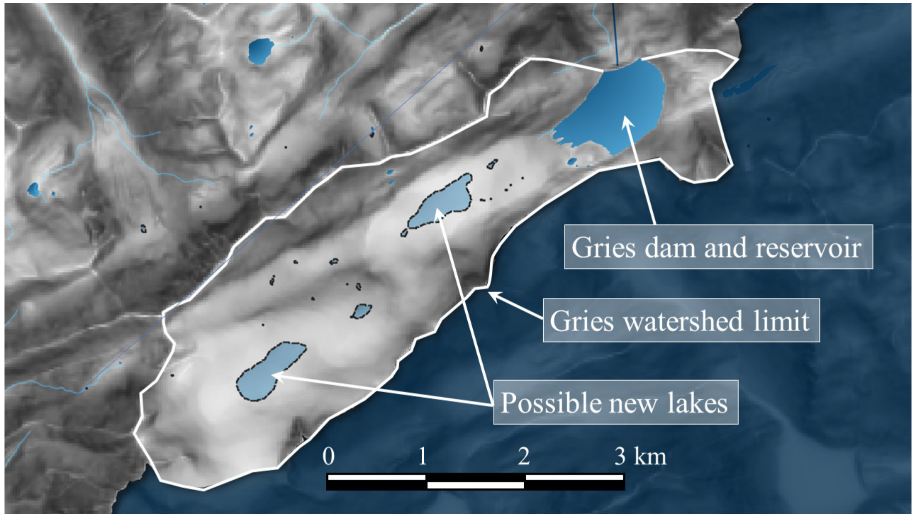
- Typically, early phases of glacier retreat and re-advance are expected to lead to the highest increase
- The latest phases of deglaciation, once glacially-conditioned sedimentary sources are either exhausted, stabilized or disconnected from active processes of sediment transfer, are likely to have the lowest rate of export.



Antoniazza, G., & Lane, S. N. (2021). Sediment yield over glacial cycles: A conceptual model. Progress in Physical Geography: Earth and Environment, 45(6), 842-865.

Was kommt auf uns zu – Gletscherschwund

- Accordingly to the climate change scenarios, the observed trend will continue, potentially even accelerate
- The foreseen evolution of the glacier predict drastic changes:
  - By 2030: the glacier will have disappeared below 2'700 m asl
  - By 2070, the glacier will have disappeared completely
  - leaving an uncovered watershed



Possible new lakes will be created in the Gries watershed after the complete retreat of the glacier, allowing for temporal storage of water and sediment before reaching the Gries reservoir (according to Steffen et al., 2022).

Was kommt auf uns zu – Gletscherschwund

- The main consequences regarding sediment yield resulting from the predicted development would be:
  - ➢ The relative contributions of the sub- and periglacial sediment sources will evolve
  - ➢ Potential significant increase of the sediment yield by transportable material (bed load) volume from the proglacial area
  - ➢ Significant reduction of the SSC release by subglacial melt
- And regarding the reservoir:
  - ➢ Potential increase of delta deposits (almost inexistent currently)
  - ➢ Reduced increase of reservoir bottom deposits

Was kommt auf uns zu – Gletscherschwund

- Hydrological regime transition from glacial to nivo-glacial and later to nivo-pluvial regime
  - which implies a greater flood events sensitivity for the watershed
- Decrease of the annual water inflow volume
- The glacier and watershed's evolution will directly affect:
  - the hydropower electricity production
  - the sustainability of the whole hydroelectric facility
  - It is thus of primal importance to consider those modifications in the framework in a long term perspective

Was kommt auf uns zu – nächste Schritte

- The Hydropower owner and operator
  - already heightened the water intake
  - Potential dam heightening
  - will potentially perform regular, ecological compatible flushing to keep the bottom outlet operational
  - is regularly monitoring the watershed and reservoir
- **To keep the hydropower reservoir, dam and production facilities functional and safe for sustainable electricity production and flood protection downstream, even when the glacier will have disappeared**

Was kommt auf uns zu – nächste Schritte

- Potential dam heightening
  - Gries reservoir is among this list of 16 Swiss priority projects
  - added annual energy production
    - estimated at 12 GWh/year
    - increased annual storage for winter energy production of 43 GWh/year
    - compared to the current cold season production of 16 GWh/year
  - intended heightening of the dam of some 15 m would add 50% of storage volume

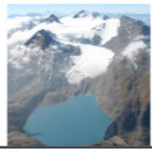
Was kommt auf sie zu – Menti-Umfrage

Join at menti.com | use code 5936 3197

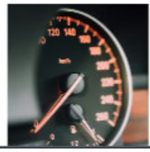
Mentimeter

WHAT HAS THE HIGHER ENERGY CONTENT:

What has the higher energy (potential or thermal) content:



1 m3 of water from Gries to Lago Maggiore



1 liter of car gasoline/ diesel

Average food supply per day per person

Menti-Umfrage -> Antworten

Potential energy content of 1m^3 water from Gries Reservoir to Lago Maggiore

- 4.64 kWh/m^3

Thermal energy content of 1 litre of standard car diesel (source: https://www.chemie.de/lexikon/Kraftstoff.html)

- ~ 9.8 kWh/l

Average food supply per day per person

- ~ 2.3 kWh/day (~ 2000 kCal)