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Control of sediment transport on an alpine catchment basin for the safe application of smart storage operations on an run-off-river HPP

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Objectives

Smart storage operations (SSO) have been implemented on an alpine run-off-river HPP (case study: KW Gletsch-Oberwald HPP) in order to enhance the flexibility of the power plant (ref poster SmallFlex). SSO operations consist on the use of available space underground, such as the settling basin, in order to store the water, particularly in periods of the year with low inflow, which can afterward be used for energy production when the demand and the remuneration tariffs are higher and at a discharge close to the optimum of the turbine to have the best efficiencies[1].

The aim of efficiently implementing the SSO operations on the settling basin requires sediment management in order to assure a safe use of this part of the system whose function is temporarily changed. In order to understand the amount of sediment inflow into the settling basin, the following actions were undertaken:

- Determine the amount of potential mobilized sediments at the catchment scale with the use of Beyer-Portner (1998) and Gavrilović (1990) formulas;
- Determine the maximum sediment transport capacity of the river Rhone upstream the intake with the use of Beyer-Portner (1998) formula.

This will allow to verify in which periods of the year the sediment basin can be used for water storage with no risk related with sediment conveyance into the waterways and therefore at the turbines.

Study Area

Gletsch catchment[6]

- Surface area: 40.34 km²
- Average altitude: 2691m a.s.l.
- River principal watercourse length: 3450m
- River secondary watercourse length: 3870m
- River discharge: 2.93m³/s
- Average slope along the course: 13.7%

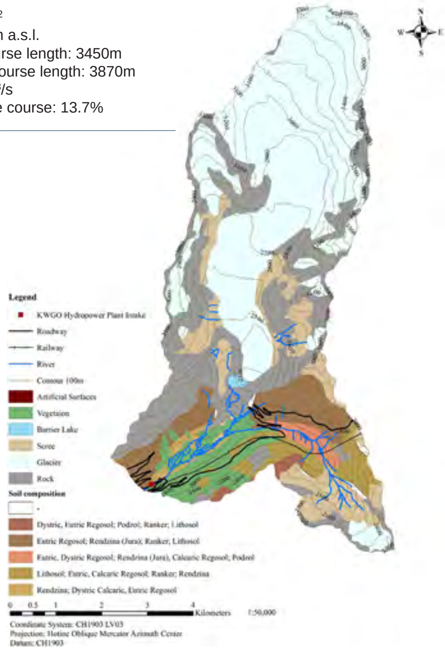
Procedure

Soil coverage analysis

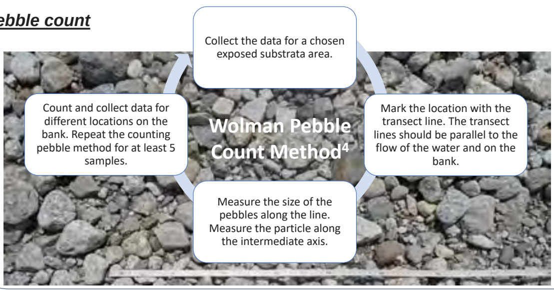
The map was created to display the land use of the case study. The values produced for calculating the erosion models and sediment transport model.

Land use[6]:

- Vegetation: 5.1 km²
- Open spaces with little or no vegetation: 15.9 km²
- Lakes and rivers: 0.2 km²
- Glaciers and perpetual snow: 18.8 km²
- Artificial surfaces: 0.3 km²
- Erodible soils: 15.5 km²



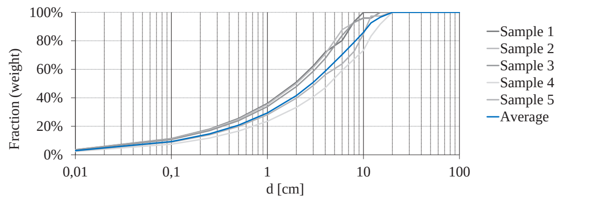
Pebble count



Results

Grain size discribution

The analysis of the measurements following the Pebble count method resulted in the compilation of the following grain size distribution:
d_{90} = 5.8cm, d_{84} = 3.8cm, d_{65} = 4.2cm, d_{50} = 3.6cm and d_{30} = 1.0cm.



Erosion Model Calculations

Beyer-Portner formula[2]

$$V_A = 93 \cdot 10^{-15} \cdot H_{été}^{0.052} \cdot SE^{0.091} \cdot SV^{8.108} \cdot \Delta L_G^{0.082} + 274$$

$$V_A = 93 \cdot 10^{-15} \cdot 323.8^{0.052} \cdot 38.54^{0.091} \cdot 39.38^{8.108} \cdot 0.44^{0.082} + 274$$

$$V_A = 275.41 \text{ m}^3 \text{ km}^{-2} \text{ an}^{-1}$$

$$V_A = 11\,110 \text{ m}^3\text{/year}$$

V_A	Specific volume of annual sediment input [m³ km⁻² an⁻¹]
$H_{été}$	Average rainfall between June and September [mm]
SE	Percentage of the catchment area made up of erodible soils [%]
SV	Percentage of watershed area without vegetative cover [%]
ΔL_G	Annual change in glacier length relative to total length [%]

Gavrilović method[3]

$$W_a = T \times P_a \times \pi \times \sqrt{Z^3} \times A$$

$$W_a = 0.8 \times 323.8 \times \pi \times \sqrt{0.5^3} \times 40.3$$

$$W_a = 11\,915.4 \text{ m}^3\text{/year}$$

W_a	Total annual volume of detached soil [m³/year]
T	Temperature coefficient
P_a	Average annual precipitation [mm]
Z	Erosion coefficient
F	Study area [km²]

Sediment Transport Model Calculations

Smart and Jaeggi formula[5]

$$q_B = \frac{4}{(s-1)} \cdot \left(\frac{d_{90}}{d_{30}}\right)^{0.2} \cdot q \cdot J^{1.6} \cdot \left(1 - \frac{\theta_{cr}(s-1)d_{50}}{h_m \cdot J}\right)$$

$$q_B = \frac{4}{(2.65-1)} \left(\frac{0.058}{0.010}\right)^{0.2} 0.74 \cdot 0.14^{1.6} \left(1 - \frac{0.05(2.65-1)0.036}{0.2 \cdot 0.14}\right)$$

$$q_B = k \cdot q = 0.13 \cdot q \quad \text{m}^3\text{/s m}$$

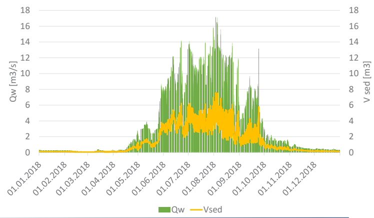
q_B	Specific sediment discharge (net sediment volume per time per unit width) [m³/s m]
$s = \frac{\sigma}{\rho}$	Relative density of sediment to water [-]
d_{30}, d_{90}	Characteristic grain sizes, 30% or 90% (by weight) of the bed material are smaller [m]
d_{50}	Mean grain size [m]
q	Specific water discharge per unit width [m³/s m]
J	Slope
θ_{cr}	Critical Shields factor at beginning of motion
h_m	Mixture (water and sediment) flow depth [m]
K	sediment transport model linearization between specific water and sediment discharges

Discussion

A detailed analysis of the catchment characteristics, in terms of **soil coverage** and **grain size,** has allowed to investigate the potential sediment input to the KWRO hydropower plant. It has been found that the sediments volume available at the catchment scale is limiting the effective sediment inflow i.e. the sediments transport capacity is reduced by the sediments availability.

The sediment transport formula has been used to calculate the sediment discharge as a function of the water discharge and linearly distributing estimated sediment availability. The hourly sediment volume at the intake can therefore be calculated as:

$$V_{sed}(h) = \frac{k\, Q_w(h)}{(325 * 24)/W_a}$$



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