Hydrological and sediment flux in alpine river systems during the Anthropocene

WASEAE: WAter, Sediment and Ecology in Alpine Environments
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Conceptual model
The processes and fluxes in an alpine river system can be represented in a conceptual hydro-morphological model (Figure 1). Climate fluctuations drive the system through temperature, causing snow/ice melt releasing sediment from (peri)glacial environments, and precipitation. Resulting flow shapes the river bed morphology through erosion and sedimentation, which in turn influences flow pattern and velocities. Lateral addition of flow and sediment from tributaries or mass movements and human extraction of water for hydropower or sediment mining will force changes in the system's behaviour and resulting output of water and sediment. We study the interaction of these model components to understand changes in alpine river hydrology and morphology.

SEDFAE project
In the Sedfate project, we aim to compare how contemporary human-induced erosion and sediment transfer rates differ from natural ones associated with climatic variability. Within this project we quantitatively analyse the disruption of sediment transfer processes caused by flow abstraction and river regulation in Val d’Herens, relate this to impacts of (non-stationary) climate change and analyse scenarios of future system evolution.

Flow in the Borgne River is extracted through a system of intakes and tunnels (Figure 2 and 3). Sediment that accumulates at the intakes is re-leased down the river during intermittent purges. How does the river system respond to the marked decrease in sediment transport capacity?

Large scale morphologic change
An archive of historic aerial photographs and Digital Elevation Models are used to characterize and quantify long term morphological development of the river bed.

Figure 1: Conceptual hydro-morphological model showing water (blue) and sediment (brown) fluxes

Since the start of hydropower operation, sedimentation has led to the progressive downstream expansion (Figure 4) and aggradation (Figure 5) of the river bed. (Figures based on B. Regamey)

Small scale morphologic change
High spatial (decimeters) and temporal (event-based: floods, purges) resolution DEMs are made using drone aerial photography and terrestrial laser scanning (Figure 6).

Taking limits of detection and spatially variable uncertainty analyses into account, volume changes are determined (Figure 7) and minimum transport rates (Figure 8) can be deduced for individual events. (Figures G. Antoniazza)

Process analyses - measurements
Using a basin-wide network of installed measurement stations (Figure 2 and 9), discharge, suspended and bed-load transport are measured.

The propagation of flood waves (Figure 10 top) and sediment waves (Figure 10 bottom) are analysed with regard to hydrologic (discharge) and geomorphic (channel dimensions, grain size, gradient, etc) forcing. Due to a difference in propagation velocity, flood waves progress faster than sediment waves, local erosion will occur during the rising limb and sedimentation during the falling limb of the wave.

Figure 2: Val d’Herens river network, hydroelectric scheme and measurement stations
Figure 4: Lateral accretion in the period 1983 - 1988 - 1994 (La Monta)
Figure 5: Vertical accretion in the period 1959 - 2010 (downstream of the intake)

Figure 6: Morphological change during flood 08.2013 (downstream of the intake)

Process analyses - modelling
A 1D-2D hydro-morphologic model will be developed to simulate flow, sediment transport and bed change, using the measured discharges, sediment fluxes and DEMs for boundary conditions and calibration (Figure 11).

The modelling will give insight in hydrological and geomorphic forcing on sediment transport and morphological response for individual events. On a larger scale, sediment storage, remobilization and net downstream flux will be quantified, both to see how climate forcing and human forcing of river response impact on river morphodynamics and to develop a basin-scale model of sediment flux.

Figure 3: Annual river discharge percentiles (La Luette) and phases of dam development
Figure 7: Volume per elevation change
Figure 8: Transport along reach derived from cumulative volume change

Figure 9: Installed pressure transducer and turbidity probe
Figure 10: Normalised flood (top) and suspended sediment wave (bottom) at 4 consecutive measurement locations (increasing number in downstream direction)

Figure 11: 2D model calibration of flow velocity - flood propagation (G. Antoniazza)