# Alteration of sediment fluxes and morphological changes in Alpine rivers

## Altération des flux de sédiments et changements morphologiques dans les cours d'eau alpins

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## RÉSUMÉ

À partir du XIXe siècle, nombreux cours d'eau alpins ont été dotés d'ouvrages artificiels tels que seuils, bassins de rétention, protections de berges et barrages. De plus, les extractions de sédiments des lits des rivières ont été très intenses dans la période des années 1960-1990. En même temps, bon nombre de ces rivières ont subi des incisions et des rétrécissements. Cette étude présente une analyse à l'échelle régionale de l'altération de l'écoulement des sédiments dans le réseau fluvial et des répercussions sur la trajectoire morphologique de 15 rivières le Sud du Tyrol. La production des rendements en sédiments grossiers a été estimée à partir des données collectées dans les bassins des barrages, des sédiments prélevés par suite de l'occurrence des crues et des données acquises auprès de 5 stations de mesure. Les variations morphologiques des rivières ont été quantifiées à l'aide de cartes topographiques et de photos aériennes multi-temporelles; celles-ci ont ensuite été corrélées avec différents types d'impacts anthropiques (ouvrages hydrauliques, altérations hydrologiques, changement d'affectation des sols, extraction de gravier dans le lit des rivières). Les résultats indiquent que de nombreuses variations morphologiques se sont produites dans ces rivières. Les relations univoques entre les changements morphologiques et les facteurs de contrôle anthropiques sont évidents seulement dans quelques cours d'eau, car dans la plupart d'entre eux, les variations semblent être liées à l'effet cumulatif de plusieurs facteurs. Néanmoins, le rôle dominant de l'extraction des sédiments des lits des rivières émerge.

## ABSTRACT

Starting from the late 19th century, Alpine channels have been equipped with structures such as check-dams, retention basins, bank protection, hydropower reservoirs. Moreover, intense gravel mining was carried out in the period 1960s-1990s. In parallel, channel incision and narrowing have been documented in the main Alpine rivers. This study presents a regional scale analysis of the alteration in coarse sediment transport and its relationship with the morphological trajectories of 15 rivers in South Tyrol (Eastern Italian Alps). Coarse sediment yields at the regional scale were estimated from sedimentation data collected at hydropower reservoirs, at sediment retention basins and following large flood events. Suspended and bedload sediment transport data were acquired at 5 monitoring stations. Morphological channel changes were quantified using multi-temporal analysis of aerial photos, and available information on vertical channel changes, and later related with anthropic pressures (hydraulic structures, hydrological alterations, land use changes, gravel mining). Results indicate that channel adjustments took place in all rivers. Simple causal links between channel changes and their potential controlling factors are apparent only in few study rivers, whereas a complex dynamic – induced by cumulative effects – appear to have been at play in most cases. Nonetheless, past gravel mining and hazard-related sediment trapping are likely the dominant factors at the regional scale.

## KEYWORDS

Sediment yield, sediment management, channel alteration, dams and control works, gravel mining

## 1 INTRODUCTION

Coarse sediment transport in mountain channels is of enormous importance due to its consequences

for stream ecology and natural hazards. However, sediment transport processes are often in conflict with hazard mitigation as well as hydropower production, as these commonly involve structures which disconnect sediment fluxes. In fact, starting from the late 19th century – but massively since the 1950s – Alpine rivers have been equipped with structures such as check-dams, retention basins and bank protections to prevent bed and bank erosion. In addition, intense gravel mining was carried out in the second half of the 20th century. Bed incision, channel narrowing and associated morphological variations have been documented for the 20th century in the main Alpine rivers (Hohensinner et al., 2020). Quantitative knowledge of coarse sediments trapped and/or removed from channel beds and the relative role of flood-control measures, of hydropower reservoir and of gravel mining is very often unknown. This work provides quantitative estimates of coarse sediment fluxes in rivers of South Tyrol (Eastern Alps) and proposes the linkages between their alterations and observed channel changes.

## 2 METHODS

This study was conducted in South Tyrol (eastern Italy, Fig. 1), that approximately corresponds to the upper portion of the Etsch/Adige river basin (about 7,400 km$^2$ in drainage area).

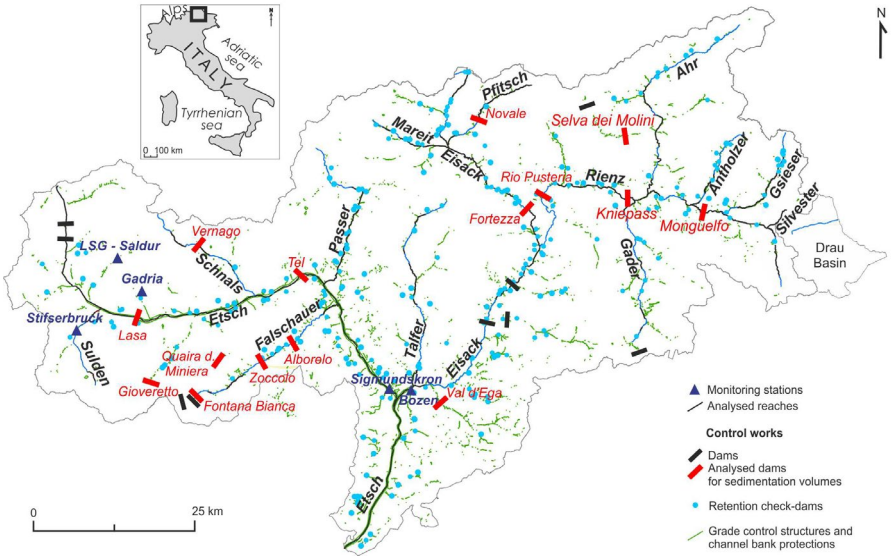


Figure 1 - Location of studied reaches, dams, control works, and monitoring stations in South Tyrol.

Coarse sediment yields and their alterations were acquired and/or estimated from several sources: technical documentation made available by public authorities and containing data about debris flows, floods, and hazard-related sediment cleaning operations; reservoir sedimentation and dredging data provided by “Alperia”, the most important manager of hydropower plants in South Tyrol; published and unpublished estimates of sediment transport from 5 monitoring stations located in South Tyrol (Fig. 1).

The morphological changes over the last 150 years in 15 rivers of South Tyrol were investigated by a multitemporal analysis of historical maps and aerial photos (from 1858 to 2014).

Anthropic pressures (hydraulic structures, hydrological alterations, land use changes), were investigated using: a geospatial database relative to all the hydraulic structures – comprising both transversal and longitudinal works – present in South Tyrol (Fig. 1); multitemporal land use maps (1958, 1976, 2006); unpublished data regarding in-channel sediment mining carried out from 1950s to 1990s (Office for Public Water Domain of the Autonomous Province of Bozen-Bolzano).

## 3 RESULTS AND DISCUSSIONS

Integrating all the data sources described in the methods, mean annual coarse sediment yields (CSY, expressed m$^3$ yr$^{-1}$) for the main rivers of South Tyrol was assessed. For the western sector of South Tyrol, sediment influx from the Sulden River – a highly-glacierised basins without hydropower dams – dominates (Fig. 2). In the eastern part of the region, relatively small bedload yields characterize now the Rienz River, which hosts the Monguelfo and Kniepass dams. By summing the values of coarse sediment yields for the Eisack (about 22,000 m$^3$ yr$^{-1}$) and Etsch rivers (about 15,000 m$^3$ yr$^{-1}$) at the node of Bozen/Bolzano, current bedload transport in the Etsch River downstream of Bozen was estimate at 30,000 – 40,000 m$^3$ yr$^{-1}$. Remarkably, such mean annual values of coarse sediment transport for the two largest rivers of South Tyrol are about one order of magnitude smaller than the

mined gravel volumes over the whole channel network from the 1960s to 1990s, which amounts to more than 6 Mi. $m^3$, that is on average about 150,000 $m^3$ per year. Comparable quantities of coarse sediments turn out to have been trapped by retention check-dams or removed after floods/debris flows starting from the 1980s, with estimated values of 100,000 - 200,000 $m^3$ per year. With regards to hydropower dams, bedload trapped in all the reservoirs of South Tyrol since the 1950s was estimated as 10,000 – 20,000 $m^3$ per year.

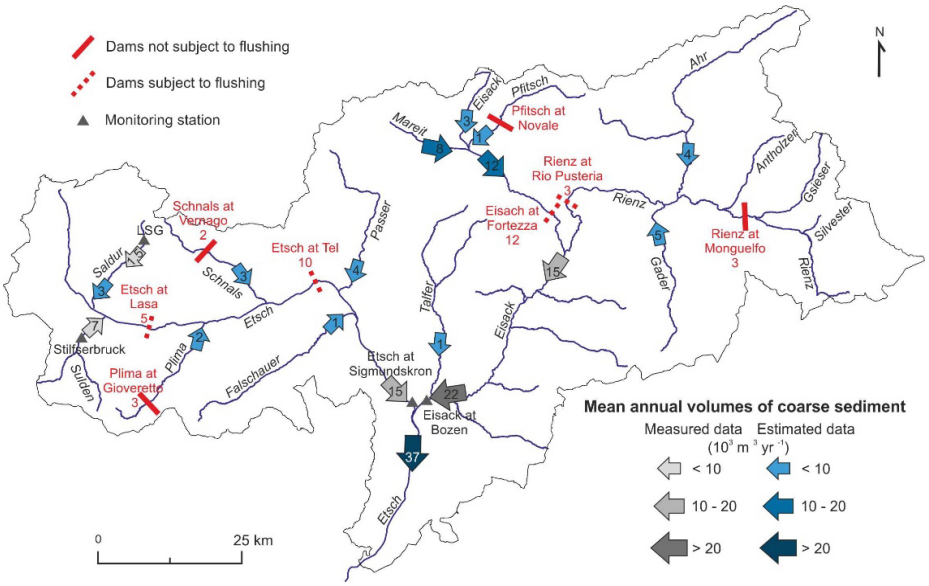


Figure 2 - Coarse sediment fluxes in the main rivers of South Tyrol assessed combining different sources.

Given the figures reported above, it is not surprising that most channels in South Tyrol underwent planimetric patter shifting from multithread to anthropically-dominated morphologies associated with channelization coupled to installation of grade-control works, channel narrowing (up to 86%) and bed incision ranging from 1 m to 9 m (Bergamin, 2017; Scorpio et al., 2020). A statistically significant relationship between post-1950s channel narrowing and the relative sediment mining intensity was obtained for some of the analyzed rivers. In others, planform changes seem to be strongly related to the presence of bank protections and transversal works, through the direct effects of channelization on channel width. Conversely, in most rivers the cumulative effects of channelization and sediment starvation – mostly from past gravel mining and upstream erosion-control works – seem to have dominated their variations in channel width and morphological pattern.

## 4 CONCLUSIONS

The regional scale analysis of the evolutionary trajectories of channel morphology within the Etsch river basin illustrates a dominant general trend of narrowing and morphological shifting from multi-channel/transitional to single-thread patterns, with larger variations observed in the wider channels. However, magnitude and timing of change varied considerably among rivers, apparently for differences in the chronology and typology of the anthropic pressures. Among these, past gravel mining has likely been the dominant factor driving direct and fast channel degradation in the Etsch River and in the lower reaches of its tributaries.

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