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# Impacts of gravel mining and renaturation measures on the sediment flux and budget in an alpine catchment (Johnsbach Valley, Austria)

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ABSTRACT

In the Johnsbach Valley (Austria), a medium size non-glaciated torrent catchment, enormous amounts of sediment have been made available due to the brittle dolomite bedrock. This occurs mainly in the Zwischenmäuerstrecke (ZMS) (English translation: "reach between the walls") and presents a major challenge to local river management. Within a renaturation project, which followed several decades of disturbance (flood protection and gravel mining) in the ZMS, it is of particular importance to understand where the sediments come from and the transport pathways through the system to prepare future forecasts.

In the present study, we investigate the recent sediment cascade in a comprehensive analysis of the ZMS that was achieved by means of airborne laser scanning campaigns in 2010 and 2015. The current bedload yield at the outlet was measured using an integrative bedload monitoring system. Historical data from 1954 was used to illustrate the effects of the mining period on the former sediment routing. Finally, we evaluated the expected sediment transport rates in the near future.

The results show that from the hillslopes sediments are mainly transported via the active side trenches to the main channel (~7000 $m^3\ yr^{-1}$). The sediment transport in the Johnsbach River consists mainly in relocating the periodically occurring sediment entries of the side trenches. The bedload transport rates at the outlet sum up to annual bedload yields of 2000 $m^3\ yr^{-1}$ to almost 12,000 $m^3\ yr^{-1}$ during the observation period. Especially those areas inside the side trenches that were heavily affected by gravel mining (excavated amount of sediment during the mining period: ~25,000 $m^3\ yr^{-1}$) are now accumulating sediment since the end of this period (~8000 $m^3\ yr^{-1}$). Future scenarios will depend heavily on the progress in the mining affected side channels. The impacts of this period are continuously being reworked and a natural sediment flow will adjust in the near future. The sediment input into the Johnsbach River will rise significantly and could lead to a doubling in the annual sediment yield at the outlet compared to now. In particular, the reaches along the Johnsbach River following the confluences with the mining affected side trenches are already showing morphological changes due to the recently imported sediments.



## 1. Introduction

Over the last decades alluvial rivers, all over the world and especially in Europe, have been significantly affected by human disturbances (Petts, 1989). The most common forms of intervention in fluvial systems are due to land-use changes, urbanization, dams and reservoirs constructed to generate hydroelectric power, flow diversions, and gravel and sand mining. Several studies (e.g., Marston et al., 1995; Bravard et al., 1997; Liébault and Piégay, 2001, 2002; Surian and Rinaldi, 2003; Liébault et al., 2005; Rinaldi et al., 2005; Rivora et al., 2005; Spink et al., 2009; Surian et al., 2009a, 2009b) have shown that these disturbances cause remarkable channel changes with substantial effects on flow and sediment regimes. Induced by a loss of sediment supply and recharge, a range of environmental and social effects result from channel incision and narrowing, such as undermining of structures, loss of groundwater storage or loss of habitat diversity (Bravard et al., 1999). Especially in the Alps, this has led to the fact that only a minor portion of all rivers are still in a natural or near-natural condition (Martinet and Dubost, 1992; Ward et al., 1999). To overcome this problem, a need for sustainable sediment management arises by defining river restoration strategies (Piégay et al., 2005; Habersack and Piégay, 2008; Liébault et al., 2008; Rinaldi et al., 2009).

From historical times alluvial rivers have been attractive sources for sediment exploitation. Notably, 'in-stream mining', which involves the removal of sediment from the river bed, directly affects the channel geometry resulting in an imbalance of sediment supply and transport capacity (Sandecki, 1989). By changing the geomorphic setting many

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different environmental and economic impacts can be expected (Bravard et al., 1999), which are summarized by Rinaldi et al. (2005) and Rivora et al. (2005). Throughout the literature it has been widely discussed what consequences can arise from mining the active river channel. Certainly it is not only the actions involving the river itself that cause a disturbed sediment management but also interventions (mining gravel in pits) affecting the contributing side channels and catchments that are connected to specific river reaches.

Several different human disturbances have heavily affected the alluvial channel in the Johnsbach catchment since the middle of the past century. These include works for flood and bank protection, gravel mining in sediment suppling side catchments to the main river system, and in recent years river restoration that includes an explicit sediment management. After a major flood event in 1949, which destroyed the only access into the Johnsbach Valley, the course of the river was armed with longitudinal barriers and check dams along the ZMS between 1950 and 1974 (Thonhauser, 2007; Kammerer, 2008). The goal was to compress the course of the river and to force the stream into a man-made river bed (Haseke, 2006). Former gravel mining in two of the biggest side catchments (in Gseng and Langgries since 1984 and 1991, respectively) was interrupting the sediment flux in those channels as huge amounts of sediment were excavated and used industrially. The annual amount of sediment being removed from those side catchments is reported to be 15,000–20,000 $m^3$ $yr^{-1}$ (Haseke, 2011). With the establishment of the National Park (NP) Gesäuse in 2002, the excavation of sediment had to be abandoned but was not terminated before 2008 because of still ongoing contracts. Finally, both former mining areas were restored from 2009 to 2010. Meanwhile, the Johnsbach River was renaturated in the cost-intensive European Union funded river-ecological LIFE-project “Conservation strategies for woodland and wild waters in the Gesäuse” controlled by the NP Gesäuse from 2006 to 2009. The main focus of this project was to dismantle and widely remove extensive engineering measures in the river and at the junctions to the side channels (Haseke, 2011). This was meant to ensure that sediment can reach the Johnsbach River and finally the River Enns in sufficient quantities according to its natural dynamics (Holzinger et al., 2012). During the LIFE-project the new concept involved several interventions: adjusting the slope of the river and avoiding high steps effectuated by building broad, but flat ground sills, expanding the obstructed banks and releasing the Johnsbach River between the sills (Haseke, 2011). In this way the Johnsbach River is now able to rebuild its original gravel banks and furcations, ballasts the new sills and therefore creates valuable habitats and ensures fish migration. Furthermore, an increase in coarse material prevents the progress of river-bed sealing through fine-grained material during the last decades and thus prevents groundwater subsidence as well as the reduction of micro habitats (Holzinger et al., 2012).

Fischlschweiger (2004) investigated the aftermath of the mining activities in the lower Langgries side catchment, concluding that 10,000 $m^3$ $yr^{-1}$ needed to be excavated (in the reference period of 1993–2002) to maintain the current state. Several authors (Kammerer, 2006a, 2006b; Zulka, 2013) were focusing on changes in the evolution of habitats due to mining and its resulting effects. They all could prove that mining activities disrupt the fragile balancing system of scree slopes, which in turn affects the habitats of certain fauna and flora. In 2013, the FWF-funded Sedyn-X project was launched to investigate sediment transport in the ensuing field of tension between nature conservation (e.g., aqua fauna habitats), hazard protection and the efficiency of hydropower stations downstream. By now, Stangl et al. (2016) have applied a sediment connectivity analysis combining upslope contributing area and downslope flow length. According to their analysis, sediment storages close to the main river are highly coupled to the outlet, whereas erodible sediments in the remote high-alpine areas are not. Rascher and Sass (2017) quantified surface changes using multi-temporal terrestrial laser scanning at the interface between the main torrent and selected tributary channels. They could show that the sediment output of tributaries is currently limited (seasonal and event based) as sediment is “missing” due to the mining history. The objective of this study is to set up a sediment budget, enabling the analysis of the impacts of gravel mining and renaturation on the sediment flux in the ZMS of the Johnsbach Valley. To this end, we investigated the recent sediment cascade focusing on several aspects. First, how much sediment is provided from rock walls to the side-catchments (quantifying the input parameter for the sediment budget). Second, where and to which extent is sediment relocation currently taking place (evaluating transport and storage in the system). Third, how much sediment is exported out of the Johnsbach Valley (quantifying and comparing the fluvial sediment transport to the sediment output). Fourth, we show the effects of the mining period on the former sediment routing by reconstructing the sediment cascade in the relevant areas. Finally, we predict the sediment transport rates in the near future once decoupled side catchments are reconnected to evaluate the overall consequences of the recent renaturation measures. Coupled investigations of sediment cascades and bedload transport have rarely been carried out. Therefore, our approach could be a showcase example describing the spatial sediment dynamics on the one hand and verifying the predicted sediment yield on the other hand, in an area that underwent significant anthropogenic modifications in the past.

## 2. Regional-scale setting and local-scale classification of the study site

### 2.1. Characterization of the study area

The Johnsbach Valley (Fig. 1) is a non-glaciated alpine catchment in Upper Styria (Austria) that covers an area of approximately 65 $km^2$ reaching from 584 m a.s.l. at the outlet to 2369 m a.s.l. (Hochtor). The valley is drained by the Johnsbach River, which runs for 14 km with a mean gradient of almost 4% before it empties into the River Enns. The geological setting is characterized by different rock types belonging to two nappes, the Northern Calcareous Alps in the north and the Greywacke Zone in the south (e.g., Ampferer, 1935; Hiessleitner, 1935; Flügel and Neubauer, 1984). Our area of investigation, the Zwischenmäuerstrecke (ZMS), is situated in Triassic carbonate rocks, mainly limestone (Dachsteinkalk) and dolomite (Wettersteindolomit) (Figs. 2B and 3A). The ZMS is a 4.5 km river reach with a catchment of around 13 $km^2$ in size that is sparsely vegetated (Fig. 3C) by fir forests and pine shrub lands, and is shaped by steep furrows and deeply incised channels (Fig. 3B) on both sides. The majority of the sediment that is relocated and transported in the Johnsbach Valley is stored in the ZMS.

The climate is characterized by annual mean temperatures of around 8 °C in the lower elevations of the valley and below 0 °C in the summit regions. Annual precipitation amounts to approximately 1500–1800 mm (Wakonigg, 2012a, 2012b). Storm precipitation occurs almost exclusively in the summer months and can reach several tens of mm per hour. Thus, runoff at the Johnsbach River peaks in spring (snow melt) and summer while the tributaries show surface runoff and sediment transport only during episodic rainstorms.

The combination of the geological setting and the climatic conditions results in high morphodynamic activity, primarily in the ZMS (Strasser et al., 2013). The brittle Wetterstein Dolomite is particularly prone to weathering, providing large amounts of sharp-edged debris. This debris is being reworked and relocated by rock falls and debris avalanches from the rock walls over the steep slopes into the channels of the side catchments. Finally, this results in high sediment input rates into the Johnsbach River (Rascher and Sass, 2017).

### 2.2. ZMS – Subdivision of river sections and side catchments

Following Lieb and Premm (2008), the ZMS can be divided into three segments (Figs. 2B and 3D) according to its landscape and its morphodynamics. The southern section (III) is dominated by a very steep landscape (with mean slope angles of >50°) and characteristic