PUBLIZIERBARER ENDBERICHT

A) Projektdaten

Kurztitel:	CLIMCATCH
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Projektübersicht

1 Kurzfassung

Mögliche Veränderungen der Niederschlagsmenge, der Niederschlagsverteilung und der Schneedeckenentwicklung durch die aktuelle Klimaerwärmung könnten sich auch auf den Sedimenthaushalt alpiner Einzugsgebiete auswirken. Um die Sedimentfracht der Wildbäche und deren mögliche Änderungen verstehen zu können und technische Schutzmaßnahmen zu optimieren, sind Messstationen zur Erfassung des Sedimenttransports erforderlich; diese sind jedoch in Österreich nur spärlich vorhanden. Die wesentlichen Ziele des Projektes sind daher (i) die Untersuchung der Sedimentquellen und Ablagerungsflächen im Schöttlbach-Gebiet (Obersteiermark), das in 2011 von einem katastrophalen Hochwasserereignis betroffen war; (ii) die Quantifizierung des Sedimenttransports im Einzugsgebiet und seinen Teilbereichen und (iii) die Abschätzung des Einflusses des Klimawandels auf die Häufigkeit, Intensität und zeitliche Verteilung von Niederschlagsereignissen.

Mittels Kartierung und GIS-Analyse wurde ein konzeptionelles Modell der Sedimentkonnektivität erstellt. Die Oberflächenveränderung im Projektgebiet wurde durch photogrammetrische Untersuchungen mit Drohnen (UAVs) ermittelt. Ausgewählte Erosionsflächen in aktiven Teilbereichen wurden mit regelmäßigen terrestrischen Laserscans (TLS) aufgenommen. Die Sedimentmächtigkeit an den Hängen und in der Tiefenlinie wurde mit geophysikalischen Methoden erfasst, wobei vor allem Refraktionsseismik eingesetzt wurde. Der fluviale Sedimenttransport im Gerinne wurde durch im Projekt weiterentwickelte Sediment-Impact-Sensoren (SIS) erfasst und mittels Geschiebefangkörben und Geschiebemessungen kalibriert. Diese Daten wurden mit Bewegungsdaten von Tracersteinen und mit regelmäßigen Volumensbestimmungen am Retentionsbecken bei Oberwölz ergänzt. Der Niederschlag im Einzugsgebiet wurde an einer neu errichteten meteorologischen Station und zwei Regenmessern, der Abfluss im Gerinne an drei Pegelstationen gemessen.

Für die Abschätzung von zukünftigen regionalen Änderungen in Bezug auf Extremniederschläge und die Erstellung von lokalen Szenarien wurden 24 regionale Klimamodelle aus den Projekten ENSEMBLES und reclip:century verwendet, wobei die Unsicherheiten in den Modellen durch verschiedene empirische-statistische Methoden abgeschätzt wurden.

Orthophoto-Auswertungen und die Befliegungen mit Drohnen zeigen, dass signifikante Erosion und Ablagerung auf einen relativ schmalen Streifen aus glazialen Sedimenten links und rechts des Schöttlbachs und seiner Zubringer beschränkt ist. Die Mächtigkeit der erodierbaren Sedimente in diesem Bereich liegt bei 20-30 m, so dass keine Erschöpfung der Speicher in absehbarer Zeit zu erwarten ist. Die höchste Transportkapazität ergeben sich in den untersten 1-2 km des Einzugsgebiets zwischen dem Zusammenfluss der beiden Hauptzubringer und dem Geschiebe-Rückhaltebecken. Die regelmäßigen Laserscans des Rückhaltebeckens zeigen einen sehr hohen Geschiebeeintrag im ersten Halbjahr nach dem Hochwasserereignis von 2011, der sich in den folgenden drei Jahren von 40.000 m^3 auf unter 4.000 m^3 pro Jahr reduzierte. Das Einzugsgebiet hat sich nach dem Extremereignis wieder weitgehend stabilisiert, in den letzten 1-2 Jahren lagen die Erosionsraten an den Seitenhängen in derselben Größenordnung wie die Ablagerungen im Rückhaltebecken. Errechnete Oberflächenmodelle aus terrestrischer Photogrammmetrie (Structure-from-Motion, SfM) zeigten dabei ein großes Potenzial; die Abweichungen von Modellen aus terrestrischen Laserscans lag meist bei unter 2 cm.

Der Bewegungsbeginn des Geschiebes (Korngrößen 1-5 cm) findet, anhand der Daten der SIS, bei einem Abfluss von 1-3 m^3/s statt. Dies stimmt mit den Beobachtungen der Tracersteine (Korngröße 10 cm, 2-3 m^3/s) gut überein. Die Werte für den Bewegungsbeginn variieren z.B. durch Hiding- und Exposure-Effekte. Die Sedimenttransportraten des Krumeggerbachs sind aufgrund des höheren Gefälles größer als die des Schöttlbachs, wobei die höchsten Transportraten nach dem Zusammenfluss dieser beiden Hauptzubringer aufgezeichnet wurden. Im Zeitraum 2014/15 konzentrierte sich der Sedimenttransport auf einige wenige höhere Abflussereignisse. Die Schneeschmelze zeigt an den beiden Zubringern unterschiedliche Auswirkungen auf den Sedimenttransport.

Der Niederschlag wird, bei gleichzeitiger Temperaturerhöhung, in diesem Jahrhundert wahrscheinlich im Sommer abnehmen und im Winter zunehmen. Daraus folgen mehr Regenereignisse und weniger Schneefall in den Wintermonaten. Potentiell schadenauslösende Niederschlagsereignisse mit einer täglichen Niederschlagssumme von 20-50 mm werden in diesem Jahrhundert vor allem in den Wintermonaten zunehmen, aber auch im Sommer ist eine stärkere Konzentration auf Starkregenereignisse (auch auf der Sub-Tages-Skala) zu erwarten; die Wiederkehrperiode von definierten Ereignissen wird sich verkürzen. Es wird erwartet, dass das 50-jährliche Niederschlagsereignis zum Ende dieses Jahrhunderts um etwa 30 mm höher sein wird als heute. Dies wird mit hoher Wahrscheinlichkeit auch zu erhöhter Sedimentfracht führen.

2 Executive Summary

The global hydrological cycle is expected to further intensify in future in the context of global warming, carrying the potential of enhanced probability of heavy precipitation events. This raises concerns about heightened sediment transport. However, bedload measurements at alpine torrents are extremely rare; in Styria, they have been altogether missing at the starting point of the project. It is necessary to understand the sediment dynamics of the torrent catchment to optimize technical protection measures and sustainable management strategies and to evaluate if an increasing frequency and/or magnitude of severe natural hazards are a real coming danger in the area. Our objectives were (i) to understand the sediment cascade of the Schöttlbach catchment including sources, sinks and sediment connectivity; (ii) to quantify bedload transport continuously at the outlets of sub-catchments and at the main catchment outlet; and (iii) to assess the impact of ongoing climate change on the frequency, magnitude and timing of precipitation events.

We set up a conceptual model of the sediment transmissivity and routing for the catchment by means of geomorphological mapping and GIS analysis. Surface changes were derived from repeated photogrammetric surveys using unmanned aerial vehicles (UAVs). The erosion in particularly active sub-areas was quantified by means of regular TLS (Terrestrial Laser Scanning) surveys. The thickness and structure of sediment bodies were investigated using geophysical techniques, mainly seismic refraction. Measuring fluvial sediment transport was carried out along cross profiles using newly developed and calibrated sediment impact sensors (SIS), by means of tracer stones and using bed load traps and sediment samplers. The precipitation was measured at a meteorological station and at two additional rainfall gauges while runoff was captured at three runoff gauges.

The estimation of regional future changes in extreme precipitation was based on regional climate scenarios (set of 24 RCM simulations from ENSEMBLES and reclip:century), which were used to derive local scenarios. Different methods were used (e.g. quantile-based empirical-statistical methods, stochastic methods to derive sub-daily parameters) to estimate uncertainties.

The Schöttlbach has become a unique test catchment for sediment transport modelling and climate change impact research by instrumentation with runoff and precipitation gauges, lines of sediment impact sensors and test sites for repeated monitoring (erosion cuts, retention basin). Airborne photogrammetry from aerial photos and from UAV flights reveal that significant surface changes are mainly restricted to a narrow stripe left and right of the Schöttlbach and its main tributary where loose, glacigenic sediments prevail. The thickness of these sediments is up to 20-30 m at the over-steepened valley slopes and thus, storage depletion is not expected in the foreseeable future. The highest erosive

energy is found in the lowermost 1-2 km between the confluence of the two main tributaries and the retention basin.

Repeated laser scanning of the retention basin showed a high sediment input in the first half-year after the flood event of 2011. In the following three years, sediment yields have been gradually decreasing from 40.000 m^3/year to less than 4.000 m^3/year and the catchment is obviously stabilizing after the erosion cuts and sediment stores of the severe disturbance event have been reworked. In the last 1-2 years, sediment mobilisation at the erosion sites along the torrent was in the same order of magnitude as the deposition in the retention basin. Terrestrial laser scanning (TLS) of erosion sites was supplemented and partly replaced by terrestrial photogrammetry (Structure-from-Motion, SfM); the respective surface models coincide very well (differences of < 2 cm in most cases), which means that the much easier-to-use SfM technology has a high potential for quick monitoring in this terrain.

The transport initiation thresholds were approx. 1-3 m^3/s derived from the impact sensors (decisive grain size 1-5 cm) and 2-3 m^3/s derived from tracer stones (grain size 10 cm). The threshold values on a specific cross section are changing during the monitoring time due to hiding and exposure effects. Krumeggerbach delivers more sediments than Schöttlbach despite lower runoff yield due to the higher slope; highest transport rates were registered at the WLV weir after the confluence of the main tributaries. Sediment transport in 2014/15 was concentrated on few events per year at all sites; the impact of snow melt was different at different sites.

During this century, precipitation is expected to decrease in summer and the liquid part of precipitation will increase in winter. Potentially hazardous precipitation events (daily P 20-50 mm) will become more frequent, particularly in the winter months. Higher concentration of precipitation is also expected on the sub-daily scale. The return interval of defined events will be shorter; for example, the average 50-yr event will be c. 30 mm higher towards the end of the century than it is today.

The combined erosion, sediment transport and accumulation measurements allow to assess the origin and transport pathways of the sediments. In the Schöttlbach basin, ample sediment is available and well coupled to the torrent. The expected increase in the frequency of heavy precipitation events will in all probability lead to increased sediment transport in the future. Quantitative approximations require hydrological as well as sediment transport modelling which is planned for a follow-up project.

3 Hintergrund und Zielsetzung

Initial situation and motivation

The global hydrological cycle became more intense during the recent past and is expected to further intensify in the future in the context of global warming. The uncertain future intensification carries the potential of enhanced probability of heavy precipitation events and raises concerns about higher frequencies of geomorphological and hydrological hazards. In alpine torrents, sediment transport is the most important factor concerning monetary damage and protection measures. For decades and centuries, it was tried to restrict sediment transport by means of barriers, sills and other river training structures. However, bedload measurements at alpine rivers or torrents are extremely rare; in Styria, they have been altogether missing. The primary motivation of the ClimCatch project was to understand the sediment dynamics of the Schöttlbach catchment in Styria, which was hit by a catastrophic flood event in July 2011; to measure sediment relocation in the catchment using a range of methods, and to evaluate if an increasing frequency and/or magnitude of severe torrential events are a real coming danger in the area.

Objectives

Sediment routing approaches investigating the entire sediment cascade and including transport in rivers are comparatively rare to date. Gaps of knowledge lie in assessing the role of coupling and decoupling of subsystems, and in linking the approaches and techniques of geomorphology and river engineering on this subject. Our objectives were (i) to understand the sediment cascade of the Schöttlbach catchment including sources, sinks and sediment connectivity; (ii) to quantify bedload transport continuously at the outlets of sub-catchments and at the main catchment outlet; and (iii) to assess the impact of ongoing climate change on the frequency, magnitude and timing of precipitation events. Achieving these targets will enable us to assess the probability of future catastrophic events and to outline strategies to ensure a sustainable management. The project was subdivided into Administration and Management (WP1) and five further work packages (WPs):

- The aims of WP2 were to establish a conceptual model of sediment routing through the catchment, to map sediment relocation using aerial photos and Airborne Laser Scan (ALS) surveys and to locate sediment sinks and assess their permanent or temporary character. The targets to achieve these aims were: (1) Geomorphological mapping from orthophotos, (2) geomorphological mapping in the field, (3) identifying active erosion and sedimentation zones by analysing aerial photos and repeated ALSs, (4) deriving a linkage model identifying the main source areas, buffers, transport and accumulation areas.

- In WP3 it was planned to quantify sediment dynamics by means of multitemporal TLS surveys, assess the volume of sediment sinks using geophysical techniques and quantify the amount of change in the storage elements by combining ALS, TLS and geophysical survey results. The specific targets were defined as follows: (1) Quantifying fluvial erosion by yearly TLS surveys, (2) measuring thickness and structure of important sediment bodies, (3) analysing multitemporal ALS and TLS surveys and (4) transferring all quantification data to the entire study area via GIS analysis.
- The aim of WP4 was to measure the sediment transport in the Schöttlbach, at the catchment outlet and on its tributaries. This includes (1) determination of the precipitation in the catchment, (2) quantifying runoff and fluvial sediment transport within a cross section of the riverbed near the outlet of the Schöttlbach catchment, (3) installation of sediment impact sensors in the main valley and in its tributaries, (4) evaluation of the temporal variability, the initiation of sediment motion and the grain size of the sediment loads, (5) comparing output to existing 1D sediment transport models.
- The specific targets of WP5 were (1) downscaling and error correction of daily precipitation sum and mean temperature of a large ensemble of regional climate simulations to the local scale, (2) estimation of uncertainty (ranges of expected change) and threshold exceedance probabilities in projections of heavy precipitation and (3) downscaling of precipitation from selected simulations to the sub-daily scale.
- WP6 includes the setup of a statistical precipitation-runoff-sediment yield model, a cross-check of the model with available sediment input, 1-D sediment routing models, uncertainty assessment and discussing possible mitigation measures.

4 Projektinhalt und Ergebnisse

WP2: Conceptual model of the sediment cascade

Orthophoto generation and erosion areas

Single aerial photographs were merged in a block of images to create ortho images of 1965 and 2010. The areas of erosion were identified and mapped from the ortho images using ArcMap 10.1. The areas were mapped manually due to the large time period between the two dates and other difficult preconditions for automatic erosion area detection (shadows, steep relief).

The overview mappings revealed that the geomorphic processes relevant for the output of the catchment are concentrated along a narrow stripe parallel to the Schöttlbach torrent and its main tributary, the Krumeggerbach. We decided thus to omit the originally planned, catchment-wide ALS surveys and to focus on the immediate reach of the valleys. To achieve the highest possible accuracy in these much smaller areas we used airborne photography from drones (UAVs).

Geomorphometric considerations

Erodible, mostly glacigenic sediments are concentrated in the lower half of the study area along Schöttlbach and Krumeggerbach. From the convex longitudinal profile of the Schöttlbach, we infer that the torrent is far from topographic equilibrium. We analysed the profile using the Stream Power Index (SPI) according to Hack (1957), which is using the distance to the spring and the gradient in a certain increment (in our case 100 m). The erosive energy is particularly high in the 1.5 km long stretch between the confluence of the two main tributaries and the retention basin (Figure 1). In these areas, plenty of erodible sediment is abundant; thus, the erosive energy will lead to further undercutting and sediment mobilisation in this area. Further SPI maxima upstream of Schöttlkapelle (at km 1 and km 5) are connected with stripes of hard rock crossing the riverbed which do not contribute to sediment supply.

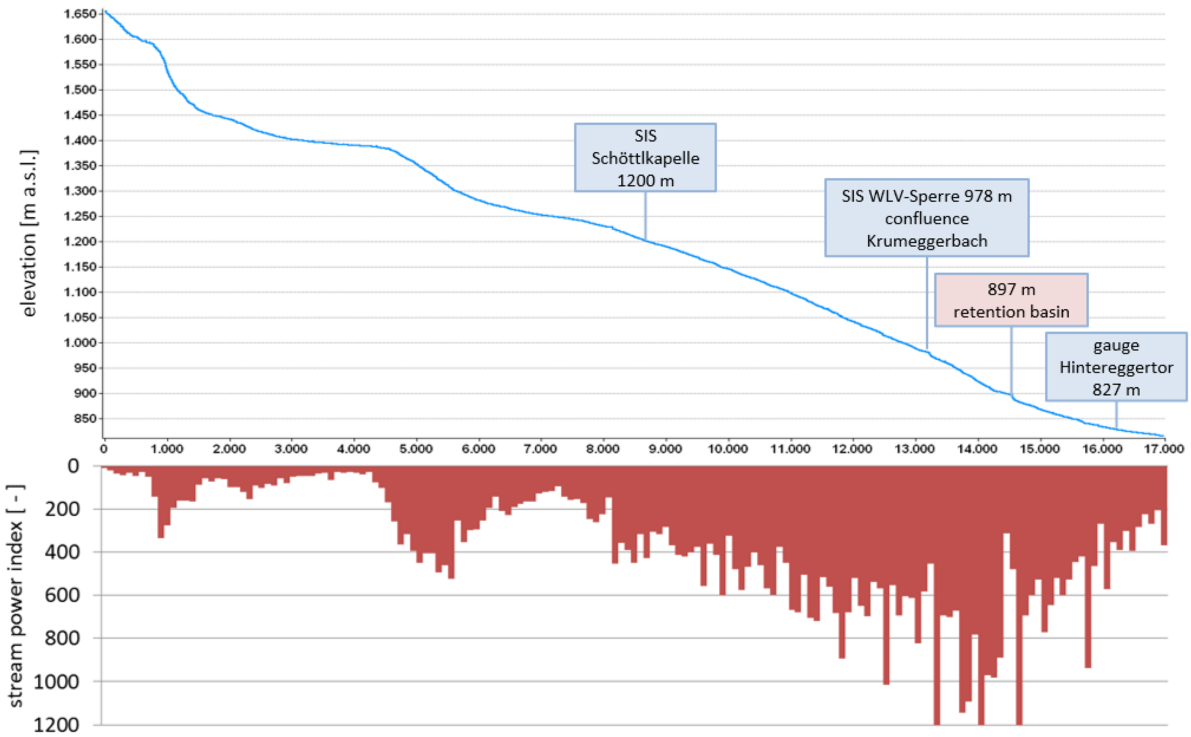


Figure 1: Longitudinal profile of the Schöttlbach from the Schöttlkapelle to the gauging station at Oberwölz, and dimensionless Stream Power Index according to Hack (1957). Longer bars indicate a higher erosive energy of the torrent.

Connectivity analysis

We applied a semi-quantitative modelling approach (Borselli et al. 2008, Cavalli et al. 2013) which relates upslope contributing areas to a gradient-weighted downslope flow length, and combined the model with maps of erodible sediment sources. The result of our approach is a map of connected and disconnected areas (Figure 2). Wide areas of erodible sediments at higher elevations are mostly (blue colours) or fully (hatching) decoupled from the torrents and are therefore relatively unimportant for the catchment-wide sediment transport. The areas left and right of the upper half of Schöttlbach are moderately coupled (slower and possibly delayed transport) and show less sediment availability. However, the glacigenic sediments along the southern (lower) half of the Schöttlbach and along Krumeggerbach are very well coupled to the main torrents which means that mobilised sediments are transferred to the torrents without significant buffering effects. This result was an additional reason for concentrating the surveys (UAV etc.) on the immediate surrounding of the channels.

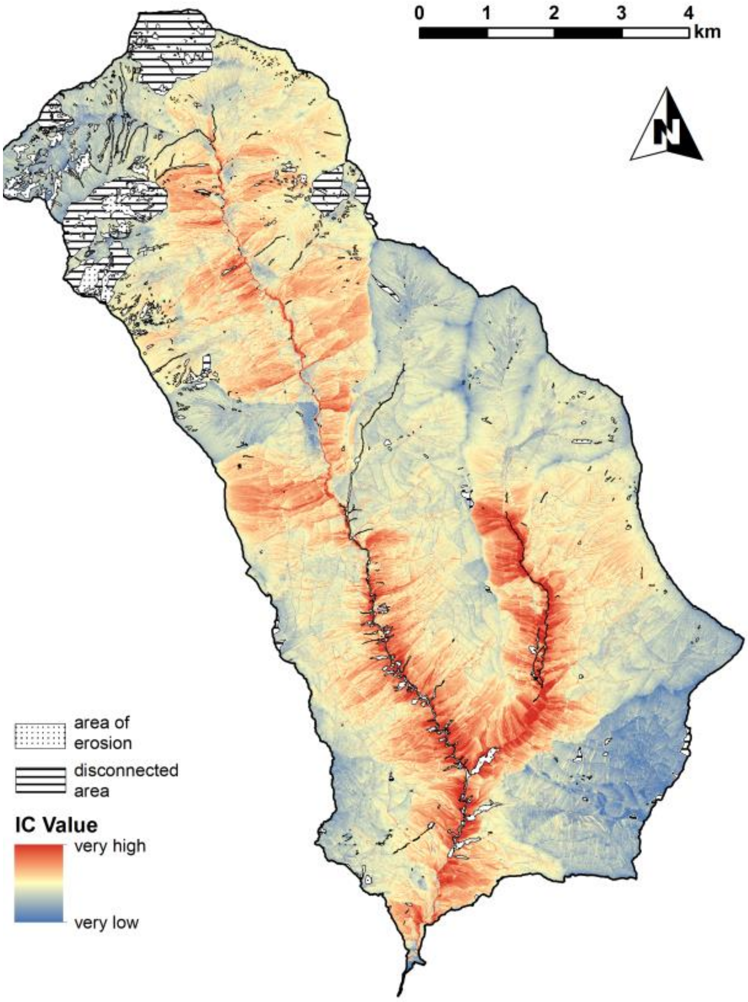


Figure 2**:** Modelled connectivity indices for the Schöttlbach-catchment, along with disconnected areas (hatching) and the areas of erosion (dots).

Repeated airborne photography surveys (UAVs)

We performed three UAV flights of the highly active lower segment of the Schöttlbach (ca. 6km). The first flight took place in June 2014, the second one in November 2014 and the third one in June 2015. Cut- and-fill analysis shows areas erosion (e.g. undercutting of river banks) and of accumulation (e.g. at the mouth of tributary trenches and in certain areas of the riverbed downstream of sediment supply areas) (Figure 3). The full evaluation of the dataset is still in progress.

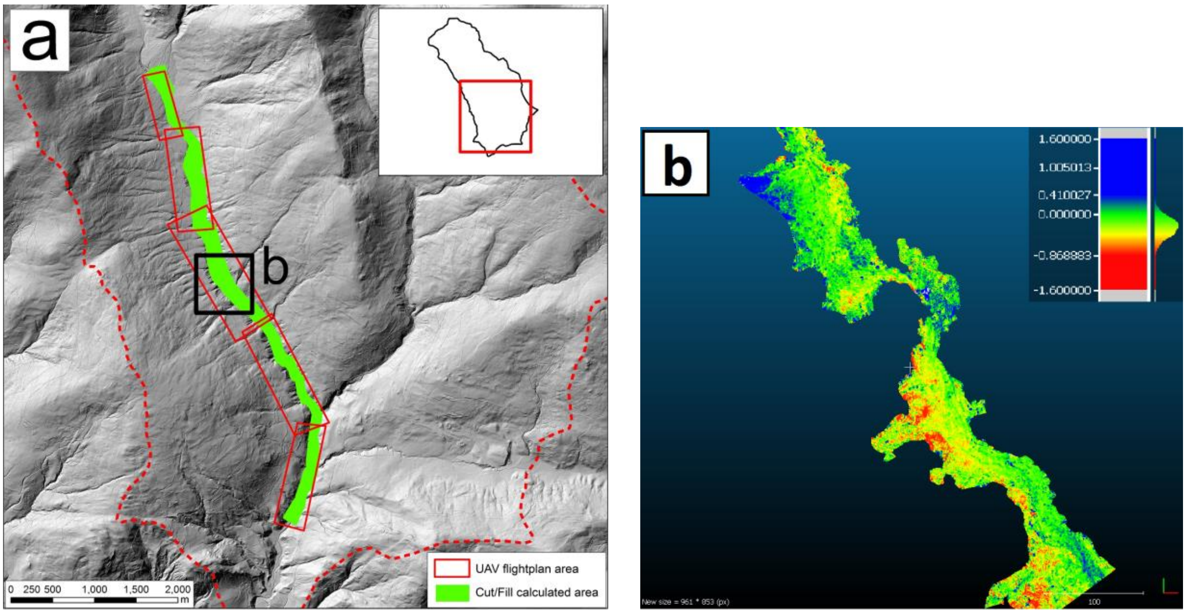


Figure 3**:** (a) Area covered by UAV surveys and cut-and fill analysis; (b) example of erosion and accumulation along an approx. 600 m long stretch, period June 2014 – June 2015. The blue zone in the upper left is a debris cone from a tributary which experienced accumulation; in the following some 100 meters accumulation prevails, until undercutting provides new sediments in the approx. middle of the image.

WP3: Quantifying catchment sediment dynamics

Using TLS and SfM for determining erosion rates

We manually mapped erodible sediments in the field using ESRI ArcMap, mainly based on a 1-m-resolution digital terrain model derived from airborne laser scanning. All mappings were verified and supplemented during on-site visits. Figure 4 shows the distribution of the sites in the middle reach of the Schöttlbach. 55 areas were classified due to size, slope angle, vegetation, grain sizes, connectivity to the main channel and approximately available sediment volume, and five types of typical surfaces were selected for performing sediment volume measurements. In each of the five classes, one site was chosen for detailed observation. Areas with dense vegetation were omitted to avoid inaccuracies caused by vegetation filtering.

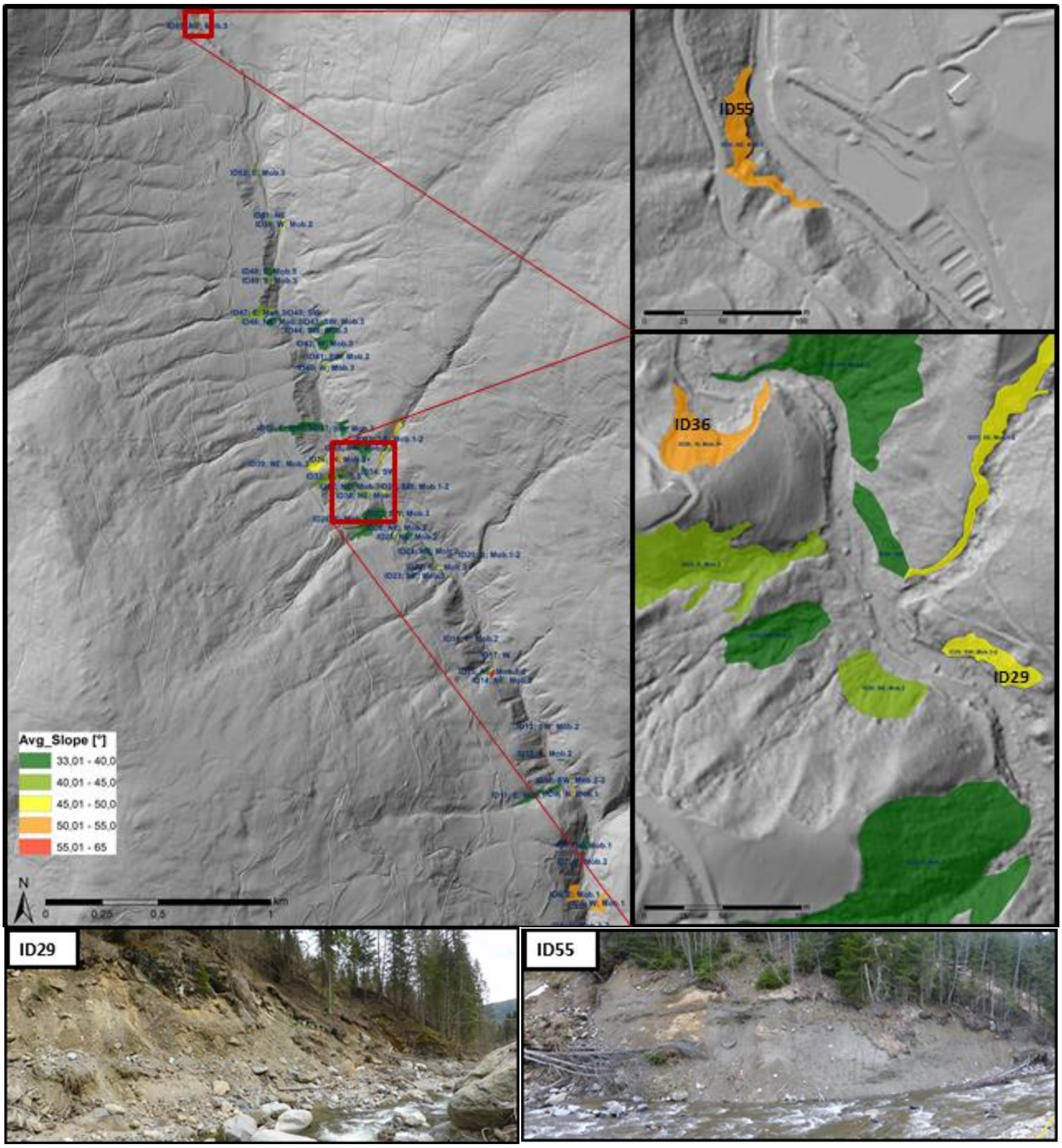


Figure 4: Examples for the mapping and classification of erosional surfaces.

Taking the respective total surface areas as a base, the rates can be extrapolated to an annual yield of 2,860 m³/yr. This is very close to the amount of sediment deposited in the retention basin in 2014 (approx. 3,000 m³, see WP4), which indicates that the catchment is approaching equilibrium between erosion and sedimentation at least under the 2014 runoff conditions. However, the pulse of sediment transport in 2011/12 (see "retention basin", total of 50,000 m³ in three years) cannot be explained by this continuous mobilisation and must have been due to extensive erosion cuts in the embankments during the flood event and reworking of sediment stores close to the channel in the months after the event. The monitoring of the erosion sites is still carried out and the dataset will be supplemented by further results in the following months.

Quantifying available sediments (geophysics)

2D-geoelectrical measurements delivered promising results at first. However, the profiles turned out to be hard to interpret because of the lack of electrical contrast between the loose sediment and the wet and fractured mica schist bedrock. Thus, seismic refraction was applied on ten profile lines using hammer blows as impact source, and on one long profile line using explosives. Sediment thickness was around 10-30 m at most profile lines. The long profile using explosives at the "Bachler" site between the Schöttlkapelle and the confluence with Krumeggerbach detected bedrock very close to the surface under the torrent bed. There is a sediment body of approx. 20 m thickness at the orographic right side of the valley (which is heavily dissected by gully erosion in this area) while there is just a shallow sediment blanket covering the left slope.

WP4: Quantifying river sediment dynamics

Precipitation and runoff

Daily precipitation sums of the ZAMG-station Oberwölz were analysed for 1971 – 2011 and compared to chronicled flood events in Oberwölz. Daily precipitation of >60 mm always caused damaging floods while P < 20 mm/d never caused flooding. In the broad range in between, flooding gets progressively more probable with higher daily precipitation. The disastrous flood of July 2011 was not exceptional at the Oberwölz station (30 mm/d); heavier events in the same year did not cause a comparable response. The reason is mainly the varying location of the precipitation field within the catchment.

The 2013 measurements of the three precipitation stations newly installed within the ClimCatch project were compared with the ZAMG station Oberwölz. The Schöttlkapelle station in the middle of the catchment registered 1069 mm compared to 769 mm at the ZAMG station. The 30-year mean (1971 to 2000) in Oberwölz is 736 mm; the year 2013 was thus roughly average in terms of precipitation. At the rain gauges stations at Luxenhütte and Feistritzalm, corrections were necessary due to blocked-up drainage of the rain gauges in autumn. There are notably few deviations between the temporal profiles of three of the stations. However, heavier rainfalls were registered at Luxenhütte in spring and summer due to local convective thunderstorms.

The water levels in the torrents were recorded by three water gauges newly installed in the catchment. The correlation of water level and discharge is possible by means of discharge rating curves based on calibration measurements using the salt tracer or the velocity-area method. Additional, the measured values were used to calibrate and enhance the rating curve by using the open source software "BedLoadAnalyzer" developed at Graz University of Technology. From 2012 until 2014 more than 50 discharge measurements had been performed at the gauges. Constant improvement and adaptation of the rating curves is necessary because of slight changes in the channel bed. Figure 5: shows an example of measured precipitation (blue columns), discharge (dark blue line) and snow depth (grey line) at “Schöttlkapelle" in 2013.

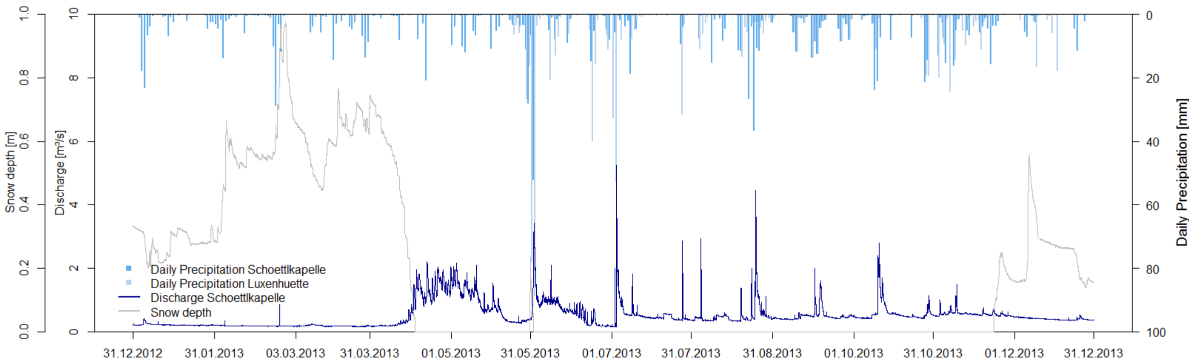


Figure 5: Measured precipitation (blue columns), discharge (dark blue line) and snow depth (grey line) at meteorological stations "Schöttlkapelle" and “Luxenhuette” in 2013 (Harb et al, 2016)

Colour and telemetry tracer stones

Tracer stones were exposed to study the bedload transport in the Schöttl- and the Krumeggerbach. The stones were scanned and mapped on regular basis approximately once a month. Exemplary results of the Schöttlbach are shown in Figure 6. Compared to several functions describing the initiation of motion (lines) the measured tracer data (dots) show relatively pronounced range of dispersion. The results indicate that the movement of the tracer stones is strongly affected by very local flow conditions and local changes of the river bed. Tracer stones deposited e.g. at the inner bank, in a pool section or behind large blocks need higher discharges for the initiation of motion in comparison to exposed tracer stones. Therefore, a clear trend is missing in the transport data, even if the critical discharge seem to change according from 2012 to 2014 most probably due to local changes of the river bed. Nonetheless, a qualitative characteristic of can be verified. Total travel distances up to 600 m in 2 years could be detected (see Figure 7).

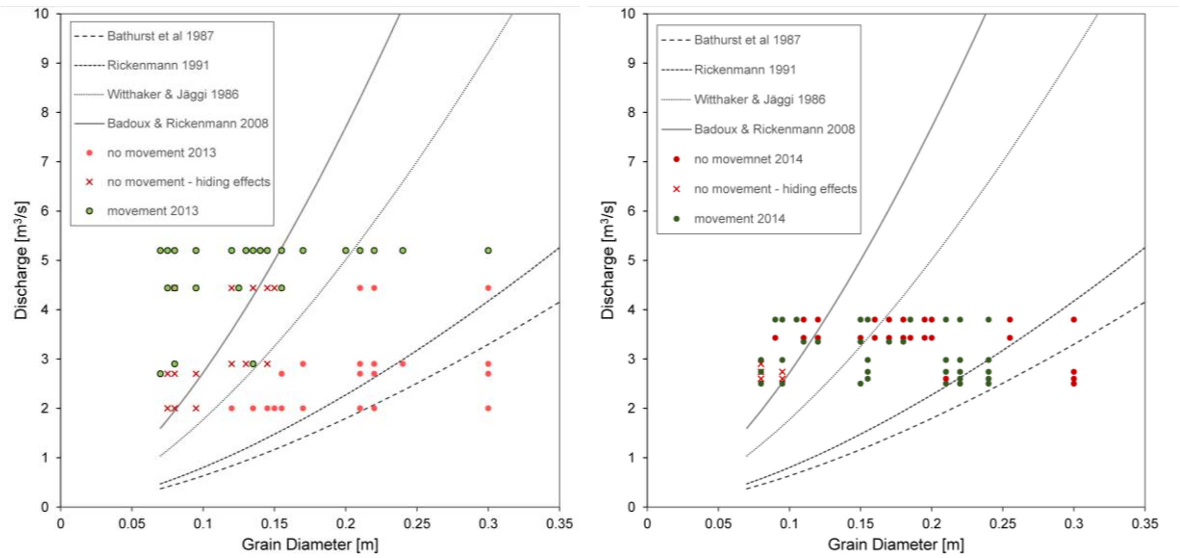


Figure 6: Verified movement of the tracer stones at different discharges in the years 2012-2013 (left) and 2014-2015 (right) at the location Schöttlkapelle (Harb et al, 2016)

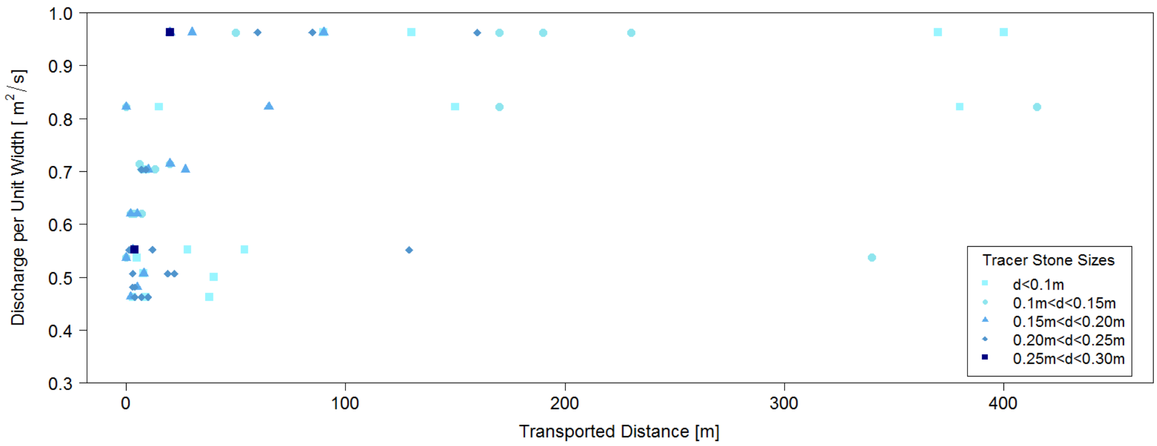


Figure 7: Observed transport distances of the tracer stones at the location Schöttlkapelle (Harb et al, 2016)

Bed load measurements using Helley-Smith-Sampler and calculation of yearly sediment yield

The bed load transport rates were measured using a small Helley-Smith-Sampler. The measured rates were used to estimate the yearly sediment yield in different section in the catchment. Figure 8 shows the calculated bed load transport (dark red line), the cumulated bed load discharge (red line) at the location Schöttlkapelle and the measured discharge (dark blue line). The cumulated discharge of 2,500 m³ sediments per year correspond well with the measured sediment yield in the retention basin, taking the additional sediment sources downstream into account.

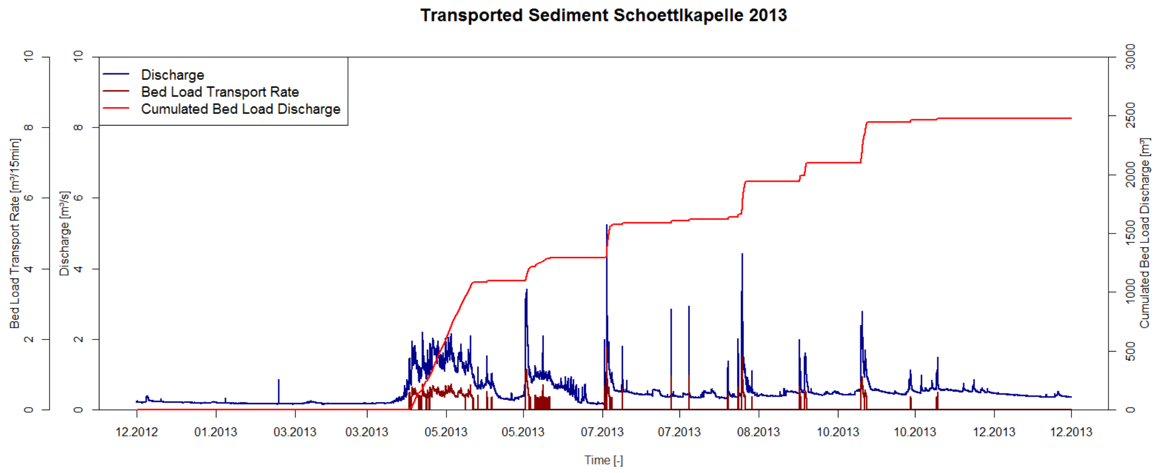


Figure 8: Cumulated bed load discharge (red line) at the location Schöttlkapelle estimated based on measured bed load transport rates (dark red) and discharge (dark blue)

Sediment impact sensors (SIS)

Implementing the Sediment Impact Sensors (SIS) required several steps of electronic engineering, calibration in the lab and in the field. Startup of the first SIS generation (TinyTag logger) was in October 2012, followed by extensive calibration tests. Over the course of the second project year, the blueprint was further improved and the first generation was replaced by a second generation of sensors which are using a piezoelectric signal generator (Murata, 7BB-35-3L0) connected to an Arduino data logger. Laboratory calibration tests have been conducted amongst other things by using a calibration bar that can be dropped from defined heights; the results show that different impact energies can be clearly distinguished. Extensive test runs for identifying sensor sensibility and reproducibility of impacts were carried out. Car batteries were used for power supply in the field. The second generation of SIS was finally installed between February and April 2014. After further field calibration tests, the field assembly and the measurement software were optimised one more time in spring 2015. This final measurement setup is in operation since May 2015. Nonetheless, the sensors delivered large volumes of valuable (if semi-quantitative) data in the project period. Because of varying micro-topography and flow characteristics around the installed sensor, comparison between different sensors has to be treated with caution.

Figure 9 shows the measured precipitation, runoff and sediment impacts of the sensors in Krumeggerbach and Salchauerbach which provides an example of the observations with the first generation of the SIS series, together with rainfall and runoff measurements. Runoff at Krumeggerbach reacts not on every precipitation event at Schöttlkapelle (3 km distance) which underlines the importance of small-scale precipitation patterns. The SIS K1 reacts on almost each of the runoff peaks;

sediment transport occurs mainly in the rising limb of the hydrograph. A particularly strong reaction was recorded in April 2013; sediment transport was probably amplified by the release of sediment during the main snowmelt period (see "depth of snow" curve). The SIS K2 and Salchauerbach recorded sediment transport only after a shift of the respective channels in the end of May.

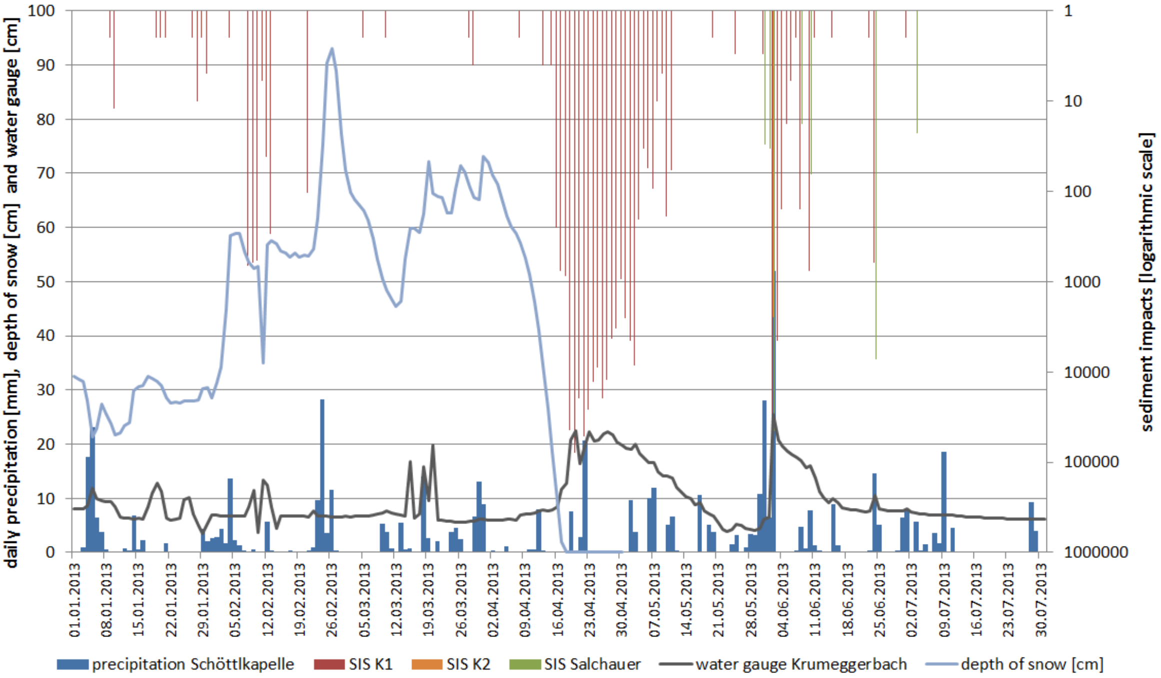


Figure 9: Precipitation, snow level, water gauge and bed load transport (SIS) at Krumegger- and Salchauerbach, Mar – Jul 2013.

Figure 10 shows the temporal distribution of impact intensity at the three test sites Schöttlkapelle, Krumeggerbach and WLV weir. Runoff peaks at the outlet correlate with precipitation event at Schöttlkapelle; however, some precipitation events are not mirrored in the runoff data and vice versa. Sediment transport at WLV weir and Krumeggerbach are mainly concentrated on three events in Aug/Sep 2014; in mid of September, the sediment yield at WLV weir seems to derive exclusively from Krumeggerbach. The quantity of sediment transport is much lower at Schöttlkapelle and is more concentrated on late spring (snow melt) in this position.

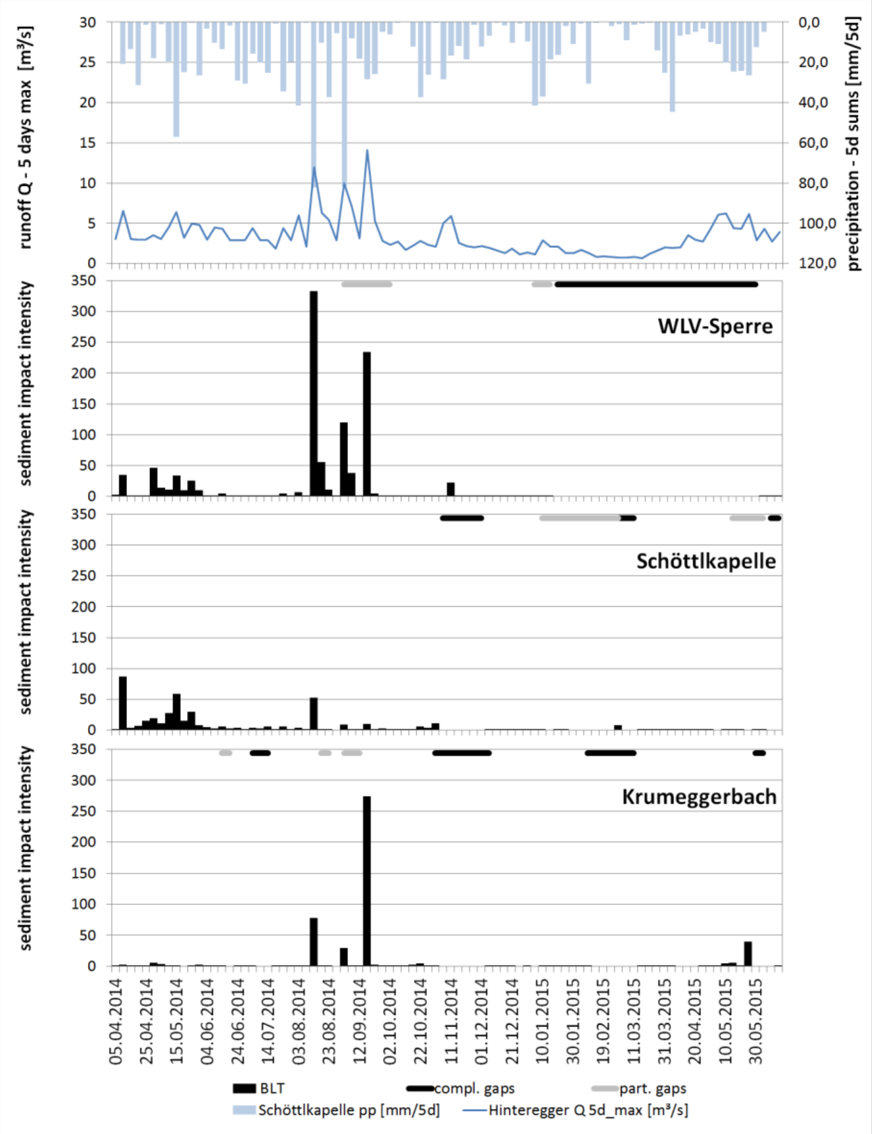


Figure 10: Precipitation at Schöttlkapelle, runoff at Hintereggertor (catchment outlet) and sediment transport intensity at three cross sections, 2014 – 2015.

The runoff threshold for the onset of fluvial transport can be derived from the sensor data. The initiation threshold (minimum grain size registered by the SIS = 1-5 cm) is 3.25 m³/s at the WLV weir (Figure 11) after the confluence of the tributaries, 1.5 m³/s at Schöttlkapelle and 0.7 m³/s at Krumeggerbach (no figures). This corresponds very well with the values derived from the tracer stone observations (considering that the minimum grain size registered by the SIS is smaller than the smallest tracer stones used). The diagram of Figure 11 furthermore shows the exponential increase of bedload transport during above-threshold runoff conditions.

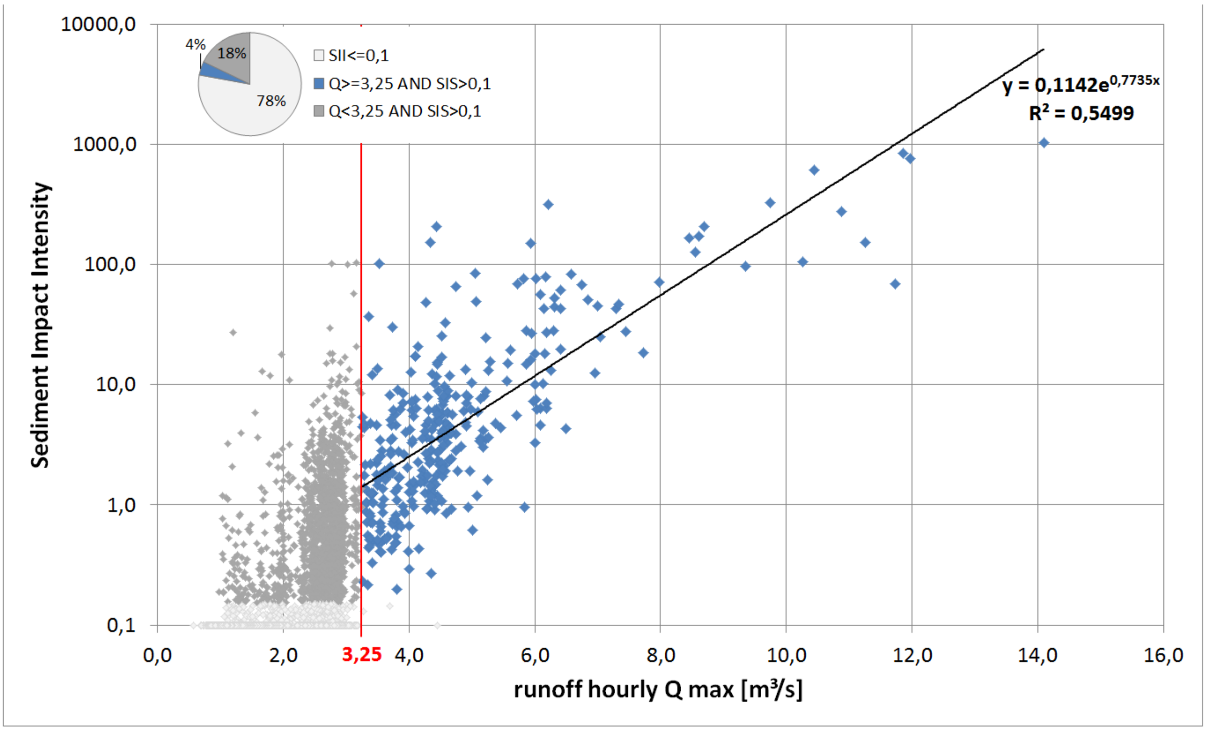


Figure 11: Motion initiation threshold derived from SIS at WLV weir. Below the threshold of 3.25 m²/s, most values are effectively "zero" (values of ≤ 0.1 kg/h are mostly caused by runoff turbulence).

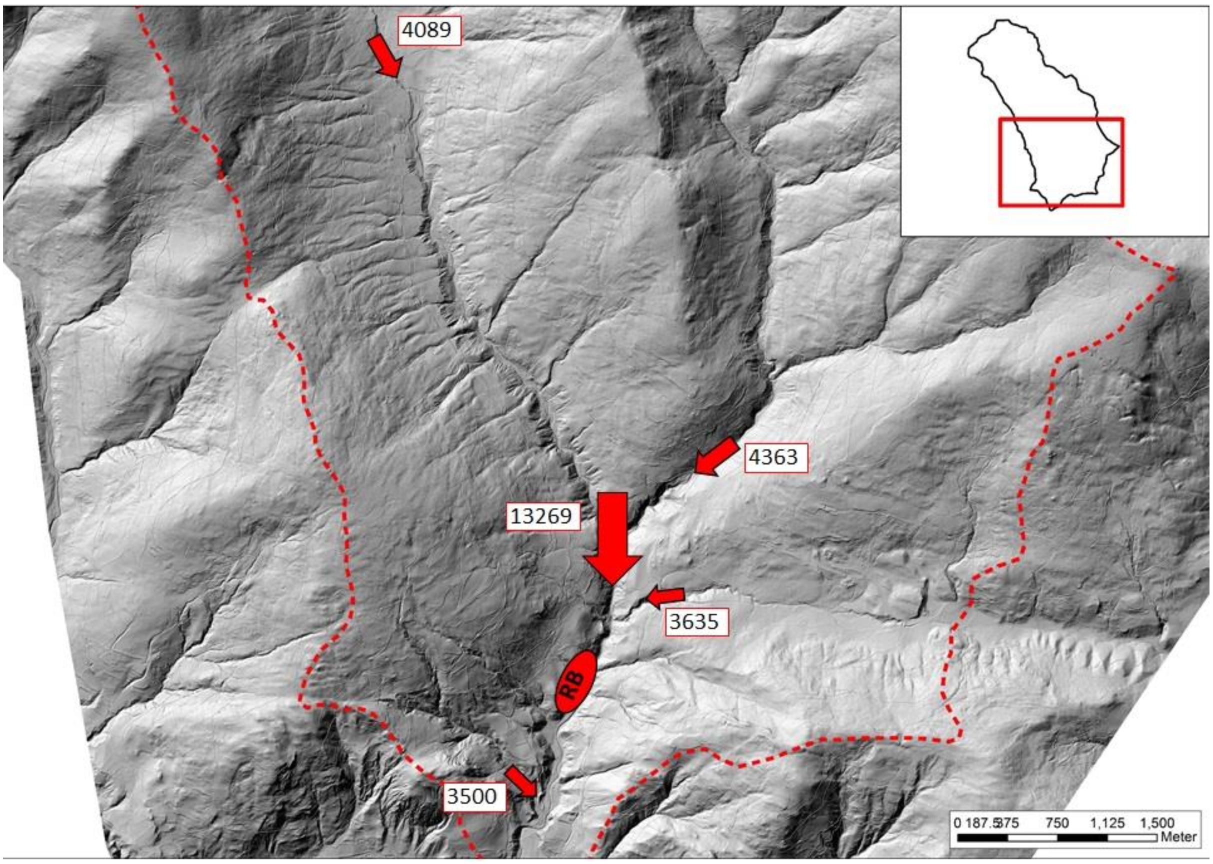


Figure 12: Visualisation of spatially distributed impact intensity (2014–2015). The numbers are relative impact intensity values (not to scale). RB = retention basin.

Absolute calibration (cumulated impact intensity to transport rate) is still difficult because of to date very limited sediment trap data. Preliminary calibration functions still underestimate the transport across the instrumented sills which is due to still insufficient calibration under high-flow conditions. This shortcoming will be overcome by an automated bedload measuring station in a planned follow-up project. However, the relative proportion between the test sites is reliable. Upper Schöttlbach (Schöttlkapelle), Krumeggerbach, Salchauerbach and Schmiedbognerbach all delivered similar amounts of sediment while at the WLV-weir after the main confluence, transport rates are roughly three times higher.

Sediment volume in retention basin

The volume of the deposited sediments in the retention basin upstream of the city of Oberwölz has been measured several times using a terrestrial laser scanner (TLS). Together with the assessment of removed sediment volumes this process enabled to calculate the total sediment yield transported to the retention basin (Figure 13).

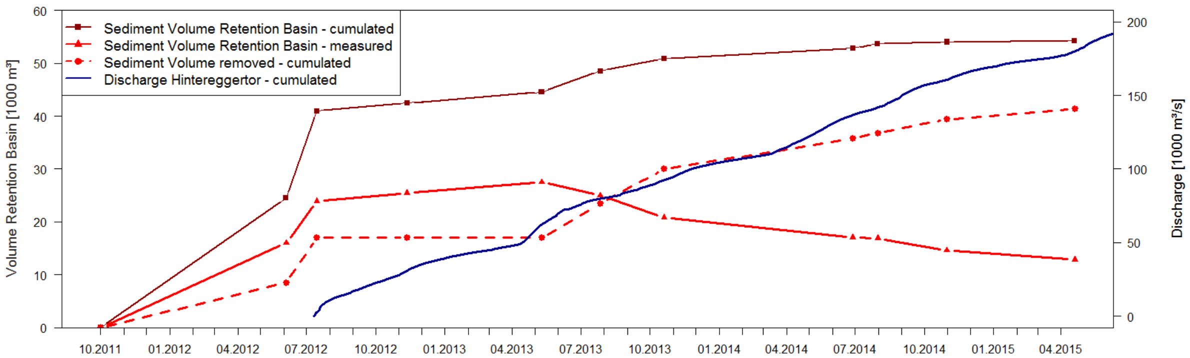


Figure 13: Change of sediment volume in the retention basin close to the outlet of the Schöttlbach basin and cumulated discharge at the gauging station Hintereggertor (Harb et al, 2016)

Figure 13 shows that a large amount of sediment was deposited in the retention basin during the winter period 2011/2012. This is remarkable, because low flow conditions occurred in winter and no significant sediment transport was expected. The surprisingly high sediment yield is very probably caused by the highly disturbed conditions in the catchment with huge erodible sediment bodies in the aftermath of the 2011 catastrophic event. The total sediment load per year decreases from more than 40,000 m^3 in 2011/12 to less than 4,000 m^3 in 2013/14. Furthermore, the progressively levelled cumulated sediment curve in comparison to the more steep discharge curve indicates the decreasing sediment availability within the river bed and banks.

WP5:   Modelling and downscaling future precipitation

A set of 24 RCM simulations from ENSEMBLES (www.ensembles-eu.org) and reclip:century (reclip.ait.ac.at/reclip_century) were analysed with regard to changes in air temperature, precipitation, snow water equivalent, and precipitation extremes under the A1B emission scenario. Empirical-statistical downscaling was applied via Quantile Mapping in order to improve the skill of RCMs in representing present-day climate characteristics of single meteorological stations close to the catchment of Schöttlbach and for the district of Murau.

In Murau, increasing air temperature is projected by all models. In the annual mean, an increase of +1.5 °C is expected, ranging from +0.9 °C to +2.4 °C. A slightly stronger increase is expected in spring. However, the projected precipitation changes are subject to rather large uncertainties: changes in mean precipitation range between -0.4 % and +15.0 %. The number of days with heavy precipitation events (defined as days with precipitation > 30 mm) show an increase of +0.7 days in the annual mean, ranging from -0.1 days to +1.7 days. The days with snow cover show a highly pronounced decrease of -24.6 days in the annual average, ranging from -29.3 days to -9.5 days.

The results of the station based analyses reveal that all stations are affected by increasing air temperature with more pronounced changes until the end of the 21st century. The projected changes are highly robust with respect to the accordance between models concerning the positive sign of the change. The precipitation changes are subject to considerable uncertainties. However, the projected changes are more apparent until the end of the 21st century, revealing pronounced decreases during summer (cf. Figure 14a and Figure 14b). Due to increasing air temperature, the liquid part of precipitation shows distinct increases in winter along with a reduction in snow water equivalent. Changes in the number of extreme precipitation events (defined as threshold exceedances) show an increase (decrease) during winter (summer). Again, the changes are generally more pronounced until the end of the 21st century. Furthermore, the number of liquid precipitation events shows particularly high changes in winter due to increasing air temperature.

Application of extreme value theory (cf. Figure 14c and Figure 14d) shows a clear trend towards an intensification of daily extreme precipitation events, particularly until the end of the 21st century. The most pronounced changes towards increasing return levels are predicted during summer and autumn. Here, a strong trend towards greater changes in the return level for extreme precipitation events with longer return periods is predicted.

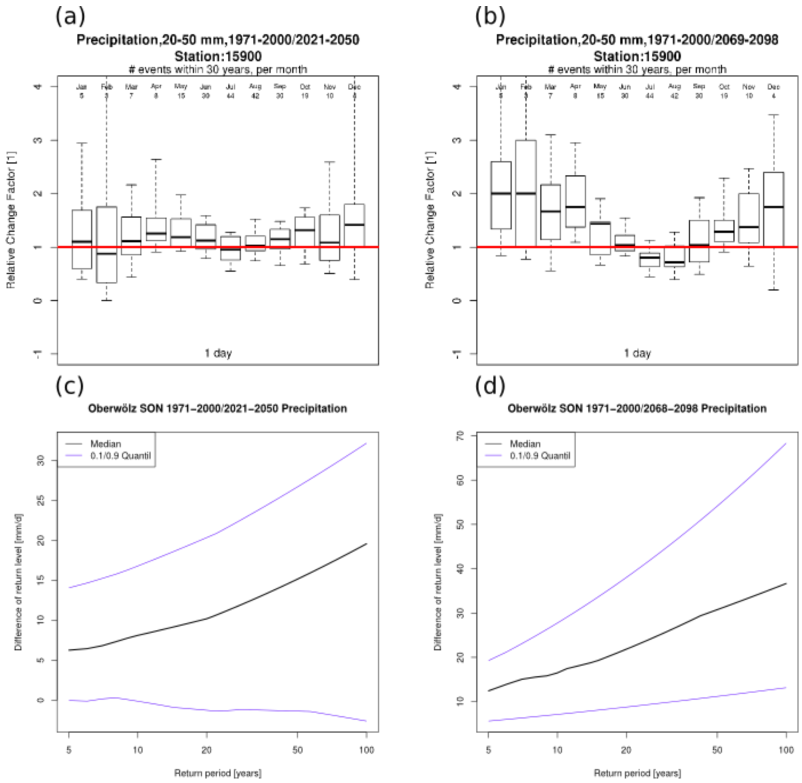


Figure 14 (a) and (b): Changes in the frequency of heavy precipitation events between 20 mm and 50 mm for Oberwölz until 2050 (left panel) and 2100 (right panel). The boxplots represent the variability among climate scenarios. (c) and (d): Changes in the return level of daily extreme precipitation events for Oberwölz until 2050 (left panel) and 2100 (right panel). The bold black line shows the median of the 24 RCM scenarios and the purple lines represent the uncertainty range between the 10 % and 90 % percentile

The exploration of QM's applicability on sub daily scale is based on a split sample test (period 1989 to 1998 is used for calibration and to predict the period 1999 to 2008) and on the arbitrarily selected regional climate model SMHI-RCA from the ENSEMBLES ensemble. Here, SMHI-RCA was driven by the re-analysis dataset ERA-40 of the ECMWF in order to achieve temporal comparability between model output and station data in the temporal sequence of weather conditions. The results reveal a high potential of QM for being used as a bias correction technique on sub daily scale. QM drastically reduces the RCM biases in the diurnal cycles of mean, minimum, and maximum temperature by a factor of up to 10. Errors in the diurnal temperature range due to under- and overestimation of maximum and minimum temperatures are strongly reduced with remaining biases in the order of 0.5 K. For sub-daily precipitation, QM generally improves the skill of the RCM in representing the diurnal and annual precipitation cycle. Especially in convective conditions in summer, where RCMs show largest errors of mean and maximum precipitation (e.g. Prein et al., 2013; Prein et al., 2015), QM is able to adjust the timing as well as the magnitude of precipitation and therefore strongly reduces the bias in both cases (cf. Figure 15).

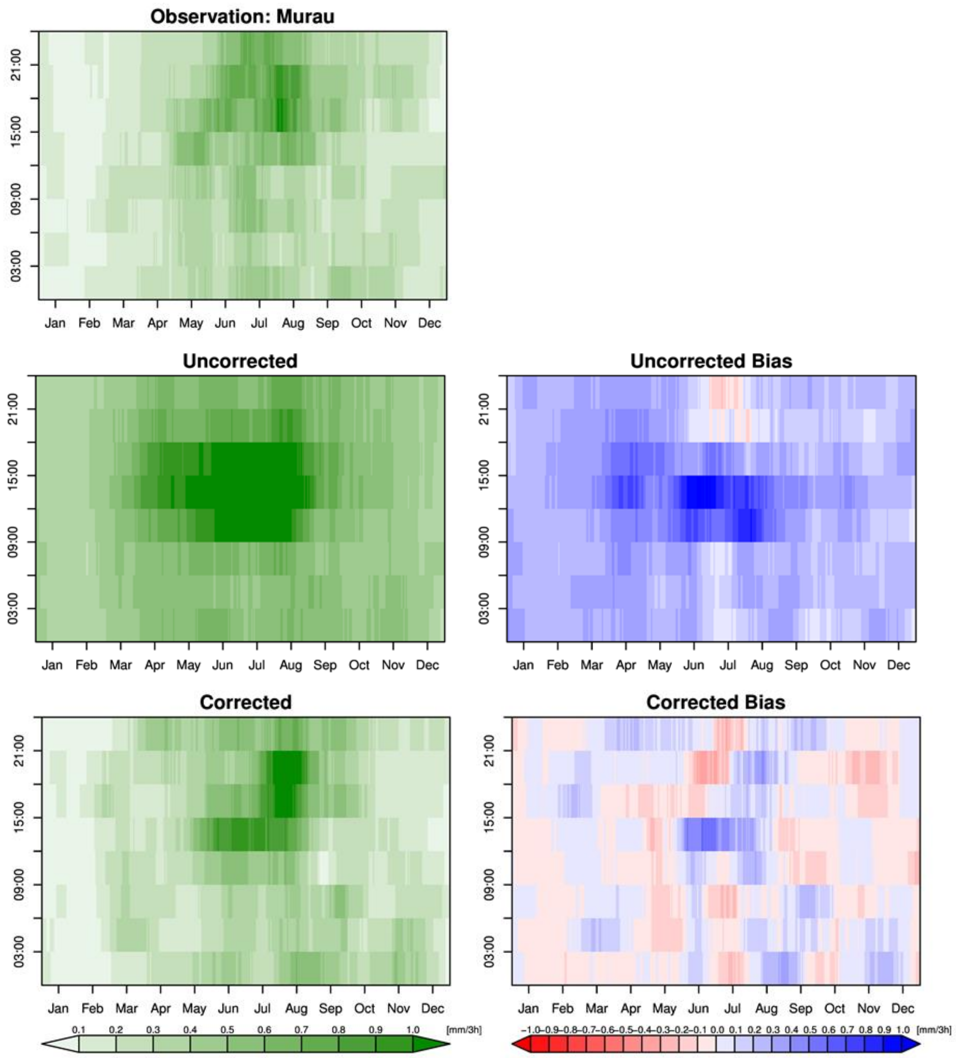


Figure 15: Left column: diurnal precipitation cycle in the course of a year (daily increments) for the station of Murau for observed, uncorrected, and corrected precipitation. Right column: difference between uncorrected and corrected model output and observations.

WP6: Understanding and managing future behaviour

Due to the expected seasonal changes (less snow and more runoff in winter) and intensified extreme events, sediment transport rates are very likely to increase in the future. The frequency of runoff events surpassing the transport initiation thresholds (established in WP4) will probably rise. However, there are uncertainties regarding the counteracting effect of higher evaporation under warmer conditions and on the role of the snow and soil buffers. Establishing a sound precipitation-runoff-relationship requires catchment-wide hydrological modelling, a task which is planned for the follow-up project ClimCatch II+.

More runoff events crossing the mobilisation thresholds are likely to cause higher sediment transport because the depletion of sediment stores is currently not to be expected. However, the results from the three project years show that runoff-precipitation relationship is not straightforward. For example, the year 2013 featured less above-average peak runoff events and less total runoff than 2014, but higher sediment transport rates due to the disturbed state of the catchment. High-magnitude events (as the flood event in 2011) destroy the armour layer, dissect the contributing slopes and lead to high transport rates in the following months. Later, stabilisation starts resulting in decrease of sediment transport under unchanging runoff conditions. During severe runoff events a new erosion and transport pulse could be initiated. We recorded a 5-year flood event in July 2015 (after the end of the project period) and visual examination suggests that channel avulsions and bedload transport were higher than at any other point in time in the project period. This event underlines that a longer observation time (particularly using the installed new generation of SIS) is desirable which is planned for the follow-up project.

Numerical 1D sediment transport model

The bedload transport rates in the lowest part of the Schöttlbach have been simulated using the numerical 1-D sediment transport model TomSed (www.bedload.at). Measured cross sections are divided by TomSed into individual strips automatically depending on the complexity of each profile. In each of these areas, the transport capacity as well as the discharge are calculated. Each cross section itself provides information about the particle size distribution, the water depth and the base inclination.

A sensitivity analysis was performed as a first step. Due to the different sediment transport processes in the river bed at different discharges concerning e.g. armour layer and pavement, hiding and exposure effects or the disturbed state of the river bed and river banks after the high flood event, it was not possible to generate an overall matching calibration of the 1D numerical model taking low flows and high flood events into account. Therefore, two parameter sets were used in the model, one for low flow and flood events with higher probability and one for extreme flood events like in 2011. Figure shows the sediment load to the retention basin in the year 2013. The dark blue line indicates the measured discharge in the Schöttlbach, the dark red line represents the calculated bedload transport rates, which are summed up to the cumulated sediment yield to the retention basin (red line). This calculated sediment volume is compared to the measured deposited sediment volume (red dotted line). The results show, that the cumulated sediment volume fits well, but the temporal distribution of the sediment transport could not be reflected in the simulation. Apparently more sediment is transported at lower discharges and less sediment at higher discharges. The difference in the temporal distribution may be explained by the fact, that the input of sediment from the steep river banks, which are transported at low discharges was partly neglected in the simple numerical model and that e.g., armour and pavement processes limit the sediment load at higher discharges.

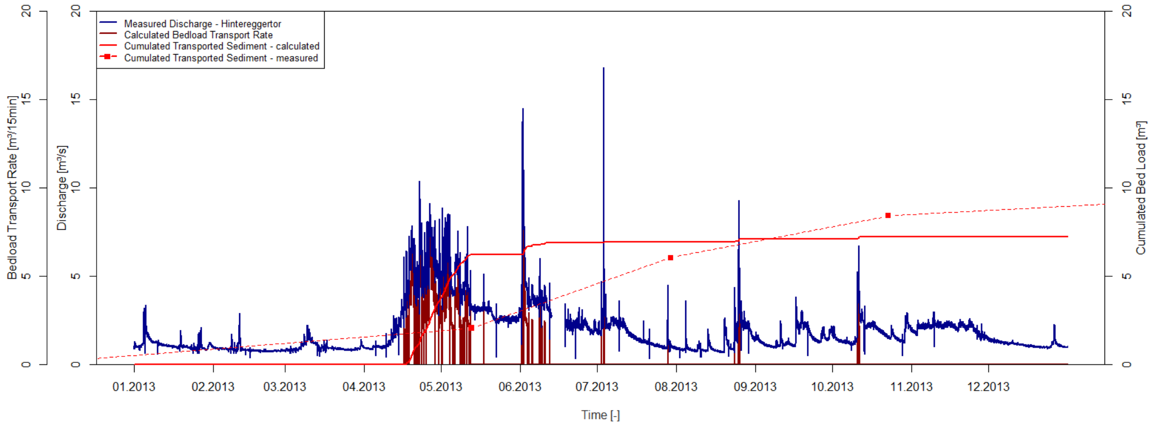


Figure 16: Change of sediment volume in the retention basin close to the outlet of the Schöttlbach basin and cumulated discharge at the gauging station Hintereggertor

5 Schlussfolgerungen und Empfehlungen

In the following, we summarize the results and structure them according to six core questions.

Where is sediment mobilised?

The main sources of erodible sediments are found along the lower and middle reaches of the Schöttlbach and Krumeggerbach. In these areas, the glacigenic sediments, typically some 100 m left and right of the channels, are very well coupled to the torrents. The erosive energy is particularly high at around 1-5 km upstream of the retention basin. In these areas, the riverbed is probably close to bedrock; however, at least 10-20 m of loose sediments are still available at the steep valleysides and will be mobilised in the future by undercutting during storm events. The total amount of sediments is finite but the sediment body will definitely not be exhausted during the coming centuries.

Where and to which extent is the sediment transported?

Sediment transport was observed along the whole reach under investigation. Transport in the middle reach of Schöttlbach (Schöttlkapelle) is slightly lower than in Krumeggerbach despite of the much smaller catchment of the latter due to the steeper slope of the river bed. Due to higher runoff, higher stream power and availability of sediments, sediment transport downstream of the confluence of the two main creeks (WLV weir) is roughly four times higher than in the single tributaries. The calculated transport rates from SIS are smaller than the deposited volumes in the retention basin; the reason for this deviation is the still insufficient calibration under high-flow conditions.

The correlation between discharge and initiation of motion, travel distance and transported grain sizes was established. The critical discharge for sediment transport seems to increase from 2012 to 2014; parallel to this development, the rate of sediment deposition in the retention basin is decreasing due to to restabilisation of the catchment after the 2011 flood event.

Are mobilisation, transport and deposition in equilibrium?

Sediment transport was exceptionally high in the year after the catastrophic event of 2011. Erosion and transport were not monitored yet in winter 2011/12; however, we can assume that transport and deposition were much higher than erosion in this period and that debris deposits in the riverbed and freshly cut slopes at the banks of the river were reworked. Between 2012 and 2015, deposition rates have been stabilizing. The surveys of the retention basin at the catchment outlet show a steady decrease of deposition since 2012 while similar discharge conditions occurred.

Currently (2014/15), the rate of mobilisation from the erosion areas roughly matches the rates of deposition in the retention basin which could indicate that no important sediment deposits in the channel are currently built up or eroded. Quantitative transport rates from SIS for comparison would underpin these considerations; however, quantification of transport rates is still surrounded by a considerable degree of uncertainty because the calibration has to be extended to higher discharge rates. The catchment experienced a five-year flood in July 2015 (= shortly after the official end of the project). We will evaluate in the coming months if this high-magnitude event caused a new sediment transport pulse.

What is the role of precipitation, and how will it change?

The catastrophic 2011 event was caused by a modest daily precipitation of 30 mm in Oberwölz (the thunderstorm cell was located above the Krumeggerbach sub-catchment, estimated 100 to 140 mm, Hübl et al., 2011). Evaluation of the Oberwölz precipitation data from 1971 – 2011 showed that daily precipitation of 20 – 60 mm can potentially cause damaging floods, the probability increasing with higher rainfall. Own precipitation measurements showed that rainfall is distributed irregularly within the catchment. Thus, correlations between precipitation and erosion/transport/deposition are not universally valid in time and space.

The results concerning future precipitation show a clear trend towards an intensification of daily extreme precipitation events, particularly until the end of the 21st century. Seasonal changes are to be expected: winter precipitation is likely to increase while the summers will probably become drier (however, precipitation will be concentrated in more/higher extreme events). Together with an earlier start of the snowmelt period this leads to a shift of the hydrological regime. Higher extreme precipitation events or increasing precipitation event in winter will in all probability lead to increased runoff pulses in the catchment. Due to higher evapo-transporation in a warmer climate, the mean annual runoff is likely to decrease. These points will be investigated in more detail in a planned follow-up project by means of hydrological modelling.

Are we facing higher sediment transport in the future and what are the consequences?

Due to the seasonal changes (less snow and more runoff in winter) and the higher expected extreme events, higher transport rates are very likely. The probability of runoff events crossing the sediment transport thresholds is likely to increase; however, hydrological modelling is necessary for accurate results (planned for a follow-up project). Higher sediment transport connected with higher runoff peaks is very probable for the future; more accurate, quantitative results require a longer observation period and sophisticated sediment transport modelling (see "further steps").

For a first, rough calculation we can assume that critical daily precipitation (20-50 mm) will be 1.2 times more frequent in 2050 and 1.5 times more frequent in 2100 (see Fig. 14). As sediment storage depletion will not be an issue in the coming decades at Schöttlbach, we assume that the increase of sediment transport will be in the same order of magnitude. The same is valid for the dimensioning of protection measures. The increasing magnitude of peak events (100-yr or larger) – as well as the concentration of summer precipitation on shorter and heavier events – have not been taken into consideration for this first approximation.

Until now, the results have not been concrete enough to be implemented into the planning process. In Oberwölz, the construction of the planned new retention basin is currently delayed due to complaints of residents. The check dam of the new retention basin will have to be designed in a way that allows the through-transport of sediments during smaller floods which enables the construction of a sufficiently large basin despite the expected higher sediment transport rates. However, adequate volume reserves have to be planned and proper management of the basin has to be guaranteed. Furthermore, the freebord of bridges as well as spatial planning issues have to be provided downstream of the retention basin in the medium to long term.

Further steps to be taken

For a full-fledged assessment of the impact of climate change on sediment yields, hydrological modelling and sediment transport modelling are required. We are planning an interdisciplinary three-party cooperation, the first aim is to investigate the hydrological response of the catchment based on sub-daily observations of meteorological input parameters and applying the deterministic Water Flow and Balance Simulation Model (WaSiM), including snow cover storage and the level of antecedent moisture. For the future projections we will use the most recent climate scenarios for Austria from the ÖKS15 project provided by the data centre of the Climate Change Centre Austria (CCCA) on a 1x1 km grid. Sediment availability will be displayed in a 3D-GIS approach and sediment mobilisation will be monitored continuously using terrestrial and airborne photogrammetry. The maintenance of the SID will be continued to capture transport along the creeks. An automatic bedload measurement station at an existing check dam will be equipped with basket samplers; the sediment transport measurements will be completed by regular surveys of the retention basin at the outlet of the catchment. The data will be fed into an adapted two-dimensional sediment transport model (Telemac) by linking the simulated runoff and the observed sediment data; uncertainty analysis will be performed. The variation of incipient motion, the influence of macro roughness elements with low relative flow depths, grain-size distributions, hiding and exposure effects and the influence of the dynamic availability of sediment will be investigated in the scale test flume in the hydraulic laboratory of TUG. We will derive estimates of future sediment transport changes based on a well-selected set of ÖKS15 climate scenarios in order to account for the associated uncertainties.

Furthermore, we want to broaden the perspective by comparing the Schöttlbach situation to other Alpine valleys in eastern Austria (pilot Master thesis just started in co-operation with the WLV Styria), and deal with the consequences for decision making.

B) Projektdetails

6 Methodik

WP2: Conceptual model of the sediment cascade

Orthophoto generation and mapping of erodible sediments was carried out for two sets of aerial photographs from 1965 and 2010, respectively.The single aerial photographs were merged in a block of images to create ortho images of 1965 and 2010. The areas of erosion were identified and mapped. We mapped and classified 55 areas in detail and chose five of them for repeated surveys in WP3.

The original plan to quantify catchment-wide erosion using repeated ALS flights was dropped and we concentrated on repeated **airborne photography surveys** using drones (UAVs). The surveys were carried out in June 2014, November 2014 and June 2015. Together with the ALS scan from 2013, surface models of four points in time are available.

Based on the high-resolution surface model of 2010 we carried out a semi-quantitative **connectivity analysis** using the index-of-connectivity (IC) approach outlined by Cavalli et al. (2013). The result displays which areas of the catchment are geomorphologically connected to the receiving channel and to the catchment outlet.

WP3: Quantifying catchment sediment dynamics

Terrestrial Laser Scanning (TLS) and terrestrial photogrammetry (Structure-from-Motion, SfM) were used to determine **erosion rates** at the active surfaces located and classified in WP2. TLS is an active surveying technique using reflected laser pulses while the SfM technique uses overlapping photos taken by a digital camera to create a surface model. Comparative TLS and SfM measurements were performed on three erosional surfaces; the point clouds were aligned manually by picking point pairs of Ground Control Points (GCP's).

Sediments available for relocation were quantified by means of **geophysical profiling**. 2D-geoelectrics (ERT) was used in the first attempt, performed with a GeoTom device equipped with 100 electrodes in 4 m spacing, allowing a penetration depth of approx. 70 m. Later, seismic refraction measurements were applied using a 24-channel Geode system. For most of the profiles, hammer blows as seismic source were used; the maximum penetration was thus restricted to approx. 30-35 m. We measured five cross profile lines; it was necessary to measure separately on both valley sides for logistical reasons. In order to be sure to reach bedrock at the crucial "Bachler" cross profile, one long profile (400 m, 96 geophones) was measured across the river and triggered by explosives.

WP4: Quantifying river sediment dynamics

Knowledge of precipitation and runoff in the catchment are the backbone of sediment transport measurements. **Precipitation** including snow depth was continuously captured by a newly installed meteorological station in the approximate middle of the catchment (Schöttlkapelle, 1251 m a.s.l.). This station was supplemented by two additional rainfall gauges (Luxenhütte, 1442 m a.s.l. and Feistritzalm, 1646 m a.s.l.) and by the ZAMG station in Oberwölz (842 m a.s.l.). **Runoff** was measured at the catchment outlet (Oberwölz) using radar sensors calibrated with discharge measurements. Additional runoff gauges were positioned at the Schöttlkapelle and at the tributary Krumeggerbach.

Bedload transport was measured with several **sediment impact sensors** (SIS). These sensors are based on the sensors developed by Carling et al. (2003) and were further developed during the ClimCatch project (based on earlier concepts), especially to achieve a catchment-wide network. Using cheap and easy-to-carry technical components, the SIS became an important part of the ClimCatch measurement network. The device consists mainly of two components connected by a shielded cable: a) the impact plate, a 15cm x 15cm steel plate mounted in the riverbed with an accelerometer fixed on the underside and b) the logging station outside the river supplied by battery. At present there are 15 SIS mounted along five different profile lines in the Schöttlbach catchment.

The sediment transport processes in the channel were observed using **radio telemetry** and **colour tracer stones**. These investigations focused on the critical discharge for specific grain sizes and on the transported distance. The applied telemetry tracer stones were taken from the river bed, drilled and the radio transmitters were assembled. Both, telemetry and colour tracer stones were weighed, measured (a, b, c-axes), painted and re-exposed in the river bed near the gauging stations. The position of the tracer stones were determined and surveyed in regular intervals and after major rainfall events in the catchment area by recording their GPS coordinates.

The sediment volume in the **retention basin** at the outlet of the catchment was determined by means of repeated TLS surveys to determine the catchment output. To date, eleven scans at different points in time have been carried out allowing a reasonably good temporal resolution. The surveys are supplemented by investigations at the municipality and at the torrent and avalanche control (WLV) because sediments were frequently removed by local people and for building purposes. The measured sediment yield was compared to the calculated sediment yield using the numerical **1D model TomSed** (WP6).

WP5: Modelling and downscaling future precipitation

For an assessment of future changes in torrential sediment transport in a small alpine watershed several important issues needed to be solved: (1) torrential sediment transport is a complex process affected/triggered by meteorological and geological conditions. (2) Climate models have a rather coarse spatial resolution (e.g. regional climate models (RCMs) with a horizontal grid spacing of about 10 to 25 km) and require further downscaling. Especially for small catchments, localized climate information down to the point scale of single meteorological stations is required. (3) RCMs are known to feature systematic errors in the Alpine region, typically up to 2 K to 3 K in air temperature and 50 % to 100 % in daily precipitation sum (e.g., Suklitsch et al, 2010). (4) Climate change is affected by uncertainty.

Issue (1) was treated by focusing on meteorological conditions (air temperature, precipitation, snow water equivalent, and precipitation extremes) that act as proxies for torrential sediment transport. Issues (2) and (3) were covered by employing the empirical/statistical downscaling and bias correction method **Quantile Mapping (QM)** (Dobler & Ahrens, 2008; Piani et al., 2010; Yang et al., 2010; Themeßl et al., 2011), which was applied in its original configuration, but which is also extended to be applicable on sub-daily scales. Issue (4) is tackled by means of an **ensemble approach**: a set of 24 RCM simulations from ENSEMBLES (Hewitt and Griggs, 2004) and reclip:century (reclip.ait.ac.at/reclip_century) is used to estimate the range of possible future developments (until the end of the 21st century) under the SRES A1B (Nakicenovic et al., 2000) emission scenario.

In all investigations, **observational data** is required to train QM properly. To derive climate change information on larger areas (local district of Murau) a gridded dataset (1 km grid spacing), provided by ZAMG (Schöner and Cardoso, 2004) was used. Climate change analyses in catchment of Schöttelbach are based on the nearby meteorological ZAMG stations Murau, Oberwölz, Oberzeiring, Pusterwald, and Stolzalpe. To investigate the extension of QM onto sub-daily scale eight representative (20 years of high quality observation) stations from Styria were selected from the ZAMG database.

WP6: Understanding and managing future behaviour

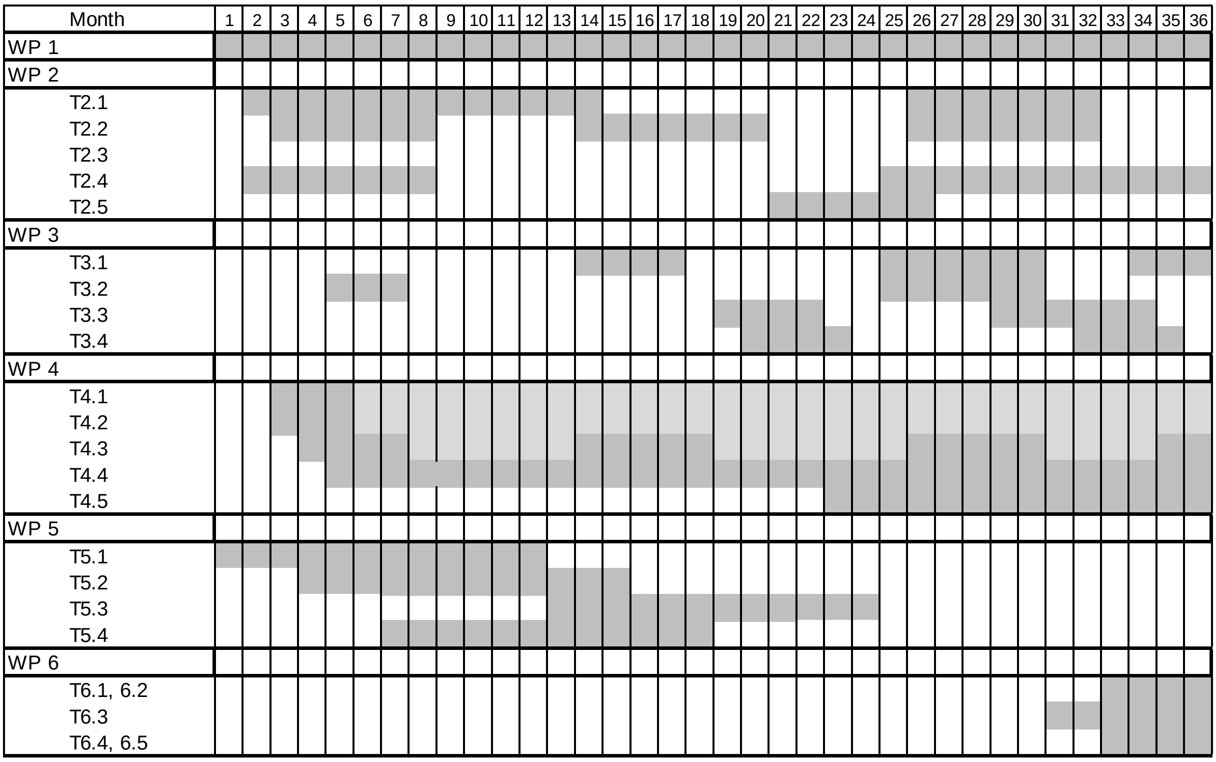
Aim of this work package was to integrate the results in a statistical precipitation – runoff – sediment yield model to allow an extrapolation of sediment transport to future scenarios of modified precipitation. Results were cross-checked with local sediment availability and sediment input from slopes and tributaries. Possible mitigation measures were discussed with authorities and local stakeholders.

For describing the sediment transport in the Schöttlbach numerical simulations were performed using the **1D model TomSed** (Chiari et al. 2010). The model was calibrated based on measured data and validated by modelling the deposited sediment volume in the retention basin in 2013.

7 Arbeits- und Zeitplan

The approximate final work schedule is summarized in the Gantt diagram below. However, it has to be stated that many tasks could not be clearly separated from each other. In reality, the Uni Graz and TUG partners worked in fact most of the time at almost all work packages. This is particularly valid for WP2 and WP3, in which we could not strictly adhere to the proposed work plan. Due to initial problems that had to be solved, parts of the field work tasks were achieved later than expected.

The only WP which was clearly separated from the others was the "future precipitation" part of the Wegener Center. Due to personnel problems mentioned before, this task also took longer than expected, however without negative effects on the rest of the project.



8 Publikationen und Disseminierungsaktivitäten

Publications

- Stangl, J. Rascher, E. & Sass, O. (in press): Comparative analysis of sediment routing in two different alpine catchments. In: Beylich, A.A., Dixon, J.C., Zwolinski, Z. (eds.): Source-to-sink fluxes in Undisturbed Cold Environments. Cambridge: University Press, in press, out in Nov 2015.
- Harb, G.; Schneider, J.; Sass, O.; Stangl, J.: Sedimentfracht und Klimawandel in alpinen Einzugsgebieten (ClimCatch). - in: Technischer und organisatorischer Hochwasserschutz - Bauwerke, Anforderungen, Modelle (2013), S. 297 – 305 Dresdner Wasserbaukolloquium; 36
- Schneider, J.; Sass, O.; Gobiet, A.; Harb, G.; Heinrich, G.; Stangl, J. (2013): ClimCatch - Sedimentfracht und Klimawandel in alpinen Einzugsgebieten, Zeitschrift für Wildbach-, Lawinen-, Erosions- und Steinschlagschutz, Journal for Torrent, Avalanche, Landslide and Rock Fall
- Schneider, J.; Redtenbacher, M.; Harb, G.; Sass, O.; Stangl, J. (2014): Flussmorphologische Prozesse in einem Wildbach-Einzugsgebiet – das Projekt ClimCatch. Korrespondenz Wasserwirtschaft 7(5): 278-284.

Publications in progress

- Stangl, J., Oberlechner, M., Harb, G., Sass, O., Schneider, J.: Using improved sediment impact sensors to assess bedload transport in an alpine torrent. Earth Surface Processes and Landforms Special Issue; submission in Dec 2015
- Stangl, J., Harb, G., Sass, O., Schneider, J.: Erosion, transport and deposition: Interaction of torrential processes in the Schöttlbach catchment (Austria). Geomorphology, to be submitted in 2016

Presentations/proceedings at conferences and external events

- Schneider, J.; Harb, G.; Sass, O.; Stangl, J.: Determination of sediment transport processes in a highly erodable Alpine catchment. - in: International workshop: Monitoring Bedload and Debris Flows in Mountain Basins. Bolzano, Italy: 10.10.2012 (Poster)
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Project workshops

- Kickoff-meeting 27.03.2012, TUG Institute of Hydraulic Engineering and Water Resources Management, attendants: members of all project partners, DI Gerhard Baumann (WLV-Steiermark), Günther Bischof (mayor of Oberwölz), DI Robert Schatzl (FA19A-Wasserwirtschaftliche Planung und Siedlungswasserwirtschaft- Hydrografie).
- Intermediate meeting 29.01.2013, KFU Institute of Geography and Regional Science, attendants: KFU (Sass, O., Stangl, J.), TUG (Schneider, J., Harb, G.), DI Gerhard Baumann (WLV-Steiermark).
- Intermediate meeting 05.02.2013, Gebietsbauleitung (GBL) Steiermark West Scheifling: KFU (Stangl, J.), TUG (Schneider, J., Harb, G.), WLV-GBL-Steiermark West (DI Max Pöllinger, DI Stefan Fieger).

- Intermediate meeting 02.07.2013, KFU Institute of Geography and Regional Science, attendants: KFU (Sass, O., Stangl, J.), TUG (Schneider, J.,Harb, G..), Wegener Center (Gobiet, A. , Heinrich,G.).
- Intermediate meeting 17.03.2014, KFU Institute of Geography and Regional Science, attendants: KFU (Sass, O., Stangl, J.), TUG (Schneider, J., Redtenbacher, M.), Wegener Center (Gobiet, A. , Heinrich,G.).
- Intermediate meeting 06.05.2015, KFU Institute of Geography and Regional Science, attendants: KFU (Sass, O., Stangl, J., M. Oberlechner), TUG (Schneider, J.,Harb, G..),
- Final meeting 11.5.2015, Oberwölz: attendants: KFU (Sass, O., Stangl, J., Oberlechner, M.,), TUG (Schneider, J., Harb G., Redtenbacher, M., Schäfauer D.), Wegener Center (Heinrich, G.), Mayor of Oberwölz (Johann Schmiedhofer), representative of WLV, approx. 10 stakeholder and residents.

Annex

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