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State of geomorphological research in 2022

Book of Abstracts

May 18 – 20, 2022 in Horní Bečva (Czech Republic)

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## State of geomorphological research in 2022

Forthcoming event is organised bilaterally and should be perceived as the common conference of both Czech Association of Geomorphologists and Association of Slovak Geomorphologists. Considering the 2-year pause due to the world pandemics, it will be a round anniversary (20<sup>th</sup> in the line of meetings started in 2000) for the Czech Association of Geomorphologists, and it will also be the 11<sup>th</sup> biennial meeting for the Association of Slovak Geomorphologists.

The thematic scope of the conference traditionally covers all geomorphological disciplines as well as those of related geosciences. The conference will culminate with a whole-day field trip. We hope the conference will be interesting and inspiring and we are looking forward for your valuable contributions.

## Organizing committee

RNDr. Veronika Kapustová, Ph.D.  
Mgr. Radek Tichavský, Ph.D.  
RNDr. Václav Škarpich, Ph.D.  
prof. RNDr. Karel Šilhán, Ph.D.  
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Mgr. Lukáš Vaverka

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ve dnech 18.–20. května 2022

v Horní Bečvě

doc. RNDr. Pavel Chromý, Ph.D.  
prezident České geografické společnosti

V Praze dne 25. dubna 2022

# Timetable

## Preconference workshop

	<b>Tuesday May 17, 2022</b>
12:00–13:00	<b>Arrival/accommodation of the participants</b>
13:00–17:00	<b>Field survey and data acquisition on the Bečva River</b>
17:00–19:00	<b>Data processing</b>
	<b>Wednesday May 18, 2022</b>
9:00–12:00	<b>Data processing and modelling, presentation of the results</b>

## Wednesday May 18, 2022

9:00–13:00	<b>Registration</b>
13:00	<b>Conference opening, invited lectures</b>
15:30	<b>Oral presentations</b>
17:00	<b>Poster session</b>
19:00	<b>Plenary meeting of the Czech Association of Geomorphologists</b>
19:00	<b>Plenary meeting of the Association of Slovak Geomorphologists</b>

## Thursday May 19, 2022

8:30–17:00	<b>Oral presentations</b>
17:00	<b>Poster session</b>
20:00	<b>Closing ceremony, Festive dinner</b>

## Friday May 20, 2022

8:30–17:00	<b>Oral presentations</b>
17:00	<b>Poster session</b>
20:00	<b>Closing ceremony, Festive dinner</b>

**Thursday, 22 of March**

## Human intervention and flood events as key factors affecting the recent degradation of the Hornád River

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Keywords: meandering; river degradation; multi-temporal analysis; flood event; the Hornád River

At the turn of the 19th and 20th century, the Hornád River in Slovakia in its middle reach was typical by passing the Hornád basin, typical by several levels of river terraces (Michaeli, 2001), well-developed floodplains and water-gaps. The wide floodplains were characteristic by free meanders which had been in the 20th century affected by human interventions, peaked in the 50s. The anthropogenic impact resulted in channel shortening and narrowing, river sinuosity lowering, erosion-accumulation processes decreasing and free meanders loss. Additionally, the long-term discharge reduction had caused simplification of channel planform in stream sections without or with minimal anthropogenic impact. This trend was later abruptly by the flood event series in 2004, 2008 and 2010. The flood events were also documented as an important factor in a morphological change in the lower part of the Hornád River in Hungary (Kiss and Blanka, 2011; Kiss and Blanka, 2012). Environmentally changed conditions (anthropogenic impact and floods) on the 72 km long channel planform of the meandering Hornád River in Slovakia were observed on three types of river segments (natural, regulated, water-gap) by seven sets of data, including the second and third military survey and five orthophoto mosaics and aerial photos (1949, 1986, 2002, 2013, 2016). The Hornád River in the pre-regulation period was represented by a natural meandering river planform (45.8%) with a high occurrence of in-channel landforms, where the lateral bar area prevailed. At present, due to the simplification of the river channel planform, only 26% of the river segments with ongoing natural erosion-accumulation processes and the last two locations with free meanders on the middle reach of the Hornád River remained.

**Acknowledgement:** *This research was supported by the Science Grant Agency (VEGA) of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (02/0086/21).*

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# Identification of benches and ledges within the braided-wandering floodplain formation

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Keywords: braided-wandering river; floodplain evolution; benches; ledges; gravel-bed river

The Belá River in the north part of Slovakia represents a braided-wandering river system (Kidová et al., 2016) with repeatedly destroying and re-forming floodplain, as a result of lateral shifting of an active river zone of braided rivers (Haschenburger and Cowie, 2009). These processes depend on flood events and a large volume of sediment transportation. Benches as unstable (Erskine and Livingstone, 1999), fine sediment storage (Kemp, 2004; Vietz et al., 2005a, 2005b) are formed by flood events (Webb, Erskine a Dragovich, 2002) in the margin of the active river zone of the Belá River and they are also destroyed by another even larger flood events (Erskine a Peacock, 2002). However, in the last decades, we are able to observe changes in the magnitude of flood events and the volume of sediment transportation of the Belá River (Kidová, et al., 2016b). The changes caused a simplification of the river planform, leading to a better-developed mature floodplain. The benches in these parts are a well-preserved component of the floodplain. Moreover, local incision of the river channel led to more-level floodplain development with benches set into them. While incision forbids to another floodplain development results of its mutual effect with flood events are ledges, as a level of bank erosion (Lehotský et al., 2015). Following previous research supplemented by new field surveys, we are focused to study of river floodplain evolution of the Belá River. In the end, it will be possible to formulate a process-oriented hypothesis of the recent lateral and vertical development of the floodplain.

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## **Coseismic Slope Failures Due to 2009 $M_w$ 6.2 Eq Near Poas, Costa Rica and Their Relevance for Landslide Research in Outer Western Carpathians**

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Keywords: Co-seismic landslides, prehistoric earthquakes, Poas Volcano, Outer Western Carpathians

Co-seismic landslides belong among the most serious secondary effects of destructive earthquakes and are considered as an environmental measure of the particular earthquake's intensity (Michetti et al., 2007). Correct identification and differentiation of respective rainfall and co-seismic prehistoric landslides may therefore significantly improve identification and characterization of particular paleoearthquakes and the seismic hazard assessment. The paper focuses on characterizing source areas of the primary co-seismic rotational landslides at Poas Volcano (Costa Rica), triggered on 8 of January 2009 by the  $M_w$  6.2 Cinchona earthquake with the hypocentral depth of 4.5 km (Mendez et al., 2009). We aim to highlight the possible morphometric parameters for recognizing their paleoseismic origin. Our direct field observation revealed that the primary rotational landslides had undergone extremely high mass mobilization resulting in high depletion rate of the source areas even at relatively moderate slopes near their upper edges. Further, we applied these outcomes onto an alternative area and searched for similar landforms in the flysch belt of the Outer Western Carpathians in the regions that are situated close to recently recognized active faults with other evidence of the co-seismic effects and which might represent earthquake-triggered landslides.

Méndez J, Soto GJ, Zamora N, Vargas A, Sjöbohm L, Bonilla E, Barahona D, Solís L, Kycl P, & Baroň I (2010) Geología de los deslizamientos provocados por el terremoto de Cinchona, Costa Rica ( $M_w$  6,2; 8 de Enero del 2009) en la ruta 126 (Varablanca – San Miguel). Xº Congreso Nacional de Geotecnia San José, Costa Rica – Agosto 2009.

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# DEPOSITION AND MOBILIZATION OF MICROPLASTICS IN A LOW-ENERGY FLUVIAL ENVIRONMENT

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Keywords: microplastic, hotspots, fibre, downstream changes, in-channel forms, deposition

The emission of organic and inorganic pollutants and plastics through improperly treated garbage and wastewater is a major environmental issue. Many studies focus on this increasingly significant environmental risk, which affects rivers, lakes, and seas. Plastics emitted into the environment (e.g., synthetic clothing, tires, packaging, PET bottles, industrial and electronic waste) are exposed to various chemical and physical impacts resulting in their fragmentation. These processes result in microplastics ( $\leq 5$  mm), which can be fibres, spheres, shreds, and fragments. These particles are transported along with the natural sediments in rivers, and their behaviour is probably similar to the natural sediments transported by the river, however, no precise data exist on it.

Therefore, our aims are not only to quantify the microplastic pollution in fluvial sediments, but we also aimed to investigate the hydrological and geomorphological factors that affect their deposition. The sediments of the Tisza River (Central Europe) and its main tributaries were sampled in 2019 (Kiss et al. 2021) and 2020 (Kiss et al. 2022) from its source in Ukraine to its Danubian confluence in Serbia. Fine-grained (clay, silt) and coarse-grained (sand, gravel) sediment samples were collected from various in-channel forms (e.g., point-bars, side-bars, and sediment sheets). After laboratory extraction, the microplastic content of the sediments was counted using a microscope.

The microplastics in the sediment samples were mostly fibres (98%), referring to the discharge of improperly treated wastewater into the river system. In 2020 the mean microplastic content of the Tisza's sediments was  $1770 \pm 1329$  item/kg, whereas the sediments of the tributaries contained more microplastics ( $1885 \pm 1541$  item/kg). The microplastic pollution increased downstream, thus the Middle Tisza was the most polluted section, however, the Lower Tisza had lower numbers. The patchy characteristic of the pollution is well reflected by the fact, that both the minimum (Záhony: 237 item/kg) and maximum (Tiszadada: 6707 item/kg) contamination were measured in the Middle Tisza, Hungary. Contrary to our hypothesis, the fine-grained samples contained less microplastic contamination (mean:  $1406 \pm 788$  item/kg) than the coarse-grained samples ( $2226 \pm 1735$  item/kg).

Among the three studied in-channel forms, the point-bars were the most polluted ( $2049 \pm 1218$  item/kg), while the average pollution of the side-bars ( $1692 \pm 1335$  item/kg) and sediment sheets ( $1584 \pm 1464$  item/kg) were lower by 18% and 23%, respectively. Besides, the microplastic pollution of the various forms shows different downstream changes. We recommend to collect samples from side-bars, which are common forms in rivers, and they reflect the average values of the microplastic content of river sections. Sediment sheets are the least favourable forms for microplastic sampling, as their longitudinal variations are different than of the other forms or the section averages, though, if the sampling aims to evaluate the microplastic content (in suspended form) of a falling limb of a flood, the sediment sheet is a perfect choice.

The comparison between the 2019 (Kiss et al. 2021) and 2020 data showed that by 2020, the number of microplastics in the sediments of the Tisza had decreased by 30%, while in the sediments of the tributaries, it decreased even more (by 48%). The former pollution hotspots have

been emptied, and the plastic-contaminated sediments have been rearranged. Therefore, long-term monitoring is needed to understand the spatio-temporal distribution of microplastics in a fluvial environment.

Kiss T, Fórián Sz, Szatmári G, Sipos Gy, (2021) Spatial distribution of microplastics in the fluvial sediments of a transboundary river – A case study of the Tisza River in Central Europe, *Science of the Total Environment* 785, 147306

Kiss T, Gönczy S, Nagy T, Mesaroš M, Balla A, (2022) Deposition and Mobilization of Microplastics in a Low-Energy Fluvial Environment from a Geomorphological Perspective. *Applied Sciences* 2022, 12, doi:10.3390/app12094367.

# Temporal Relationship of Deglaciation Phases and Palaeodischarges on the Catchment of River Maros, Central Europe

Tamás Bartyik<sup>1\*</sup>, György Sipos<sup>1</sup>, Dávid Filyó<sup>1</sup>, Tímea Kiss<sup>1</sup>, Petru Urdea<sup>2</sup>, Fabian Timofte<sup>2</sup>

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Keywords: OSL dating, River Maros deglaciation, luminescence sensitivity, sediment delivery

River Maros has one of the largest alluvial fans in the Carpathian Basin. On the surface of the fan several very wide, braided channels can be identified, resembling increased discharges during the Late Glacial. In our study we investigated the activity period of the largest channel of them, formed under a bankfull discharge three times higher than present day values. Previous investigations dated the formation of the palaeochannel to the very end of the Pleistocene by dating a point bar series upstream of the selected site (Kiss et al. 2014). Our aim was to obtain further data on the activity period of the channel and to investigate temporal relationships between maximum palaeodischarges, deglaciation phases on the upland catchment and climatic amelioration during the Late Pleistocene. The age of sediment samples was determined by optically stimulated luminescence (OSL). The investigation of the luminescence properties of the quartz extracts also enabled the assessment of sediment delivery dynamics in comparison to other palaeochannels on the alluvial fan. OSL age results suggest that the activity of the channel is roughly coincident with, but slightly older than the previously determined ages, meaning that the main channel forming period started at  $13.50 \pm 0.94$  ka and must have ended by  $8.64 \pm 0.82$  ka (Kiss et al. 2015). This period cannot directly be related to the major phases of glacier retreat on the upland catchments, and in terms of other high discharge channels only the activity of one overlaps with a major deglaciation phase at ~17–18 ka (Ruszkiczay-Rüdiger et al. 2016). Based on these, high palaeodischarges can be rather related to increased Late Glacial runoff, resulted by increasing precipitation and scarce vegetation cover on the catchment. Meanwhile, the quartz luminescence sensitivity of the investigated channel refers to fast sediment delivery from upland subcatchments. Therefore, the retreat of glaciers could affect alluvial processes on the lowland by increasing sediment availability, which contributed to the development of large braided palaeochannels.

Kiss T, Sümeghy B, Sipos Gy (2014) Late Quaternary paleo-drainage reconstruction of the Maros River Alluvial Fan. *Geomorphology* 204, 49–60.

Kiss T, Hernesz P, Sümeghy B, Györgyövícs K, Sipos Gy (2015) The evolution of the Great Hungarian Plain fluvial system - Fluvial processes in a subsiding area from the beginning of the Weichselian. *Quaternary International* 388, 142–155.

Ruszkiczay-Rüdiger Zs, Kern Z, Urdea P, Braucher R, Madarász B, Schimmelpfennig I, ASTER TEAM (2016) Revised deglaciation history of the Pietrele-Stânișoara glacial complex, Retezat Mts, Southern Carpathians, Romania. *Quaternary International* 415, 216–229.

# Chronology and Morphology of Rock Glaciers in the Western Tatra Mts., Western Carpathians

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Keywords: rock glacier, exposure dating, Schmidt hammer test, morphometry, Western Tatra Mts.

Relict rock glaciers are significant indicators of paleoclimate and permafrost conditions and their morphology reflects the development of mountain slopes after the deglaciation. The dating of rock glaciers therefore contributes to a better understanding of the post-glacial development of high mountain environments. In this paper we present initial results of cosmogenic <sup>10</sup>Be exposure and relative-age dating of five rock glaciers in the Western Tatra Mts. Three to six rock samples were collected for the cosmogenic nuclide dating on investigated rock glaciers and the Schmidt hammer test was carried out on the same boulders (30 measurements per boulder). The weighted mean exposure ages for the sampled rock glaciers range from 11.9±0.4 ka in the Smutná Valley to 17.3±0.7 ka in the Spálená Valley whereas mean the R-values range from 37.7±4.8 (Spálená Valley) to 42.0±3.8 (Smutná Valley). The fronts of the rock glaciers extend to elevations of ~1370 to 1810 m a.s.l. indicating the lower boundary of discontinuous paleopermafrost. Younger exposure ages obtained in the north-facing valleys suggest later ice decay in shaded mountain slopes compared to the south-facing valleys. The cosmogenic data imply that rock glaciers in the Western Tatra Mts. developed during the Lateglacial period following the glacier retreat from the main valleys. Rock glacier stabilization in this region started around 15 ka and terminated at the turn of the Late Glacial and Holocene. The observed ages are consistent with the published exposure data from moraines and rock glaciers in the Tatra Mts.

*The research was supported by the GAUK project No. 1528119 (Morphology and age chronology of rock glaciers in the Western Tatra Mts.).*

# CGS Development Cooperation Project "Georgia 2021" - Assessment of Geological Hazards in the Kazbegi Area

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Keywords: development cooperation, Georgia, Caucasus, Kazbek, debris flow, landslides, hanging glacier, geological hazard

The Challenge Fund, as one of the components of the Czech-UNDP Partnership (<https://undp.cz>) between the Czech Development Agency and the UN Development Program, supported the CGS project called "Methodology for assessing the territory in terms of the danger of torrential currents using innovative technologies". The project was solved by CGS experts in engineering geology together with CGS experts in remote sensing. The role of partner organization has been accepted by the Georgian National Environment Agency (NEA) as the institution responsible for monitoring, assessing and mapping geological hazards in Georgia.

The general objective was to eliminate the dangers associated with the very frequent catastrophic slope movements, technically called debris flow, which cause serious socio-economic damage and loss of life, especially in the mountainous areas of Georgia. Geodynamic natural processes are very difficult to prevent, but it is possible to mitigate their consequences to avoid disasters and losses. This is mainly due to effective spatial planning with high-quality engineering and geological data. The project offered conceptual solutions for risk reduction and prevention. Georgia's traditional risk management system is rather reactive. That means to deal with the consequences of natural disasters and therefore requires significant recovery costs. The results of this cooperation have contributed to the improvement of spatial planning, which will lead to a reduction in remediation costs. This model study has also the ambition to serve as a model approach for other highland regions of Georgia.

The aim of the cooperation was to develop a harmonized methodology for geological risk assessment and to implement it in the activities of the partner organization NEA. The object of interest of the research was the surroundings of Mount Kazbek, which is historically known for the high frequency of catastrophic debris flows threatening strategic infrastructure. However, this area is also threatened by other geodynamic processes, such as: various types of slope deformations, floods or avalanches, etc. This relatively young 5,000 meters high volcano on the northern border of Georgia is covered by glaciers that are melting according to a global trend. Some of the tragic debris flows, for example from 2002 and 2014, were caused by the rupture of a mountain glacier. It turns out that climate change in such glacial areas can increase the susceptibility to geodynamic processes.

Two expeditions to the Kazbegi area were organized as part of this international project. In addition to theoretical and field workshops, CGS experts managed to visit and document several hard-to-reach alpine areas in the Kazbegi region. The most important results of the project are in particular:

1. a series of maps of the main geological hazards of the Kazbegi area such as hanging glaciers and rock walls prone to collapse and activating debris flows, sources of transportable material, previously documented debris flow paths, glacial lakes threatening to rupture;



2. the interactive Flow 2020 web tool, which assists in the assessment of geological risks;
3. joint Czech-Georgian Scientific Publication (Dostalík et al. 2022\*);
4. a series of theoretical and field workshops in which know-how in the field of geological risk prevention was transferred;
5. stimulation of cooperation between CGS and NEA.

The project was very positively evaluated both by NEA, which appreciated the amount of work done in a very short time, as well as by the sponsoring organization Czech-UNDP Partnership for the SDGs, which emphasized the thoroughness and complexity of processing the results and very good communication by CGS.

This year, we would like to build on the successful cooperation with a new project proposal dealing with the issue of geological hazards in the Khevsureti region in eastern Georgia.

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Dostalík M., Novotný J., Jelének J. (2020a): Koncepční inženýrskogeologický model na příkladu hodnocení geologického hazardu oblasti horského masivu Kazbek –Džimara. In Jana Frankovská, Martin Ondrášek: Inžinierska geológia 2020. ISBN 978-80-227-5014-1

Dostalík M., Novotný J., Kurtsikidze O., Gaprindashvili G. (2020b): Catastrophic Debris Flows in Kazbegi Mountain Area, Georgia – Use of Available Free Internet Information as a Source to Generate Conceptual Engineering Geological Model. – Lowland Technology International Journal 22, 1, pp. 48-63. ISSN 1344-9656

Dostalík M., Novotný J., Gaprindashvili M., Kurtsikidze O., Gaprindashvili G. (2022\*): Examples of infrastructure objects failure and hazard in terms to the engineering geological model importance – Kazbegi municipality, Georgia, IAEG XIV Congress 2022 in Chengdu, China (\*in review proceedings)



# DEGLACIATION IN KAZBEGI HIGH MOUNTAIN REGION IN GEORGIA AND ITS IMPACT ON THE ACTIVATION OF CATASTROPHIC DEBRIS FLOWS

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Keywords: Caucasus, Kazbek, Debris flow, Deglaciation, Hanging glacier, Geological hazard

Alpine glaciers have been melting around the world due to climate change. With the retreat of these glaciers, certain parts of them get into a very unstable position on steep slopes. Dangerous hanging glaciers with a high susceptibility to collapse are generated this way. Likewise, the instability of the rock walls originally supported by glaciers increases. Research on this topic was conducted in the High Caucasus in the high mountain region of Kazbegi in Georgia. By comparing historical maps, it was possible to demonstrate the intensity of glacier retreat in this area, which is historically known for the frequent catastrophic debris flows initiated by the collapse of a hanging glacier. It turned out that in some glacial valleys of the Kazbek massif debris flows are produced much more often than in the others (Dostálík et al., 2020a).

Currently, the greatest risk is posed in the Devdoraki Glacier Valley, where catastrophic debris flows have been regularly activated (Dostálík et al., 2020b). A map of the Devdoraki Glacier Valley and its surroundings was compiled by field expeditions, including drone survey combined with an analysis of the available satellite data. The map involves the extent of all recorded rock and glacial avalanches at the this valley closure and simultaneously presents locations with increased debris flow activity. It is clear from the map that these areas clearly correspond to the areas of mapped hanging glaciers as the source of debris flow phenomena.

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Dostálík M., Novotný J., Jelének J. (2020a): Koncepční inženýrskogeologický model na příkladu hodnocení geologického hazardu oblasti horského masivu Kazbek –Džimara. In Jana Frankovská, Martin Ondrášek: Inžinierska geológia 2020. ISBN 978-80-227-5014-1

Dostálík M., Novotný J., Kurtsikidze O., Gaprindashvili G. (2020b): Catastrophic Debris Flows in Kazbegi Mountain Area, Georgia – Use of Available Free Internet Information as a Source to Generate Conceptual Engineering Geological Model. – Lowland Technology International Journal 22, 1, pp. 48-63. ISSN 1344-9656

# Development and recent dynamics of rockslide in the Hercynian orogeny (the Rudohorský potok basin; the Hrubý Jeseník Mts.)

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Keywords: Rockslide, dendrogeomorphology, structural compass measurements, kinematic analysis, Schmidt-hammer, the Hrubý Jeseník Mts.,  $I_t$  index.

A rockslide in the Hrubý Jeseník mountains was studied to unravel its development and recent activity. Four methods were applied: dendrogeomorphologic dating, rock hardness measurement using Schmidt-hammer, structural compass measurement, and kinematic analysis. For the purposes of dendrogeomorphologic dating, reaction wood, eccentric growth and sudden growth suppression of 43 Norway spruces (*Picea abies* (L.) Karst.) were used. The Schmidt-hammer was used to measure hardness of rocks of rock walls and colluvial accumulations. Structural compass measurements were used to reveal the strike and dip direction of joints and foliation planes of the landslide slope. Kinematic analysis was performed to reveal possible slope predisposition to planar failures, wedge failures and toppling. According to the results, the rockslide is in its dormant state. Despite its dormancy, movements of shallow-bedded blocks were recorded as well as probable movements of a deeper character of a larger landslide unit. Movements are indistinct, probably within mm to cm. The landslide blocks move by sliding in the direction of the foliation inclination, toppling of the blocks is present as well, and rotational character of rock block movement is also probable. Overall, the surface of the landslide body is considerably weathered evenly over its entire surface. It results in rock walls copying tectonic faults, and numerous rock accumulations originating from the rockfalls, covering the rest of the slope surface and accumulating at its base. In case of dendrogeomorphology, it was the first use of this dating method on almost bare rock surfaces. It turned out that it is possible to detect movements of rock blocks, but at least two trees per block are needed alongside with evaluation of their spatio-temporality, whether the trees react logically on the landslide blocks/units. Moreover, it is suitable to use a three-year period during which the trees on the blocks could react. The result of this work offers a unique view of the only landslide examined so far in the Hrubý Jeseník mountains and tests/complements the methodological procedures for dendrogeomorphologic dating of these specific slope deformations.

# Verification of the "Čirá - Kopanina" fault zone using morphostructural analysis and geophysical methods

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Keywords: Krušné hory Mts, fault zone, active tectonics, digital elevation model, morphostructural analysis, geophysical survey, electrical resistivity tomography

The aim of the research is to verify the existence of the "Čirá - Kopanina" fault zone in the western part of the Jindřichovice Highlands (Krušné hory Mts), which appears to be a potential source area for earthquake swarms at the boundary of the Cheb Basin and the Krušné hory crystalline complex. It is a possibly seismically active (seismogenic) structure and therefore a potentially active tectonic area. At the same time, it is a structure that is partly manifested on the surface, i.e. in the morphology of the terrain. The work builds on research already carried out in the area and aims to validate the hypothesis of a relatively less known fault structure that could predispose tectonic activity in the area. Thus, the research is focused on (i) characterizing the manifestations of the studied tectonic structure in the landscape by means of morphometric and morphostructural analyses of the area and (ii) subsequent verification of its occurrence directly in the field using geophysical methods. Morphometric and morphostructural analyses of the detailed digital elevation model (DMR 5G) were chosen as the basic methods of investigation, on the basis of which survey sites were selected for subsequent verification of the course of the searched fault zone using applied geophysical methods. Electrical resistivity tomography was selected as the primary method of geophysical survey as it is commonly used to verify the fault zones course. On the selected profile, the geoelectrical survey will also be complemented with seismic and gravity measurements. Preliminary results of the DEM analyses and initial geophysical measurements suggest that the investigated fault could indeed predispose the morphotectonic evolution of the area.

# Transport, Retention and Geomorphic Impact of Large Wood in a Meandering River

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Keywords: meandering river, large wood, river morphodynamics, Odra

Large wood (LW) is an integral part of rivers that supports habitat heterogeneity and biodiversity by its impact on flow hydraulics, channel morphodynamics and sediment transport (Gurnell et al., 2002). The majority of the research related to the geomorphic impact of LW was realised in wadeable channels, and we lack complex knowledge of the processes related to LW from large meandering rivers wider than the height of riparian trees (Wohl, 2017). This contribution presents the predictors of the interannual variability of the LW and its mobility during the 2016-2021 period in a 3.65 km long active meandering reach of Odra (Oder), Czechia (Galia et al., in review). We employed a repeated complete LW inventory and monitoring of tagged LW pieces. We found interannual variations in LW volumes (8.3-9.2 m<sup>3</sup>/ha), which did not allow us to develop any robust single model predicting LW volumes at the scale of meander bends (n = 14). Characteristics derived from riparian stands were found as important predictors of LW volumes. However, both positive and negative correlations between these characteristics and LW volumes were observed, which likely points to the complex recruitment-retention role of riparian stands. The dimensions of LW (i.e., length and diameter) together with the initial anchorage of the LW (i.e., its partial burial in sediments or racking by living trees or other LW) were determined as predictors of the LW mobility. The ratio between the LW channel width and the LW length was of greater importance for narrower channel segments, which points on some degree of equimobility of LW in the widest channel sections independently on the LW length. We also observed that local channel morphodynamics can be driven by the presence of single but stable LW. On the other hand, the noticeable spatiotemporal variation in jams between 2016 and 2021 was not only a product of the (suggested) frequent transport of relatively short LW pieces and related destruction of jams but also of the burial of jams in fine sediments during the process of channel migration. These field observations demonstrate the complex relationship between the channel morphodynamics and the biogeomorphic impact of vegetation in meandering rivers.

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# Spatiotemporal Dynamics of Gravel Bars and Vegetation Cover of Two Carpathian Rivers

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Keywords: river, gravel bar, vegetation cover, channel heterogeneity

Carpathian gravel-bed rivers are characterized by the abundance of gravels and when naturally behaved, they form a braided river system along with the formation of gravel bars. Most of the Carpathian gravel-bed rivers were regulated or managed in a way that changed the course of the river to a single-threaded channel with weirs and, in some cases, they were dammed by valley dams (Škarpich et al., 2020). These changes affect the sediment regime (sediment deficits, limited discharges) and thus the formation and behaviour of the gravel bars. Examples are including weir induced occurrence of gravel bars, overgrown with vegetation and a general decrease of new gravel bars (Hajdukiewicz and Wyżga, 2019).

The aim of our research is to evaluate the spatial and temporal changes of the gravel bars in two Czech Carpathian rivers: the Olše (73 km) and the Ostravice (downstream of the valley dam, 46 km) in 20 years (2000–2020), with a focus on the progression of the succession of vegetation cover compared to hydrological events, and the possible influence of the heterogeneity of the river channel on river bar occurrence including sinuosity, relative channel width, weirs, and tributaries. We used 9 orthophotos, as well as hydrological data from the studied period, and ArcGIS Pro software for mapping and spatial analysis.

In the study period, the reference year of 2000 was represented by a relatively high percentage of the total unvegetated bar area in both rivers (the Olše = 58%, the Ostravice = 46%), which shows the probable influence of major floods in 1997 and another flood event in 1999. Vegetation cover progressively increased from 2003 to 2009, when it reached 81,8% in the Olše and 92% in the Ostravice river. Subsequently, in year 2012, vegetation cover decreased to 62,2% in the Olše and 68% in the Ostravice, as a result of major floods in 2010. Vegetation continued to decrease in 2014 (the Olše = 53,2%, the Ostravice = 54,3%) due to another flood event that occurred shortly before the aerial images were taken. This year we also observed the highest occurrence of unvegetated gravel bars (the Olše = 13,3%, the Ostravice = 14,1%). The following years showed a significant increase in total vegetation cover in the bars (the Olše = 87,1–93%, the Ostravice = 84,5–96,4%) and the occurrence of completely vegetated bars, particularly in the Ostravice which is regulated by a valley dam (the Olše = 23,5–36,1%, the Ostravice = 26,8–58,3%). From the channel heterogeneity analysis, only the relative width of the channel and, in some cases weirs and tributary locations could be associated with fluctuations in the occurrence of the gravel bar throughout the studied period. The sinuosity index per km of the river showed only a few fluctuations in the case of the Olše river and very stable values in the case of Ostravice. Generally, the areas with the highest average bar areas were the locations of relatively wider channels, not dammed by weirs or other grade control structures, and in some cases, there was evident support by sediment flux from a tributary.

Our findings suggest the importance of major floods in the dynamics of the gravel bar vegetation, as well as significant progress in the vegetation cover on bars over the past few years. Although the gravel bars are associated with inducing occurrence in the vicinity of weirs, the loca-

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# Geomorphological Approach to Identification of Flood Hazard Hotspots Within Marginalized Roma Communities in Slovakia

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Keywords: flood hazard, height above nearest drainage, downslope distance to stream, Roma, segregation, Slovakia

Climate change has become one of the most acute problems of human society in recent decades. One of its manifestations is the worldwide increase in the intensity and frequency of extreme hydrological events, such as floods or droughts, which pose a direct threat to affected communities. In Slovakia, a significant number of settlements lie close to rivers and are therefore potentially exposed to flood hazard. Their local character also determines the uneven distribution of the threat they pose to individual communities. In addition, the unevenness of flood risk is reinforced by the different resilience and coping capacities of different social groups. Processes such as spatial segregation can then affect an excluded community twice. On the one hand, by pushing them into otherwise uninhabited floodplains, which are more susceptible to flooding and, on the other hand, by increasing their flood vulnerability. A prime example of spatial segregation in Slovakia are marginalised Roma communities (Rochovská a Rusnáková 2018). While the aspect of their increased vulnerability has been addressed in several studies (Filčák 2012; Harper, Steger, a Filčák 2009), the natural hazards that their environment poses to them has not been addressed so far. This presentation therefore focuses on the assessment of the flood hazard in those communities, based on their distances to nearest drainage, namely height above the nearest drainage (Rennó et al. 2008) and downslope distance to stream. Since the extent of the inundation zone is flow-dependent, the interpretation of the same distance differs for e.g., a mountain stream and a river of continental significance. We therefore attempted to minimize these differences by classification of streams based on flow accumulation. The geographic representation of marginalized Roma communities in the centroid form was derived from the buildings layer of the ZB GIS. In this way, we were able to automatically extract 120 out of 697 concentrations of segregated Roma population mentioned in the Atlas rómskych komunít (2019), which contains information only at the level of the cadastral territory of the municipality. By comparing this representation with the layer of flood occurrence in Slovak towns and villages between 1996-2019, we were able to identify hotspots of flood hazard within marginalised Roma communities, which will be addressed in future research.

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## Local Geomorphological Factors Influencing Flood Hazard, Lower Tisza, Hungary

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Keywords: flood hazard, local factors, aggradation, channel narrowing, riparian vegetation, levee lowering

Besides catchment-scale processes, various local processes influence the peak flow level, however, they are often neglected in flood management. The aim of our study is to analyse those local geomorphological processes that contribute to rising local flood levels in the regulated channel and on the artificially confined floodplain of the Tisza River, Hungary. Our goals were to evaluate the role of (1) cross-sectional channel changes, (2) overbank floodplain aggradation, (3) riparian vegetation changes on local flood level increases since the late 19th century and early 20th century; and (4) to assess the elevation changes of artificial levees.

Along the Lower Tisza (92 km) since 1931 the channel narrowed by 9% (max. 30%) and its cross-sectional area decreased by an average of 2% (max. 22%). These in-channel processes increased flood levels by an average of 13 cm (max. 134 cm). Simultaneously, the flood conveyance capacity of the floodplain decreased by overbank floodplain accumulation, which is 1.1 m in average (max. 2.6 m). The accelerated aggradation further increased the flood levels by 112 cm. The land-use of the floodplain also changed considerably (from meadows to forests). As the vegetation roughness (Manning's  $n$ ) increased from 0.048 to 0.11, it increased flood levels by 42 cm (Scenario A roughness increase: 10%) or 139 cm (Scenario B roughness increase: 30%) on average.

By overlapping these data, the results showed that since the 19th century river regulation works the actual flood level increased by an average of 175 cm (maximum = 350 cm) in the case of Scenario A and 272 cm (maximum = 443 cm) in the case of Scenario B. The latter is more consistent with the actual flood stage measurements.

As these processes are still active, further increase in the flood level could be expected. In addition, the height of artificial levees decreased by an average of 23 cm (max 75 cm). Therefore, some levee sections became more susceptible to overtopping during record high floods, especially along the eastern levee.

Based on this approach, local hydrological managers can identify the processes that contribute more to peak flow level increase at a given location, and determine the correct management actions at the correct locations, which could lead to decrease in local peak flow levels.



# The Impact of the River Training on the Multi-Thread River System as a Part of the Natura 2000 Protected Area

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Keywords: river management, morphology, hydraulics, multi-thread river, river training, Belá River

The results of the river training impact investigation deals with the evaluation of the morphology and hydraulic parameters of the Belá River belonging to the Natura 2000 protected area in Slovak Carpathians (Kidová et al. 2021). The most serious consequences of the river training related to the simplification of the river planform, the reduction of the geomorphic diversity (Kidová et al. 2016) of the in-channel landforms, as well as the reduction and loss of lateral connectivity (Lehotský et al. 2018) between the low flow channel and floodplain. Analysed hydraulic parameters before and after river training revealed an increased flow rate, increased values of shear stress, as well as water energy on all studied cross-sections. Identifying the main conflicts in the management of the Belá River by using an objective scientific approach contributed to revealing the negative consequences of the current engineering approach of stakeholders in the studied area. On the basis of these results, the authors of the study were officially asked to provide the results of this research for the needs of the Žilina Environmental Inspectorate within the administrative tort proceedings pursuant to § 90 para. 1 letter a) of Act no. 543/2002 Coll. in the matter of a change in the state of the watercourse, which should have occurred during the implementation of river training after the flood of 19 July 2018 in selected river reaches of the Belá River without the consent of the competent nature protection authority. The presented analyses could help in future management issues as well as in the more critical decision-making process in vulnerable and scarce braided river systems in the present when we are losing so many natural rivers by human decisions.

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# Activity of landslide processes in the area of Hřebečský hřbet

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Keywords: Hřebečský hřbet, dendrogeomorphology, landslides, cuestas

Slope movements are currently the main geomorphological factor and, in terms of their sudden and unpredictable activities, can cause not only material damage. Therefore, it is necessary to monitor and document these events. The activity of slope movements is historically known in the area of the Hřebečský hřbet, several recent landslide events even threatened the Hřebeč tunnel and a busy road. Thus, the study may also have a practical impact on the determination of landslide hazard and risk. Hřebečský hřbet is a typical example of a cuestas, thanks to which there are different manifestations of landslide activity on different slopes within one locality. Despite the same precipitation conditions, the geological structure and slope of the layers play a key role in the nature of the events. Based on dendrochronological methods were growth disturbances found, which can be read from the core of the annual ring of selected trees. The definition of mechanism of slope movement and the structure of the geological subsoil on differently oriented slopes can be based on the character of the events (duration, intensity, spatial extent, ratio of reaction wood). From the first slope with an orientation to the SE were taken 100 samples and confirmed 16 events in the last 60 years. The character of the landslides is mostly shallow and plastic on the layered faces. The M-W test confirmed that in landslide years there was an above-average amount of precipitation in 3-day and monthly intervals compared to the years without a recorded event, and the test did not confirm this in 1-day and 5-day intervals. The M-W test confirmed that in landslide years there was an above-average amount of precipitation in 3-day and monthly intervals compared to the years without a recorded event, and the test did not confirm this in 1-day and 5-day intervals. On the second slope with NW orientation were taken 74 samples and confirmed 4 events in the last 40 years. The character of the landslide and the spatial behavior is, in contrast to the first slope, deep and block in the middle layers. Different depth and internal structure were verified by ERT method. On this slope, the M-W test did not confirm any extreme precipitation fluctuations at the examined intervals. Although the detected events correspond to the general assumption of a specific type of landslide on differently oriented slopes, it is likely that some of the dated events are the result of the creeping movements themselves, which are also corresponding to the nature of the slope. The data obtained from this study can potentially help predict processes regarding landslide behavior in the past. This information can be compared with a number of values of extreme hydrometeorological or seismic indicators and established a most accurate relationship for them, which can be approximated in the future.

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# 3D Rockfall Modeling, Natural Hazard and Risk Assessment for Rockfall Protection in Hřensko (Czechia)

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Keywords: Rockfall, 3D modeling, Hazard, Risk, HY-STONE, Rockfall assesment, Dynamic Barriers, Hřensko (Czechia)

The Hřensko area (Czechia) is characterised by sandstone landscape with rock plateaus, deep canyons with several levels of steep cliffs, which forms favourable conditions for rockfalls. Šafránek (2016) describes several dozen rockfall events with volume  $\sim 1 \text{ m}^3$  per year here. Therefore, the rockfall barriers were installed in Hřensko area in 2015. These barriers are 4 m high and their total length is 2.5 km. However, many other rockfall events are situated in ares without rockfall monitoring and the damages of buildings and infrastructure are quite probable.

In these cases, the numerical simulations of rockfall trajectories are a standard procedure for evaluating rockfall hazards. For these simulations, corresponding software codes must be calibrated and evaluated based on field data. This study addresses 3D modelling of repeatable rockfall barrier tests, and risk determination in other readings of Hřensko.

The aim of this paper is to provide a knowledge base for researchers and practitioners involved in projects dealing with rockfall protection. And the results of rockfall barriers test should be considered by design engineers and could potentially lead to future improvements in the design of rockfall protection.

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# Linking Geomorphological and Archaeological Research at Geoarcheological Site Holedná Hill in Brno, Czech Republic

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Keywords: geoarcheology, geoheritage, cultural heritage, Bronze Age, environmental education, geotourism

The Holedná Hill (Brno, Czech Republic) can be considered an example of geocultural (or more precisely geoarcheological) site. It is important from the geomorphological point of view and it includes specific cultural and archaeological issues that are closely related to the geodiversity (especially anthropogenic landforms). The site is situated in the north-western part of the Brno City and represents the end of ridge above the deep incised Svatka Valley. Based on the analysis of LiDAR Data, unknown elongated structures were identified. The fieldworks proved the anthropogenic origin of these landforms (embankments composed of stones and small boulders, sometimes with shallow ditches along them). The structures symmetrically surround the dominant peak of the Holedná Hill. Consequently, an archaeological research was conducted. Based on the occurrence of Neolithic and Eneolithic localities in the vicinity, a similar age was estimated. Nevertheless, the radiocarbon dating of organic material confirms the age between 1200 – 1050 BC which refers to the Bronze Age. Until now, only the accidental occurrence of ceramics was found. The question is what the purpose of the structures on the Holedná Hill was: the hypothesis about the sacred place or abandoned unfinished fortress was formulated.

The Holedná Hill is also important from the geological point of view: the bedrock consists of Proterozoic rocks of the Brno massif (diorites with veins of metagabbros), the occurrence of remnants of a crust rich in iron has been noticed and the area is important thanks to the presence of specific hydrogeological features as well. Other cultural features are represented by historical border stones dating back to 16th Century. Moreover, the site has high relevance concerning the living nature (natural oak-beech forests, occurrence of protected species). The Holedná Hill also represents a traditional tourist and recreational background for Brno citizens thanks to the presence of forests and dense tourist network including basic tourist infrastructure. The new lookout tower complements the tourist attractiveness of the study area. These aspects represent a significant potential for the development of geotourism and environmental education. Based on the evaluation within the geomorphosite concept, proposals for further use are designed including those related to the legal protection of the natural and cultural heritage.

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## Human intervention and flood events as key factors affecting the recent degradation of the Hornád River

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Keywords: meandering; river degradation; multi-temporal analysis; flood event; the Hornád River

At the turn of the 19th and 20th century, the Hornád River in Slovakia in its middle reach was typical by passing the Hornád basin, typical by several levels of river terraces (Michaeli 2001), well-developed floodplains and water-gaps. The wide floodplains were characteristic by free meanders which had been in the 20th century affected by human interventions, peaked in the 50s. The anthropogenic impact resulted in channel shortening and narrowing, river sinuosity lowering, erosion-accumulation processes decreasing and free meanders loss. Additionally, the long-term discharge reduction had caused simplification of channel planform in stream sections without or with minimal anthropogenic impact. This trend was later abruptly by the flood event series in 2004, 2008 and 2010. The flood events were also documented as an important factor in a morphological change in the lower part of the Hornád River in Hungary (Kiss and Blanka, 2011; Kiss and Blanka, 2012). Environmentally changed conditions (anthropogenic impact and floods) on the 72 km long channel planform of the meandering Hornád River in Slovakia were observed on three types of river segments (natural, regulated, water-gap) by seven sets of data, including the second and third military survey and five orthophoto mosaics and aerial photos (1949, 1986, 2002, 2013, 2016). The Hornád River in the pre-regulation period was represented by a natural meandering river planform (45.8%) with a high occurrence of in-channel landforms, where the lateral bar area prevailed. At present, due to the simplification of the river channel planform, only 26% of the river segments with ongoing natural erosion-accumulation processes and the last two locations with free meanders on the middle reach of the Hornád River remained.

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# Geomorphic-Sedimentary Adjustment of a River Reach With Groynes to Channel Bypassing

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Keywords: Gabčíkovo Waterworks; spatio-temporal variability; groyne-induced bench; vertical accretion; conveyance; flood; Danube

The article is focused on the investigation of spatio-temporal variability of the vertical accretion thickness as the response of the Danube River reach to bypassing. Five groyne-induced benches (GIB) of the bypassed channel were developed after water diversion in 1992 and represent our study area. Their topography was created from LiDAR point cloud dataset and DEM models for three time spans (for original gravel surface, for surface before flood 2013, surface after flood 2013) were calculated and the allostratigraphic approach was applied on 548 drilling probes at five GIB cross-sections. Head, supra-platform, tail and back channel geomorphic units have been identified at each GIB. The accretion was influenced mostly by large flood events when the 100-yr contributed to the its total volume by almost 26%. The head geomorphic unit, as the main impact zone on the stream, exhibits the highest median values of vertical accretion in time and space. The median of the vertical accretion thickness does not decrease with height above mean channel water level and the thickness of accretion varied likely due to variability of the vegetation cover conditioning variable hydraulic conditions. The bend setting, lower radius of curvature, lower width-depth ratio, connectivity with side arm and well-developed alternate bench upstream conditioned higher vertical accretion of the benches and its slight migration downstream. Moreover, higher portion of the area was formed as backwater geomorphic unit. The comparison of sediment depth over time spans (22 and 20 years and a large flood event) allowed us to conclude that the it is spatially variable by individual GIB, however its sedimentation trend over time is the same.

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# Erosion Process and Abandonment as Main Drivers of Traditional Vineyards Degradation: A Case Study Vráble Viticulture District, Slovakia

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Keywords: erosion, deposition, erosion measurements, levelling method, vineyards, abandonment

We evaluated the effect of increased erosion events and decreased management on degradation of traditional vineyards near Vráble (Slovakia). For the erosion measurements we used poles height method, that uses vineyards poles as a passive marker. To assess the accuracy of the poles height method, we used the measurements on vineyard located on relatively flat area. The measurements were first performed between 2008 and 2011 (Lieskovský and Kenderessy, 2014) and repeated after 10 years in 2021.

To evaluate the degree of abandonment, we visited all 633 fields and mapped the land cover classes and management practices.

The erosion rates on ploughed vineyards were doubled in period 2010-2011, but the total soil loss decreased due to the increased deposition. The erosion rates on vineyard that has been hoed and later covered by grass did not change due to the protective effect of the grass cover. The land cover and management practices have been dramatically changed in last decade. Only 27.2% of vineyard area near Vráble is now tilled and potentially threatened by soil erosion. On the other hand, 35.7% of vineyards is abandoned and it seems that abandonment will also continue within next years. The results also show that the most significant factors causing the degradation of traditional vineyards is not soil erosion anymore, but decreasing management that leads to the abandonment.

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# Using Airborne Lidar Data for Detecting Anthropogenic Landforms in Poiplie Region

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Keywords: LiDAR, landscape palimpsest, Kiarov, Kováčovce, landscape archaeology, anthropogenic landforms

We present the use of Light Detection and Ranging (LiDAR) data for mapping the anthropogenic landforms in Kiarov and Kováčovce villages, located in Poiplie region. The benefits of LiDAR are the speed of data acquisition on a landscape scale, the quality of its surface data, and its ability to identify macro- and micro-topographical features that are otherwise undetected by terrestrial surveys. LiDAR is now used for detailed topographical research in many disciplines including geomorphology. The area of Slovakia is being scanned from 2017 at a resolution of 20–30 points per square metre and is scheduled to be completed by 2023.

For the interpolation of the LiDAR points to digital elevation model with resolution 25cm, we used points classified as ground and buildings. We applied the visualisation techniques based on a simple local relief model (Kokalj & Hesse, 2017) but we also added a local dominance to relief curvature representation and also added a combination of slope steepness and sky view factor to relief contrast visualisation (Lieskovský et al., in press). We visually identified the topographic signatures of geomorphic anthropogenic landforms and consulted our findings with historical maps and aerial images. We followed the anthropogenic landform ontology proposed by Tarolli et al. (2019) and we categorized the landforms in the following categories: (1) 'symbolic' were represented by cemeteries and chapel; (2) 'habitation' were represented by habitation areas and dispersed settlements; (3) 'transport and exchange' were represented by paved and unpaved roads, including traces of roads that are not used anymore; (4) 'subsistence' were represented by traditional and socialistic agricultural terraces, house gardens, agricultural enterprises, vineyards and orchards and hedgerows; (5) 'mining' were represented by surface mining pits (6) 'water infrastructure' consisted of melioration canals and artificial river bed of Ipeľ river; (7) 'waste disposal' was found in central part of Kováčovce cadastral area; and (8) 'warfare infrastructure' was represented by trenches and ditches from the Second World War.

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# Land Surface Temperature Controls Stability in Gentle Clay Slopes

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Keywords: Slow flows; land surface temperature; landslide susceptibility; slope unit; clay

The effect of temperature on the stability of slopes in temperate climates is poorly constrained. Experiments demonstrate a clear thermo-hydro-mechanical (THM) response in expansive soils, and evidence of thermally-induced activity exists for some landslides (Scaringi and Loche, 2022). However, building a representative thermal variable suitable for catchment or regional-scale studies is challenging, owing to heterogeneities in materials and stress histories and the complexity of THM processes (Loche et al., 2022). We performed a landslide susceptibility modelling of the portion of Italian territory featuring clay deposits. We utilised the geo-lithological map of Italy and the Italian National Inventory (IFFI), that differentiates among landslide types, and we focused on slow flows, often associated with creep movements. We relied, as one of the inputs, on a ten-year series of Land Surface Temperature (LST) data from MODIS, freely available in Google Earth Engine, and implemented a slope unit-based Generalized Additive Model (GAM) approach to account for nonlinearities in the possible temperature-slope stability relationship (Alvioli et al., 2016). We produced a susceptibility map for clay deposits over the entire Italian territory and observed a positive dependence of landslide abundance on LST on warmer and gentle slopes, where creep phenomena are common. Higher temperatures are in fact associated with decreased soil and water viscosity and hence enhanced shear creep rates in clays.

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# Long-Term Monitoring of the Recruitment and Dynamics of Large Wood in Kamienica Stream, Polish Carpathians

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Keywords: large wood, wood dynamics, wood monitoring, wood inventory, Polish Carpathians

Quantifying wood delivery and mobility in small mountain streams requires long-term and repeatable observations, so far very scarcely described. Recently, observations using a number of remote sensing methods have gained popularity. However, classical methods of fieldwork still seem to be indispensable in more detailed studies. Such observations were conducted on the length of 8.7 km of the upper course of Kamienica Stream, Polish Carpathians, where recent bark beetle infestation of riparian spruce forest might have considerably increased the delivery of fallen trees to the channel. This part of the stream course is located in the Gorce Mountains National Park and large wood is not removed from the stream under the national park regulations.

In October 2009, numbered metal plates were installed on 429 trees growing along three stream sections located 2500–2950 m (section A), 4000–4450 m (section B) and 7850–8300 m (section C) from the stream source. Different metals were used in each section to allow for finding tagged trees with a metal detector in case the plates on them are inaccessible. The monitoring of standing and fallen trees tagged with metal plates has been conducted a few times per year, especially after heavy rainfall and windstorms. Moreover, the mode of location and the degree of decay of wood pieces stored in the study reach were determined in 2012.

During twelve years of observations, 111 trees (26% of the tagged sample) were supplied to the stream as a result of bank erosion, windthrow of living trees or those killed by bark beetle infestation, snow overload and landslides. In October 2009, 80 cm of wet snow fell in two days and snow overload caused breaking of two tagged trees. Five events with high water stage occurred in May 2010, May 2014, July 2016, May 2018 and May 2019. Those from 2016 and 2018 can be considered as major floods as they caused significant channel changes and damage to local infrastructure. About half of trees supplied to the channel were not transported, and numerous wood dams occurring in the stream limited transport of any fallen trees. Forty-six fallen tagged trees (48%) were transported during some of the five floods. In sections A and B, mean distance of the displacement of tagged trees over the study period was small and did not exceed 32 m, whereas in section C it was a few times longer. As a result of the flood in 2010, three trees were displaced relatively short distances (Mean = 42 m, Max = 100 m) and retained in in-channel jams. A definitely larger flood from 2014 was marked only in the lowermost section C, where the wood occurring in the channel was crushed into small pieces and flushed out downstream. The flood of July 2016 was the only major flood in all study sections; during this event 11 trees were displaced a mean distance of 97 m (Max = 230 m). In May 2018, a major flood caused by heavy rainfall resulted in considerable bank erosion in the lowest study section. During this event, 41 trees from this section were recruited to the channel and transported (Mean = 275 m, Max = 1003 m), while no transport occurred in the other sections. As trees in the upstream sections remained practically untouched, the course of this flood showed a strongly localized occurrence of the triggering rainfall. A small flood in May 2019 did not displace any tagged trees occurring in the stream.

A large wood inventory performed in 2012 indicated that in the second-order reach wood was

relatively uniformly distributed among different location types (Wyżga et al., 2015), with logs with their top or bottom located in the channel being the most abundant (21% of all wood pieces). Moreover, near-perpendicular orientation of wood pieces in relation to the channel axis prevailed in the reach (Mikuś et al., 2016). All this indicates a negligible role of transport and redistribution of wood, which was predominantly retained where it fell. This reach was typified by the largest proportion of logs forming wood dams (12%) and spanning the channel (10%) among the study reaches, which can be attributed to the relatively large length of wood pieces in relation to channel width. The third-order reach was characterized by a similar pattern of wood location as the second-order reach. It was distinguished by only one feature: a small amount of wood spanning the channel. In the fourth-order reach, large wood spanning the channel was very scarce because of larger stream width and considerably larger flood discharges. Here, large wood was predominantly retained along channel margins (41%), on gravel bars (19%), and with only the top or bottom located in the channel (17%). This reach was typified by variable orientation of wood pieces in relation to the channel axis, with a proportion of the pieces being apparently reoriented by the stream current. Most of wood pieces were shorter than channel width, as they originated from the breakage of trees into smaller fragments during their fall to the channel or transport by flood flows.

The inventory also indicated that in the second-order reach of Kamienica, 16% of wood pieces were in a relatively good condition, representing class 1 and 2 of wood decay, whereas a more advanced degree of decomposition, typical of class 3 and 4, typified 84% of pieces. In the third-order stream reach, this distribution was more even, with 41% of pieces representing class 1 and 2 of wood decay, and 59% class 3 and 4. In the fourth-order reach, classes 1 and 2 constituted 31% of all wood pieces, and 69% had typical features of classes 3 and 4.

To conclude, large wood is recruited to the upper course of Kamienica Stream by a few processes, with bank erosion and windthrow having been most effective during 12 years of monitoring. Large wood was recruited to the stream only during high-intensity meteorological and hydrological events. With 22% of tagged trees recruited to the channel during 12 years, the rate of turnover of the riparian trees was estimated at 45 years. As the riparian area supports trees with ages up to 160 years, the rate evidences substantial intensification of large wood recruitment to the channel in the recent period resulting from bark beetle infestation of riparian trees. The mobility of wood in the stream increases downstream because of increasing flood discharges and the decreasing ability of fallen trees to anchor on the banks of increasingly wide channel. Wood is transported longer distances only during major floods, which tend to deposit wood pieces along channel margins and on gravel bars, where wood is subjected to relatively rapid decomposition under subaerial conditions. During a subsequent large flood, most wood pieces already occurring in the channel are thus likely to rapidly disintegrate, rather than being flushed out downstream. Thus, large wood retained in the upper stream course does not constitute an important flood hazard to downstream, inhabited valley reaches.

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# Large landslides along the eastern margin of Patagonian Ice Sheet: distribution, causes and timing

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Although ice retreat is widely considered to be an important factor in landslide origin, many links between deglaciation and slope instabilities are yet to be discovered. Here we focus on the origin and chronology of exceptionally large landslides situated along the eastern margin of the former Patagonian Ice Sheet (PIS). Accumulations of the largest rock avalanches in the former PIS territory are concentrated in the Lago Pueyrredón valley at the eastern foothills of the Patagonian Andes in Argentina. Long-runout landslides have formed along the rims of sedimentary and volcanic mesetas, but also on the slopes of moraines from the Last Glacial Maximum. At least two rock avalanches have volumes greater than 1 km<sup>3</sup> and many other landslide accumulations have volumes in the order of tens to hundreds of million m<sup>3</sup>. Using cross-cutting relationships with glacial and lacustrine sediments and using OSL and <sup>14</sup>C dating, we found that the largest volume of landslides occurred between ~17 and ~11 ka. This period coincides with the most rapid phase of PIS retreat, the greatest intensity of glacial isostatic uplift, and the existence of a dropping glacial lake along the foothills of the Patagonian Andes. The position of paleoshorelines in the landslide bodies and, in many places, folded and thrustsed lacustrine sediments at the contact with rock avalanche deposits indicate that the landslides collapsed directly into the glacial lake. Although the landslides along the former glacial lobe of Lago Pueyrredón continue today, they are at least an order of magnitude smaller than the rock and debris avalanches that occurred before the drainage of the glacial lake around 10-11 ka. Preliminary numerical modeling results indicate that large postglacial landslides may have been triggered by a combination of rapid sequential glacial lake drawdowns and seismicity due to glacial isostatic adjustment. We conclude that in addition to direct links such as glacial oversteepening, debuitressing and permafrost degradation, the retreat of ice sheets and the subsequent formation of transient large glacial lakes can fundamentally alter stability conditions, especially if the slopes are built by weak sedimentary and volcanic rocks.

# Flash Flood Simulation in the Urbanised Catchment: A Case Study of Bratislava-Karlova Ves

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Keywords: Čierny potok stream, flash flood, GRASS GIS, LiDAR, CORINE Land Cover, Bratislava

Flash floods are a dangerous phenomenon that usually affects small drainage basins. They are primarily initiated in the upper parts of the slopes, but their injuring effects are manifested mostly in residential areas, where underground channelized streams disappeared from the surface. Therefore, there are not precise data about stream water levels available and only using surface runoff modelling is possible to simulate what happened during flash floods. Karlova Ves (Bratislava city District), formerly a small viniculture village, was threatened by floods (most probably including those of pluvial type) in the history. In this paper, we simulate surface runoff of a flash flood that occurred in the summer of 2014 in the catchment of Čierny potok using r.sim.water module in GRASS GIS. The flood in August 2014 was reported as with the highest rainfall per hour ~40 during the time of local meteorological measurements. Current orthophotomap was used to classify CLC land cover classes, which were assigned the value of the Manning's roughness coefficient and infiltration rate. The topography was expressed by DTM from high resolution LiDAR data. Our preliminary results indicate that land cover and land use are the essential factors influencing flash floods initiation, although the main driver in lower infiltration and change in flow direction is caused by urbanisation and high proportion of impervious areas. The simulation using r.sim.water module showed that during 60-minute extreme rainfall (40mm/hr) a surface runoff can reach a water depth up to 2 meters in terrain depressions by maximum discharge of 25 cubic meters per second. Natural urban areas revitalisation with increasing the vegetation cover in the areas prone to water flow and accumulation during higher rainfalls helps to prevent the damage caused by floods.

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# Fluvial Habitat Assessment Using High-Resolution 3D Models

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Keywords: UAV, river channel, bathymetry, classification, fluvial habitats

The paper aims to create a detailed automatic classification of the river landscape habitats based on high-resolution data obtained by drones. We apply automatic classification of the floodplain landscape structure and in-channel physical habitats. As part of automated classification, we test the accuracy of pixel-based and object-oriented supervised classification, using data sets composed of traditional spectral characteristics (RGB) and the geometric properties of the point cloud. The channel bathymetry was identified by modelling the relationship between spectral parameters of the image and field measured water depth or by the correction of the photogrammetrically generated bathymetry model by the refraction coefficient. The accuracy of the automatic classification was evaluated based on KAPPA indices using the validation layer, and the RMSE error was used for bathymetric models. In total, we classify nine main classes of land cover: water; low vegetation (less than 0.5 m); medium vegetation (0.5 - 3 m); high vegetation (more than 3 m); gravel bar; flood facies; bedrock and LWD. The submerged physical morphology was divided into four classes based on water depth. For object-oriented classification on the data layer using only the colour spectrum RGB, the accuracy of vegetation classification was 98.1 %. The water depth in the riverbed was identified based on a bathymetric model with a determination coefficient of 0.8161 and an RMSE error of 0.2419 m. The physical habitat in the river includes different continuums (grain size, water depth, topographic elevation and flow velocity) as a main physical river habitat parameter constituted by the flow regime (hydrology and hydraulics) and the physical template (fluvial sedimentology and geomorphology). Physical habitat parameters will be extracted from a detailed bathymetry model, reconstructing the channel bed structure, gravel bars and identifying habitat patterns essential for maintaining fish assemblage biodiversity. From hydraulic modelling, we used flow velocity. For final class mapping, we used velocity data, water depth and morphology unit classification (pool, glide, run, riffle).

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# Dendrogeomorphic Dating in the Ostrava-Karviná Mining Landscape: Processes, Events, Responses

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Keywords: mining landscape, dendrogeomorphology, subsidence, landslide, compression wood, Ostrava-Karviná mining district

Mining-induced subsidence is a worldwide environmental problem that leads to damage to infrastructure and property; thus, knowledge of its past-recent development is critically needed during land-use planning. We dated the activity of gravitational processes related to mining-induced subsidence using dendrogeomorphic methods at four sites in the Upper Silesian Coal Basin near the former mines of the Karviná mining district. The landslide/subsidence sites were characterised by scarps, rotated blocks, stepped relief with grabens, pressure folds, and shallow movements within landslide toes or within flat undulating relief. Based on 644 increment cores from 161 trees, we were able to identify subsidence/landslide activity, with the most frequent responses occurring from the late 1950s to the early 1970s and from 2005 to 2011. The highest number of tree ring records dates back to 1973. Moreover, more than 30% of tilted trees from the landslide sites created compression wood at multiple directions indicated complex deformations. At the other sites, the occasional occurrence of single rings with isolated compression wood was included as a possible indicator of events due to frequent coincidence with common series of compression wood. A comparison of tree-ring-based chronology with in situ monitoring revealed good synchronicity with the periods of increased subsidence rates (between 1 and 3 m.year<sup>-1</sup>). In addition, not only mining operations, but also the occurrence of extreme rainfall seems to be responsible for the recent surface activity. We identified that the 3-year precipitation and the Simple daily intensity index were significantly higher during event years at the site with a flatter topography and clay soils ( $p=0.02$  and  $0.01$ , respectively). Since dendrogeomorphic research on subsidence is influenced by multiple factors, including geological settings, soil conditions, or surface morphology, future research should focus on small research plots that provide detailed tree, surface, and sub-surface characteristics. In addition, another challenge is to compare broadleaved and coniferous trees in terms of their sensitivity to recording subsidence movements on the same geomorphic forms.

# Impact of Flood Events and Eurasian Beaver (*Castor Fiber*) Activity on Spontaneous Renaturalization of Łososina River in the Polish Western Carpathians

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Keywords: spontaneous renaturalization, river channel development, channel migration zone, flood, European Beaver (*Castor fiber*), Beskid Wyspowy Mts.

Rivers in Polish part of Carpathians are heavily modified. Valleys are urbanized, banks are enforced, channels are straightened and various types of barriers are employed to regulate the flow. All these alterations cause disturbance of natural morphodynamic processes and destruction of habitats. Anthropogenic pressure may also increase risks related to floods and droughts.

Contrary to the trends prevailing in the industrial era, more and more attention is now being paid to the negative effects of river regulation (e.g. Gregory, 2006). Growing awareness of the importance of preserving or restoring the natural state of rivers and water resources for the proper functioning of the environment and people leads to implementation of river restoration projects (e.g. Wohl et al., 2005). However, such actions are expensive and therefore not carried out on a large scale. That is why all factors that may cause renaturalization process to occur without technical treatment deserve special consideration.

Some rivers display tendencies to partially compensate for the disturbances via spontaneous changes of various parameters such as sinuosity and wideness (e.g. Bollati et al., 2014). When left not maintained training structures may deteriorate in time. Eventually such constructions collapses and therefore natural hydromorphological processes may be restored to some extent, especially with external help.

One of the key features characteristic for the multithread natural or semi-natural river is heterogeneity of the flow. Frequently such conditions are not met in regulated part of rivers. To help restore natural state we may employ various expensive technical measures or we can let it be done by the beavers (*Castor fiber*) which are known for their ability to create heterogeneous (aquatic and terrestrial) habitats (e.g. Rosell et al., 2005).

We examined channel development of gravel-bed river Łososina in Beskid Wyspowy Mts. (Western Carpathians). During this project both of these factors were found to be important for spontaneous renaturalization. Analyses were conducted using data concerning river training made by RZGW (1973–2015), orthophotos, aerial photos, topographic maps (1845–1877, 1963–2018) and field surveys (2018–2019).

Historically (in XIX century) Łososina had multithread planar course on most of its length and wide channel migration zone. Intensification of the river training in second half of XX century resulted in simplification of planar pattern and shrinking of migration zone. From XX to XXI century riverbed was also incised by 2.5 m. During our study we determined five distinctive river sections that spontaneously increased its sinuosity and migration area despite continuous river training efforts.

So defined process of spontaneous renaturalization took place both gradually and abruptly during research period. The greatest changes in sinuosity coincided in time with flood events. Such



processes resulted in development of wandering pattern. While manoeuvring on a greater area river gets access to a wider range and bigger amounts of materials to promote channel heterogeneity and evolution. When it erodes new areas it acquires wood debris, gravel and sand which later becomes foundations for bars, islands, backwaters etc. Newly created sediments becomes unique dynamic habitats for pioneer plants and animals in constant cycle of destruction and recreation.

Beavers occupy almost the entire length of Łososina river but their dams were observed only on the analyzed five sections. In zones of active channel migration water in old abandoned threads is preserved for years by impoundments created by beavers. Furthermore thus created more stagnant waters present new ecological niches.

Though the area covered by those five more dynamic sections is much smaller than the historical extent of active migration it serves as so called “beads on string” (as described by Ward et al., 2002). Such system of retention zones and areas more resilient to disturbances may work as stepping stones for river connected species. Unfortunately due to continuous river management ability to spontaneously restore natural processes in Łososina is restricted.

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# Changes of Fluvial Processes Caused by the Restoration of an Incised Mountain Stream

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Keywords: channel incision, stream restoration, block ramp, hydraulic modelling, floodwater retention, hydromorphological quality, Polish Carpathians

Construction of a high check dam on mountain Krzczonówka Stream, Polish Carpathians, in the mid-20th century resulted in a number of detrimental changes to the downstream reach. Entrapment of bed material behind the dam caused long-lasting sediment starvation of the downstream reach leading to channel incision and transformation of the former alluvial channel into a bedrock-alluvial or bedrock channel. High flow capacity of the incised channel was reflected in high velocity and bed shear stress associated with flood discharges of given recurrence interval, which prevented in-channel deposition of bed material in case of its delivery from the upstream reach. Concentration of flood flows in the incised channel considerably reduced floodwater retention in the floodplain area, hence contributing to rapid downstream passage of flood waves and increase in their peak discharges. Finally, hydromorphological quality of the stream was degraded as a result of morphological, sedimentary and hydraulic changes in the downstream reach coupled with the disruption of longitudinal stream continuity for aquatic biota caused by the check dam.

In 2012 a restoration project was initiated to lower the check dam and make the structure passable for fish. To trap the sediment flushed out from the dam reservoir in the incised channel, several block ramps were constructed in 2013, before the onset of the works on the check dam. The check dam was lowered in 2014 and when the works were underway, a 7-year flood occurred on the stream, flushing out a considerable amount of sediment from the dam reservoir. The sediment was efficiently trapped by the block ramps in the downstream reach. This study aims at investigating how the environmental problems caused by the long-term sediment starvation of the stream were mitigated by the restoration works.

Channel morphology was surveyed after the installation of block ramps but with still unmodified check dam (2013) and after the check-dam lowering (2015). These surveys were done in 10 cross-sections delimited in the downstream reach of the stream. Data about cross-sectional stream morphology, channel slope as well as channel and floodplain roughness were used in hydraulic modelling of flood conditions typifying the stream before (2013) and after (2015) deposition of the sediment trapped by block ramps. The modelling was performed using HEC-RAS software. Moreover, hydromorphological quality of the stream was evaluated in 2012 and 2015 according to the River Hydromorphological Quality method, which is especially suitable for the assessment of effects of river restoration activities (Hajdukiewicz et al., 2017).

Deposition of the sediment flushed out from above the lowered check dam caused burying of the boulder ramps on the distance of 1.2 km from the dam, whereas the sediment wave reached

1.6 km from the dam. About 15650 m<sup>3</sup> of bed material were retained in the stream, resulting in re-establishment of alluvial channel bed and an average aggradation of the channel bed by 0.50 m. Bed aggradation and the resultant increase in the elevation of low-flow water surface were relatively large close to the check dam, attaining maximum values of around 1 m at the distance of 440 m from the dam, and decreased in the downstream direction. As bed aggradation reduced flow capacity of the channel, unit stream power and bed shear stress in the channel zone of the stream decreased, with the largest decrease of these parameters by 36% and 30%, respectively, recorded for a 20-year flood. These changes were reflected in reduced competence of the stream, with the average reduction of entrainable grain size of bed material by 18% for a 2-year flood and by 31% for the 20-year flood. The reduction in flow capacity of the channel increased retention potential of the floodplain, i.e. a proportion of the total cross-sectional flow area in which floodwater would remain motionless, thus being temporarily retained on the floodplain (Wyżga, 1999; Czech et al., 2016). However, this effect was not statistically significant in the set of 10 study cross-section, but was relatively large where the channel bed aggraded substantially, while small in the cross-sections with a small increase in bed elevation. Before the restoration works, only 1 of the 5 evaluated stream cross-sections was classified as representing good hydromorphological quality, whereas after the works 4 cross-sections fell in this class of hydromorphological quality. The hydromorphological quality improvement mainly reflected changes in bed substrate, erosional and depositional channel features and longitudinal stream connectivity.

To conclude, inventories performed before and after the restoration works demonstrated effectiveness of block ramps in mitigating problems in the physical functioning of an incised mountain stream. With the entrapment of bed material by block ramps, channel bed considerably aggraded and changed from the bedrock to an alluvial one. The bed aggradation significantly decreased bed shear stress and entrainable grain size of bed material. Floodwater retention in the floodplain area increased, although this effect was largely dependent on the amount of bed aggradation in the study cross-sections. The hydromorphological quality of the stream improved in 4 out of the 5 evaluated cross-sections, with 3 cross-sections being upgraded from moderate to good quality class.

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