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Deriving Key Input Data for Hydraulic Modelling of Sediment Transport in an Alpine Proglacial Outwash Plain

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Abstract

The evident mass loss of glaciers in recent decades causes shifting runoff dynamics and highly intensified geomorphic processes particularly in headwater catchments where glaciers are vanishing. Bedload-rich outwash plains are a widespread feature in deglaciating catchments and often serve as a deposition area for glacier debris under average runoff conditions. During high, respectively extreme runoff events, the proglacial areas connect with the downstream catchment, delivering subglacial sediments to lower stream sections.
Quantifying bedload transport in the paraglacial transition zone is a challenging task and robust data on sediment yields from glaciated catchments is needed to understand global to local and inter- and intra-catchment controls on sediment yield.

In this work we present a new method to parameterize key characteristics of an Alpine proglacial outwash plain (A=0.035 km^2, avg. channel inclination 4.8 %). High-resolution RGB imagery from terrestrial and UAV-borne cameras are used to obtain 3-D topography, geometric surface roughness, areal grain size distribution, and flood flow extent and frequency. The portion of labor-intense and time-consuming manual surveying, such as measuring cross-sections and pebble counting were significantly minimized. This contributes to overcoming the scarcity of data in the paraglacial process domain, enabling hydraulic modelling on sub-catchment scale.

Keywords: Sediment; Glacier; Hydraulic Modelling; Parameterization; Outwash Plain

1. INTRODUCTION

The evident mass loss of glaciers over the past decades is coupled with shifting runoff dynamics and highly intensified geomorphic processes particularly in headwater catchments on the verge of deglaciation (Fischer et al., 2021; Heckmann et al., 2016). The progressive down wasting of glaciers results in an increasing exposure of unconsolidated sediments impacting the catchment-scale sediment dynamics. The induced changes in sediment fluxes can have considerable implications for the operation and management of water resources, especially for hydro-electric power facilities in otherwise non-regulated glaciated catchments. Bedload-rich outwash plains are a widespread feature in deglaciating catchments and often serve as a deposition area for glacier debris under average runoff conditions (Porter et al., 2019). During high, respectively extreme runoff events, the proglacial areas connect with the downstream catchment, delivering subglacial sediments to lower stream sections (Comiti et al., 2019; Lane et al., 2017).

As such, they represent key elements in high-alpine river systems and are an important component in determining the upstream boundary conditions of a catchment. Yet quantifying bedload transport in the paraglacial transition zone is a challenging task. The typically remote location of outwash plains in the proximity of retreating glaciers usually complicates direct measurements, especially as the area under study is subject to intensive geomorphic processes and thus frequent changes. However, quantitative data on sediment yields from glaciated catchments is needed to contribute to the sustained effort of the research community to understand global to local and inter- and intra-catchment controls (Carrivick and Tweed, 2021) on sediment yields.

In this work we present a new methodological approach to parameterize key characteristics of an Alpine proglacial outwash plain (Jamtal valley, Austria) with an area of A=0.035 km^2 and an average channel inclination of 4.8 %. Close range sensing techniques such as RGB imagery obtained from terrestrial and UAV-borne cameras are used in addition to discharge data from a non-contact flow velocity and water level sensor (~3 km downstream of the investigated outwash plain) to overcome data scarcity in the paraglacial process domain, enabling modelling of sediment fluxes on sub-catchment scale.

The key parameters considered in this study include (i) topographic modelling with high spatial and temporal resolution of the frequently changing channel geometry, (ii) surface sediment properties such as roughness and grain size distribution and (iii) spatio-temporal flood flow variability in the investigated proglacial outwash plain. These interrelated factors are crucial for model parameterization and calibration in the context of hydro-morphological modelling (Schneider et al., 2015; Recking, 2013; Mueller and Pitlick, 2005).

2. PARAMETRIZATION OF HYDRAULIC KEY DATA

2.1 Channel and Outwash Plain Topography

The geometry of the braided channel network in the outwash plain was mapped with a customer-grade Unmanned Aerial Vehicle (UAV) equipped with a high-resolution RGB-sensor (20 MP) to perform Structure-from-Motion analysis with multi-view stereo photogrammetry (SfM-MVS) (Eltner and Sofia, 2020). The surveys were conducted under low to average water discharge conditions in the summer seasons of 2020 and 2021. The derived detailed 3-D point clouds with a finest ground sampling distance (GSD) of ~1.1 cm allow calculations of topographic models for each survey and intra-annual elevation differences for the outwash plain. The resulting geo-referenced digital elevation models (DEMs) and orthophotos reveal current channel dynamics in the observation period.

2.2 Surface Sediment

The topographic 3-D point clouds were subsequently used for geometrical surface roughness analysis based on the method of ‘best fitting plane’ discretization, showing zonal patterns of surface sediment texture and distribution on non-permanent wetted gravel plains. A total of 30 test plots confined as 1 m^2 raster were used to test the sampling of grain size distributions of the surface layer. On these plots, imagery suitable for SfM-MVS photogrammetry was captured with a handheld digital camera (24,2 MP) from 1,5 -2 m height above ground resulting in a GSD of ~0.1 cm. Manual pebble counts analogous to the grid sampling method (Bunte and Abt, 2001) were performed in the 30 test plots, truncating grain sizes at an b-axis < 1.0 cm. The statistical link between the geometric surface roughness calculated from 3-D point clouds and grain size characteristics based on manual pebble counts was tested. A linear regression model was developed to predict characteristic grainsizes (percentiles) between D16 and D95 based on the geometric surface roughness. The model was calibrated and verified with a leave-one-out cross-validation (LOOCV) (Woodget et al., 2018) using the 1 m^2-plots as training and testing data. This way, the regression models were used to derive grain size distribution maps for a range of predicted percentiles, covering the entire active outwash plain with a raster cell size of 1 m (Figure 1). Thus, in addition to the temporal evolution of channel geometry and topography, the change of spatially distributed geometric surface roughness and grain size distribution were derived based on UAV-based imagery.

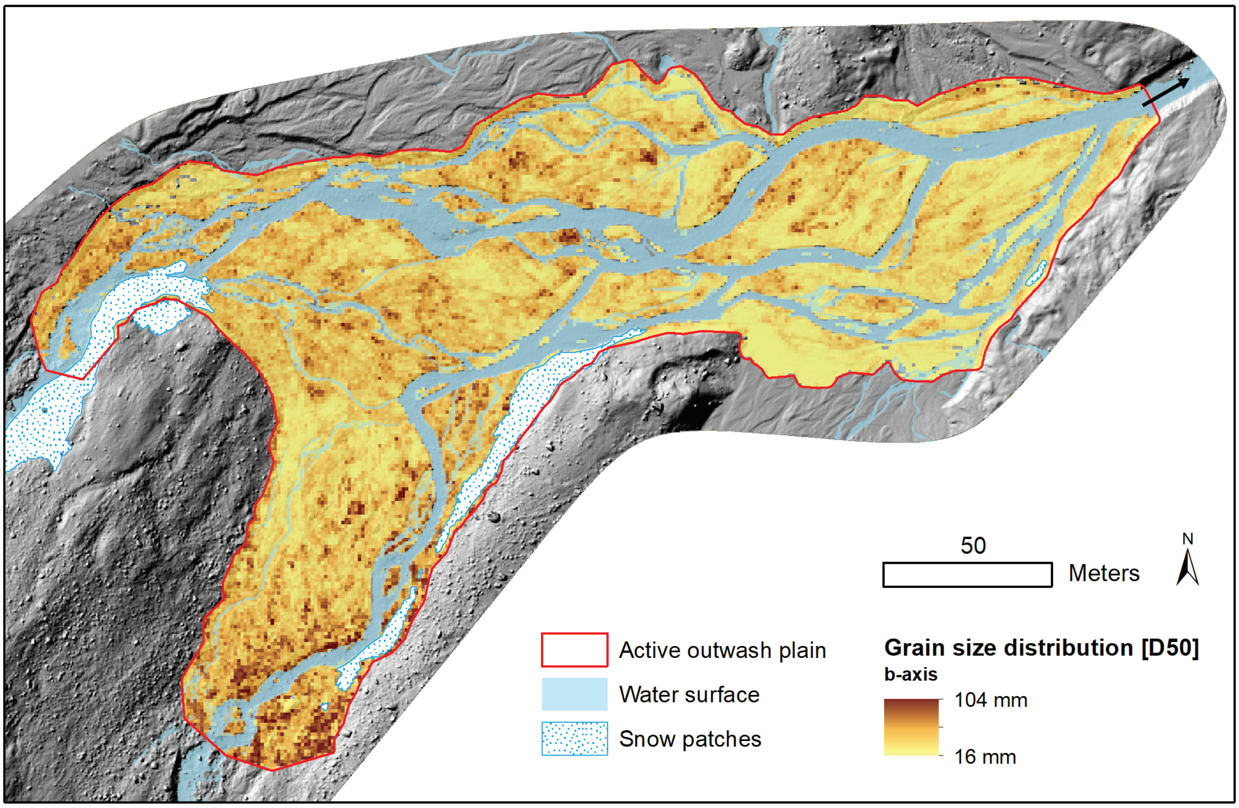

Figure 1. Grain size distribution (D50), derived from geometric surface roughness in the outwash plain of the Jamtalferner glacier. The underlying topographic model is based on SfM-MVS photogrammetry taken on 20 July 2021. The outlines of water surfaces and snow patches were mapped from a corresponding orthophoto.

2.3 Flood Flow Patterns

The flood flow variability in the investigated outwash plain was semi-automatically derived from stationary time-lapse images (Hiller et al., 2022). Previous research has proven the value of oblique digital imagery to monitor the planform, topography and rates of change in braided river channels (Gleason et al., 2015), as well as discharge patterns in remote, steep and boulder-strewn channels (Leduc et al., 2018). We applied this approach to the outwash plain, utilizing a terrestrial camera with a high-resolution RGB-sensor. Available records from 2018-2020 were used to map the inundated area to constrain spatial and temporal dynamics of surface runoff. The semi-automatic lineation of flooded areas was performed with the open-source software ImageJ (Schindelin et al., 2012). Back-to-back scripts were designed capable of extracting pixel-based information to identify inundated areas in the camera view. The pixel classification based on greyscale values from oblique hourly recordings re-turned plausible results of the spatial and temporal variability of surface runoff in the investigated glacier forefield during daylight hours. The image sets allowed geo-rectification to produce inundation frequency maps that provided novel insights into the evolution of the proglacial channel network over a period of three years. We detected an increasing degree of channel concentration within the observation period. The maximum inundation from one event alone took up 35 % of the analyzed area.

3. CONCLUSIONS

The presented multi-method approach, largely based on terrestrial time-lapse and UAV-borne RGB imagery, provides a feasible way to robustly estimate the following key input and calibration data for applied hydraulic modelling: 3-D topography, geometric surface roughness, areal grain size distribution, and flood flow extent and frequency. The portion of labor-intense and time-consuming manual surveying, such as measuring cross-sections and pebble counting, was significantly reduced. Future enhancements include the installation of maximum water level gauges in the outwash plain to validate and calibrate water level estimations from the presented close-range sensing methods.

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5. REFERENCES

Bunte, K., Abt, S.R., 2001. Sampling frame for improving pebble count accuracy in coarse gravel-bed streams. Journal of the American Water Resources Association, 37(4), 1001-1014.

Carrivick, J.L., Tweed, F.S., 2021. Deglaciation controls on sediment yield: Towards capturing spatio-temporal variability. Earth-Science Reviews, 221, 103809.

Comiti, F., Mao, L., Penna, D., Dell'Agnese, A., Engel, M., Rathburn, S., Cavalli, M., 2019. Glacier melt runoff controls bedload transport in Alpine catchments. Earth and Planetary Science Letters, 520, 77-86.

Eltner, A., Sofia, G., 2020. Chapter 1 - Structure from motion photogrammetric technique. In: P. Tarolli, S.M. Mudd (Eds.), Developments in Earth Surface Processes. Elsevier, pp. 1-24.

Fischer, A., Schwaizer, G., Seiser, B., Helfricht, K., Stocker-Waldhuber, M., 2021. High-resolution inventory to capture glacier disintegration in the Austrian Silvretta. The Cryosphere, 15(10), 4637-4654.

Gleason, C.J., Smith, L.C., Finnegan, D.C., LeWinter, A.L., Pitcher, L.H., Chu, V.W., 2015. Technical Note: Semi-automated effective width extraction from time-lapse RGB imagery of a remote, braided Greenlandic river. Hydrol. Earth Syst. Sci., 19(6), 2963-2969.

Heckmann, T., McColl, S., Morche, D., 2016. Retreating ice: research in pro-glacial areas matters. Earth Surface Processes and Landforms, 41(2), 271-276.

Hiller, C., Walter, L., Helfricht, K., Weisleitner, K., Achleitner, S., 2022. Flood Flow in a Proglacial Outwash Plain: Quantifying Spatial Extent and Frequency of Inundation from Time-Lapse Imagery. Water, 14(4), 590.

Lane, S.N., Bakker, M., Gabbud, C., Micheletti, N., Saugy, J.N., 2017. Sediment export, transient landscape response and catchment-scale connectivity following rapid climate warming and Alpine glacier recession. Geomorphology, 277, 210-227.

Leduc, P., Ashmore, P., Sjogren, D., 2018. Technical note: Stage and water width measurement of a mountain stream using a simple time-lapse camera. Hydrol. Earth Syst. Sci., 22(1), 1-11.

Mueller, E.R., Pitlick, J., 2005. Morphologically based model of bed load transport capacity in a headwater stream. Journal of Geophysical Research: Earth Surface, 110(F2).

Porter, P.R., Smart, M.J., Irvine-Fynn, T.D.L., 2019. Glacial Sediment Stores and Their Reworking. In: T. Heckmann, D. Morche (Eds.), Geomorphology of Proglacial Systems: Landform and Sediment Dynamics in Recently Deglaciated Alpine Landscapes. Springer International Publishing, Cham, pp. 157-176.

Recking, A., 2013. Simple Method for Calculating Reach-Averaged Bed-Load Transport. Journal of Hydraulic Engineering, 139(1), 70-75.

Schindelin, J., Arganda-Carreras, I., Frise, E., Kaynig, V., Longair, M., Pietzsch, T., Preibisch, S., Rueden, C., Saalfeld, S., Schmid, B., Tinevez, J.-Y., White, D.J., Hartenstein, V., Eliceiri, K., Tomancak, P., Cardona, A., 2012. Fiji: an open-source platform for biological-image analysis. Nature Methods, 9(7), 676-682.

Schneider, J.M., Rickenmann, D., Turowski, J.M., Kirchner, J.W., 2015. Self-adjustment of stream bed roughness and flow velocity in a steep mountain channel. Water Resources Research, 51(10), 7838-7859.

Woodget, A.S., Fyffe, C., Carbonneau, P.E., 2018. From manned to unmanned aircraft: Adapting airborne particle size mapping methodologies to the characteristics of sUAS and SfM. Earth Surface Processes and Landforms, 43(4), 857-870.

