

Near-surface hydrological characteristics of moraines in the Swiss Alps

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3. Data Description

The German-Swiss Hillslope project focuses on the vertical and lateral redistribution of water and matter along hillslopes and how this redistribution is affected by soil, vegetation and landscape development. The overall research question of the project is: How does the hillslope feedback cycle evolve in the first 10,000 years and how is this related to the evolution of hillslope structure? In order to tackle this research question, chronosequences in alpine glacier forelands were selected and artificial rainfall experiments were conducted. These datasets specifically contain data at the interface of sediment transport and hillslope hydrology. Specifically, they contain data about changes in soil surface characteristics (saturated hydraulic conductivity for three soil depths, soil aggregate stability for the surface soil layer), overland and shallow subsurface flow (runoff characteristics as peak flow rates, duration of flow, runoff ratios, event water fractions) and sediment yield values for overland flow along the moraine chronosequence.

We measured the near-surface hydrological characteristics of four moraines with different age on a carbonate glacier foreland (forefield of the Griessfirn, close to the Klausenpass alpine road) and silicate glacier foreland (glacier forefield of the Steingletscher, close to the Sustenpass alpine road). The ages of the four moraines were ~30, ~160, ~3000 and ~10000 years (Sustenpass) and ~80, ~160,

~4900 and ~13500 years (Klausenpass). We selected 3 plots (dimensions: 4m x 6m) on each moraine, based on the vegetation complexity (low, medium and high), to cover as much of the potential variability within each moraine as possible. The structural vegetation complexity was based on the vegetation cover, number of different species, and functional diversity (based on stem growth form, root type, clonal growth organ, seed mass, Raunkiaer's life form, leaf dry matter content, nitrogen content and specific leaf area (Garnier et al., 2016).

We measured the near-surface hydrological properties of each plot (the saturated hydraulic conductivity and the soil aggregate stability) because the properties are essential for the runoff response on each plot. The runoff response and its characteristics for each plot was determined for sprinkling experiments of different intensities and during natural rainfall events (only at Klausenpass). We used tracers (Deuteriumoxid and NaCl) that we added to the sprinkling water and took samples of the soil water, then rainfall and the runoff to perform a 3-end-member hydrograph separation, using the method of Gibson et al. (2000). With that, we were able to identify the mixing (e.g. event water fraction), storage and flow pathways of the overland flow and subsurface flow. We filtered the overland flow samples to define the total sediment flux per experiment.

3.1. Sampling method

- Saturated hydraulic conductivity (K_{sat}):

At each plot, the saturated hydraulic conductivity K_{sat} was determined at three locations for three different depths (0-5 cm, 5-20 cm and 20-40 cm below the soil surface) from the steady state infiltration rate. For the surface (0-5 cm), we used a Double-Ring-Infiltrometer with an inner diameter 227 of 20 cm. For the subsurface, we used a Constant Compact Head Permeameter (Amoozometer; Amoozegar (1992)). The diameter of the borehole was 6 cm; the height of the water level was 15 cm for the measurements at 5-20 cm depth and 20 cm for the measurements at 20-40 cm depth.

- Soil aggregate stability (SAS)

Six soil samples were collected from 0-10 cm depth per plot with a Humax probe to determine the soil aggregate stability according to the method for stone-rich soils of Bast et al. (2015). This method is based on the wet-sieving method using only a 20 mm sieve. An Aggregate Stability Coefficient (ASC) value of 1 indicates a completely stable soil sample, whereas a value of 0 indicates complete dispersion.

- Overland flow measurements

The plots were bounded using plastic sheeting that was inserted ~ 5 cm into the ground to minimize lateral in- and outflow of OF. At the bottom of the plot, a trench was excavated and pond foil was inserted about 2-5 cm into the ground and connected to a gutter. At 2-10 cm below the surface, the foil was inserted. Thus, the gutter did not only collect OF but also biomat flow and very shallow subsurface flow. The gutter was covered by plastic panels so that rainfall could not enter the gutter. During the rainfall simulation experiments and natural rainfall events, water flowed from the gutter via a 5 cm diameter hose to an Upwelling Bernoulli Tube (Stewart et al., 2015), which contained a pressure transducer (DCX-22-CTD, Keller), which recorded the flow rate of overland flow. Samples of

the OF were taken from the outflow of the Upwelling Bernoulli Tubes using 500 ml wide-mouth polyethylene bottles (filled completely to the top). Sampling started as soon as flow started and continued until outflow stopped after the end of the experiment. After collection, the OF samples were filtered using 1.6 μm filters (GF/A Whatman) to remove the sediment.

- Subsurface flow measurements

At the bottom of each plot, a trench was excavated down to the first lower permeability layer (clay-rich horizon, rock flour layer or underlying bedrock). Installation was similar to that described by Bachmair and Weiler (2014). The trench sloped to one side, where a small ditch was excavated. A drainage mat was inserted into the trench (covering the whole cross section of the soil profile, except for the top 5 cm) to prevent downslope subsurface flow. The drainage mat was folded to reduce losses to the bottom of the trench and to channel the SSF into the lateral ditch, where the mat was attached to a gutter and stabilized with larger stones and rocks. The trench was refilled with soil after the installation of the drainage mat to avoid any slope movement.

- Soil moisture measurements

Four soil moisture sensors (Trübner SMT100 & Decagon 5TE) were installed at the top and bottom of each plot along the outside border (one sensor at 30 cm depth and another sensor in 50 cm at each position). In addition, four sensors (Trübner SMT100 & Decagon 5TE) were installed along the outside border of each plot in 10 cm depth below the surface.

- Sprinkling experiments

We conducted three sprinkling experiments on each plot. Three adjustable sprinklers (Senninger I-Wob; nozzle number 22) were installed 2 m above the soil surface along a transect through the middle of each plot. The sprinklers were connected via garden hoses (Gardena) to a water meter and a fire hose that drained two 4 m³ water reservoirs filled with water from a nearby stream. The reservoirs were located at least ~20 m above the plots to guarantee sufficient pressure for the sprinklers. The sprinklers applied rainfall to an area that extended at least 0.5 m upslope from the plot, 6 m to the left and right of the plot and several meters below the plot. The aim was to irrigate each plot with an intensity that reflects the 2.3, 30 and 100 year return period event (20, 40 and 60 mm/hr). The events are referred to as low, medium and high intensity experiments. To obtain the different rainfall intensities, either one, two or all three sprinklers were used to apply water to the plots. The three sprinkling experiments on each plot were conducted on three consecutive days, with the lowest intensity experiment on the first day and the highest intensity experiment on the third day. We measured the rainfall volume and intensity with two tipping buckets (RK400-04) and four manual rain gauges on each plot.

3.2. Analytical procedure

- Runoff characteristics

For each sprinkling experiment we monitored overland flow (OF) and subsurface flow (SSF) and defined runoff characteristics. We determined for each experiment that resulted in OF the time until OF occurred (t_{lag}), the total amount of rainfall before OF occurred (P_{lag}), the peak flow rate (Q_{peak}), the total OF volume (Q_{total}), the percentage of the rainfall volume that contributed to OF (runoff ratio) and the volume of OF that drained after more than 5 min had passed since the end of the sprinkling experiment, which was assumed to be the maximum time for pure OF to reach the gutter (drainage volume D). For OF, we calculated the total sediment flux of the experiment by calibrating the continuous turbidity measurements of the OF (in NTU) with the weight of the suspended sediment of the OF samples. For SSF, we calculated the time of drainage, which was defined by the time between the end of the experiment and the end of SSF.

- Antecedent Soil Moisture Index

To quantify the antecedent soil moisture of the moraines, we calculated the Antecedent Soil Moisture Index ASI (Penna et al., 2015). For this, we averaged the mean volumetric water content of a certain soil depth and multiplied it with the thickness of the respective soil layer (e.g. for the ASI of the OF we calculated the ASI for the top 10 cm of the soil by multiplying the average volumetric water content of the top 10 cm of the soil with 100 (soil layer depth in mm). For the SSF, we took the ASI of the top 50 cm of the soil. We multiplied the average volumetric soil water content at 10 cm soil depth with 200, the average volumetric soil water content at 30 cm soil depth with 200 and the average volumetric soil water content at 50 cm soil depth with 100 and added these numbers.

4. File description

4.1. File inventory

The dataset includes 10 data files, of which 8 files are the data files, stored in the .txt-format (tab separated). The other two files are the “2021-011_Maier-van-Meerveld_Data-Description.pdf”-file and the “2021-011_Maier-van-Meerveld_List-of-all-files.pdf”-file, respectively. The 8 .txt-files are “2021-011_Maier-van-Meerveld_Table_1_Aggregate-Stability.txt” (the soil aggregate stability data for the top 10 cm of the soil of the plots on the moraines), “2021-011_Maier-van-Meerveld_Table_2_Ksat-Surface.txt” (the saturated hydraulic conductivity data for the top 5 cm of the soil of the plots on the moraines), “2021-011_Maier-van-Meerveld_Table_3_OF-Characteristics.txt” (the observed overland flow characteristics for the sprinkling experiments), “2021-011_Maier-van-Meerveld_Table_4_ASI-OF.txt” (the calculation of the sum of the Antecedent Soil Moisture Index in the top 10 cm of the soil and the precipitation volume for the low vegetation complexity plots at Klausenpass during sprinkling experiments and natural rainfall events), “2021-011_Maier-van-Meerveld_Table_5_Ksat-Subsurface.txt” (the saturated hydraulic conductivity data at 5-20 cm soil depth for the plots on the moraines), “2021-011_Maier-van-Meerveld_Table_6_Ksat-Subsurface-2.txt” (the saturated hydraulic conductivity data at 20-40 cm soil depth for the plots on the moraines), “2021-011_Maier-van-Meerveld_Table_7_SSF-Characteristics.txt” (the observed subsurface flow characteristics for the sprinkling experiments), “2021-011_Maier-van-Meerveld_Table_8_ASI-SSF.txt” (the calculation of the sum of the Antecedent Soil Moisture Index in

the top 50 cm of the soil and the precipitation volume for the low vegetation complexity plots at Klausenpass during sprinkling experiments and natural rainfall events).

4.2. File naming convention

The 9 files are named as follows:

2021-011_Maier-van-Meerveld_Data-Description.pdf

2021-011_Maier-van-Meerveld_Table_1_Aggregate-Stability.txt

2021-011_Maier-van-Meerveld_Table_2_Ksat-Surface.txt

2021-011_Maier-van-Meerveld_Table_3_OF-Characteristics.txt

2021-011_Maier-van-Meerveld_Table_4_ASI-OF.txt

2021-011_Maier-van-Meerveld_Table_5_Ksat-Subsurface.txt

2021-011_Maier-van-Meerveld_Table_6_Ksat-Subsurface-2.txt

2021-011_Maier-van-Meerveld_Table_7_SSF-Characteristics.txt

2021-011_Maier-van-Meerveld_Table_8_ASI-SSF.txt

4.3. Description of data tables

4.3.1. 2021-011_Maier-van-Meerveld_Table_1_Aggregate-Stability.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Measurement_number		Number of the measurement per plot (between 1 and 6; 6 samples taken per plot)
SAS		Value of the soil aggregate stability of the measurement (value between 0 and 1; value of 1 indicates a completely stable soil sample, whereas a value of 0 indicates complete dispersion of the soil sample)

4.3.2. 2021-011_Maier-van-Meerveld_Table_2_Ksat-Surface.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Measurement_position		Position of the measurement on each plot (top, middle or low position)
Ksat	mm/hr	Value of the saturated hydraulic conductivity for the top soil layer (between 0 and 5 cm soil depth)
Soil_depth	cm	Ksat for tor the soil layer from 0 cm to 5 cm soil depth

4.3.3. 2021-011_Maier-and-Meerveld_Table_3_OF-Characteristics.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Plotsize	m ²	Size of the plot in square meters
Intensity		Intensity of the sprinkling experiment (low, medium or high rainfall intensity)
Slope	degrees (°)	Average steepness of the plot in degrees
Tlag	min	Time between the start of the experiment and the onset of overland flow
Plag	mm	Rainfall volume between the start of the experiment and the onset of overland flow
Runoffratio	%	Fraction of rainfall that contributed to overland flow
Fe	%	Average fraction of event water (the actual applied rainfall of the respective experiment) in overland flow
Error_Fe	%	Uncertainty range of the average event-water fraction in overland flow
Qpeak	mm/hr	Peak flow rate of overland flow
Qtotal	mm	Total amount of overland flow
D	mm	Total amount of overland flow drainage (overland flow volume from 5 min after the end of the experiment until the end of overland flow)
Flow_duration	min	Duration of the total overland flow
Sed_flux	grams (g)	Total sediment flux of the experiment, transported by overland flow
P_mm/hr	mm/hr	Rainfall intensity of the experiment

4.3.4. 2021-011_Maier-van-Meerveld_Table_4_ASI-OF.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Plotsize	m2	Size of the plot in square meters
Intensity		Intensity of the sprinkling experiment (low, medium or high rainfall intensity)
Date	DD.M.	Date of the sprinkling experiment or natural rainfall event (either one day or from...to)
P_tot	mm	Total rainfall volume
VWC10_1 - VWC10_5		Ratio of water volume to soil volume at five different positions at 10 cm soil depth. Values between 0 (0% water volume) and 1 (100% water volume)
MeanASI10	mm	Antecedent Soil Moisture Index as the average of VWC10_1 – VWC10_5 multiplied by 100 (soil depth of the respective surface soil layer in mm)
P_tot+ASI	mm	Sum of MeanASI10 and the precipitation volume for the respective sprinkling experiment or natural rainfall event
Q_acc	mm	Accumulated overland flow volume from the respective plot during the respective sprinkling experiment or natural rainfall event

4.3.5. 2021-011_Maier-van-Meerveld_Table_5_Ksat-Subsurface.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Measurement_position		Position of the measurement on each plot (top, middle or low position)
Ksat	mm/hr	Value of the saturated hydraulic conductivity for the top soil layer (between 0 and 5 cm soil depth)
Soil_depth	cm	Ksat for the soil layer from 5 cm to 20 cm soil depth

4.3.6. 2021-011_Maier-van-Meerveld_Table_6_Ksat-Subsurface-2.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Measurement_position		Position of the measurement on each plot (top, middle or low position)
Ksat	mm/hr	Value of the saturated hydraulic conductivity for the top soil layer (between 0 and 5 cm soil depth)
Soil_depth	cm	Ksat for the soil layer from 20 cm to 40 cm soil depth

4.3.7. 2021-011_Maier-van-Meerveld_Table_7_SSF-Characteristics.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_position		Position of the plot on the moraine (either the left, central or right plot looking towards the moraine)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Plotsize	m2	Size of the plot in square meters
Intensity		Intensity of the sprinkling experiment (low, medium or high rainfall intensity)
Slope	degrees (°)	Average steepness of the plot in degrees
Tlag	min	Time between the start of the experiment and the onset of subsurface flow
Plag	mm	Rainfall volume between the start of the experiment and the onset of subsurface flow
Runoffratio	%	Fraction of rainfall that contributed to subsurface flow
Fe	%	Average fraction of event water (the actual applied rainfall of the respective experiment) in subsurface flow
Error_Fe	%	Uncertainty range of the average event-water fraction in subsurface flow
Qpeak	mm/hr	Peak flow rate of subsurface flow
Qtotal	mm	Total amount of subsurface flow
T_drainage	min	Time between the end of the experiment and the end of subsurface flow
Flow_duration	min	Duration of the total subsurface flow
P_mm/hr	mm/hr	Rainfall intensity of the experiment

4.3.8. 2021-011_Maier-van-Meerveld_Table_8_ASI-SSF.txt

Column header	unit	Description
Study_area		Data was obtained from to study areas (Sustenpass=Susten or Klausenpass=klausen)
Moraine		Name of the moraine where the data was measured on (10k=moraine with the age of ~10000 years, 3k=moraine with the age of ~3000 years, 1860=moraine with the age of ~160 years, 1990=moraine with the age of ~30 years, 13.5k= moraine with the age of ~13500 years, 4.9k=moraine with the age of ~4900 years, 1940=moraine with the age of ~80 years)
Plot_complexity		Vegetation complexity of the plot (low, medium or high)
Intensity		Intensity of the sprinkling experiment (low, medium or high rainfall intensity)
Date	DD.M.	Date of the sprinkling experiment or natural rainfall event (either one day or from...to)
P_tot	mm	Total rainfall volume
VWC10_1 - VWC10_5		Ratio of water volume to soil volume at five different positions at 10 cm soil depth. Values between 0 (0% water volume) and 1 (100% water volume)
VWC30_1 and VWC30_2		Ratio of water volume to soil volume at two different positions at 30 cm soil depth. Values between 0 (0% water volume) and 1 (100% water volume)
VWC50_1 and VWC50_2		Ratio of water volume to soil volume at two different positions at 50 cm soil depth. Values between 0 (0% water volume) and 1 (100% water volume)
MeanASI_all	mm	Antecedent Soil Moisture Index as the sum of the average of VWC10_1 – VWC10_5 multiplied by 200 (soil depth of the respective surface soil layer in mm), the average of VWC30_1 and VWC30_2 multiplied by 200 (soil depth of the respective soil layer in mm) and the average of VWC50_1 and VWC50_2 multiplied by 100 (soil depth of the respective soil layer in mm)
P_tot+ASI	mm	Sum of MeanASI_all and the precipitation volume for the respective sprinkling experiment or natural rainfall event
Q_acc	mm	Accumulated subsurface flow volume from the respective plot during the respective sprinkling experiment or natural rainfall event

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