Possible impacts of a hydropower reservoir on the flood hazard of an Alpine valley

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1. Motivation

Alpine catchments are characterised by steep slopes and high precipitation sums, making them both prone to **frequent flood events and attractive for hydropower production**. The flood retention properties of the Alpine headwater catchment areas can thus be affected by the operation of storage power plants, which could have an impact on residential areas downstream. Recently, it has been reported that climate change driven processes will increase flood intensity and frequency in Austria (APCC, 2014) resulting in an increase in flood hazard (Blöschl et al., 2019). With this background in mind, it is of particular interest to understand **how hydropower reservoirs alter flood dynamics**.

2. Study Area

The study was performed on a cascade of reservoirs situated in the catchment of the Kapruner Ache, which is a headwater of the river Salzach in the central Austrian Alps (see Table 1 and Figure 7). The hydropower reservoirs are operated by Verbund AG.

Table 1: Gauges and catchment properties including mean discharge (MQ) for the period 2000 to 2015.

Number	Gauge	River	HZB-Nr.	MQ m³/s	Area km²
1	Wald	Salzach	203026	7,8	176,1
1_2	Sulzau	Obersulzbach	203034	5,3	80,7
2	Mittersill	Salzach	203075	25,2	551,9
2_3	Kaprun	Kapruner Ache	203109	10,7	169,0
3	Bruck	Salzach	203125	54,9	1230,5
4	Wallnerau	Salzach	203968	90,4	2188,3
5	Golling	Salzach	203323	145,7	3601,1
6	Salzburg	Salzach	204297	183,2	4447,1
7	Oberndorf	Salzach	203539	248,9	6165,4
8	Schärding	Inn	206201	732,8	25520,0
9	Achleiten	Donau	207019	1374,2	76653,3

Since commissioning the cascade of storage power plants in 1955, six flood events (HQ) with a return period exceeding 10 years were observed at the gauging station Kaprun downstream of the hydropower reservoirs (see Table 2 and Figure 1).

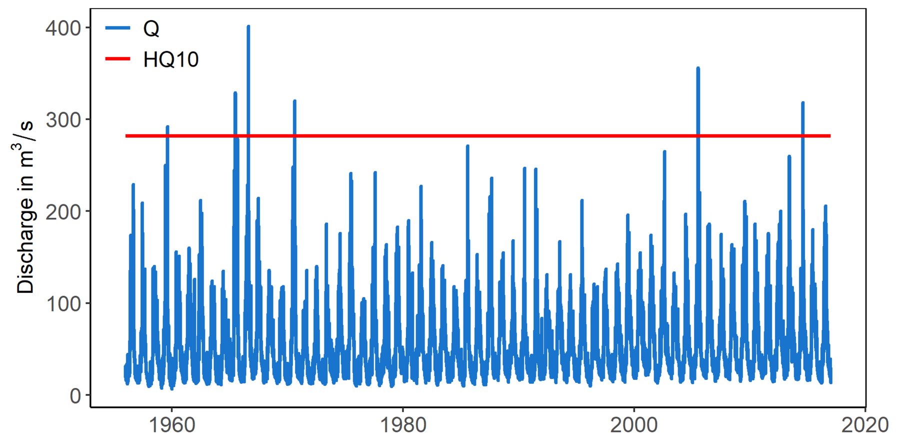

Figure 1: Observed mean daily discharge at the gauge Kaprun downstream the reservoirs (1956-2015).

Table 2: Observed flood events downstream the reservoirs at the gauge Kaprun (1956-2015). Discharge (Q) and determined return periods (Gumbel) are based on mean daily discharge.

Date	Q m³/s	Return period years
18.08.1966	401	109
12.07.2005	356	39
28.06.1965	329	24
10.08.1970	320	17
31.07.2014	318	13
13.08.1959	292	11

3. Data & Methods

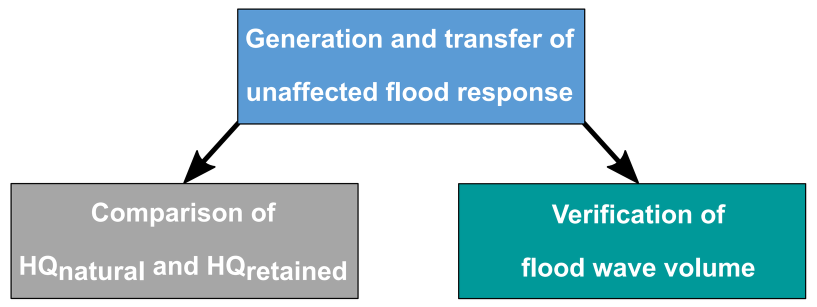

Figure 2: Schematic workflow.

The cascade of hydro power plants is altering the natural discharge at Kaprun. To estimate the unknown natural discharge we transferred the (specific) discharge from an unaffected neighbouring catchment to Kapruner Ache. We analysed observed discharge and storage data and assessed the flood retention by relating observed and transferred flood discharge.

Generation and transfer of unaffected flood response

- $HQ_{natural}$ = transferred flood response from a neighbouring catchment (Obersulzbach) sharing similar properties to Kapruner Ache
- Transfer via specific discharge considering similarities
- Data: Corine land cover 2018 (European Env. Agency., 2019), digHAO (BMLFUW, 2007), HZB

Comparison of possible $HQ_{natural}$ and $HQ_{retained}$

- $HQ_{retained}$ = observed flood response at several gauges downstream
- Analyse propagation downstream via relation of retained and possible natural flood events
- Data: HZB (2000-2015)

Verification of flood wave volume

- Determine volumes of possible natural mean annual and maximum occurred flood event at Kaprun
- Comparison of volumes of 5 day flood events and the mean annual available storage
- Data: HZB, storage data Verbund AG (2007-2015)

4. Results

Generation and transfer of unaffected flood response

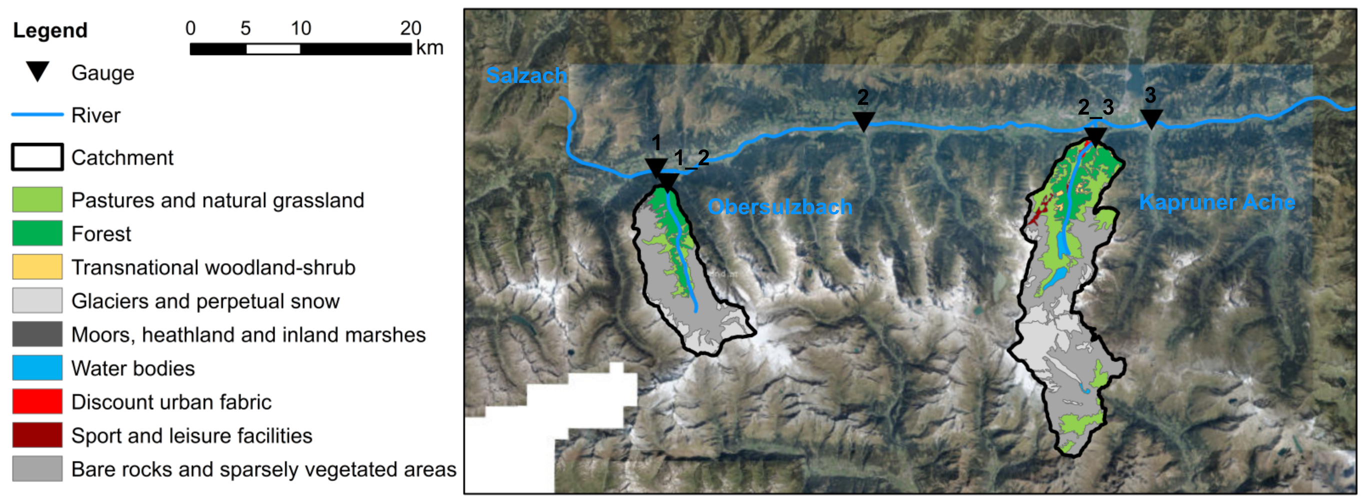

Figure 3: Corine land cover of Kapruner Ache (right catchment), where the cascade of hydropower reservoirs is located, and the nearby unaffected catchment of Obersulzbach (left) in the central Austrian Alps.

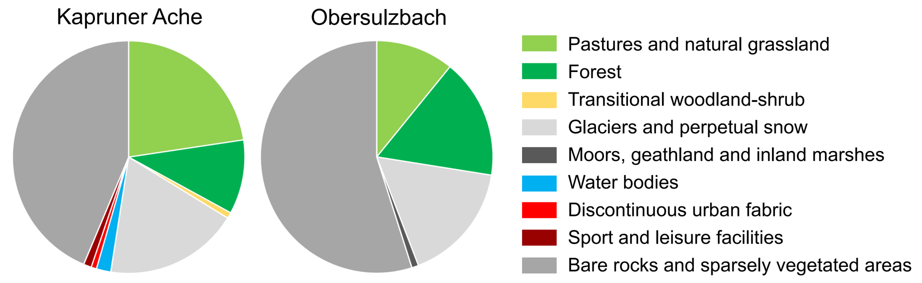

Figure 4: The comparison of Corine land cover shares highlights the high similarity of the analysed catchments.

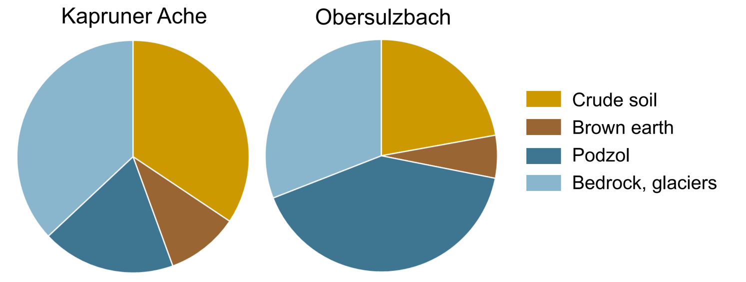

Figure 5: The comparison of soils within the analysed catchments confirms the similarity.

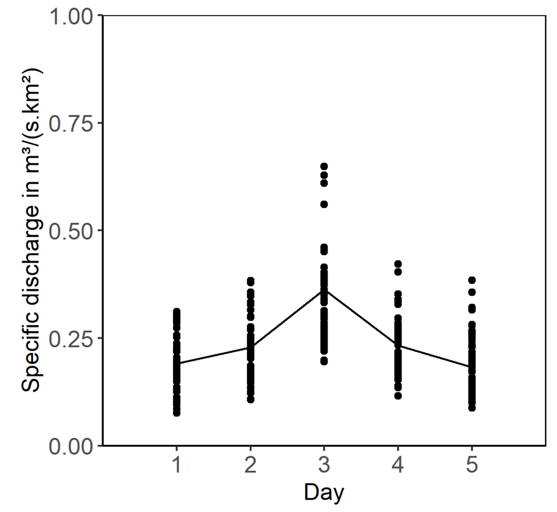

Figure 6: Highest annual flood waves (dots) and mean annual flood wave (line) within 5 days at Obersulzbach (1961-2015).

Comparison of $HQ_{natural}$ and $HQ_{retained}$

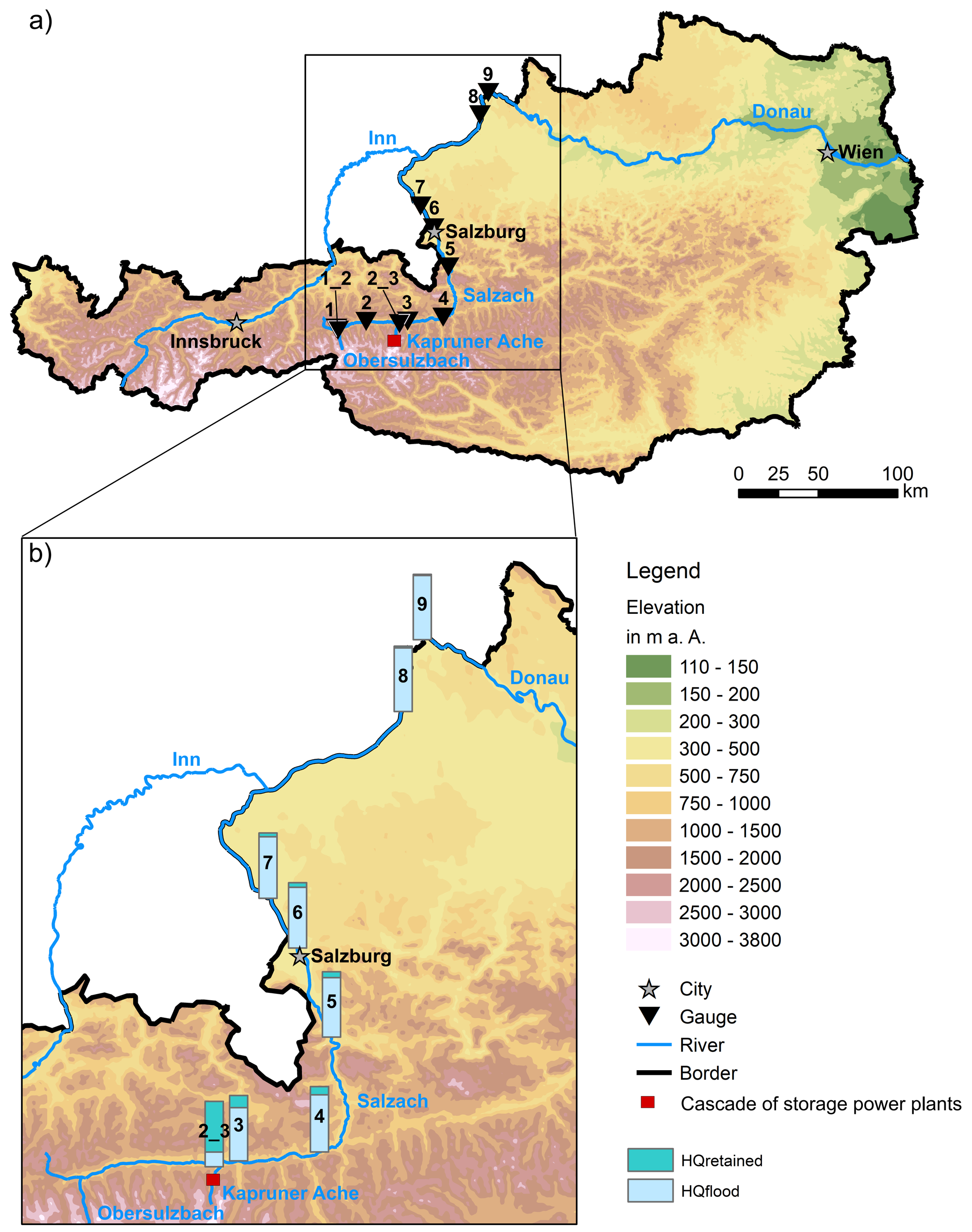

Figure 7: a) Overview map of Austria showing the location of the cascade of storage power plants at Kapruner Ache and the analysed gauges on the Salzach, Inn and Danube. The power plant group Glockner-Kaprun includes 4 reservoirs, which are considered as one reservoir to simplify the analysis.
b) The bars resemble the flood peak reduction in percent of a mean flood event in the period 2000-2015 for the gauging stations shown in Table 1. Summary statistics of the flood peak reductions are shown in Table 3.

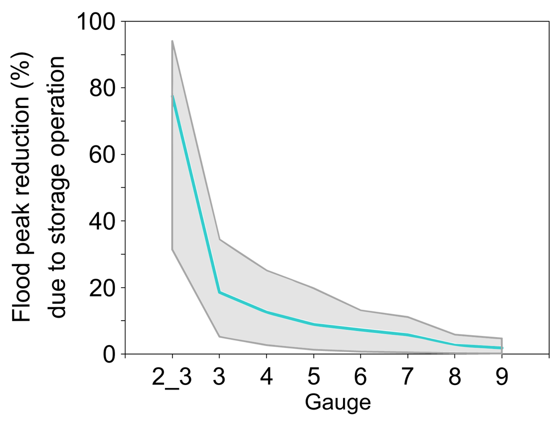

Figure 8: Flood peak reduction for several gauges (see Table 1) downstream of the cascade of the hydropower group Glockner-Kaprun induced by changes in the retention properties in the headwater catchment. The grey shading shows the range of reductions based on analysed annual maximum floods in the period 2000-2015. The blue line shows the mean reduction.

Table 3: Reduced flood peak (percentage) based on the highest annual flood events and observed retained floods between 2000 and 2015. See also Figure 7 and Figure 8.

Flood peak reduction in %								
Number	2_3	3	4	5	6	7	8	9
Gauge	Kaprun	Bruck	Wallnerau	Golling	Salzburg	Oberndorf	Schärding	Achleiten
River	Kapruner Ache	Salzach	Salzach	Salzach	Salzach	Salzach	Inn	Donau
min	31	5	3	1	1	0	0	0
mean	78	19	13	9	7	6	3	2
max	94	34	25	20	13	11	6	5

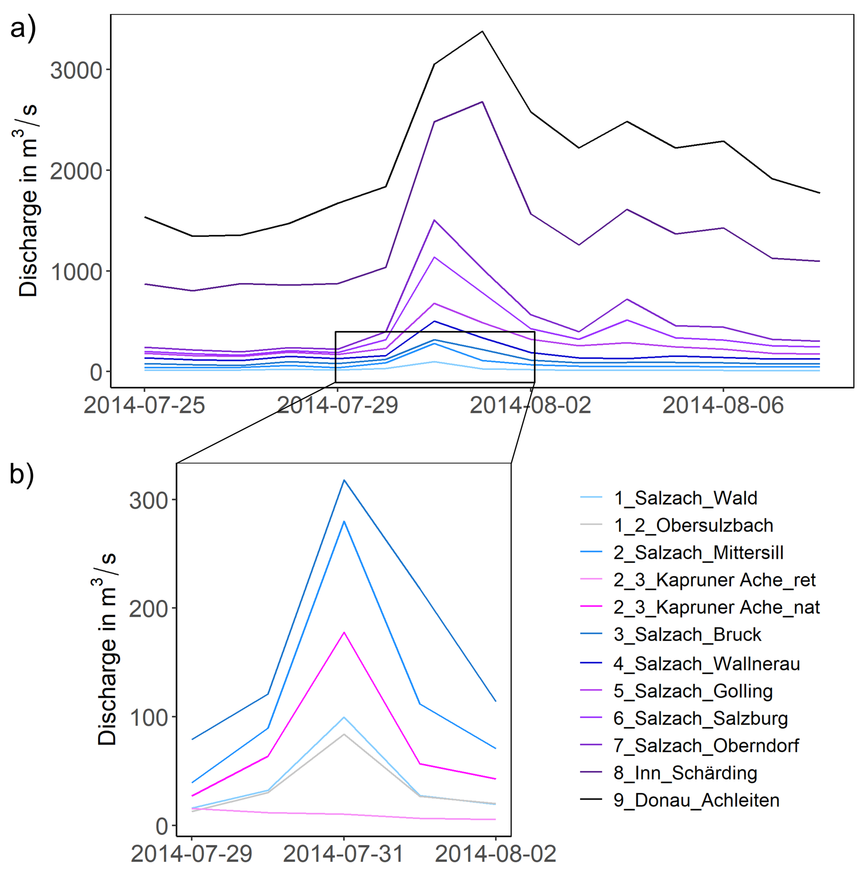

Figure 9: a) Observed flood wave propagation at the analysed gauges during the highest flood in the period 2000-2015 in Bruck.
b) Comparison of 5 day flood waves during the event in 2014 in the headwaters of the river Salzach. The observed retained discharge downstream the reservoirs at Kaprun is significantly lower than the generated natural flood wave and has no peak.

Verification of flood wave volume

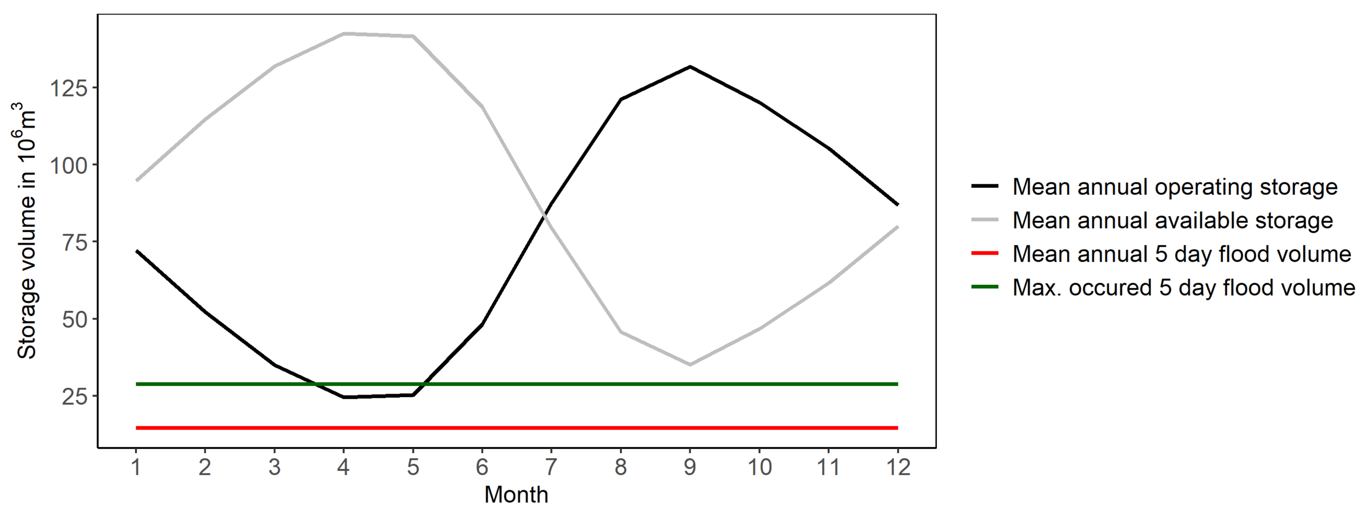

Figure 10: The mean annual total storage volume was derived by merging storage data of the single reservoirs. The highest discharges were observed during May and September, which is also the period when the reservoirs are filling up. Both the generated natural mean annual flood as well as the highest observed flood in 2014 can be retained in the reservoirs.

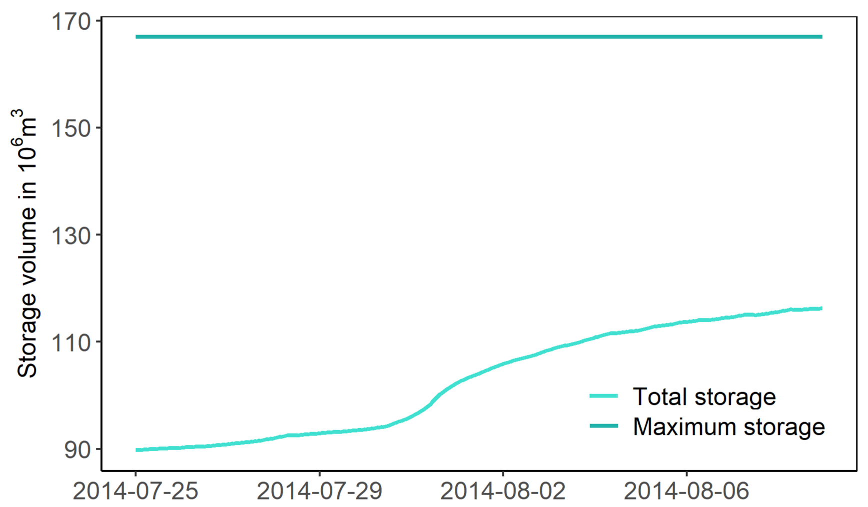

Figure 11: Reservoir filling during the highest observed flood event on July 31 2014.

Table 4: 5 day flood volumes during the highest observed flood event in July 2014 and generated natural mean annual flood event transferred from Obersulzbach to Kapruner Ache.

Highest observed flood (HQ 2014) Period day	$HQ_{natural}$ 10^6 m³	$HQ_{retained}$ 10^6 m³	Natural mean annual flood Period day	$HQ_{natural}$ 10^6 m³
29.07.-30.07.	3,9	1,2	1 - 2	3,0
30.07.-31.07.	10,4	1,0	2 - 3	4,2
31.07.-01.08.	10,1	0,7	3 - 4	4,3
01.08.-02.08.	4,3	0,5	4 - 5	3,0
Sum	28,8	3,4	Sum	14,5

5. Conclusions

- A high retention potential could be confirmed for the analysed casade of storage power plants Glockner-Kaprun.
- Both a generated natural mean annual flood and the highest observed flood could be retained by the reservoirs.
- The retention is most significant in the valley, where the reservoirs are located (Kaprun | Kapruner Ache 31-94 %). The mean retention effect downstream is less pronounced, but also leading to a reduction in flood hazard downstream (Bruck | Salzach 19 % to Achleiten | Donau 2 %).

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