



# Supplement of

# Exploring implications of input parameter uncertainties in glacial lake outburst flood (GLOF) modelling results using the modelling code r.avaflow

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#### This supplementary information contains:

Supplementary text: Description of DEM dataset Supplementary figure: Figures S1 to S8 Supplementary table: Tables S1 to S3

### **Description of DEM**

HMA-DEM with a spatial resolution of 8 m and vertical accuracy of up to 2m, covers glaciated regions of HMA. It provides temporal coverage ranges from 2008 to 2016 depending on the source imagery it was derived from. It was derived from stereo pairs of very-high-resolution (VHR) imagery from Digital Globe satellites, including GEOEYE-1 QUICKBIRD-2, WORLDVIEW-1, WORLDVIEW-2, and WORLDVIEW-3 (Shean, 2017). AW3D30 was derived from stereo pairs ALOS-PRISM and has global coverage with a ground resolution of 30 m and its vertical accuracy in HMA is estimated at 6.87 (Japan Aerospace Exploration Agency, 2021). NASADEM is the modernization of SRTM DEM with improved accuracy, spatial coverage and minimised voids. This improvement is achieved by reprocessing the original SRTM raw radar data using improved algorithms and incorporating ancillary data such as ICESat, ASTER, and GDEM V2. NASADEM provide global coverage with a spatial resolution of 30 m and an estimated vertical accuracy of 5.3 m over the United States (NASA JPL, 2021). SRTM GL3 is a global digital elevation model (DEM) derived from radar data collected during an 11-day mission on the Space Shuttle Endeavour in February 2000 (NASA Shuttle Radar Topography Mission (SRTM), 2013). It provides global coverage with a spatial resolution of 90 m and an estimated vertical accuracy of 9.5 m.



**Figure S1.** The conservative range of r.avaflow flow parameter values, commonly used in previous studies. The upper panel (a) shows the flow parameter values used in all types of

r.avaflow mass movement flow simulation while the lower panel (b) indicates the value used in the GLOF simulations.



**Figure S2.** Hydrograph generated by conducting a sequence of r.avaflow simulations, varying values of parameters including (a) volume of mass movement entering lake, (b) grain density of mass movement (c) volume of lake (c) entrainment coefficient, (e) basal friction angle, (f) internal friction angle and (g) fluid friction number.



**Figure S3. Maximum flow height**. The profile of maximum depth of total flow and debris components along the river centreline resulted from the input value variations of the (a, b) volume of mass movement entering the lake, (c, d) grain density of mass movement entering the lake, (e, f) the origin of mass movement entering the lake and (g, h) volume of the lake.



**Figure S4. Maximum flow depth.** The profile of the maximum depth of total flow and debris components along the river centreline resulted from the input value variations of (a, b) entrainment coefficient (c, d) basal friction angle, (e, f) internal friction angle and (g, h) fluid friction number.



**Figure S5. The maximum flow velocity**. The profile of maximum flow velocity along the river centreline resulted from the input value variations of all parameters tested in this study: (a) volume of mass movement entering the lake, (b) the origin of mass movement entering the lake, (c) grain density of mass movement entering lake, (d) volume of the lake (e) entrainment coefficient, (f) basal friction angle, (g) internal friction angle, and (h) fluid friction number.



**Figure S6. The flow arrival time**. The profile of flow arrival time along the river centreline resulted from the input value variations of all parameters tested in this study: (a) volume of mass movement entering the lake, (b) the origin of mass movement entering the lake, (c) grain density of mass movement entering lake, (d) volume of the lake (e) entrainment coefficient, (f) basal friction angle, (g) internal friction angle, and (h) fluid friction number.



**Figure S7**. A comparison of the (a) elevation profiles from four DEM datasets and (c) the corresponding flow depths across the cross sections 1-10 along Phochu River within the first 10 km (b). The cross sections were taken from the first 10 km since the GLOF modelled

utilizing HMA-DEM and AW3D30 attenuates within about the first 15 km downstream of Thorthormi Tsho.



**Figure S8.** Impact of mass movement into the lake from the various locations surrounding the lake: (a) location-1, (b) location-2, (c) location-3, (d) location-4, (e) location-5, (f) location-6.

**Table S1.** r.avaflow parameter. The parameters considered for sensitivity analysis in this study are highlighted in bold (Mergili et al., 2017; Mergili and Pudasaini, 2024)

SL n.	Parameter	Unite	Value considered in this study	Remarks
1	Elevation (Digital Elevation Model)	m	HMA-DEM, NASA- DEM, AW3D30, SRTM GL3	
2	Mesh size	m		
3	Volume of mass movement entering the lake	m3	1 x 10 <sup>6</sup> to 10 <sup>6</sup>	
4	Volume of fluid	m3	294×10 <sup>6</sup> m <sup>3</sup>	
5	Density of mass movement entering lake	Kg m⁻³	1098 to 2700	
6	Density of lake (fluid)	kg m <sup>-3</sup>	1000	Used constant value throughout
7	Entrainment height	m	moraine damming lake	Used constant value throughout
8	Entrainment coefficient	kg⁻¹	5.85 to 6.95	
9	Stopping criterion		0	Default
10	Internal friction angle	Degree	25° to 35°	
11	Basal friction angle	Degree	10° to 14°	
12	Fluid friction number		0.027 to 0.05	
13	Cohesion	N m <sup>-2</sup>	0	Default
14	Kinematic viscosity of		0	Default (only relevant to slow flow)
15	Deformation coefficient		1	Default
16	Shearing (Energy loss through shearing parameter)		0	Default
17	Fragmentation (Fragmentation parameter)		0	Default
18	C <sub>AD</sub> Ambient drag coefficient	M⁻s	0	Default
19	K <sub>Drag</sub> Mass flux parameter for drag		1	Default
20	m <sub>Drag</sub> Exponent for scaling of the fluid- like drag contributions to flow resistance		3	Default

21	nDrag Exponent for scaling PDrag with solid fraction		1	Default
22	Ut Terminal velocity		0	Default
23	Re <sub>p</sub> Particle Reynolds number		1	Default
24	j Exponent for drag		1	Default
25	N <sub>vm</sub> Virtual mass number		10	
26	Ivm Parameter related to the virtual mass coefficients		0.12	
27	n <sub>vm</sub> Parameter related to the virtual mass coefficients		1	
28	Temperature evolution and ice melting		0 (disabled)	
29	Transformation coefficient P1-P2		0	
30	Transformation coefficient P1-P3		0	
31	Transformation coefficient P2-P3		0	
32	Landslide temperature		0	
33	Atmospheric temperature		0	
34	Ground temperature		0	
35	Melting efficiency		0.2	
36	Sliding fraction		0.5	
37	Time interval for output	Second	10	
38	End time of simulation	Second	1500	

**Table S2.** The volume of Thorthormi Tsho calculated using various empirical area-volume scaling equations.

Empirical formula	Equation	Description	Calculated volume (10 <sup>6</sup> m <sup>3</sup> )
Evans, 1986	V=0.035A <sup>1.5</sup>	A-Lake area	
Huggel et al. 2002	V=0.104A <sup>1.42</sup>	A-lake area	278.31
Fujita et al. 2013	V=A.D, where D=55A <sup>0.25</sup>	A- lake area; D- mean lake depth	309.27
Emmer and Vilimek, 2014	V=0.054393A <sup>1.483009</sup>	A-Lake area	381.38
Cook and Quincy, 2015	V=A·D, where D=0.1697A <sup>0.3778</sup>	A-lake area; D-mean lake depth	238.24
Kapista et I., 2017	V=0.036A <sup>1.49</sup>	A-lake area	280.89
Loriaux and Casassa, 2013	V=0.2933A <sup>1.3324</sup>	A-Area	205.70
Zhang et al. 2022	V = 42.95 × A <sup>1.408</sup>	A-lake area	341.03

Mean	294.13

**Table S3.** Solid grain density calculated for the corresponding ice-to-rock ratio of the avalanche for each experiment (Ex-1 to Ex-10).

Experiment	Rock component (%)	Ice component (%)	Density kg/m <sup>3</sup>	Remarks
Exp-1	100	0	2700	Completely rock avalanche
Exp-2	90	10	2530	
Exp-3	80	20	2360	
Exp-4	70	30	2190	
Exp-5	60	40	2020	
Exp-6	50	50	1850	
Exp-7	40	60	1680	
Exp-8	30	70	1510	
Exp-9	20	80	1340	
Exp-10	10	90	1170	
Exp-11	0	100	1000	Completely ice-avalanche

## References

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