Supplementary information for

Exploring implications of input parameter uncertainties on GLOF modelling results using the state-of-the-art modelling code, r.avaflow

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This supplementary information contains:

Supplementary text: Description of DEM dataset

Supplementary figure: Figure S1 to S7

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 (JAXA, 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 ((SRTM), 2013). It provides global coverage with a spatial resolution of 90 m and an estimated vertical accuracy of 9.5 m .

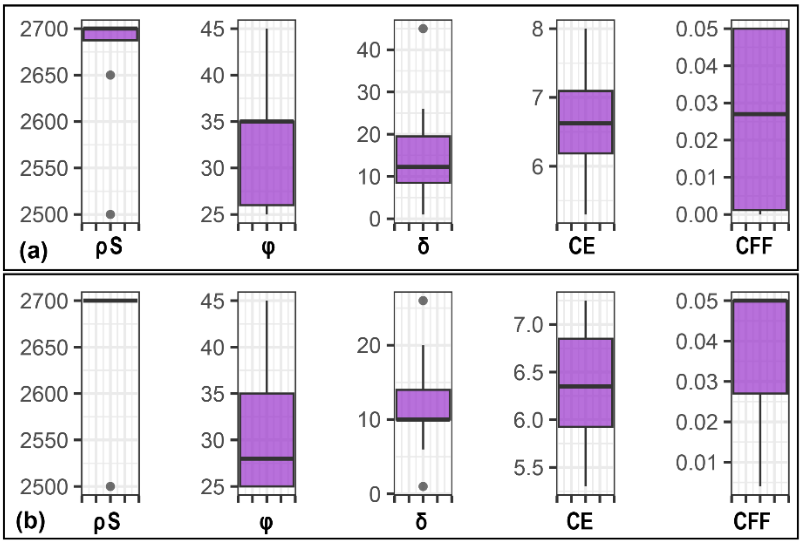

Figure S1. The conservative range of r.avaflow flow parameter values, commonly used in previous studies. The upper panel (A) shows the flow parameter values used in all types of r.avaflow mass movement flow simulation while the lower panel (B) indicates the value used in the GLOF simulations.

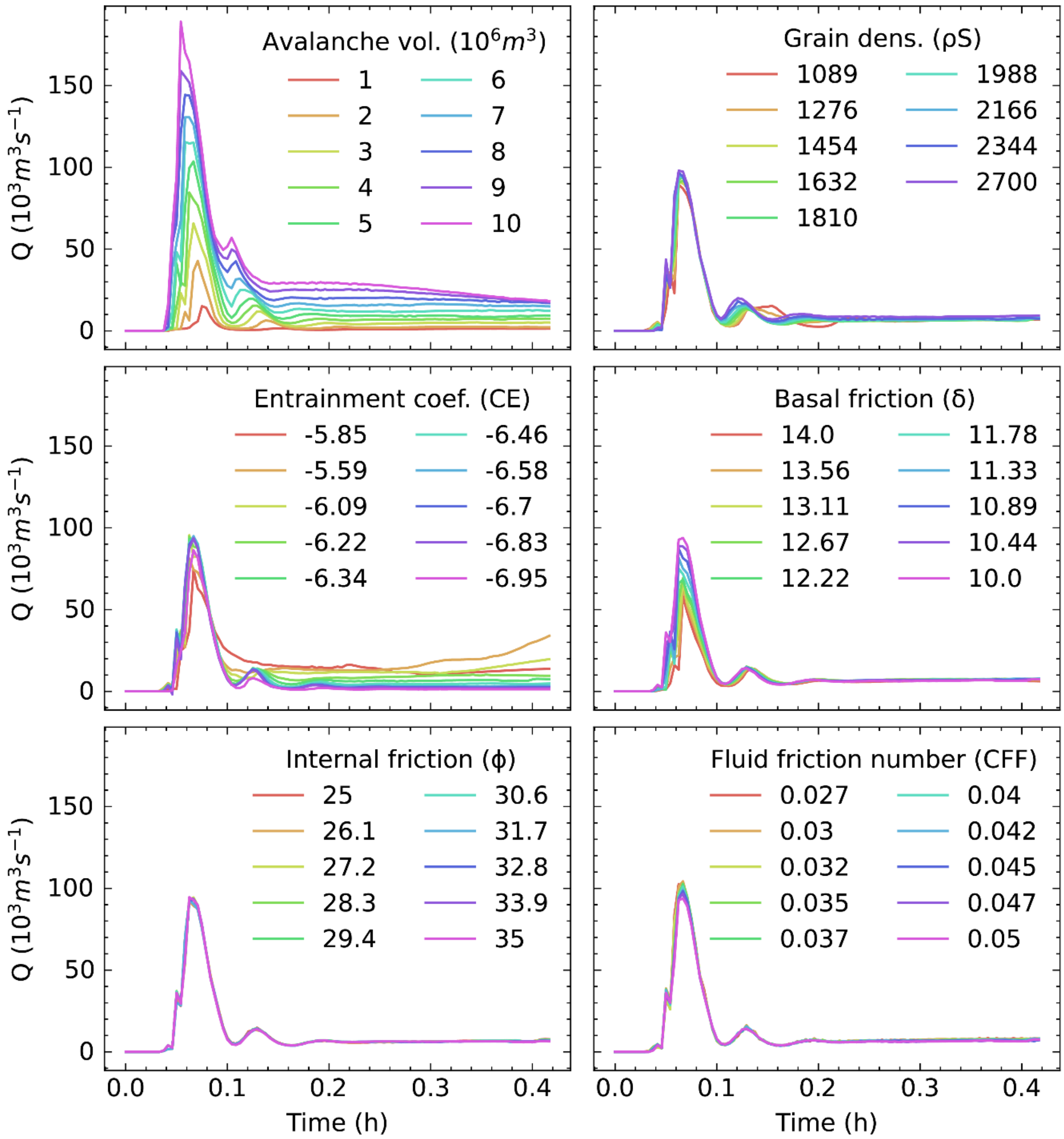

Figure S2. Hydrograph generated by conducting a sequence of r.avaflow simulations, varying values of parameters including avalanching volume entering lake (A), grain density (B), and entrainment coefficient (C). The lower panels are peak discharge (D), total discharge (E), and arrival time (F) for each parameter variation.

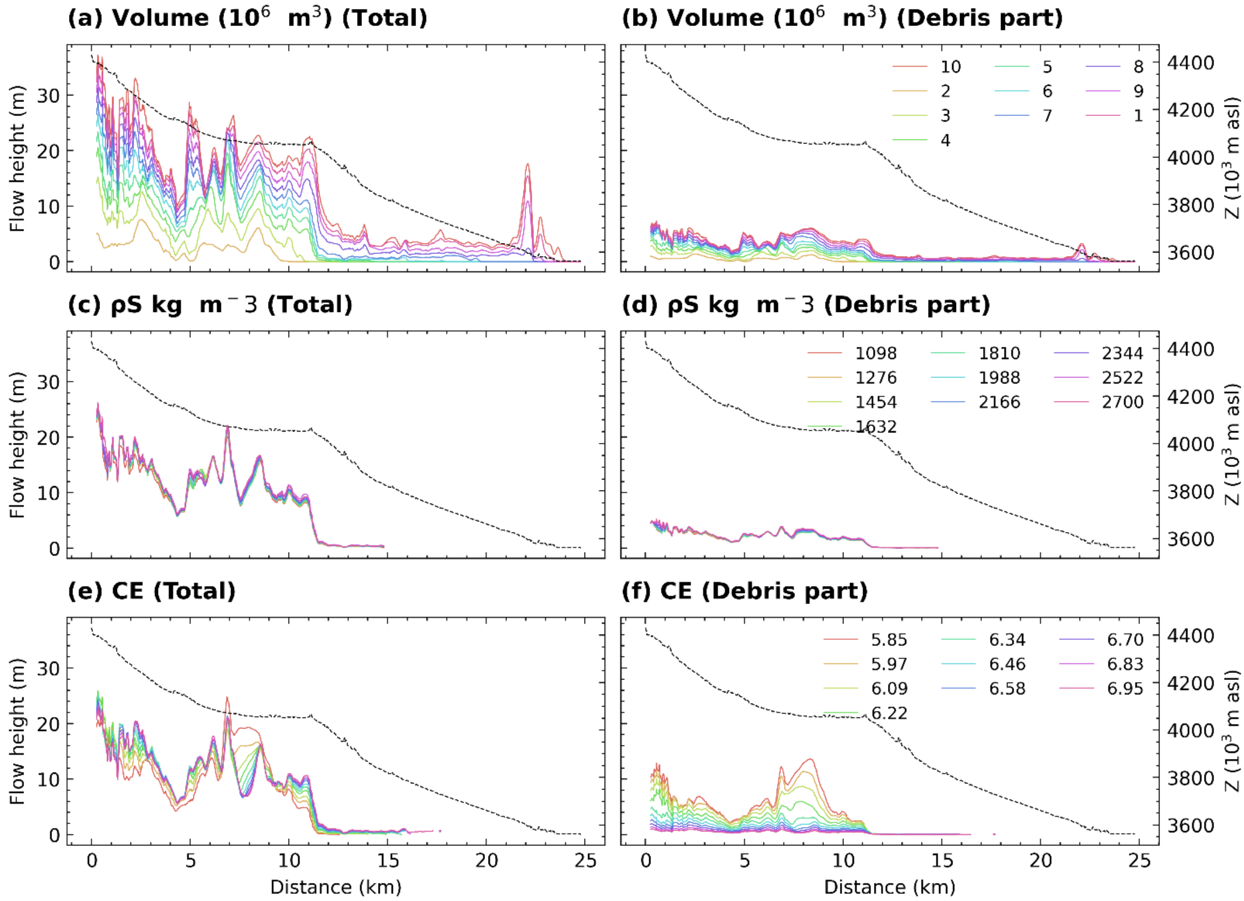

Figure S3. Maximum depth of total flow and solid components along the river centreline resulted from the input value variations of the volume of avalanching into the lake (a, b), grain density (c, d) and entrainment coefficient (e, f).

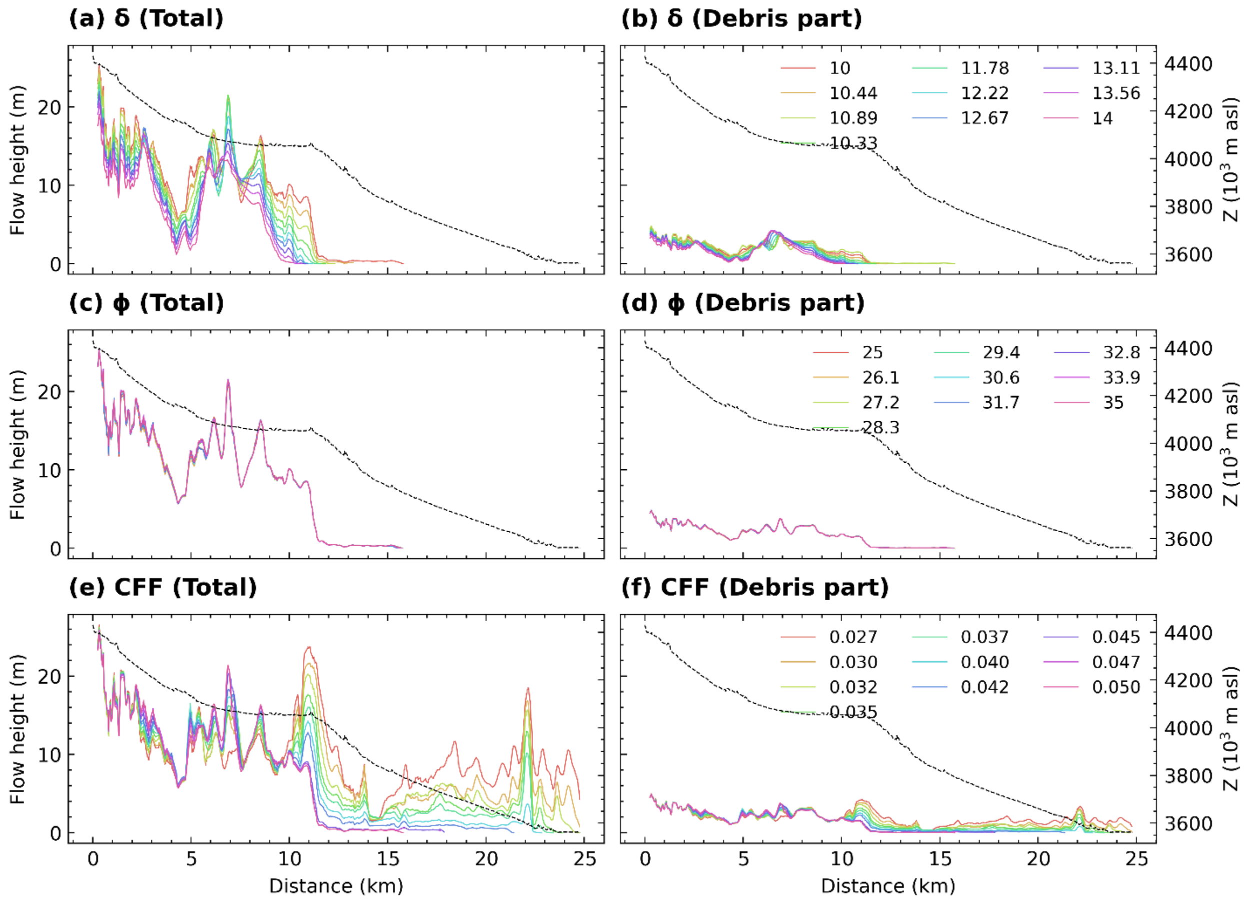

Figure S4. Maximum depth of total flow and solid components along the river centreline resulted from the input value variations of basal friction angle (a, b), internal friction angle (c, d) and fluid friction number (e, f).

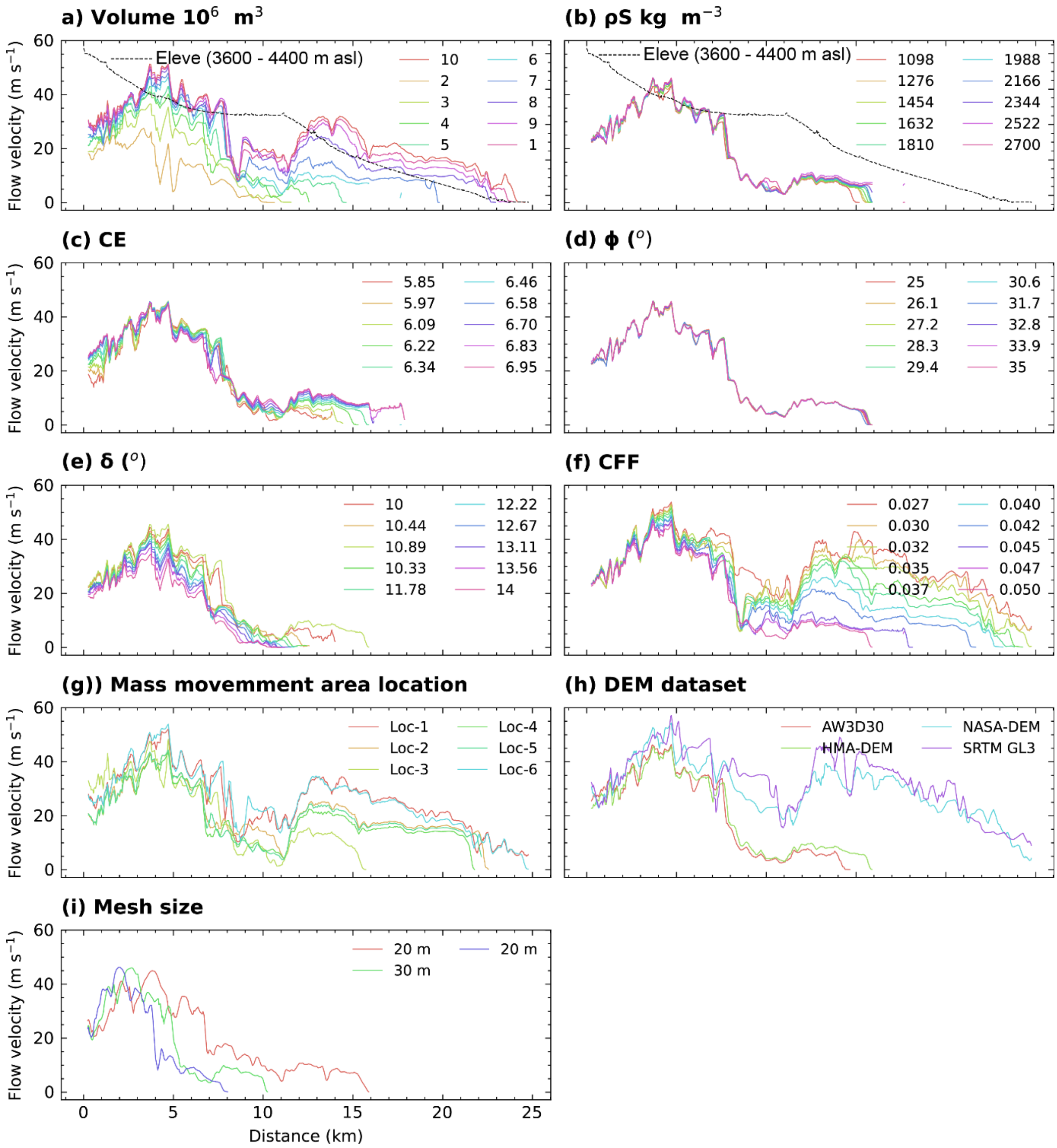

Figure S5. The velocity of flow along the river centreline resulted from the input value variations of all input parameters tested in this study: (a) Volume of mass movement entering lake, (b) grain density of mass movement entering lake, (c) entrainment coefficient, (d) internal friction angle, (e) basal friction angle, (f) fluid friction number, (g) origin of mass movement entering lake, (h) DEM dataset, (i) mesh resolution. The black dashed line in the first two plots is the elevation profile along the river centreline.

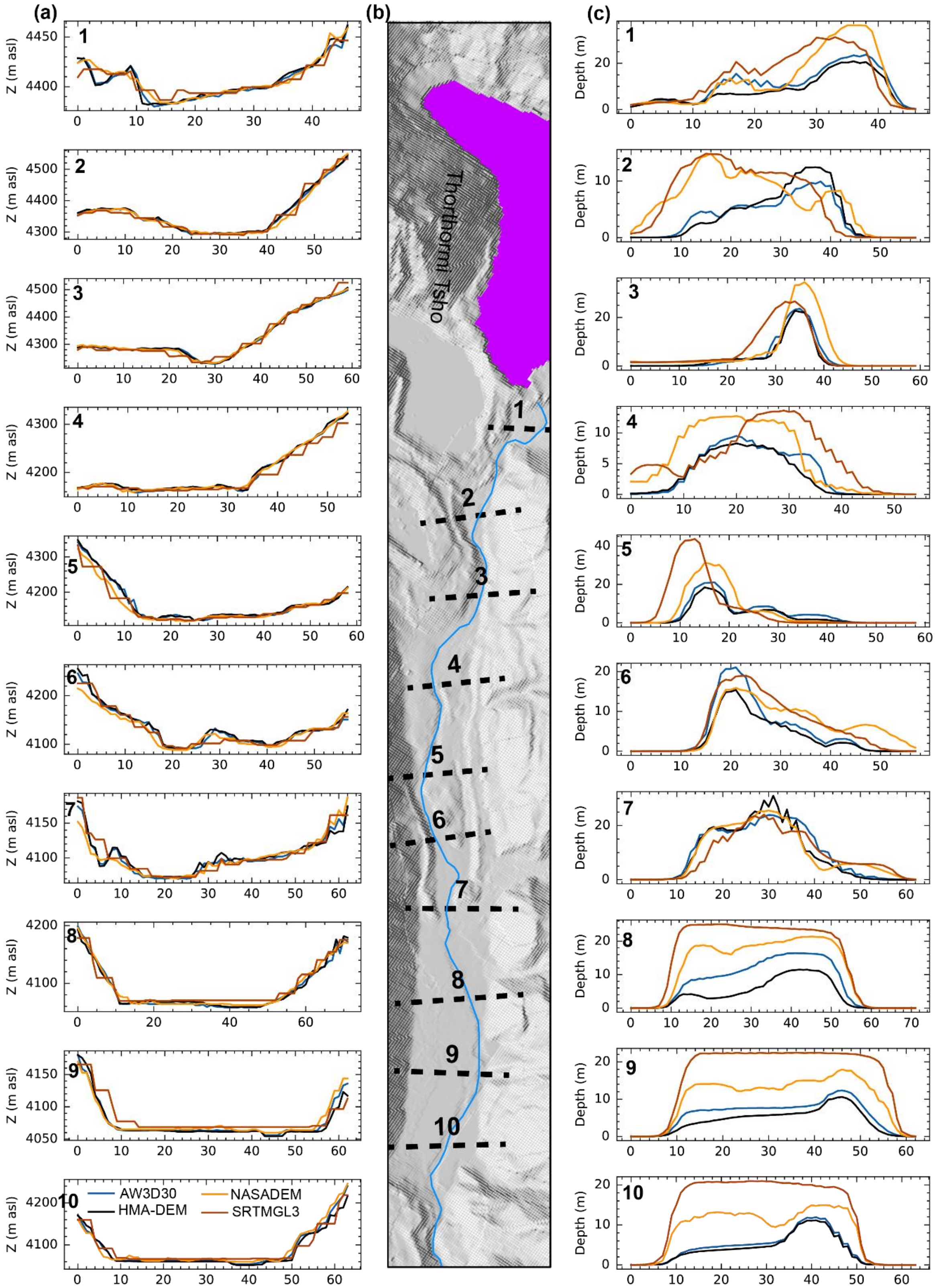

Figure S6. A comparison of the elevation profiles from four DEM datasets (A) and the corresponding flow depths (C) across the cross sections 1-10 along Phochu River within the first 10 km (B). The cross sections were taken from the first 10 km since the GLOF modelled utilizing HMA-DEM and AW3D30 attenuates within about the first 15 km downstream of Thorthormi Tsho.

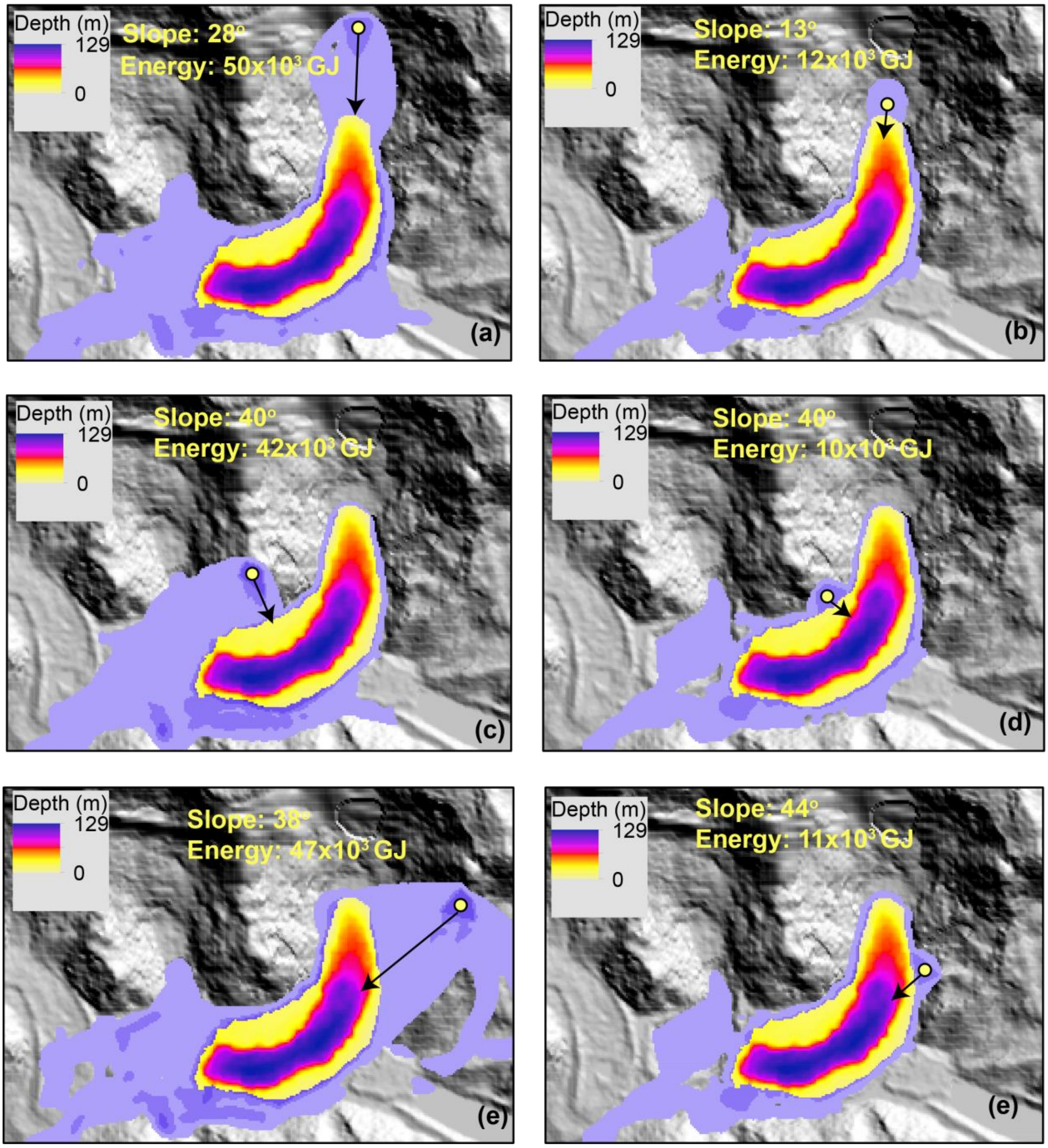

Figure S7. Impact of avalanching into the lake from the various locations surrounding the lake.

Table S4. 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**	**20, 30, 40**	
3	**Volume of mass movement entering the lake**	**m3**	**1 x 10^6 to 10^6**	
4	**Volume of fluid**	**m3**	**294×10^6 m^3**	
5	**Density of mass movement entering lake**	**Kg m^{-3}**	**1098 to 2700**	
6	Density of lake (fluid)	Kg m^{-3}	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^{-2}	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_{AD} Ambient drag coefficient	$M^{-}s$	0	Default
19	K_{Drag} Mass flux parameter for drag		1	Default
20	m_{Drag} 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	U_t Terminal velocity		0	Default
23	Re_p Particle Reynolds number		1	Default
24	j Exponent for drag		1	Default

25	N_{vm} Virtual mass number		10	
26	l_{vm} Parameter related to the virtual mass coefficients		0.12	
27	n_{vm} 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 (10^6 m^3)**
Evans, 1986	$V=0.035A^{1.5}$	A-Lake area	
Huggel et al. 2002	$V=0.104A^{1.42}$	A-lake area	278.31
Fujita et al. 2013	V=A.D, where $D=55A^{0.25}$	A- lake area; D- mean lake depth	309.27
Emmer and Vilimek, 2014	$V=0.054393A^{1.483009}$	A-Lake area	381.38
Cook and Quincy, 2015	V=A·D, where $D=0.1697A^{0.3778}$	A-lake area; D-mean lake depth	238.24
Kapista et l., 2017	$V=0.036A^{1.49}$	A-lake area	280.89
Loriaux and Casassa, 2013	$V=0.2933A^{1.3324}$	A-Area	205.70
Zhang et al. 2022	$V = 42.95 \times A^{1.408}$	A-lake area	341.03
Mean			**294.13**
Volume from ice thickness			**822.78**

Table S3. Solid grain density is calculated for the corresponding ice-to-rock ratio of the avalanche.

Experiment	Rock component (%)	Ice component (%)	Density kg/m^3	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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