

Supplement of Hydrol. Earth Syst. Sci., 18, 3461–3479, 2014
<http://www.hydrol-earth-syst-sci.net/18/3461/2014/>
doi:10.5194/hess-18-3461-2014-supplement
© Author(s) 2014. CC Attribution 3.0 License.



Supplement of

New method for assessing the susceptibility of glacial lakes to outburst floods in the Cordillera Blanca, Peru

A. Emmer and V. Vilímek

Correspondence to: A. Emmer (aemmer@seznam.cz)

INPUT DATA, RESULTS

PRE-FLOOD CONDITION OF LAKES WHICH HAVE ALREADY PRODUCED GLOFS:

Characteristic (input data)	Lake										References
	Artesoncocha 7/1951	Artesoncocha 10/1951	Artizon Alto	Artizon Bajo	Jancarurish	Lake No. 513	Palcacocha 1941	Palcacocha 2003	Safuna Alta 1970	Safuna Alta 2002	
Dam type	moraine	moraine	bedrock	moraine	moraine	bedrock	moraine	moraine	moraine	moraine	FS; RSI
Distance between the lake and glacier [m]	0	0	90	450	0	155	0	0	0	0	RSI
Maximal lake width [m]	250	240	NN (Dis > 0 m)	NN (Dis > 0 m)	390	NN (Dis > 0 m)	520	440	420	460	RSI
Width of calving front [m]	270	270	NA (Dis > 0 m)	NA (Dis > 0 m)	430	NA (Dis > 0 m)	550	440	450	260	RSI
Mean slope between lake and glacier [°]	NA (Dis=0m)	NA (Dis=0m)	27	40	NA (Dis=0m)	80	NA (Dis=0m)	NA (Dis=0m)	NA (Dis=0m)	NA (Dis=0m)	CL; FS; RSI; [2]
Mean slope of last 500 m of glacier tongue [°]	NN (Dis=0m)	NN (Dis=0m)	17	30	NN (Dis=0m)	26	NN (Dis=0m)	NN (Dis=0m)	NN (Dis=0m)	NN (Dis=0m)	CL; [2]; [3]; [4]
Maximal slope of moraines surrounding the lake [°]	65	65	85	80	65	NA (no moraines surrounding the lake)	75	72	70	70	CL; FS; [2]; [4]; [5]; [8]
Maximal slope of distal face of the dam [°]	15	13	NN (bedrock dam)	12	35	NN (bedrock dam)	34	8	50	45	CL; FS; [5]; [6]; [8]
Lake area [m ²]	115	100	137,661	31,87	110	207,585	185	342,322	85	371,56	RSI; [2]; [3]; [8]
Dam freeboard [m]	0	0	0	0	2 (provisional 2 m high wooden gate)	20	0	8	41	80	FS; RSI; [1]; [3]; [5][6]; [8]
Lake perimeter [m]	NN (Df=0m)	NN (Df=0m)	NN (Df=0m)	NN (Df=0m)	1753	2250	NN (Df=0m)	3220	1550	2830	RSI
Mean slope of lake surrounding [°]	NN (Df=0m)	NN (Df=0m)	NN (Df=0m)	NN (Df=0m)	45	65	NN (Df=0m)	58	60	53	CL; FS; [2]; [5]; [8]
Dam width [m]	520	540	NN (bedrock dam)	100	230	NN (bedrock dam)	400	160	420	420	FS; RSI; [4]
Dam height [m]	82	75	NN (bedrock dam)	16	62 (lowered for 27 m during remedial work)	NN (bedrock dam)	130	20	165	165	CL; FS; RSI; [2]; [3]; [4]
Piping	NO	NO	NA (bedrock dam)	NO	YES	NA (bedrock dam)	YES	YES	YES	YES	FS; RSI; [2]; [3]; [8]
Piping gradient [°]	NA (No evidence of piping)	NA (No evidence of piping)	NA (bedrock dam)	NA (No evidence of piping)	15	NA (bedrock dam)	21	6	18	11	CL; FS; [2]; [3]; [5]
Remedial work	none	none	none	none	Under way	tunnel	none	artificial dam, open cut	tunnel	tunnel	FS; [2]; [3]; [6]; [7]

NN: not needed for the assessment; NA: no available information for the particular lake (dam) type;

FS: field survey; RSI: remotely sensed images; CL: calculated from topographical maps 1:25000, Google Earth Digital Globe 2013 and RSI;

[1]: Carey et al., 2012; [2]: Cochachin and Torr s, 2011; [3]: Cochachin et al., 2010; [4]: Huaman, 2011; [5]: Hubbard et al., 2005; [6]: Liboutry et al., 1977; [7]: Reynolds, 2003; [8]: Vilimek et al., 2005

SUSCEPTIBILITY OF THE LAKE TO OUTBURST FLOOD:

Scenario 1:	1.000	1.000	0.996	0.985	0.983	0.378	1.000	0.961	0.604	0.589
Scenario 2:	0.000	0.000	0.000	0.996	0.000	0.000	0.000	0.000	0.000	0.000
Scenario 3:	0.259	0.225	0.000	0.205	0.554	0.000	0.559	0.000	0.279	0.261
Scenario 4:	0.000	0.000	0.000	0.207	0.000	0.000	0.000	0.000	0.000	0.000
Scenario 5:	0.025	0.019	0.000	0.026	0.135	0.000	0.217	0.026	0.231	0.147

CONDITION OF LAKES WHICH HAVE NOT YET PRODUCED GLOFS

Characteristic (input data)	Lake										References
	Auquiscocha	Chechiquacochoa	Churup	Churupito	Ishinca	Llaca (lower basin)	Mullaca	Quitacochoa	Rajucolta	Tararhua	
Dam type	bedrock	moraine	bedrock	moraine	moraine	moraine	moraine	moraine	moraine	moraine	FS; RSI
Distance between the lake and glacier [m]	1200	330	1300	690	270	540	450	50	0	190	RSI
Maximal lake width [m]	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	NN (Dis > 0 m)	450	NN (Dis > 0 m)	RSI
Width of calving front [m]	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	NA (Dis > 0 m)	220	NA (Dis > 0 m)	RSI
Mean slope between lake and glacier [°]	33	40	17	25	30	4	27	70	NA (Dis=0m)	34	CL; FS; [1]; [2]
Mean slope of last 500 m of glacier tongue [°]	29	28	38	38	35	7	22	17	NN (Dis=0m)	33	CL; [1]; [2]
Maximal slope of moraines surrounding the lake [°]	30	35	35	25	20	50	30	50	45	40	CL; FS; [1]; [2]
Maximal slope of distal face of the dam [°]	NN (bedrock dam)	25	NN (bedrock dam)	25	25	30	30	35	10	8	FS; [1]; [2]
Lake area [m ²]	774,894	351,611	185	23	87,902	44	110,695	130,407	512,723	358,026	RSI; [1]; [2]
Dam freeboard [m]	0	0	0	2	5	12	4	30	14	0	FS; [1]; [2]
Lake perimeter [m]	NN (Df=0)	NN (Df=0)	NN (Df=0)	610	1650	1080	1340	1860	3555	NN (Df=0)	RSI
Mean slope of lake surrounding [°]	NN (Df=0)	NN (Df=0)	NN (Df=0)	25	15	25	20	30	35	NN (Df=0)	CL; FS; [1]; [2]
Dam width [m]	NN (bedrock dam)	500	NN (bedrock dam)	350	270	250	430	330	190	320	RSI
Dam height [m]	NN (bedrock dam)	92	NN (bedrock dam)	97	70	86	165	99	30	40	CL; FS; [1]; [2]
Piping	NA (bedrock dam)	NO	NA (bedrock dam)	YES	NO	YES	NO	YES	NO	NO	FS; RSI; [1]; [2]
Piping gradient [°]	NA (bedrock dam)	NA (No evidence of piping)	NA (bedrock dam)	16	NA (No evidence of piping)	6	NA (No evidence of piping)	12	NA (No evidence of piping)	NA (No evidence of piping)	CL; FS
Remedial work	none	none	none	none	artificial dam, open cut	artificial dam, open cut	artificial dam, open cut	none	artificial dam, open cut	none	FS; [3]

NN: not needed for the assessment; NA: no available information for the particular lake (dam) type;

FS: field survey; RSI: remotely sensed images; CL: calculated from topographical maps 1:25000, Google Earth Digital Globe 2013 and RSI;

[1]: Cochachin and Torr s, 2011; [2]: Cochachin et al., 2010; [3] Reynolds, 2003

SUSCEPTIBILITY OF THE LAKE TO OUTBURST FLOOD:

Scenario 1:	0.500	0.574	0.423	0.553	0.612	0.651	0.483	0.594	0.668	0.643
Scenario 2:	0.574	0.000	0.553	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Scenario 3:	0.000	0.243	0.000	0.225	0.000	0.000	0.000	0.261	0.000	0.089
Scenario 4:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Scenario 5:	0.000	0.034	0.000	0.147	0.067	0.072	0.147	0.122	0.025	0.016

REFERENCES:

Carey, M., Huggel, C., Bury, J., Portocarrero, C., and Haerberli, W.: An integrated socio-environmental framework for glacial hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru, Climatic Change, 112, 733-767, DOI: 10.1007/s10584-011-0249-8, 2012.

Cochachin, A.R., and Torres, L.A. (Eds.): Memoria anual 2011: Estudio y monitoreo de lagunas, Autoridad nacional del agua, Unidad de glaciolog a y recursos h dricos, Huar z, Peru, 150 pp, 2011.

Cochachin, A.R., G mez, O.D.V., and Torres, L.A. (Eds.): Memoria anual 2010: Estudio y monitoreo de lagunas, Autoridad nacional del agua, Unidad de glaciolog a y recursos h dricos, Huar z, Peru, 153 pp, 2010.

Huaman, A.A.C.: Estudio de vulnerabilidad y seguridad f sica de la laguna Artizon Bajo, Instituto Nacional del recursos naturales, Unidad de glaciolog a y recursos h dricos, Huar z, Peru, 36 pp, 2001.

Hubbard, B., Heald, A., Reynolds, J.M., Quincey, D., Richardson, S.D., Zapata, M.L., Santill n, N.P., and Hambrey, M.J.: Impact of a rock avalanche on a moraine-dammed proglacial lake: Laguna Safuna Alta, Cordillera Blanca, Peru, Earth Surface Processes and Landforms, 30, 1251-1264, DOI: 10.1002/esp.1198, 2005.

Liboutry, L., Morales, B.A., Pautre, A., and Schneider, B.: Glaciological problems set by the control of dangerous lakes in Cordillera Blanca, Peru, I. Historical failures of moranic dams, their causes and prevention. Journal of Glaciology, 18(79), 239-254, 1977.

Reynolds, J.M.: Development of glacial hazard and risk minimisation protocols in rural environments: Methods of glacial hazard assessment and management in the Cordillera Blanca, Peru, Reynolds Geo-Sciences Ltd., Flintshire (UK), 72 pp, 2003.

Vilimek, V., Zapata, M.L., Klimeš, J., Patzelt, Z., and Santill n, N.: Influence of glacial retreat on natural hazards of the Palcacocha Lake area, Peru, Landslides, 2, 107-115, DOI: 10.1007/s10346-005-0052-6, 2005.