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SHORT NOTES

THE MAGNITUDE OF JÖKULHLAUPS

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Abstract. A review of available information on six self-dumping glacier-dammed lakes indicates that instantaneous discharge during a jökulhlaup is proportional to some power of the cumulative volume of water released rather than being a direct function of time. Information on these and four other self-dumping lakes, moreover, indicates that the peak discharge at the end of each jökulhlaup is approximately proportional to the two-thirds power of the total volume of water released during the flood.

Résumé. *L'importance des vidanges de lacs glaciaires (jökulhlaups).* Une étude de l'information disponible sur six lacs endigués par des glaciers et se vidant d'eux-mêmes, démontre que le débit instantané au cours d'un "jökulhlaup" est proportionnel à une certaine puissance du volume total d'eau déjà libéré, plutôt qu'elle n'est en fonction directe du temps. En outre, l'information sur ces lacs et quatre autres lacs se vidant spontanément, démontre que le débit maximum à la fin de chaque "jökulhlaup" est approximativement proportionnel à la puissance deux-tiers du volume total d'eau libéré pendant l'écoulement.

Zusammenfassung. *Das Ausmass von Gletscherläufen.* Das Studium der vorhandenen Informationen über sechs eisgedämmte Seen mit selbsttätiger Abflussregelung weist darauf hin, dass der momentane Abfluss während eines Gletscherläufes eher proportional zu einer Potenz des kumulativen Volumens abfliessenden Wassers als eine direkte Funktion der Zeit ist. Die Informationen über diese und vier weitere selbstentwässernde Seen zeigen weiterhin, dass das Abfluss-Maximum am Ende jedes Gletscherläufes annähernd proportional zur Potenz 2/3 der Gesamtwassermenge ist, die während des Flutens abfloss.

Analyses of the hydrographs for two successive jökulhlaups from glacier-dammed Summit Lake, British Columbia (Mathews, in press) show that instantaneous water discharge, Q_t, is related not to time, t, since the start of each flood but to the volume of water, V_t, released from the lake during this time. For all but the initial stages of the flood discharge can be expressed by a formula of the form:

$$Q_t = K(V_t)^b \qquad (1)$$

(in which for Summit Lake $K = 0.72$ and $b = 1.5$ if Q_t is expressed in m^3/s and V_t in $m^3 \times 10^6$). Equations of this same form apply to jökulhlaups from five other ice-dammed lakes, although the coefficient and exponent differ for each lake (Table I). Hydrographs for these floods, based on calculated or measured discharges plotted against cumulative volume lost, instead of time, are shown in Figure 1.

Values of K and b for the six examples show large variations, with extreme values found at two British Columbia lakes, Summit and Tulsequah. Possible factors influencing these values include: the head loss, H, between the high-water mark in the reservoir and the toe of the ice dam where the escaping water generally emerges, the distance, L, from reservoir to point of emergence, the depth, D, of the reservoir at the dam, and the capacity, V_{max}, of the reservoir (Table I). A plot of V_{max} against the ratio H/L for the data in Table I indicates, as one might expect, that small reservoirs are in general impounded by dams with large height-to-length ratios. Likewise, K displays a negative relationship to V_{max}, albeit a weak one. For a small dam the passage of 10^6 m^3 of water (for this volume, $Q_t = K$ in Equation (1)) can be expected to generate a larger leak, a higher discharge, and hence a higher value of K than is the case for larger ice dams with generally smaller values of H/L. Thus the size of the dam may control both the available reservoir storage and the coefficient of Equation (1), and, accordingly, K and V_{max} are not wholly independent of one another. However, the interrelationships of V_{max}, K and H/L all show large scatter, far beyond that of the individual points on the rising curves of the hydrographs, and none of the other factors investigated can be clearly associated with variations in values of K and b.

In Figure 1 the peak discharge, Q_{max}, occurring at the end of each jökulhlaup is designated by a dot. Curiously, all peak discharge values fall close to a common line despite the variations in slope and position of the individual hydrographs. Peak discharges for floods from four additional ice-dammed

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TABLE I. JÖKULHLAUP DATA: K AND b, COEFFICIENT AND EXPONENT OF EQUATION (1); H, HEIGHT OF LAKE SURFACE ABOVE TOE OF ICE DAM; L, DISTANCE FROM LAKE TO TOE OF DAM; D, DEPTH OF LAKE AT ICE DAM; V_{max}, RESERVOIR STORAGE; Q_{max}, MAXIMUM INSTANTANEOUS WATER DISCHARGE. THE JÖKULHLAUPS ARE HISTORIC EXCEPT FROM LAKE MISSOULA WHICH IS OF LATE PLEISTOCENE AGE. FLOODS RESULTING FROM VOLCANIC ACTIVITY ARE EXCLUDED. SOME OF THE DATA WERE COMPILED BY J. J. CLAGUE FROM TOPOGRAPHIC MAPS AND AIR PHOTOGRAPHS

Lake	*Year*	K	b	H m	L km	H/L	D m	V_{max} 10^6 m³	Q_{max} m³/s	*Reference*
Strupvatnet, Norway	1969	88	0.84	186	1	0.19	29*	2.6†	150	Whalley, 1971
Ekalugad Valley, Baffin Island	1967	46	0.91	120	2	0.06	120	4.8	200	Church, 1972
Demmevatn, Norway	1937	—	—	406	3‡	0.14	79	11.6	1 000	Ström, 1938
Gjánúpsvatn, Iceland	1951	30§	0.72§	167	5	0.03	20‖	20	370	Arnborg, 1955
Vatnsdalur, Iceland	1898	—	—	372	10	0.04	188	120	3 000	Thorarinsson, 1939
Tulsequah Lake, British Columbia	1958	150	0.49	210	8	0.03	73	229	1 556	Marcus, 1960
Summit Lake, British Columbia	1965, 1967	0.72	1.5	620	12	0.05	200	251	3 260	Mathews, 1965
Graenálon, Iceland	1939	24	0.77	535	19	0.03	230	1 500	5 000	Thorarinsson, 1939
Lake George, Alaska+	1958	—	—	40	9	0.004	40	1 730	10 100	Stone, 1963
Lake Missoula, Montana	Pleistocene	—	—	640	—	—	610	2×10^6	1.87×10^6**	Bretz, 1925; Pardee, 1942

* Depth to bedrock knob limiting magnitude of jökulhlaup = 13 m.
† Volume stored in lake = 4.6×10^6 m³; water released in jökulhlaup = 2.6×10^6 m³.
‡ Very approximate.
§ Coefficient and exponent determined from hydrograph of jökulhlaup of June 1951; other data pertain to jökulhlaup of October 1951.
‖ Lowering of lake surface during jökulhlaup.
\+ Drains at surface along ice margin.
** Q_{max} estimated for flood wave at Wallula Gap in south-eastern Washington.

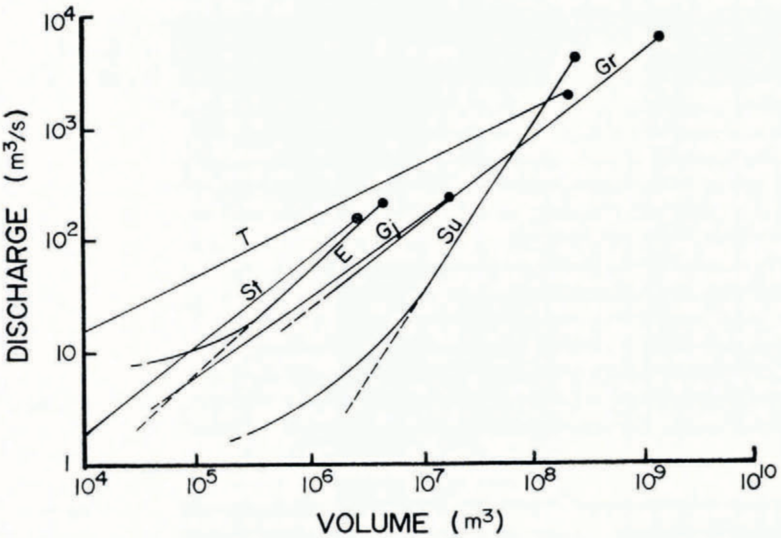

Fig. 1. Relation of cumulative volume drained during jökulhlaups and instantaneous water discharge. Equations are of the form $Q_t = K(V_t)^b$, *in which the coefficient,* K, *and exponent,* b, *for each flood are listed in Table I. The peak discharge for each jökulhlaup is indicated by a dot. E, Ekalugad Valley; Gj, Gjánúpsvatn; Gr, Graenálon; St, Strupvatnet; Su, Summit Lake; T, Tulsequah Lake.*

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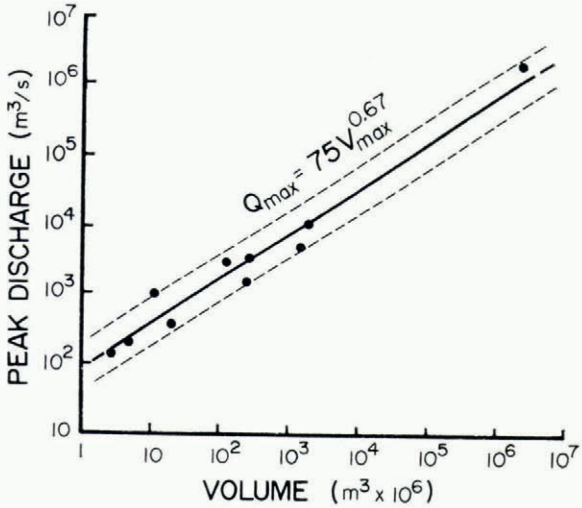

Fig. 2. Relation of total volume drained during jökulhlaup (V_{max}) and peak water discharge (Q_{max}); $r^2 = 0.96$. Dashed lines indicate 95% confidence interval for estimates of peak discharge (residuals are assumed to be normally distributed).

lakes are presented in Table I, and Figure 2 shows the resultant relationship between maximum flood discharge (in m^3/s) and available water storage (in $m^3 \times 10^6$) for the ten lakes. The data points cluster about a line represented by:

$$Q_{max} = 75 V_{max}^{0.67} \tag{2}$$
$$(r^2 = 0.96).$$

This relationship is a remarkably good one considering that the data include peak discharges measured at varying distances from the toes of ice dams and are derived from lakes of widely differing size and other characteristics.

More data from other jökulhlaups and from other ice-dammed lakes are clearly needed to clarify and explain the relationships, but in the meantime the log–log plot of Q_t against V_t is a useful tool for investigating jökulhlaups, and Equation (2) offers an empirical basis for estimating possible maximum discharges from self-dumping ice-dammed lakes.

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