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Exercises: Glacial hydrology

1. Glacial water balance. We are interested in knowing when water is accumulating within a glacier, when it is steady, and when it is losing water. Kennicott Glacier is 40 km long and 4 km wide. The average (water-equivalent) melt rate at the glacier surface over the melt season is 5 cm/day, as measured using ablation stakes. Water discharge is also measured at the terminus of the glacier.
• Estimate what the discharge of water should be, in m^3/s, when the water outputs from the glacier equal the water inputs.

The rate of generation of melt volume is derived from the product of the area of the glacier with the rate of surface melt. One must then transform this from a daily rate to a rate in m^3/s:

$$dV / dt = A\dot{m}$$

$$Q = dV / dt = 40x10^3 m * 4x10^3 m * 5x10^{-2} m / d = 8x10^6 m^3 / d$$

$$Q = 8x10^6 \frac{m^3}{d} * \frac{d}{24 * 3600 s} = 92.6 m^3 / s$$

2. Calculate the expected thickness of ice that can be melted from the base of a glacier due to geothermal heat flux. Assume that the glacier is temperate to its base (why is this important?), and that the geothermal heat flux is 60 mW/m^2.
Assume L=3.34x10^5 J/kg, ρ_i=917 kg/m^3.
Compare this with typical melt rates driven by solar insolation.

If the glacier is temperate, the temperature profile actually has an inflection in it at the base of the ice. All geothermal heat arriving at the base therefore goes into melt of ice.

The rate of ice melt at the base of the glacier is therefore derived by combining the rate at which heat is provided and the heat needed to melt a volume of ice. The latter quantity requires knowledge of the latent heat of melting of ice, and of the density of ice:

$$\dot{m} = \frac{Q}{\rho L} [=] \frac{\frac{J}{s-m^2}}{\frac{kg}{m^3}\frac{J}{kg}} = \frac{m}{s}$$

$$\dot{m} = \frac{60mW / m^2}{917kg / m^3 * 334kJ / kg} = \frac{0.06W / m^2}{917kg / m^3 * 3.34x10^5 J / kg} = 1.96x10^{-10} m / s$$

$$\dot{m} = 1.96x10^{-10} \frac{m}{s} * \frac{365 * 24 * 3600s}{yr} = 0.0062m / yr = 6.2mm / yr$$

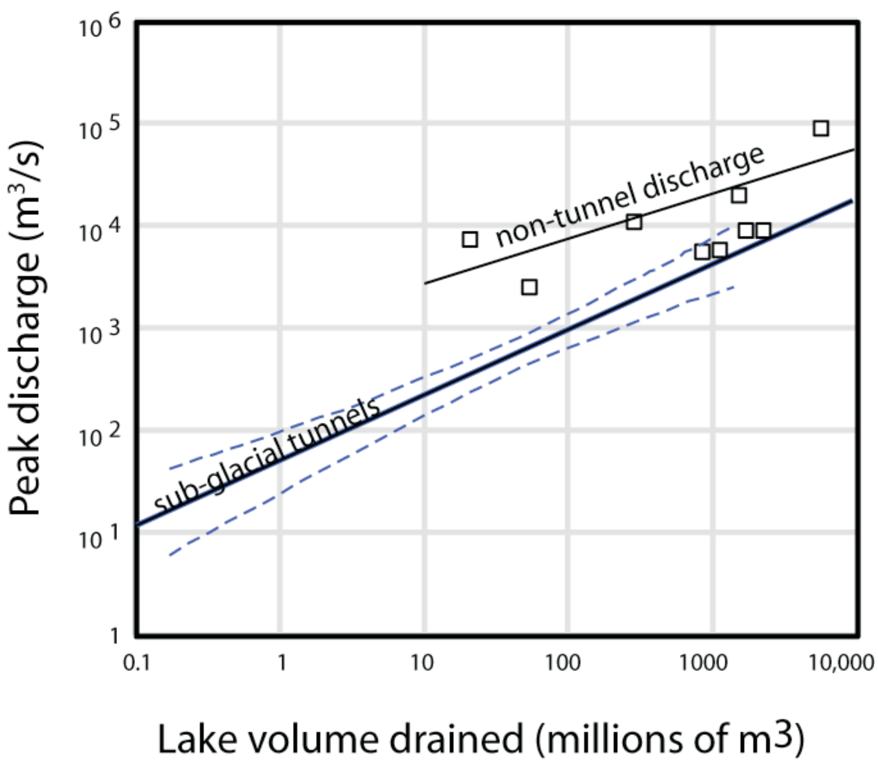
This is a trivial contribution to the water balance of temperate glaciers, and is usually ignored. It nonetheless aids in the generation of a thin film of water at the base of these glaciers.

3. How much would sea level rise if a flood of 120,000 km^3 occurred (one estimate for the size of the Lake Agassiz flood)?

Change in sea level can be estimated by dividing the volume of the flood by the surface area of the ocean.

$$\Delta z = \frac{V}{A_{ocean}} = \frac{120{,}000km^3}{0.7x4 * \pi * 6370^2} = 3.4x10^{-4} km = 0.34m = 34cm$$

4. You are the mayor of a town immediately downstream from a glacier with a side-glacier lake that could catastrophically drain through a subglacial tunnel. The geometry of the lake basin is such that failure will most likely occur when the lake has achieved a level corresponding to a lake volume of 100 million m^3.
i) what is your estimate of the peak discharge of the flood?
ii) what is your estimate of the duration of the flood, given the lake volume and peak discharge? Report your answer in days.



$Q_{peak} \sim 10^3$ m^3/s by inspection of the graph.

$T = V/Q = 10^8 m^3 / 10^3\ m^3/s = 10^5\ s \sim 1$ day

Reason through what the shape of the hydrograph, *Q(t)*, is likely to be when a glacially dammed lake is breached. List the assumptions you are making as you do this.

It should decline roughly exponentially with time as the thickness of the water coming through the breach declines. See discussion in Walder and Costa, as reviewed in Anderson and Anderson (2010), chapter 17.