Minimum Discharge Rates Required for Sustained Water Flow on the Martian Surface; G.D. Clow (U.S. Geological Survey, MS975, Menlo Park, CA 94025)

Small streams with depths $d \leq 1$ m are unstable on Mars under current climatic conditions and will freeze solid within 10 days [1]. One of the main factors affecting the energy balance of a river is the heat flux F_f associated with the conversion of gravitational potential energy to heat as the water flows downhill. Because F_f is proportional to $d^{5/3}$, stable perennially ice-covered rivers are expected to exist if water discharge rates can be maintained at sufficiently high levels. For such rivers, the rate at which ice accretes to the base of the ice-cover just balances the rate of sublimation loss from the surface. The objective of this study is determine the minimum discharge rates that would be required to sustain water flow within a perennially ice-covered river. One of our motivations is to determine if moderate-sized ice-covered rivers could have flowed within the Martian outflow channels and hence participated in their modification.

For an ice-covered river to stably exist, the latent heat flux due to freezing within the river (F_L) plus F_f must exceed the rate at which heat is conducted out of the river bed into the cold surrounding terrain F_c, i.e. $F_L + F_f > F_c$. For equilibrium conditions, the freezing rate associated with F_L must equal the sublimation rate E_0 from the surface of the ice-cover. E_0 was evaluated for current Martian conditions in the Kasei Vallis region using the planetary boundary layer model described in [2,3]. At the latitude of Kasei Vallis, diurnal variations are far greater than seasonal variations. Thus, conditions were evaluated over one diurnal cycle on an "average" day ($L_s = 115^o$). During the day, atmospheric conditions were found to be very stable within 1 m of the ice-cover as warm air from the surrounding ice-free areas blow over the relatively cold ice-cover; at night, the situation is reversed. Taking into account the effects of atmospheric stability on the sensible and latent heat fluxes at the ice-cover's surface, the mean surface temperature of the ice was found to be $T_s = 201.6$ K, assuming an atmospheric optical depth $\tau_d = 0.4$, ice albedo $A = 0.6$, and a downwelling IR flux from the atmosphere taken from [4]. For a geostrophic windspeed of 10 m s^{-1}, sublimation rates peak at 1.12x10^{-7} kg m^{-2} s^{-1} during midafternoon while mean daily sublimation rates are 5.26x10^{-8} kg m^{-2} s^{-1}. Thus, the flux F_L is quite small for current Martian conditions ($\approx$ 18 mW m^{-2}) and can be ignored in determining the minimum discharge rates. The conductive heat flux F_c was evaluated using a 2D steady-state thermal model and was found to be $F_c \simeq c/w$ where w is the river's width and c is a constant that evaluates to 150 W m^{-1} for current Mars. The flux F_f is given by $F_f = \rho g Q S/w$, where ρ is the density of water, g is the gravitational acceleration of Mars, Q is the discharge rate, and S is the slope. Thus, the requirement for sustained water flow can be simply expressed in terms of the water discharge rate,

$$Q > c/(\rho g S). \tag{1}$$

If the discharge rate fails to satisfy this condition at any point along a river, the river will freeze solid at that point. In Upper Kasei Vallis, the regional slope is about 0.001 [5]. Based on Eq. 1, the minimum discharge rate for sustained water flow in this area is about 40 m^3 s^{-1}. By comparison, the typical flow of the South Fork of the American River (Calif.) is 80 m^3 s^{-1}

during the white-water rafting season.

If Eq. 1 is satisfied, the equilibrium ice thickness at any point along the river is given by,

$$Z = \frac{(a/b)[e^{-bT_s} - e^{-bT_m}] - (1-A)S_o h}{F_L + F_f - F_c}, \tag{2}$$

where $a = 9.828$ W m^{-1} K^{-1}, $b = 0.0057$ K^{-1}, T_s is the mean surface temperature, $T_m = 273$ K^{-1}, S_o is the mean incident solar flux, and h is the extinction pathlength for visible light in ice. Due to the presence of F_f in the denominator of Eq. 2, the equilibrium ice thickness is sensitive to the product of the discharge rate and the slope (QS). Fig. 1 shows the dramatic decrease in equilibrium ice thickness as the discharge Q is increased. Note that Z drops to about 10 m on a slope of 0.001 if the discharge rate can be maintained at 100 m^3 s^{-1}. In the steepest portion of Kasei Vallis, the slope has been estimated to be 0.009 [5]. With discharges of only 40 m^3 s^{-1}, the equilibrium ice thickness is predicted to be only 1.0 m in this area.

Finally, if the discharge rate should drop below that needed to sustain water flow, the ice-cover would sublime away during a time interval $\tau = Z\rho/E_o$. For a 10 m thick ice-cover, the expected lifetime is about 6 ka. A 1000 m thick glacier would potentially sublime away in 600 ka if its source was somehow cutoff. These lifetimes assume the ice is not protected by a layer of dust or other material.

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