FACTORS CONTROLLING WATER VOLUMES AND RELEASE RATES IN MARTIAN OUTFLOW CHANNELS. L. Wilson[1], J. W. Head[2], H.J. Leask[1], G. Ghatan[2] and K. L. Mitchell[1]. [1]Planetary Science Research Group, Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, U.K. [2]Geological Sciences Department, Brown University, Providence RI 02912, U.S.A

Summary: We discuss estimates of water fluxes on Mars and suggest that many are overestimates. Even so, we can only explain very high martian outflow rates by either unusually permeable aquifer systems or sudden release of shallow concentrations of water.

Estimates of water fluxes: Many assessments of water fluxes producing martian outflow channels used Viking data, e.g. for Mangala [1], Maja [2, 3], Kasei [4] and Ares [5] Valles and the Tiu-Simud-Hydraotes complex [6]. More recently MOLA data were used to infer massive ancient floods in NW Tharsis [7, 8], and MOLA data and MOC images were used to estimate water fluxes in the Kasei [9] and Athabasca Valles [10-12]. We recently obtained water fluxes for Mangala Valles [13] and Ravi Vallis [14] using MOLA, MOC and THEMIS data. All of these measurements are summarized in the first 4 columns of Table 1.

The presence of erosional sub-channels, revealed by high resolution imagery, on the floors of the main channels at Kasei [9], Mangala [13] and Ravi [14] strongly suggests that these channels were very far from being bank-full for most of their erosional lifetime, by a factor of 5-10. However, many of the early channel analyses did assume bank-full or near-bank-full conditions. The flow speed U of water of depth D in a channel having a slope S and a floor friction coefficient f is

$$U = [(8\,D\,g\,S)\,/\,f\,]^{1/2} \qquad (1)$$

where g is the acceleration due to gravity, 3.74 m s^{-2}. Equation (1) shows that a tenfold overestimate of D leads to a $10^{1/2}$ = ~3.2-fold overestimate of U and, assuming that the same channel width W is used in both estimates, to a 32-fold overestimate of the volume flux V given by ($U\,D\,W$). If D is overestimated then given the typical shapes of valley cross-sections, W will also be overestimated, by as much as a factor of 2, so that flux overestimates by a factor of 50 are easily achieved. If the depth overestimate is only a factor of 5, the volume flux will be overestimated by a factor of about 15. A final subtlety is that most analyses to date have used some version of the Manning equation to calculate U, whereas in eq. (1) we have used the Darcy-Weisbach formulation in which the floor roughness friction coefficient f is dimensionless and varies, in an easily quantifiable way [15], with the nature of the bed roughness and the ratio of the water depth to bed roughness height. In a detailed study to be reported elsewhere we have found that, for water depths in the 50-100 m range, which our measurements suggest was common on Mars, and using the rock size distributions found at the Viking and Sojourner landing sites, our water flow speeds differ from those found by other workers by a factor of up to 2 (in some cases larger and in others smaller). As a result of these considerations we strongly suspect that all of the larger water discharge rates given in Table 1 may be overestimates by up to at least one order of magnitude, as was found for Kasei Vallis by Williams et al. [9]. However, it appears still to be necessary to explain water fluxes approaching 10^8 m^3 s^{-1}.

Implication of water fluxes: Proposals in the literature as to the origin of the water producing outflow channels on Mars include (1) sill-like shallow intrusions melting cryosphere ice, (2) dike-like intrusions fracturing the cryosphere and releasing water from pressurized aquifers, and (3) collapse (as a result of volcanic action, earthquake fluidization or meteoroid impact) of high-standing ridges of cryosphere retaining subterranean lakes or lakes capped by dust-covered ice. These mechanisms vary as to (a) the likely ratio that they imply of water to sediment load in the released flood, (b) the total volume of water immediately available, and also (c) the limitations on the release rate.

Melting of cryosphere ice, whether by sills or dikes, facilitates water movement but is almost certainly not the way to generate large water volumes. Dikes are in general far less efficient than sills because the fraction of a dike that can intersect the cryosphere is limited to the cryosphere thickness whereas all of a sill can tranfer heat to the cryosphere if intruded within or close to it [16, 17]. Given that the maximum sediment load that a flood can carry is likely to be no more than 40% [18], and that estimates of the maximum ice content of the bulk of the cryosphere are of order 20% [19], making the potential sediment load of thawed cryosphere material 80%, it is hard to see how melting of cryosphere alone can possibly supply an outflow event. Additional water is needed, by a factor of at least about 3, as we have found in analyzing the Aromatum-Ravi system [14].

Where water must be fed through one or more fractures from an aquifer system, it will clearly be the permeability of the aquifer, not the geometry of the fracture, that controls the release rate [12]. The total water flux will then be the product of the flow rate of water through the aquifer and the vertical cross-sectional area of the aquifer intersected by the fracture. This cross-sectional area is in turn the product of the vertical extent of the aquifer, which we take to be up to ~5 km based on crustal porosity models [19], and the horizontal extent, L, of the fracture. In some cases the active fracture length of outflow channel sources can be deduced from the surface morphology, as at Athabasca Valles [12] and Mangala Valles [13] where dikes inducing graben-bounding faults provide the fracturing. Elsewhere, water release has been accompanied by cryosphere melting and chaos formation as sediment is removed by the excess water [14]. The perimeter length of the chaos (actually that fraction of the perimeter through which the regional topography suggests inflow of water took place, typically one half) then provides an estimate of the fracture length, L: values are given in the fifth column of Table 1. Column 6 of the Table then gives the implied flux divided by the fracture length. If this quantity is in turn divided by our 5 km adopted vertical extent of aquifer, it yields in column 7 the required Darcy velocity, U_{Darcy}, which is the flux per unit area of water in the aquifer.

The Darcy velocity in an aquifer is given by

$$U_{Darcy} = (k / \eta) (\rho\, g\, dH/dx) \qquad (2)$$

where k is the intrinsic permeability of the aquifer medium, η is the dynamic viscosity of water, ~1.5 x 10^{-3} Pa s, ρ is the density of water, ~1000 kg m^{-3}, and dH/dx is the lateral water head gradient in the aquifer. Typical aquifer slopes implied by large-scale topographic slopes on Mars might be as much as 5 km per 500 km, i.e. $dH/dx = 0.01$. If we assume that martian aquifers have properties similar to those of very porous aquifers on Earth, with k up to ~10^{-9} m^2 [20], then the maximum value of U_{Darcy} = 0.025 mm s^{-1}. This is more than 100 times too small to explain all but the smallest of the discharges shown in Table 1. Only by increasing the permeability assumed for martian aquifers one hundred-fold to that of a porous gravel on Earth, ~10^{-7} m^2 [20], can we come close to accounting for the Darcy velocity values of up to ~10 mm s^{-1} which are common in the Table.

Conclusions: Even after allowing for the probable overestimates of water fluxes in martian outflow channels based on Viking data, new flux estimates imply that martian aquifer systems have an unusually high permeability, as we have noted elsewhere [12, 21]. If verified by analysis of higher-resolution data, the highest discharges in the Table, especially for Maja and Ares Valles and NW Tharsis, cannot readily be explained by simple aquifer flow, and require some other circumstance of water supply.

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1) Valley Name	2) Ref.	3) Source Name	4) Flux /(m^3/s)	5) Fracture Length, L /km	6) (Flux/Width) /(m^2 s^{-1})	7) U_{Darcy} /(mm/s)
W. Tharsis	[7, 8]	(Hidden)	10^9 - 10^{10}	1000??	1000?	200??
Kasei	[4]	Echus Chasma	9-23 x 10^8	130-500?	1800-7000?	360-1400
Ares	[5]	Ianni Chaos	10^8 - 10^9	360	278	55.6
Hydraotes	[6]	Hydraotes Chaos	7-40 x 10^7	500?	140?	28.0
Tiu	[6]	Hydraotes Chaos	3-20 x 10^7	500?	60?	12.0
Maja	[3]	Juventae Chasma	9 x 10^7	240?	375?	75.0
Mangala	[12]	Memnonia Fossa	1-8 x 10^7	223	48	9.5
Simud	[6]	Hydraotes Chaos	1-5 x 10^7	500?	20?	4.0
Mangala	[1]	Memnonia Fossa	8-40 x 10^6	210	38	7.6
Ravi	[13]	Aromatum Chaos	3-30 x 10^6	50	60	12.0
Athabasca	[9-11]	Cerberus Fossae	2-4 x 10^6	35	57	11.4
Kasei	[8.5]	Echus Chasma	0.1-20 x 10^6	130-500?	0.2-154	0.03-30

Table 1: Summary of measurements of martian outflow channels.