FLOW ROUTING IN A CRATERED LANDSCAPE: 1. BACKGROUND AND APPLICATION TO MARS. A. D. Howard[1] and Y. Matsubara[1], [1]Department of Environmental Sciences, Univeristy of Virginia, P.O. Box 400123, Charlottesville, VA 22904-4123, ah6p@virginia.edu.

Introduction: When fluvial erosion was active during the Noachian, creation and integration of drainage networks competed with disruption by impacts. As a result, drainage networks were composed of valley networks interspersed with crater and intercrater basins which would have overflowed only if contributing basin size and rainfall amounts exceeded evaporation in basin lakes [*1-6*]. The determination of which enclosed basins on early Mars overflowed thus provides information on the prevailing climate. We report here on the development of an areally explicit hydrologic routing model balancing runoff, evaporation, and lake overflow and its preliminary application to Mars.

A Hydrologic Balance: Consider an enclosed drainage basin of total area A_T with an included lake of area A_L. We consider a multi-year water balance with the average precipitation rate P_B over the non-submerged (upland) portions of the basin and rate P_L directly on the lake. On the uplands the fractional runoff yield is R_B. Yearly evaporation rate on the lake is E. With sufficient precipitation the lake may overflow at a yearly volumetric rate V_O, and overflow from other basins may contribute to the present basin at a rate V_I. A yearly water balance for the basin is thus:

$$V_O = V_I + (A_T - A_L)P_B R_B + A_L P_L - E A_L \,. \qquad (1)$$

If the lake does not overflow (V_O=0), then (1) can be solved for the requisite size of the lake. Each basin has a maximum lake area A_{LM} at which overflow into an adjacent basin occurs, which depends upon the basin topography. If the solution assuming V_O=0 and V_I=0 indicates a lake area A_L>A_{LM}, then V_O is determined by substitution of A_{LM} for A_L into (1).

In order to determine the water balance for a large basin with multiple enclosed sub-basins an iterative approach must be used, because the output from several overflowing enclosed sub-basins can serve as inputs for the next sub-basin downstream. The solution for given input parameters P_B, P_L, R_B, and E starts by routing water through the channel network to the low point of the basin assuming no en-route evaporation losses. In addition, the basin area A_T and maximum lake area A_{LM} are determined. Then the lake area A_L is calculated for each basin from (1) assuming V_I=0. If A_L>A_{LM} then V_O is calculated and this is used as an input, V_I for the next sub-basin downstream during the next iterative calculation cycle. Iterations continue until there is no change of V_I into any sub-basin. Additional complications arise since two or more overflowing basins may mutually drain, and filling of a downstream basin may submerge the outlet for an upstream basin. In such occurrences the basins are combined into a new sub-basin for subsequent iterations.

Preliminary Application to Mars: In the general case P_B, P_L, R_B, and E may have areally-varying values. For example, in mountainous terrain these parameters are generally strong functions of elevation and latitude. For exploratory simulations we assume that all of these parameters are spatially invariable, and in addition we assume that P_B=P_L. We define a parameter X which is the ratio of net lake evaporation rate to runoff depth:

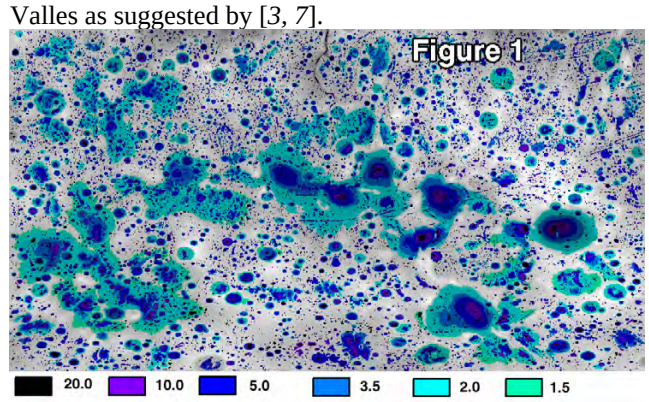
$$X = (E - P_L)/P_B R_B \,, \qquad (2)$$

so that the lake area is given by:

$$A_L = A_T/(X+1) \,. \qquad (3)$$

All lakes overflow as $X \rightarrow 1$, and lakes become indefinitely small as $X \rightarrow \infty$.

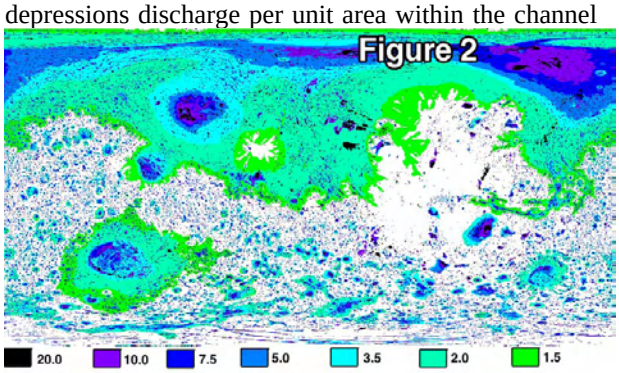
Fig. 1 shows an example simulation for the highland region between 140-210°E and 20-55°S, showing extent of lakes as a function of X. For X<2 the lakes overflow to the north through Ma'adim Valles as suggested by [*3, 7*].



For this simulation precipitation and evaporation was assumed to be areally uniform. Simulations can also be conducted for a global water balance, again (and clearly not realistic in this case) assuming globally uniform precipitation and evaporation ***[Fig. 2]***.

Concept of relative channel discharge: When runoff occurred on early Mars, large basins with small contributing areas probably never overflowed, but small depressions easily overflowed. Layered sediments are common within basins [*8*], suggesting that the climate of early Mars underwent similar quasi-

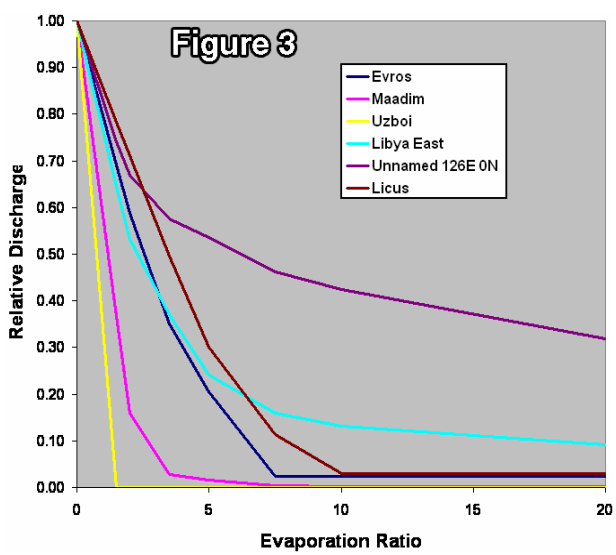
periodic fluctuations similar to those of the recent past (although wetter). In a landscape with enclosed depressions discharge per unit area within the channel



network probably increased non-linearly with precipitation as additional enclosed upstream basins were added to the drainage network.

This was explored by examining the relative discharges within selected Martian channel systems as a function of the parameter X using the simulated results from the runs shown in ***Fig. 2***.

The discharge when X=1 and all depressions overflow is used as a reference discharge, Q_R, for each selected location within a stream network. As X becomes larger, fewer upstream depressions contribute to the channel, and the actual discharge, Q is less than Q_R. If there were no enclosed depressions, as in typical terrestrial networks, then Q would not be function of Q_R, and Relative Discharge, Q/Q_R, would plot as a horizontal line with value unity. Predicted Relative



Discharge ***[Fig. 3]*** drops rapidly with X for channels like Uzboi Valles, which receive appreciable drainage only when large contributing basins (Argyre in this case) overflow. Other basins with few large enclosed upstream depression, such as the unnamed valley at 126°E and 0°N show a less precipitious drop with increasing X ***[Fig. 3]***.

The Issue of Ephemeral Lakes: The model assumes that runoff and precipitation are contstant, continuous processes. Thus each basin must have a lake of finite size to balance contributing runoff. In arid landscapes, however, many enclosed basins have temporary playa lakes, where episodic runoff is balanced by intervening evaporation. We can identify those predicted lakes which might be ephemeral by the endmember case of instantaneous yearly delivery of the total runoff volume to the basin center, so that the temporary volume of the lake is, $V_L=P_B R_B A_T$ (assuming $A_L \ll A_T$). Given the topographic shape of the basin floor, the maximum lake depth D_L can be calculated, and the lake will be ephemeral if $D_L<E$. For example, if the basin floor is conical with an angle α to the horizontal, the lake will be ephemeral if

$$E > \sqrt[3]{3\tan^2\alpha\, P_B R_B A_T / \pi}\,. \qquad (4)$$

Discussion: Future work with the model include calibration and validation against the enclosed basins of the Great Basin, USA [*9*]. One application of the model is to infer past relative values of the precipitation/evaporation ratio, X, on early Mars, and regional variations of this ratio, based upon which enclosed basins overflowed (creating, e.g. crater breaches and downstream valleys). Examples of such overflows are discussed by [*1-4*, *7*]. The model will also be incorporated into Global Circulation Models for Mars to provide a closure to the water cycle, to permit interaction between modeled precipitation, runoff, and atmospheric recharge from evaporation from standing water- or ice-covered lakes. Finally, a simple model of subsurface groundwater interchange between basins will also be incorporated.

References: [1] Irwin, R. P., III, Howard, A. D. (2002) *JGR.*, *107*, 10.1029/2001JE001818; [2] Irwin, R. P., III *et al.* (2005) *JGR*, *110*, E12S5, doi:0.1029/2005JE002460; [3] Irwin, R. P., III *et al.* (2004) *JGR 109*, E12009, doi:10.1029/2004JE002248; [4] Howard, A. D. *et al.* (2005) *JGR 110*, doi:10.1029/2005JE002459; [5] Kramer, M. G. *et al.* (2003) *EOS Trans. AGU*, *84*, 1-6; [6] Newsom, H. E. *et al.* (2003) *JGR 108*, 8075, doi:10.1029/2002JE001993; [7] Irwin, R. P., III *et al.* (2002) *Science*, *296*, 2209-12; [8] Malin, M. C., Edgett, K. S. (2000) *Science*, *290*, 1927-37; [9] Matsubara, Y., Howard, A. D. (2006) *LPSC XXXVII*, Abstract.