# Estimates of groundwater divides and basins on Noachian Mars.

E. Hiatt[1,2,4], M. A. Shadab[2,3,4] and M. A. Hesse[1,3,4], S. P. S. Gulick[1,2,4], and T. A. Goudge[1,4]. [1]Department of Geological Sciences, [2]Institute of Geophysics, [3]Oden Institute for Computational Science and Engineering, [4]Center for Planetary Systems Habitability, The University of Texas at Austin, Austin, TX 78757 (eric.hiatt@utexas.edu,).

**Introduction:** We are investigating the compartmentalization of the hypothesized deep aquifer beneath Mars' southern highlands on Noachian Mars [1,2]. Specifically, we investigate a scenario where the northern lowlands, as well as the Hellas and Argyre basins, contained coeval large water bodies and that groundwater recharge was spatially uniform. The different shorelines proposed for these water bodies [3,4] create regional hydraulic gradients that interact with the recharge to determine the compartmentalization of the groundwater system and hence the potential communication between these proposed water bodies. We conduct models both with and without Hellas and Argyre basins being emplaced to investigate the response of the groundwater system to their formation.

**Aquifer model:** To investigate the large-scale aquifer dynamics, we use the Dupuit-Boussinesq model [5,6], similar to other Mars groundwater models [7,8]. At steady state, the elevation, h, of the unconfined groundwater table above the base of the aquifer is determined by the following equation

$$-\nabla \bullet (\mathrm{Kh}\nabla \mathrm{h}) = r$$

Here $K$ is the hydraulic conductivity of the aquifer and $r$ is the recharge. For this analysis, we assume that $K$ and $r$ are constant, but our analysis can be extended to variable properties. This governing equation is solved on a spherical shell bounded by the topographic contours associated with different inferred paleo-shorelines in the northern lowlands, and Hellas and Argyre basins, denoted $h_o$, $h_h$ and $h_a$, respectively. We use a conservative finite difference discretization on a latitude-longitude grid that has been benchmarked against analytic solutions [5].

*Parameter values.* For all models presented here, we assume a crustal aquifer with a depth $d$ of 10 km and a base at -9 km elevation [7,8]. We set the hydraulic conductivity to $K$=$10^{-7}$ m/s and the aquifer recharge to $r$=$5\cdot10^{-6}$ m/Earth year. This combination allows the groundwater table beneath the south pole to reach an approximate elevation of 1 km in azimuthally symmetric case presented by [5]. The solution is invariant in the ratio $\mathrm{r/K}$ so that any increase of $r$ requires an equivalent increase in $K$ for the solution to remain unchanged [5]. For this abstract we set $h_o$ and $h_a$ to the Arabia shoreline at an elevation of -2090 m [3], but vary $h_h$ to illustrate the interplay of hydraulic gradients and recharge.

**Results:** Numerical solutions for the steady unconfined aquifer are shown in Fig 1 for a case with and without Hellas and Argyre basins. In the absence of the basins the solution is similar to the one-dimensional analytic solution [5] with a groundwater table that increases monotonically toward the south pole where it reaches its maximum at an elevation of 1008 m.

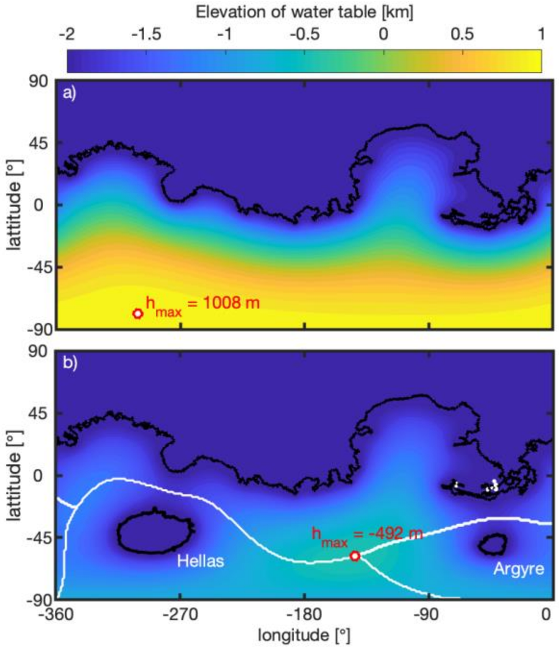

**Figure 1:** Computed steady groundwater tables in the southern highlands' aquifer assuming the Arabia shoreline [6] in the northern plains. Red circle shows the location of the maximum elevation of the groundwater table. a) Water table in absence of Hellas and Argyre basins. b) Water table with Hellas and Argyre basins all set to the Arabia shoreline at -2090 m. White lines show groundwater divides.

*Effect of large impact basins.* The presence of Hellas and Argyre basins has a dramatic effect on the southern highlands' aquifer, even if we assume that both fill to the same elevation as the northern ocean. The additional groundwater flow into those basins lowers the maximum elevation of the water table by 1.5 km. The location of this maximum moves from near the south pole to 58ºS and -143ºW, located approximately between the two basins and south of Tharsis.

More importantly, the southern highlands aquifer is now divided into three groundwater basins, one associated with each surface water body. All three surface water bodies act as sinks for groundwater that is supplied by recharge in the highlands. To sustain this steady state, water must be lost from the surface water bodies by evaporation (or sublimation) to supply the groundwater recharge. Even in a steady state scenario, a dynamic water cycle is thus required.

In Fig. 1b all three water bodies are isolated, in the sense that they do not exchange water through the common aquifer. This disconnect is due to the absence of regional hydraulic gradients that would be produced by differing water table elevations. In the absence of these gradients, the recharge generated groundwater divides act to compartmentalize the aquifer into isolated groundwater basins. These groundwater basins are distinct from the surface water drainage basins of these features. For impact basins where the topographic rim may initially limit surface drainage, the groundwater basins computed here are larger.

*Regional hydraulic gradients.* Above we have prescribed the elevation of all surface water bodies to be the same, an assumption commonly made in climate models [7]. To explore the effect of regional hydraulic gradients induced by differing water levels in the considered surface water bodies, we lower the water level in Hellas to the proposed paleo-shorelines at -3100 m and -5800 m [8] (Fig. 2). As the water level drops, Hellas' groundwater catchment expands, and the maximum elevation of the groundwater table drops by an additional 230 m. The groundwater divide that separates Hellas from the putative northern ocean moves north and for the lowest water level it intersects the shoreline of the northern ocean at Isidis Planitia. At this point, the regional gradient is sufficient to overcome the recharge and water drains from the northern ocean and flows into Hellas through the southern highlands' aquifer.

**Discussion:** We have explored the compartmentalization of the southern highlands' aquifer into different groundwater basins after Noachian basin formations. Compartmentalization is determined by the interplay of regional hydraulic gradients produced by differences in elevation between the main surface water bodies and the groundwater recharge. Recharge between two surface water bodies creates a groundwater divide that isolates these water bodies (Fig. 1b). Strong differences in water levels can overcome recharge and connect two water bodies (Fig. 2c).

From these general principles and the fact that new impact basins generate very large hydraulic gradients, we expect them to initially draw water from all surrounding water bodies. Once the water level in the basin has risen sufficiently to reduce the hydraulic gradient, they may remain isolated from neighboring water bodies and are fed entirely by groundwater recharge and surface runoff if present.

Note, here we simply prescribe the elevations of the three water bodies at steady state. In a more realistic model, the elevation of each water body would be determined by the balance of groundwater and surface water inflows with evaporative losses. Given the different surface areas of the water bodies, drainage basin areas, and groundwater basins, the dynamic water levels in the three surface water bodies are unlikely to be the same. These dynamics present interesting directions for further work. The element cycling, redox environments associated with hydrothermal systems are considered biologically environments [11]. A globally connected aquifer has implications for pre-biotic or microbiologic transport from one post impact hydrothermal system to another while moving between basins, should conditions and development have occurred. This could possibly provide a sustained, habitable environment on early Mars.

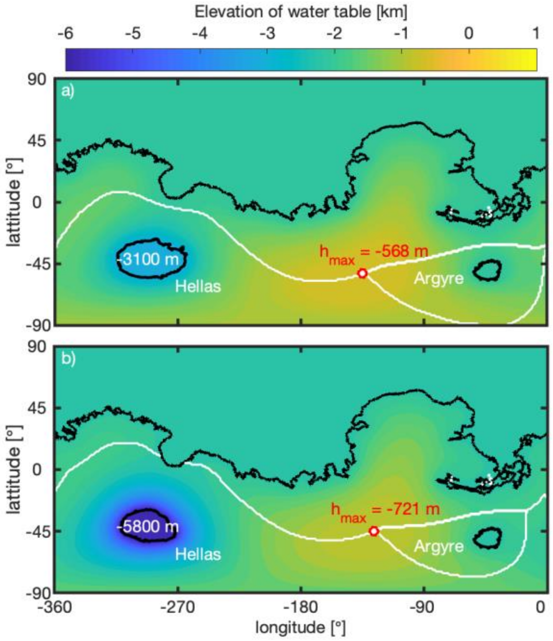

Figure 2: Groundwater basins for decreasing water levels in Hellas basin. a) Hellas water level at elevation -3100 m. b) Hellas water level at elevation -5800 m. The other two water levels are unchanged an elevation of -2090 m. White lines- groundwater divides. Red dot -location of max. elevation of the groundwater table.

**References:** [1] Clifford (1993) *JGR, 98(E6)*. [2] Kite and Daswani. (2019) *EPSL*. [3] Carr and Head (2003) *JGR, 108(E5)*. [4] Wilson et al. (2010) *Lakes on Mars.* [5] Dupuit (1863) *Dunod*. [6] Boussinesq (1904) *J. de mathématiques pures et appliquées*. [7] Luo and Howard (2008) *JGR, 113(E5)*. [8] Andrews-Hanna et al. (2010) *JGR, 115(E6).* [9] Shadab et al. (2022) LPSC 2022, Abs #1775. [10] Wordsworth et al. (2015) *JGR, 120(E6),* 1201-1219. [11] Westall et al. (2013) *Astrobiology 13(9).*