Hydraulic Modeling of Megaflooding Using Terrestrial and Martian DEMs

Tao Liu
Department of Hydrology and Atmospheric Sciences
The University of Arizona
Tucson, USA
liutao@email.arizona.edu

Victor R. Baker
Department of Hydrology and Atmospheric Sciences
The University of Arizona
Tucson, USA
baker@email.arizona.edu

Abstract—**Megaflooding generated from Glacial Lake Missoula (GLM) during the late Pleistocene, swept across the Columbia Plateau and Columbia Basin regions of the northwestern U.S., producing the Channeled Scabland, an assemblage of landforms comprising a regional anastomosing complex of overfit stream channels scoured into basalt bedrock. This region provides the best-studied example of a landscape created by catastrophic flooding. Using DEM data and the HEC-RAS 2-D hydraulic model, we analyzed both (1) the GLM flood propagation from the Clark Fork in northern Idaho to the eastern Pacific Ocean, and (2) the cataclysmic flooding from Valle Marineris to the northern plains of Mars in the form of enormous spillover discharges. The GLM flood simulation generally covers the tracts of the Channeled Scabland and captures the paleohydraulic conditions that have been inferred in the field and documented by previous hydraulic studies. The Mars simulation generally explains the in-situ discovery by the 1997 Mars Pathfinder Mission of fluvial features emplaced by catastrophic flooding. Initial hydraulic analyses for the megafloods and their relations to the field evidence provide important insights into cataclysmic flood processes and associated landforms.**

I. INTRODUCTION

The Channeled Scabland is the best-studied example of a landscape created by catastrophic flooding. The region's landforms provide exceptional analogs for the study of similar features that have been discovered on the planet Mars [1-3]. The cataclysmic flood landforms, including both erosional and depositional features, are associated with various flow strengths [4-5]. The paleohydraulic implications for the scabland landforms are generally understood from previous hydraulic modeling studies [6-7, in which the expected landforms in a channel were inferred through forward modeling i.e., from process to landform.

There has long been controversy as to the paleoflow magnitudes that generated both Earth's scabland-type landforms and features in the Martian circum-Chryse outflow channels. The levels of flow strength for scabland channel development were inferred to be orders of magnitude larger than what is achieved in most contemporary terrestrial rivers [8], but comparable to the values for other ancient megafloods [9]. In contrast, recently published theoretical work [10-11] claims that much lower threshold flow strength values apply to scabland-type bedrock erosion, implying that much smaller formative discharges occurred in the Channeled Scabland region. This controversy has motivated our current paleohydraulic studies of the two regions

Numerous remote-sensing observations of Martian outflow channels have linked their origin primarily to large-scale erosion by cataclysmic floods [1], [3]. These floods likely had typical depths ranging from ~30 to ~300 m, and flow velocities of up to ~30 m/s [12]. Using the size of the largest boulders and inferred regional slope values, in combination with empirical relationships derived from terrestrial floods [13-14], Smith et al. [15] computed that paleoflow velocities reached ~8 m/s, and depth ranged from ~10 to ~20 m at the Pathfinder Landing Site.

The initial hydraulic studies reported here use greatly improved modern hydraulic modeling schemes (adjusted for Mars gravity) for megaflooding simulations applicable to morphological analyses for both the Channeled Scabland and Martian outflow channels.

II. METHOD

The hydraulics of the mega flooding on both Earth and Mars were modeled using the HEC-RAS 2-D hydraulic model. The gravitational acceleration for the Martian example was modified to 3.711 m/s^2. The model simulated two-dimensional unsteady flow solving either Diffusive Wave or full Saint-Venant equations with an implicit finite volume solution algorithm on both structured and unstructured meshes [16]. These capabilities enable more accurate and efficient calculation of flow strength parameters, including mean flow velocity, bed shear stress, and stream power per unit area of bed. The full momentum based equation set can more accurately capture the flow dynamics in the following situations: 1) Highly dynamic flood waves generated from a very rapid dam failure; 2) Mixed flow regimes and hydraulic jumps when flooding passes through channel constrictions; 3) Detailed velocities, water depth, and other hydraulic parameters at a specific spot of interest.

A. *Topographic data*

The NED-DEM (National Elevation Dataset, Digital-Elevation-Model) provides basic elevation information for Channeled Scabland study area with a 1/3 arc-second resolution (approx. 10 meters). The Mars MGS-MOLA (Mars Global Surveyor-Mars Orbiter Laser Altimeter) DEM provides the most accurate global topographic dataset for Mars with a 463-meter resolution. The original grid datasets were mosaicked together into one raster dataset for the study domain.

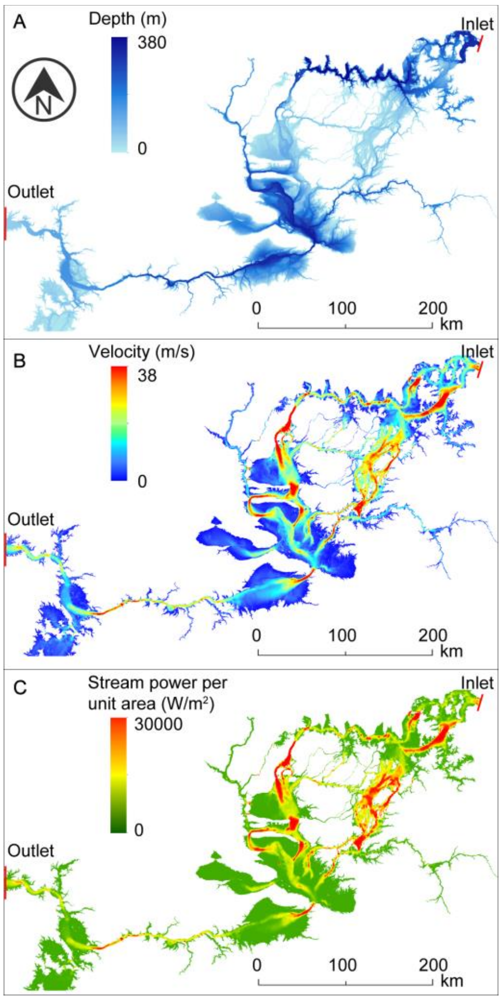

Figure 1. Flow depths (A), velocity (B), and Stream power per unit area (C) calculated by the 2-D hydraulic modeling run on a 500-m computational mesh of Channeled Scabland.

B. *Boundary conditions*

For the Channeled Scabland case, the upper boundary was based on geomorphological evidence and one-dimensional hydraulic calculations for flow near the GLM outlet [5]. The flow hydrograph has a triangular shape with a 1.7 x 10^7 m^3/s peak discharge and a duration of 70 h. For the Mars outflow channels case, the upper boundary represents a cataclysmic flood from an instantaneous failure of enormous paleo-lakes within Valles Marineris. The flow hydrograph has a 1 x 10^9 m^3/s peak discharge and a release of the about 1.2 x 10^{14} m^3 of lake water within 72 h. The normal depth boundary condition was used in both cases to take flow out of the simulation domains.

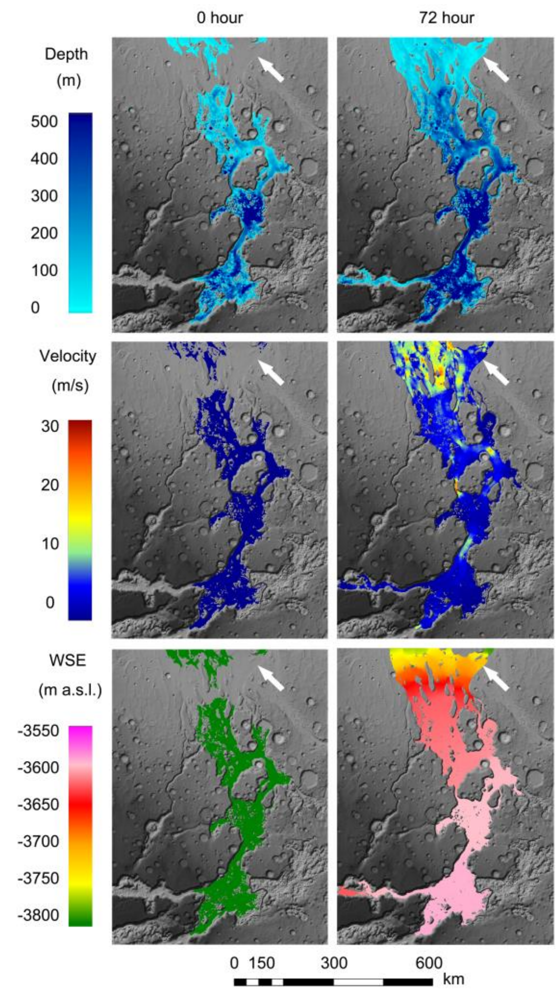

Figure 2. Flow depths, velocity, and water surface elevation (WSE) calculated by the 2-D hydraulic modeling run a 2000-m computational mesh of the Martian circum-Chryse outflow channels. The white arrow in each subplot indicates the Mars Pathfinder Lander site.

III. RESULTS

The simulations shown in Fig. 1 and 2 show our initial results for the mega-flooding that impacted both the terrestrial Channeled Scabland region and the Martian circum-Chryse outflow channels.

A. *The GLM flood*

The first case (Fig. 1) simulated the Glacial Lake Missoula (GLM) flood that swept the Channeled Scabland, using a 500-m computation mesh with an upper boundary based on geomorphological evidence and one-dimensional hydraulic calculations for flow near the GLM outlet [5]. The simulated flooding areas generally cover the tracts of the Channeled Scabland and capture much of the paleohydraulic behavior that was found in both field interpretations and previous hydraulic modeling studies [6-7], as summarized in Table 1, including comparable stream power and velocity values for the inner channel of Grand Coulee, Wallula Gap reaches, the Palouse/Snake Divide, the Cheney/Palouse tract, Drumheller Channels, Othello Channels, the Rathdrum Prairie, and the Columbia River Gorge.

B. *Martian Spillover Flood*

The second case (Fig. 2) shows the propagation of cataclysmic flooding that was released from enormous paleo-lakes within the Vales Marineris of Mars. The simulation results generally explain the in-situ discovery by the 1997 Mars Pathfinder of fluvial features emplaced by catastrophic flooding. The modeled flow lasts 96 hours with a total volume of ~1.2 x 10^{14} m^3. The peak discharge of 1 x 10^9 m^3/s occurs at around 24 hours with respective water surface elevations above the -3800 m (WSE) and velocity values of ~250 m and ~30 m/s.

TABLE I. RELATIONSHIP OF FLOW HYDRAULICS TO STAGE OF SCABLAND CHANNEL CROSS-SECTIONAL MORPHOLOGY[7]

Erosional Stage	***Description***	***Mean velocity (m/s)***	***Depth (m)***	***Power per unit area (W/m^2)***
I-II	Streamlined loess hills	3-5	30-100	500-2000
II-III	Stripped basalt, grooves	3-9	35-125	500-3000
III-IV	Butte-and-basin scabland	7-15	100-250	2000-20 000+
IV-V	Inner channels	15-25	100-250+	5000-25 000+

IV. DISCUSSION

The GLM flood simulation indicates that various scabland-type landforms are related to measures of flow strength (Fig 1), that generally agree with previous studies [4-6], [17]. The respective mean velocity, depth, and power per unit area of megaflood flows in inner channels, such as Grand Coulee, are 17-31 m/s, 87-212 m, and 4500-35 000 W/m^2. These values confirm well-established relationships between landforms and flow strength. The simulated mega-flood flows across the eastern Washington State generally covers the major scabland tracts. However, only very shallow or no water covers portions of the Telford-Crab Creek Tract and Moses Coulee in accord with the field evidence. We suggest two possible reasons for this: (1) an insufficient volume of water emanating from Glacial Lake Missoula to cover the entire Channeled Scabland region, or (2) the fact that the DEM used in the hydraulic modeling represents the present-day topography, and effects of glacial isostatic adjustment (GIA) on the topography may have been considerable, and this factor was not involved in our initial hydraulic analysis.

Morphological analysis of the Martian study site shows that uphill sloping channel floors occur within a vast outflow channel interior basin that separates the downstream reaches of numerous outflow channels from the northern plains. Consequently, flooding that ensued from the Valles Marineris must have produced an inland sea before reaching the northern plains in the form of enormous spillover discharges [18]. The simulated Martian megaflooding, released from paleo-lakes within Valles Marineris, rushed into this inland sea, and flows became shallower due to their propagation over the sea's surface. The simulation results explain the in-situ discovery by the 1997 Mars Pathfinder of fluvial features emplaced by catastrophic flooding that was at least an order of magnitude deeper than what has been documented by previous remote-sensing studies.

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