Hydraulic Modeling of Megaflooding Using Channeled Scabland DEMs

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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 the GLM flood propagation from the Clark Fork in northern Idaho to the eastern Pacific Ocean, and 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. A test simulation on the Columbia Gorge suggest the other sources of water besides Lake Missoula may have been involved in producing the megaflooding. 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. Also, there is a long-lasting controversy about the megaflood sources. The controversy arose since Bretz proposed catastrophic flood origin for scabland [12]. Until recently, Shaw et al. [13] reported the geomorphic and sedimentary evidence of CIS source flood arising the argument again [14-19] (Komatsu et al., 2000; Atwater et al., 2000; Miyamoto et al., 2006, 2007; Denlinger and O'Connell, 2010; Waitt et al., 2009). The water volume left the scablands is the key about this controversial discussion.

The initial hydraulic studies reported here use greatly improved modern hydraulic modeling schemes for megaflooding simulations applicable to morphological analyses for the Channeled Scabland.

II. Method

The hydraulics of the mega flooding on both Earth and Mars were modeled using the HEC-RAS 2-D hydraulic model. 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 [20]. 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.

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

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(approx. 10 meters). The original grid datasets were mosaicked together into one raster dataset for the study domain.

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 normal depth boundary condition was used in both cases to take flow out of the simulation domains. The Manning's n value is assigned as 0.06 for the whole domain.

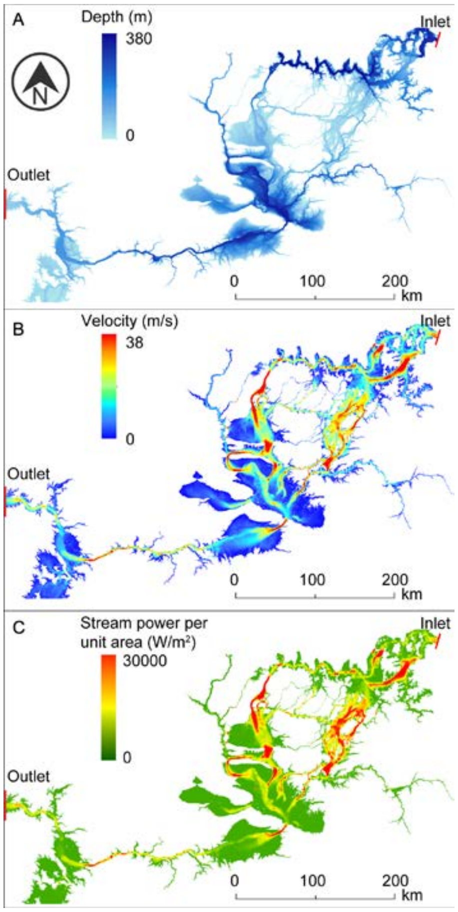

Figure 1. Flow depths (A), velocity (B), and Stream power per unit area (C) calculated by the 2-D hydraulic modeling run on a 500-m computational mesh of Channeled Scabland.

III. Results

The simulations shown in Fig. 1 shows our initial results for the mega-flooding that impacted the Channeled Scabland region.

The simulated Glacial Lake Missoula (GLM) flood (Fig. 1) 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.

The input water has a water volume of 2181 km^3 keeping in line with geological evidence of the GLM (Fig.2 A). The simulated peak discharge rate at Wallula Gap (WG) was only 6×10^6 m^3/s which is much lower than the expected [5]. The simulated flood elevation was also lower than the high-water marks (HWM) by forty meters in average. We then set up a new simulation for flood routing through the Columbia Gorge with a constant input discharge of 10×10^6 m^3/s (Fig.2 B). The simulated hydrograph shown a 80-hour propagation could make the outlet peak discharge at the ending of the gorge reach 9.5×10^6 m^3/s, which coordinates the geological features. A total volume of water required in this process is ca. 3820 km^3. It is more than 1.5 time of the GLM capacity suggesting the other sources of water besides Lake Missoula may have been involved in producing the megaflooding.

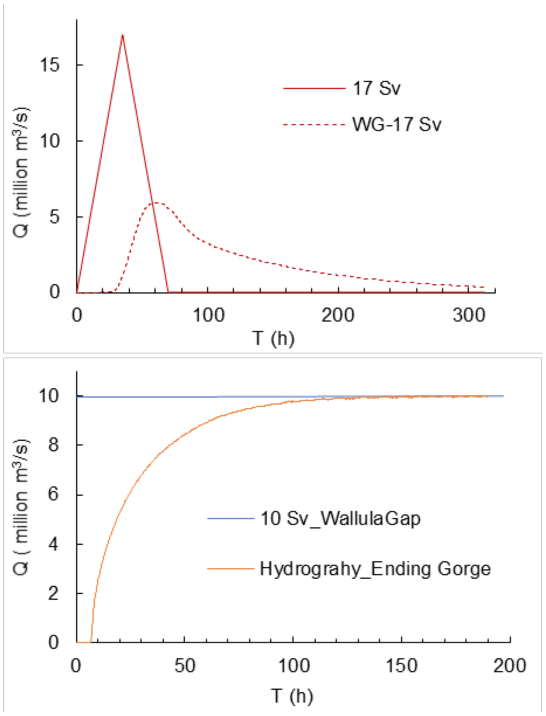

Figure 2. (A) Input hydrograph (solid) and the simulated hydrograph (dashed) at Wallula Gap (WG); (B) Input hydrograph at the WG (blue) and the simulated hydrograph at the ending of the Columbia Gorge.

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]. 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. The minimum water volume required to match the geological features on the Columbia Gorge is about 1.75 times of the maximum that was achieved by Glacial Lake Missoula (GLM). This result suggests the other sources of water besides Lake Missoula may have been involved in producing the megaflooding. Other boundary conditions may also have impact on the flood behavior, so the future research could be quantification of these effects.

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