FLOOD RISK REDUCTION STRUCTURE FOR MORGAN LAKE DAM

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Extended Abstract

Morgan Lake Dam is located near the City of La Grande, Oregon (Figure 1). A dam breach analysis of Morgan Lake Dam was completed in 2008 (WEST, 2008). The dam breach analysis was completed using a 1-dimensional Hydrologic Engineering Center's River Analysis System (HEC-RAS) software (USACE, 2022) to route the breach hydrograph through Deal Canyon down to the end of the canyon, and a FLO-2D model to route the breach hydrograph within the City of La Grande. The analysis indicated that a dam breach would result in high life loss and economic damages to the City of La Grande. Therefore, the Oregon Water Resource Department (OWRD) Dam Safety Program, in conjunction with the City of La Grande, plan to build a flood risk reduction structure that will redirect a portion of the dam breach hydrograph away from Deal Canyon and into Sheep Canyon. The desired outcome is to reduce the unbulked peak breach discharge of 26,800 cfs to a maximum discharge of 360 cfs conveyed to the City of La Grande.

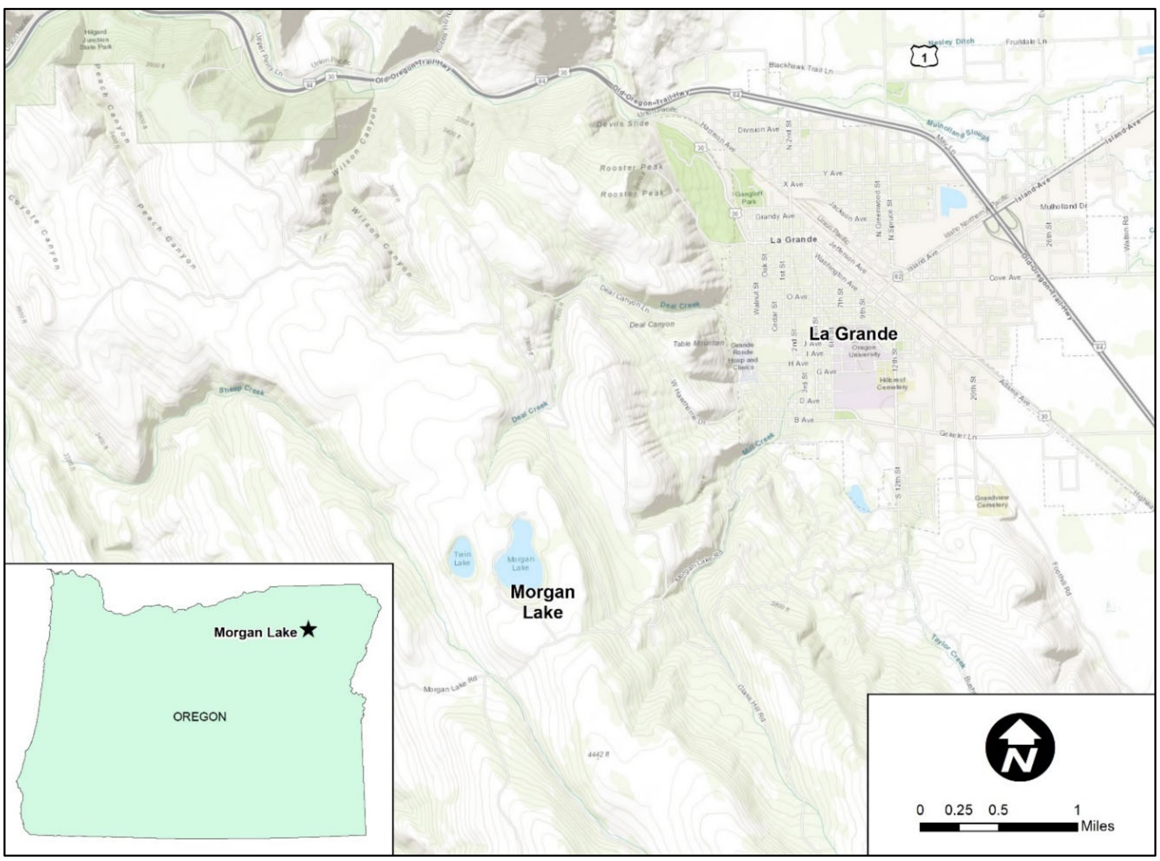

Figure 1. Location map of Morgan Lake

The U.S. Army Corps of Engineers HEC-RAS (Version 6.2 and later) software (USACE, 2022) can simulate non-Newtonian flows (or those fluids that do not follow Newton's law of viscosity). For a Newtonian fluid, the relation between the shear stress and the shear rate is linear and passes through the origin (zero shear stress for a zero shear rate), and the relation is related to the fluid viscosity. A non-Newtonian fluid has either a non-linear shear stress and shear rate relationship or has a shear stress yield that needs to be exceeded for the shear rate to have an influence on the shear stress.

The HEC-RAS Mud and Debris Flow Manual (USACE, 2020) documents detailed information about non-Newtonian flow. As described in the manual, there are several regimes for non-Newtonian flow and the regimes are dependent on sediment concentrations and sediment sizes. As the sediment concentration increases and the sediment mixture coarsens, the fluid passes through various stages that can be analyzed in the HEC-RAS software:

(1) Hyperconcentrated flow: This regime describes a two-phase flowing mixture of water and sediment with properties between fluvial and debris flow. It occurs when sediment concentrations by volume exceed 20 to 30 percent. The method available in HEC-RAS for this regime is Bingham, which requires the user to define the yield strength and mixture dynamic viscosity. This method was considered for this study since the dam breach flow conditions would be classified as hyperconcentrated flow.

(2) Mud and debris flow: This regime occurs when the sediment concentration exceeds 55 to 60 percent. The methods available in HEC-RAS for this regime are the O'Brien's Quadratic method and the Generalized Herschel-Bulkley method. The O'Brien's Quadratic method requires the user to define the yield strength, mixture dynamic viscosity, and representative grain size. The Generalized Herschel-Bulkley method requires a yield strength and consistency index factor. Neither of these methods were considered for the study since they are not applicable to the anticipated flow conditions for the dam breach scenario.

(3) Clastic flow: This regime occurs when a fluid is composed entirely of solids. The Coulomb and Voellmy methods are available in HEC-RAS for this regime. Both methods require the user to provide the Mohr-Coulomb yield stress, and the Voellmy method also requires the user to provide the Voellmy turbulence coefficient. Neither of these methods were considered for the study since they are not applicable to the anticipated flow conditions for the dam breach scenario.

A 2-dimensional (2D) HEC-RAS model (Version 6.3) was developed in support of the design of the diversion structure. The sediment introduced into the flow (sediment existing within the reservoir and from erosion of the embankment and streambed within the downstream reach) during the dam breach event could possibly result in non-Newtonian flows near the diversion structure. As a result, an evaluation was completed to determine if non-Newtonian flows can occur during a dam breach. The analysis was completed by estimating the scour depth using the contraction scour equations provided in Hydraulic Engineering Circular No. 18 (FHWA 2012). This approach indicated that the sediment concentration by volume would range from 12 to 50 percent, with the average being about 26 percent and the higher concentration occurring at the initiation of the breach.

The HEC-RAS 2D models were developed for both the existing and proposed conditions and for Newtonian and non-Newtonian flow conditions. The models for both conditions extend from Morgan Lake Dam to about 4,000 feet downstream. The inflow hydrograph was the 2008 dam breach hydrograph that was bulked for the non-Newtonian scenarios by manually adjusting the flows in the unsteady flow editor. HEC-RAS has the capability to bulk the hydrograph as part of the non-Newtonian editor, but this approach was not used because of the temporary variation of the sediment concentration during the breach event. The peak discharge from a dam breach was estimated to be about 32,500 cfs for bulked conditions and about 26,800 cfs for unbulked conditions. The non-Newtonian conditions were simulated using the Bingham approach because the average concentrations were about 26 percent. The Bingham method requires information about the yield strength and mixture dynamic viscosity. The following options were considered for these parameters: (1) the exponential method with default values; (2) condition 1 with the inclusion of turbulence; and (3) the exponential method with values defined as the lower, median, and upper limits from field data presented by FLO-2D (FLO-2D 2012).

The existing model results (Figure 2) revealed that a portion of the flow will already be conveyed to Sheep Canyon (about 9,200 cfs or about 30% of peak breach flow for unbulked conditions) and that the original assumption that the entire breach hydrograph would be conveyed through Deal Canyon was incorrect. Anderson-Perry & Associates used the existing conditions results in their 30% design of the diversion structure. The diversion structure will be located about 1,200 feet northwest of Morgan Lake Dam. It will have a total length of about 1,000 feet and a maximum height of about 16.2 feet. Material will be excavated near the west side of the structure for use in constructing the structure and to help in redirecting the flow. The model results for the proposed conditions are shown in Figures 2 through 4 and summarized in Table 1. Figure 2 shows the maximum inundation extents for both the existing and proposed conditions. Figure 3 shows the water surface profile adjacent to the structure for the clear water and two non-Newtonian scenarios (only two scenarios are shown because there were only minor changes for all scenarios considered). Figure 4 shows the flow hydrograph for Deal Canyon.

The following can be concluded from reviewing the results: (1) the proposed design would meet OWRD's requirements, (2) the maximum change in the maximum water surface elevation along the diversion structure ranges from 0.67 to 0.99 feet for the non-Newtonian conditions and the maximum change just for bulking the flow is 0.67 feet, and (3) the maximum discharge to Deal Canyon of 226 cfs would be below the maximum allowable discharge of 360 cfs.

References

FLO-2D. 2021. "Simulating Mudflow," October 2021

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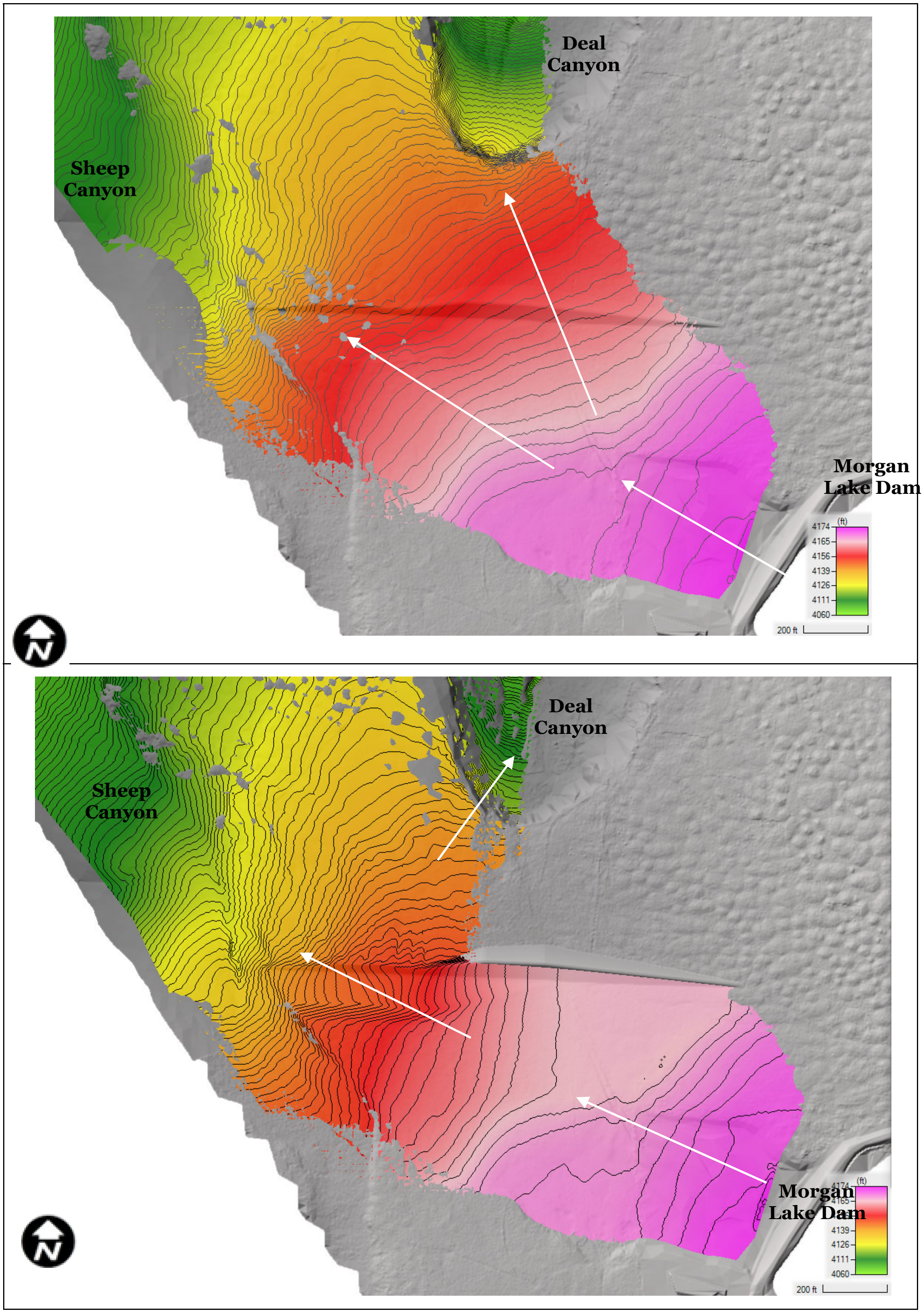

Figure 2. Existing and Proposed conditions water surface elevation results

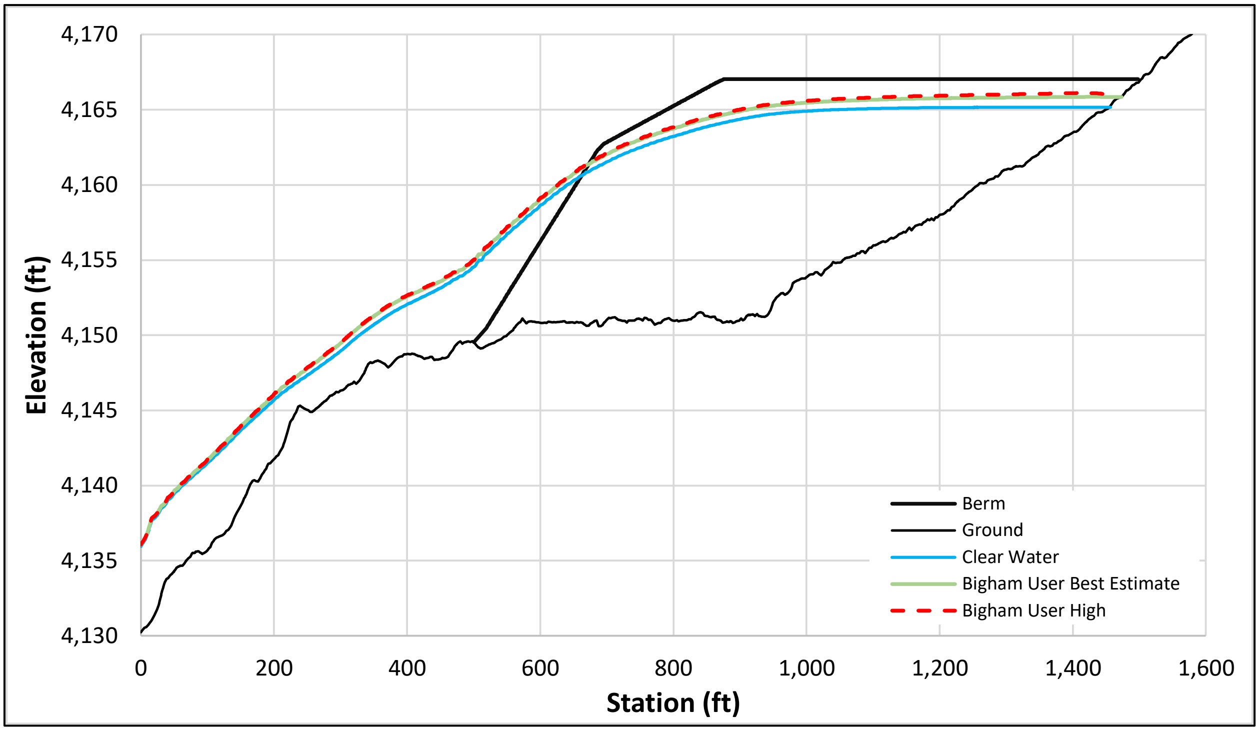

Figure 3. Comparison of water surface profiles along proposed diversion structure

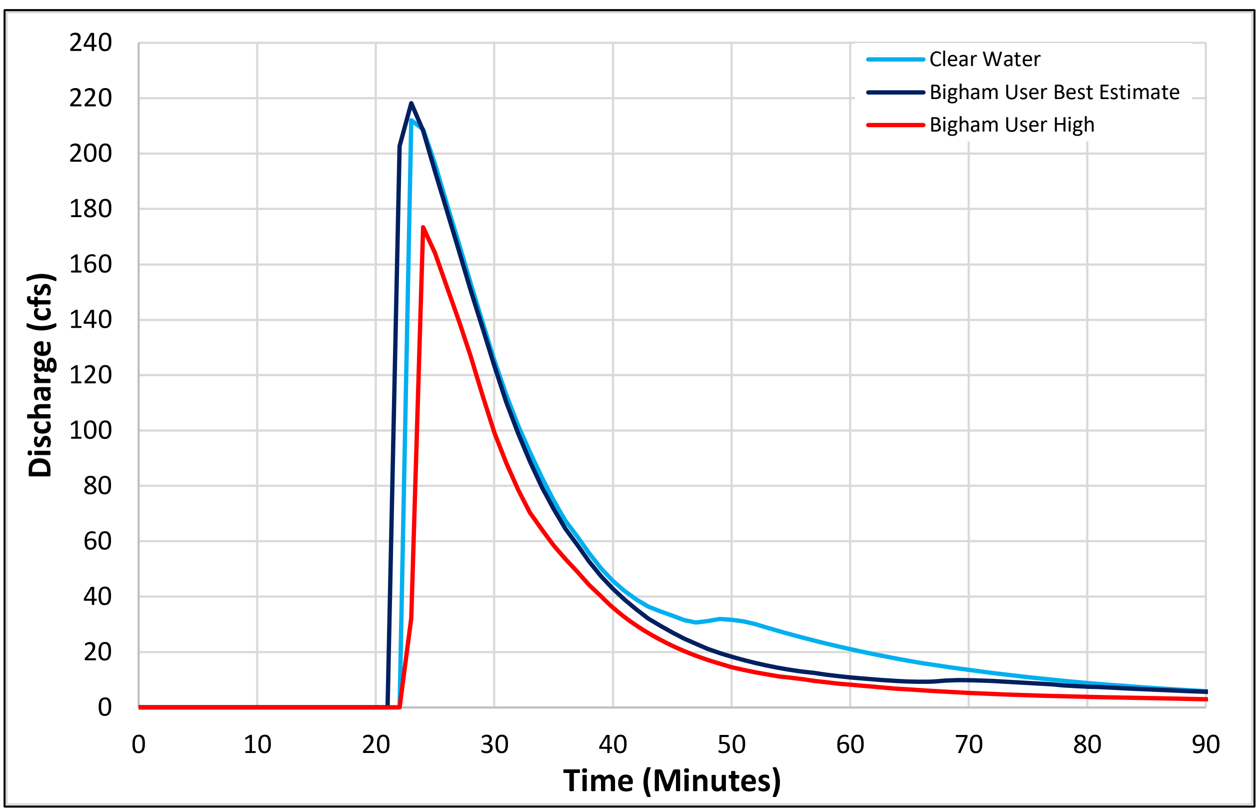

Figure 4. Comparison outflow hydrograph to Deal Creek

Table 1. Comparison of HEC-RAS model results

Condition	Max WSEL at Berm (ft)	Freeboard (ft)	Peak Discharge for Deal Canyon (cfs)
Clear Water	4165.15	1.88	212
Clear Water + Turbulence	4165.19	1.84	195
Bingham - Exponential (Default)	4165.81	1.22	229
Bingham - Exponential (Default) + Turbulence	4165.84	1.19	215
Bingham (User Defined - Low)	4165.82	1.21	226
Bingham (User Defined - Best)	4165.85	1.18	218
Bingham (User Defined - High)	4166.11	0.92	173