HEC-RAS simulation of the India Dam Break

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March 4, 2022

Abstract

The February 2021 India dam break in Uttarakhand took away hundreds of lives and destroyed the Tapovan dam in construction. It's hypothesized that the melting of the Kagbhusandi glacial lake north east near the Nanda Devi national park induced flooding along the Dhauliganga river. Debris and mud flow carried by the flood caused significant damage to the downstream Tapovan dam. Using HEC-RAS simulation, we are able to estimate the time at which the flooding arrived at Tapovan dam from the meltdown of the glacial lake at about 31 hours from the onset of the glacial meltdown. Along the flooding path, there are several populated residential areas that could give advanced warning of the flood. In particular flooding arrived at the NPTC Tapovan power station after 18 hours which means at least 13 hours of warning time available for the downstream Tapovan dam. Various magnitudes of glacial lake meltdown are modelled to examine their effect on the flooding pattern down stream of the Dhauliganga river. Water flow arrives at the Tapovan dam at about the same time for the various magnitudes of the meltdown simulated. Global warming is considered as the main cause of the meltdown of the glacial lake. Increased global and local atmospheric temperature has increased the temperature of the glacial ice resulting in higher risk of glacial avalanche and downstream flooding.

Keywords: Dam Break, Tapovan, HEC-RAS, Global Warming, Glacial Lake

1 Introduction

In February 7, 2021, a glacier in Uttarakhand broke causing the Tapovan dam to collapse and 125 workers to be missing. The Tapovan dam was build a few miles from the Nanda Devi glacier, on India's second highest mountain. Witnesses saw a flood of water completely wash away not only the dam, but nearby buildings, trees, and people.

The cause of the Himalayan glaciers collapsing was ultimately due to global warming and constant environmental changes. Throughout the past decade, the effects of global warming have become abundantly clear as there has been an increase in landslides and avalanches. Based on Dan Shugar's observations- [1] a geomorphologist from the University of Calgary- another plausible cause for the glacier collapse was a rock-avalanche. However, scientists are still unsure where the great amount of water had originated from, given that in this case, they do not believe that a glacial lake outburst flood was the culprit. India's national crisis management committee believe that the increase in water levels was due to a mountain glacier partially breaking off into the Rishiganga river.

Many citizens of Uttarakhand blame the government for beginning a project in such close proximity to the glaciers while the area was so vulnerable to extreme weather events. They believe that the government simply disregards environmental laws by approving dozens of dam projects in order to exploit hydro-power for income.

The developing economy of India requires growing supply of electricity and water that can be met by constructing additional dams. There is increased awareness within the India Academia that the government should conduct careful evaluation of the risk associated with constructing the additional dams [2], [3].

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), a program developed by the US Army Corp of Engineers, is capable of running 1D and 2D unsteady flow simulations and is ideal for flood prediction. HEC-RAS is also capable of performing sediment transport, movable boundary simulations and water quality analysis. Because of the program's support and versatility, HEC-RAS has been gaining popularity for flood simulations after the release of its version 5 [4] [5]. Various studies of flooding and dam break simulations have been conducted using HEC-RAS since its early conception [6] [7] [8] [9] [10] [11].

In this work, we use the (Shuttle Radar Topography Mission) SRTM [12] satellite data covering the Tapovan area and HEC-RAS to set up flooding simulation. We examine the effect of various magnitudes of glacial melt on the downstream flooding pattern and the arrival time of the flooding at the Tapovan dam. We also look into the recent temperature record of the local area and examine its effect on melting of the glacial ice.

2 Area of Interest

Figure 1 shows the area that are affected by the February flooding from Dhauliganga river.

The glacial ice on top of the mountains is near the Nanda Devi national park. The flood due to glacial ice melt flows downstream along the Dhauliganga river which follows approximately the yellow trail in the figure. The Tapovan dam under construction is downstream relatively far from the glacial lake.

The distance between Bhalgaon at Nanda Devi national park to the Tapovan Retreat (Figure 2) is close to 25.5 km. From Bhalgaon to Tapovan Hydro Powerplant (Figure 3) the distance is close to 80 kilometers. The Tapovan Retrea (Figure 2) is relatively populated with residential housing and commercial buildings visibly seen on the satellite image.

It can been see from the satellite image the glacial ice are concentrated on top of the mountains near the Nanda Devi national park. Under usual circumstances, the ice remains frozen and the flow rate in the Dhauliganga is ideal for hydro powerplant downstream. Unfortunately due to global warming, the glacial ice started meltling on top of the mountains and forming glacial lake (Figure 4 and 5). The large height from which the water falls from the glacial lake significantly increases its gravitational potential energy which subsequently leads to significant flooding downstream.

3 Theory of hydrology modelling

The fundamental 2D shallow water equations in flux form solved by HEC-RAS are

Figure 1: Local area of interest, graph shows the local road (the yellow trail), the Dhauliganga river along the local road, the Glacial lake at Nanda Devi national park, and populated residential area along the road. The tapovan dam under construction is marked bottom left in the picture.

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F_x}}{\partial x} + \frac{\partial \mathbf{F_y}}{\partial y} = \mathbf{S} \tag{1}$$

$$\mathbf{U} = \begin{bmatrix} h \\ hu \\ hv \end{bmatrix} \tag{2}$$

$$\mathbf{F_x} = \begin{bmatrix} hu \\ huu + 1/2gh^2 \\ huv \end{bmatrix} \tag{3}$$

$$\mathbf{F_y} = \begin{bmatrix} hu \\ huv \\ hvv + 1/2gh^2 \end{bmatrix} \tag{4}$$

$$\mathbf{S} = \begin{bmatrix} 0 \\ -gh\frac{\partial z}{\partial x} - c_f u \\ -gh\frac{\partial z}{\partial y} - c_f v \end{bmatrix} \tag{5}$$

where $\mathbf{U}$ is the state vector containing height and momentum of fluid, $\mathbf{F_x}$ and $\mathbf{F_y}$ are the flux vectors containing mass flux and momentum flux, $\mathbf{S}$ is the source term describing bottom topography and friction. The bottom friction coefficient c_f can be calculated from the Manning formula $c_f = \frac{n^2 g\sqrt{u^2+v^2}}{R}$ and is dependent on the Manning's coefficient n [13]. HEC-RAS can also take into account the Coriolis terms to the source term when instructed.

Figure 2: This map shows Tapovan Retreat, Uttarakhand, where several homes and shops are located, that is flooded after the Tapovan dam breaks.

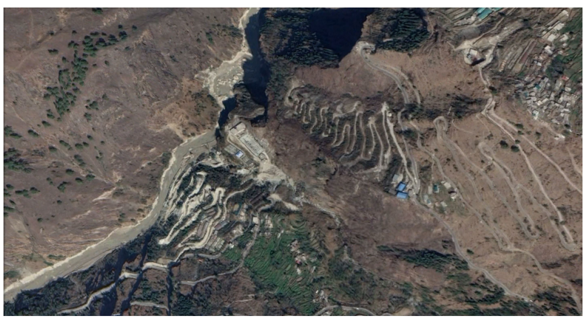

Figure 3: This shows the Tapovan Vishnugad Hydro Power Project where the Tapovan dam is located.

4 HEC-RAS Setup

NASA's SRTM mission made available the satellite data to create digital elevation map for the area near Uttarakhand at 1 arc second resolution or about 30 meters. To simulate the flood flow, a mesh is set up in HEC-RAS at the same 30m x 30m resolution (Figure 6) with 184178 number of cells.

Figure 4: Satellite image of the glacial lake before it's melted.

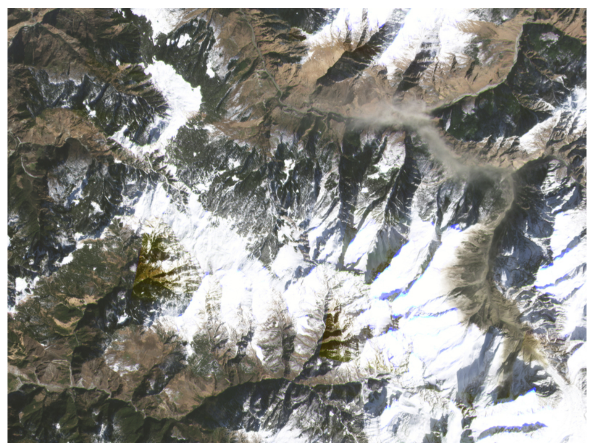

Figure 5: Satellite image of the glacial lake after it's melted. A chunk of ice is noticeably missing from the image near bottom right.

5 Results and Conclusions

Multiple simulations are performed for the Indian Dam break at the hydro power plant in Uttarakhand. To estimate the time of arrival at the power plant, different initial flow rate conditions are used in HEC-RAS for mud flow simulation.

Figure 6: Computational mesh used for the HEC-RAS simulation at 30m x 30m resolution. The customized mesh is shown in the purple outlined area.

The arrival time since the outburst are calculated in HEC-RAS shown in figure 7.

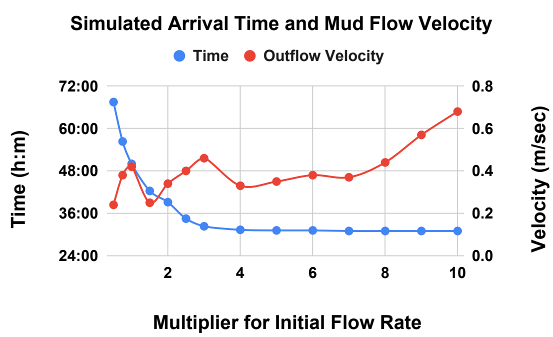

Figure 7: Simulated Arrival Time and Mud Flow Velocity as a function of the outlet flow rate at the melted glacial lake.

From the simulation using different flow rate from the melted glacial lake, we see that the arrival time of the mud flow can be predictable. We can regress the arrival time a as a function of the multiplier m:

$$a(m) = 3271 - 632\ln(m) \tag{6}$$

Result of the regressed arrival time is shown in Figure 8

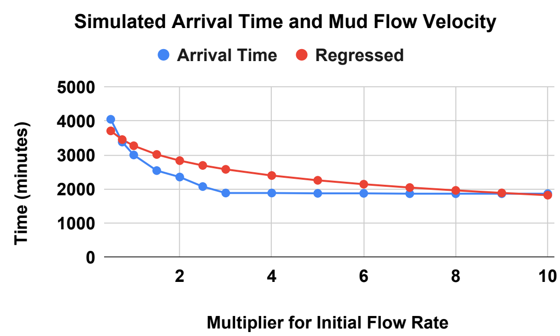

Figure 8: Simulated and Regressed Arrival Time as a function of the outlet flow rate at the melted glacial lake.

The multiplier translates into the volumetric flow rate of the mud flow that can be observed upstream, then a predicted arrival time can be calculated from Equation 6. This arrival time can be used as a warning for the power plant downstream.

The annual average temperature over land globally has been rising steadily in the past several decades (Figure 9). The annual mean, anual mean of daily high temperature, and annual mean of daily low temperature (Figure 10 11 12) in India have been rising as well. This can contribute to the melting of glacial in the India region where the dam break has occured.

It's hypothesized such events may occur again in the future supported by the continual increase in temperature globally and regionally. We hope the result from this study can aid in policy making and allow people living downstream of such

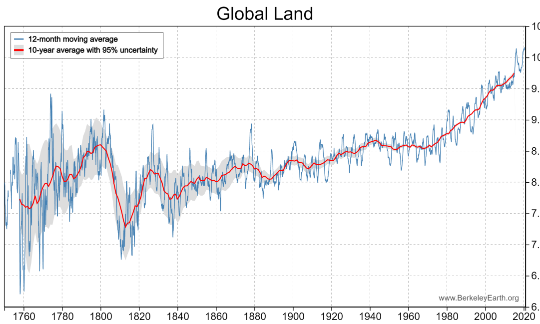

Figure 9: The global average annual temperature over land (courtesy Berkeley Earth)

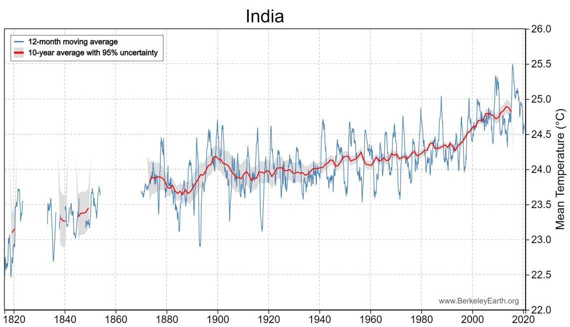

Figure 10: The average annual temperature in India (courtesy Berkeley Earth)

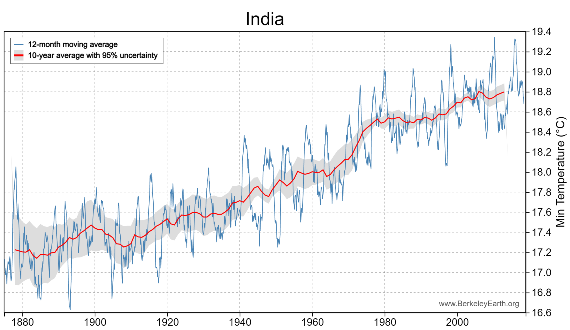

Figure 11: The mean daily high temperature in India (courtesy Berkeley Earth)

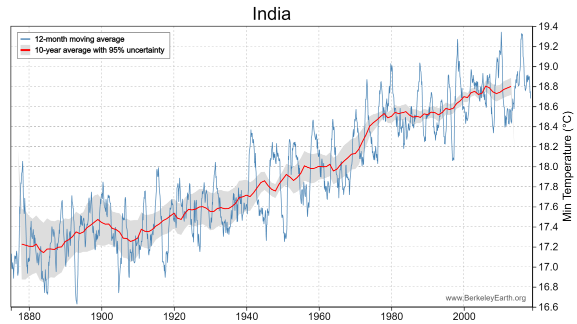

Figure 12: The mean daily low temperature in India (courtesy Berkeley Earth)

dangerous area to receive advanced warning with sufficient time to prepare evacuation.

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