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On the Underestimation of Flood Risk for Locationsdownstream from Flood Control Reservoirs

ON THE UNDERESTIMATION OF FLOOD RISK FOR LOCATIONS DOWNSTREAM FROM FLOOD CONTROL RESERVOIRS

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ABSTRACT

We investigate changes to flood frequency curves for locations immediately downstream from flood control reservoirs. Our goal is to investigate the steps necessary to estimate the regulated flood frequency curve based on several reservoir variables. We illustrate these steps using a simplified case of reservoir operation and inflows, which allows us to show how different physical features of the system quantitatively control the regulated flood frequency curve. Our work is relevant to the empirical analysis of volume-duration-frequency (VDF) curves and towards a more realistic, physics-based framework for estimating regulated flood frequencies. We highlight that, specific assumptions in the VDF methodology, can lead to underestimation of the flooding risk for locations downstream from reservoirs.

1. INTRODUCTION

Reservoirs attenuate incoming flood peaks. The magnitude of the attenuation of the incoming flood peak depends on the reservoir's storage capacity at the time of flood wave arrival, the release capacity, and the operation rules determined by the purpose of the reservoir. Other factors pertain to the dynamics of incoming flood waves that are characterized by their total water volume and the time interval between flood waves. Despite the practical significance of this problem, it is not well known is how all these factors combine when random flood events interact with the reservoir, modifying the flooding frequency for locations immediately downstream from the reservoir. Currently, the standard methodology for estimation of regulated flow frequencies is empirical (Goldman, 2001; USACE, 2010). Consider a single reservoir with the main purpose of flood mitigation. Figure 1a, shows the expected shape of the relationship between peak inflow (Q_I), and peak outflow (Q_O) from a generic reservoir. For low flows, we would not want to change the outflow. Consequently, the inflows and the outflows will lie on a one-to-one line. For higher flows we want to reduce the outflow peak as much as possible. Therefore, the associated outflow will veer to the right of the 1:1 line so that lower outflows correspond to the high inflows. As the inflow increases in peak and volume, the potential for reducing the outflow is diminished because the storage capacity is limited. For very high flows, such reduction is a small (insignificant) portion of the inflow, and the corresponding flows will come back to the 1:1 line.

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2. METHODOLOGY

We use a Monte Carlo based long-term continuous simulation procedure in which a stochastic rainfall model is used to force a physics-based hydrologic model of stream flow generation. The resulting stream flow time series is then used as input to the reservoir, which is operated according to pre-established rules. Rainfall is generated using a modified BLP model Cowpertwait et al. (2007). Runoff is generated using is a simple conceptual hydrologic model proposed by Chow et al. (1988) that is based on the determination of runoff hydrograph by the linear-reservoir method. Finally, the reservoir is simulated as a passive dam with an orifice opening at the bottom. Figure 1b shows the results of the simulated peaks generated by the storms at the basin outlet (inflow) and the peak flow obtained after regulation by the flood control reservoir. The blue line is the quantile-quantile plot of the two time series and it is the curve that should be used to relate flood frequencies upstream and downstream from a flood control reservoir. A careful inspection of the empirical methodology used by the Army Corps of Engineers reveals that they use the red-line in Figures 1a and 1b to map flood frequencies from upstream locations to downstream locations, leading to an underestimation of the flood risk.

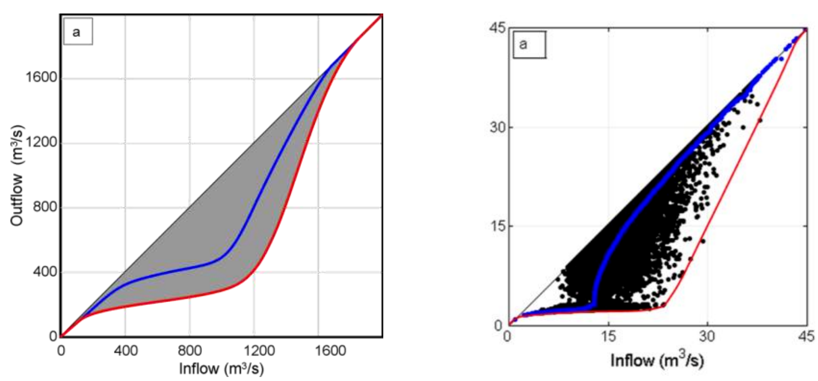

Figure 1 (a) The inflow-outflow relationship that we hypothesized and a quantile-quantile relationship between inflow and outflow. (b) Outflow peak from simulating randomly generated storms over the basin draining a flood control reservoir

3. CONCLUSIONS

We used Monte Carlo simulation approach to investigate the effect of flood control reservoirs on downstream flood frequency curves. Our simulation allow us to conclude that the empirical methodology used in current engineering practice, known as VDF, is incorrect and it leads to an underestimation of the flood risk. This underestimation is primarily due to the implicit assumption made about the relationship between unregulated inflow volume and regulated outflow. In the VDF methodology, it is assumed that the relationship between unregulated inflow volume and regulated outflow for the critical duration is unique, when in actuality it is non-unique. The non-uniqueness arises because: (1) the reservoir's water level at the time of flood wave arrival is a random variable that is determined by antecedent inflow sequences, and (2) the operation rule of a reservoir is often a function of the water level, which implies that the operation rule is also a random variable.

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