Journal of Hydrology: Regional Studies 13 (2017) 11–25

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Probable maximum flood in a changing climate: An overview for Canadian basins

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ARTICLE INFO

Keywords:
Probable Maximum Precipitation (PMP)
Probable Maximum Flood (PMF)
Regional Climate Models (RCM)
Climate Change (CC)
Canada

ABSTRACT

Study Region: In Canada, dams which represent a high risk to human loss of life, along with important environmental and financial losses in case of failure, have to accommodate the Probable Maximum Flood (PMF). Five Canadian basins with different physiographic characteristics and geographic locations, and where the PMF is a relevant metric have been selected: Nelson, Mattagami, Kénogami, Saguenay and Manic-5.

Study Focus: One of the main drivers of the PMF is the Probable Maximum Precipitation (PMP). Traditionally, the computation of the PMP relies on moisture maximization of high efficiency observed storms without consideration for climate change. The current study attempts to develop a novel approach based on traditional methods to take into account the non-stationarity of the climate using an ensemble of 14 regional climate model (RCM) simulations. PMPs, the 100-year snowpack and resulting PMF changes were computed between the 1971-2000 and 2041-2070 periods.

New Hydrological Insights for the Region: The study reveals an overall increase in future spring PMP with the exception of the most northern basin Nelson. It showed a projected increase of the 100-year snowpack for the two northernmost basins, Nelson (8%) and Manic-5 (3%), and a decrease for the three more southern basins, Mattagami (-1%), Saguenay (-5%) and Kénogami (-9%). The future spring PMF is projected to increase with median values between -1.5% and 20%.

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http://dx.doi.org/10.1016/j.ejrh.2017.07.003
Received 26 April 2017; Received in revised form 17 July 2017; Accepted 18 July 2017
Available online 01 August 2017
2214-5818/

1. Introduction

In Canada, there are over 15,000 dams owned by federal and provincial governments, hydropower utilities, industrial companies (including mining), municipalities and private individuals (Canadian Dam Association, n.d.). Some of the larger dams are used for hydropower with many of the medium to small sized ones used for irrigation, flood control, and water supply. Regardless of the size, all dams must be designed, operated and maintained to avoid unacceptable risk to inhabitants downstream. With the abundance of freshwater resources in Canada, about 63% of the electricity in the country is produced through large hydropower dams (Canadian Hydropower Association, 2017). Many of these hydropower dams have long life spans of up to 100 years which make them highly vulnerable to environmental change, especially the potential impacts of climate change.

In Canada, for most provinces, dam safety is legislated at the provincial level with regulations often inspired by the Canadian Dam Association's Safety Guidelines (Canadian Dam Association, 2013). Dams classified in the "extreme hazard" category are those that, in case of failure, have the potential to cause human loss of life and severe environmental and financial losses. Consequently, they have to meet strict design requirements regarding the maximum flow the dam must be able to pass based on the concept of Probable Maximum Flood (PMF). "Under disadvantageous conditions, PMP could be converted into PMF-the theoretical maximum flood" (WMO, 2009, p.1) that could occur "[…] at a particular geographical location in a given watershed […]" and at a particular time of year, "[…] with no allowance made for long-term climatic trends." (WMO, 2009 p.xxv). Many meteorological variables have an impact on the intensity of the PMF. One of the major drivers is the Probable Maximum Precipitation (PMP), which is the largest amount of precipitation that could accumulate in a given watershed, for a specific duration and for a particular time of year (WMO, 2009). Soil moisture, snowpack, temperature sequence, upstream regulation and reservoir capacity can also influence the impact of a PMP on runoff and increase the likelihood of a large flood event. Both recent historical observations and climate change simulations show increasing trends in the frequency and intensity of extreme precipitation events over Canada and most of the U.S.A. (IPCC, 2012). Since traditional methods for estimating PMPs and the resulting PMFs assume stationary conditions, there is a need to develop a methodology to account for changing climate conditions in the PMF calculations (Canadian Dam Association, 2013; WMO, 2009).

The approach suggested by the World Meteorological Organisation to estimate PMPs is based on observed meteorological data (WMO, 2009). It relies on the principle of moisture maximization of high-efficiency storms. The maximization technique finds the maximum amount of rainfall that each storm could have generated by assuming that all available moisture within an atmospheric column, commonly called the precipitable water, will indeed precipitate.

Recent studies have explored the use of climate models to compute PMPs in a future climate and their results clearly underline its sensitivity to climate change (Beauchamp et al., 2013; Kunkel et al., 2013; Rouhani, 2016; Rouhani and Leconte, 2016; Rousseau et al., 2014). Using global climate model (GCM) simulations from the CMIP5 ensemble with Representative Concentration Pathways 8.5 (RCP8.5), Kunkel et al. (2013) showed an increase in maximum precipitable water of 20–30% in the USA for the period 2071–2100 relative to 1971–2000. Since precipitable water is one of the key drivers in the calculation of PMP events, higher levels of atmospheric moisture will impact the PMFs.

In the province of Quebec (Canada), several studies have used outputs from the Canadian Regional Climate Model (CRCM4; De Elía and Côté, 2010; Music and Caya, 2007) to compute PMPs. Using two simulations over the Manic-5 basin, Beauchamp et al. (2013) found that summer-fall PMPs would increase by 0.5–6% over the 2071–2100 period. Using four simulations of the same regional climate model (RCM), Rousseau et al. (2014) showed an overall significant increase of summer-fall and spring PMPs for the Kénogami and Yamaska basins. Finally, Rouhani and Leconte (2016) used eight CRCM4 simulations for their PMP assessements over the Chaudière, Moisie and Great Whale basins. They found a significant increase for future summer-fall PMPs for the Great Whale, a small decrease for the Moisie and a significant decrease for the Chaudière.

Since there is no widely accepted method to either integrate the effect of a non-stationary climate in the determination of PMF magnitudes or to incorporate resulting adaptation changes into the design, operation, or maintenance of hydropower facilities, Manitoba Hydro, Ontario Power Generation, Hydro-Québec, Rio Tinto, and the Minister of Sustainable Development, the Environment and the Fight Against Climate Change[1] partnered with the Ouranos Consortium and the Water Earth Environment Centre of the National Institute of Scientific Research[2] to develop a robust method to evaluate future PMF values under climate change. The rationale behind this collaboration was to put together a team of climate experts and hydrologists to compute reference and future PMFs using operational hydrological models. This study considers multiple rainfall storm sizes, basins with different characteristics across Canada and covers some of the uncertainties related to climate model representation, and natural climate variability, by using an ensemble of simulations from the North American Regional Climate Change Assessment Program (NARCCAP; Mearns et al., 2009) and from multi-member CRCM4 simulations produced at Ouranos. As far as the authors are aware, the current study is the first to use an ensemble of RCMs to compute PMPs and PMFs and to address the uncertainty related to modelling through the use of different RCMs and driving GCMs. RCMs were used to take advantage of their fine spatial resolution (compared to GCM) which can better represent extreme precipitations and associated spatial variability over the study basins (Kopparla et al., 2013).

This paper is organized as follows: Section 2 presents the study domain, the climate data and the general methodology; Section 3 introduces the results of the simulated PMPs, the 100-year snowpack, and the PMFs. A discussion on the limitation of the approach is proposed in Section 4, followed by the main conclusions in Section 5.

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