Modeling precipitation uncertainty effect on flood flows in a medium sized watershed

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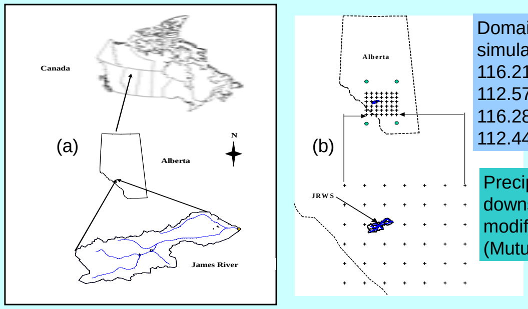
1. INTRODUCTION

Water resources managers are increasingly facing the challenge of assessing the impacts of potential climate changes on floods. While significant effort has been made to investigate climate uncertainties and their impacts on hydrology, a gap exists in understanding how uncertainties inherent in modeling individual hydrometeorologic processes influence flood hydrograph simulation. One such process is the excess precipitation which is critical in determination of a flood hydrograph. A popular method used to model excess precipitation is the loss accounting method of Natural Resources Conservation Service Curve Number (NRSC-CN).

2. METHODOLOGY AND EXPERIMENTAL APPLICATION

This study investigates elasticity theory based sensitivity of flood flows to uncertainties in precipitation when NRSC-CN is applied to compute flood runoffs. The James River watershed (Fig 1), subalpine watershed with an area of 823 km^2, located in south western Alberta, has been chosen as a case study in this investigation.

The HEC-1 model is first calibrated and validated for hourly rainfall-runoff events for the base period (1961-1990). Daily maximum data from the Canadian Coupled General Circulation Model (CGCM1) simulations during the doubling of CO$_2$ (warmer climate) are then used to drive the HEC-1 model to generate ensemble of 5,000 flood hydrographs at every single run using Monte Carlo Simulations.



Domain of CGCM1 simulation bounded by
116.21º W, 50.70 º N
112.57 º W, 50.68 º N
116.28 º W, 52.64 º N
112.44 º W, 52.61 º N

Precipitation has been downscaled based on a modified Kridging method (Mutulu, 2003)

Fig. 1 (a). Location of the James R. watershed, (b) Domain of study showing grid points from the CGCM1simulation

The MCS is based on probability models developed for different hydrologic processes required to run HEC-1 model. The main processes and their probability distributions are : -

a) Storm Depth described byGumbel Distributiob)
b) Antecedent Moisture Conditions are represented by of 5-Day Rainfall described by two- parameter Gamma distribution.
c) Initial Abstraction ; Log Pearson Type III
d) Baseflow at start of direct runoff flood hydrograph; Log-Pearson Type III
e) Flood hydrograph flow at cessation of direct runoff is defined by historical mean of the ration of peakflow to the flow at start of exponential recession of flood hydrograph recession rate of falling limb.

The following figure is a flow diagram depicting the MCS-HEC-1 operation.

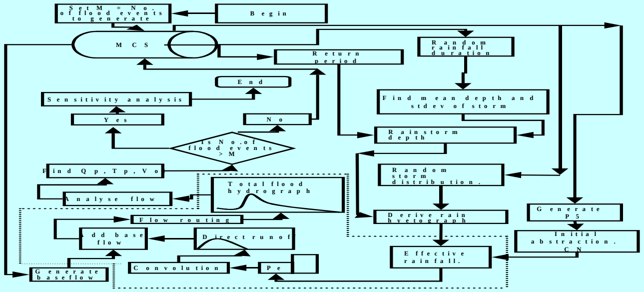


Fig 2. The MCS-HEC-1 SIMULATOR; HEC-1 module enclosed by dashed line

The NRCS - CN Runoff Curve Number Method and Elasticity Theory Sensitivity

The following formulation of the NRCS method reveals how the NRCS-CN model translates varying changes in input storm depths to changes in excess rainfall, which subsequently transforms into flood runoff. Faced with potentially warmer climate, hydraulic design for water resources systems need to incorporate uncertainty analysis of extreme flood events. An extreme case of excess precipitation is considered below.

The NRCS-CN equation which gives excess hourly maximum : precipitation as :-

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad \text{for } (P\text{-}I_a) \geq 0 \qquad (1)$$

where P_e is excess hourly maximum precipitation, I_a is the initial abstraction and comprises mainly interception and infiltration losses, plus surface storage, all of which occur before runoff begins, and S is the maximum potential retention capacity of the soil and is estimated from the curve number as a function of land use.
From Eq. (1), when $I_a = 0$, a condition for immediate ponding arises which is a special case, that can potentially generate large flood events.

Letting potential runoff, $\Omega = P - I_a$, then,

$$P_e = \frac{\Omega^2}{\Omega + S} \qquad \text{i.e.} \qquad \frac{\partial P_e}{\partial \Omega} = \frac{\Omega^2 + 2\Omega S}{(\Omega + S)^2} \qquad (2)$$

Elasticity of potential runoff, $\varepsilon(\Omega, \mathrm{Pe})$ is computed from the expression

$$\frac{\partial P_e}{P_e} = \varepsilon(\Omega, \mathrm{Pe}) \frac{\partial \Omega}{\Omega} \quad \text{which combined with Eq. (2) to give} \quad \varepsilon(\Omega, \mathrm{Pe}) = \frac{\Omega + 2S}{\Omega + S} \qquad (3)$$

Evidently $\Omega \geq 0$ and $S > 0$ which implies that, from Eq. (5.3), $\varepsilon(\Omega, Pe) > 1.0$. For the special case of immediate ponding, $Ia = 0$, we have $\varepsilon(P, Pe) > 1.0$, that is total storm depth elasticity of excess rainfall is greater than one, implying that changes in precipitation are associated with greater changes in excess rainfall which would clearly translate into amplified changes in direct runoff. Application for immediate ponding is illustrated in Fig. 3.

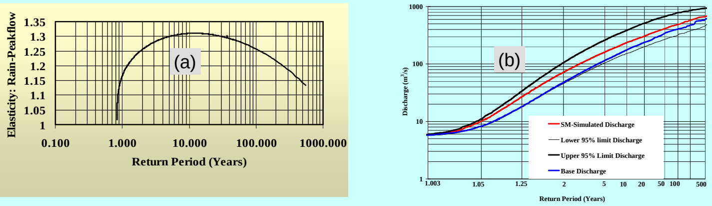


Fig. 3. (a)Precipitation elasticity of peakflows, (b) Simulated peakflow frequency curve based on CGCM outputs (2xCO$_2$), for James River Watershed Showing 95% Lower and Upper Bounds confidence limits.

Results indicate that the change in flow rate with recurrence intervals between 2 and 200 years is more than 1.2 times the corresponding change in precipitation depths (Fig. 3(b). An important observation is that the NRSC-CN indicates that the simulated flood flows are elastic with respect to precipitation depth, i.e. changes in the latter generate amplified changes in the former. For doubling of CO$_2$ (Fig. 3(b) shows that variability in extreme flood flows can be significant as a result of variabilities in due to potential climate changes.

3. CONCLUDING REMARKS

It is proposed that further studies be carried out using other loss accounting methods like the Green-Ampt model to find out how these uncertainties change. This work is a part of the principal authors research as a graduate student and research associate at the University of Calgary.

Reference

Mutulu, P.M. (2003): Flood Sensitivity to Climate Change Based on Semi-Distributed Modelling: A Case Study of James River Watershed in Alberta. Unpublished Ph.D. Thesis, University of Calgary