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IMPACT OF EXCESSIVE RAINFALL ON WATERBORNE DISEASES IN SOUTHERN ONTARIO: THE WALKERTON CASE STUDY

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ABSTRACT: The occurrence of excessive rainfall over a five day period resulted in one of Canada's most severe waterborne disease outbreaks, killing 7 people with thousands becoming ill in the Walkerton area of southern Ontario. Many factors are associated with the transportation of contaminated water, including rainfall, runoff, soil moisture status, temperature and evapotranspiration. The unique synoptic situation leading to this excessive rainfall event was characterized by two slowly moving deep low-pressure systems, which passed through southern Ontario consecutively, with both of the low-pressure centers crossing the Walkerton area. The five-day cumulative rainfall, beginning with four days of 15-20 mm each day, followed on the fifth day by a 70 mm rainfall, exceeds both the 90th percentile and the two standard deviation of the 30-year rainfall mean for Walkerton. Further analysis of soil moisture budgets showed saturated soil conditions were present during this rainfall event, resulting in surface runoff, an effective mechanism for the transport of contamination into drinking-water systems. Radar images provided an assessment of the spatial extent of this rainfall event plus the timing of the rain events over the five-day period. Interestingly, most of the rain occurred during the late evening or nighttime hours, raising the question whether residents fully understood the amounts and the impact of accumulated rain, runoff and contamination. This paper explores the meteorological forecast potential to develop a WellHead Protection Alert System (WELLPASS) for either municipal or private drinking-water systems. It is proposed that advisories, based on the Quantitative Precipitation Forecast and 90% thresholds, would be issued to warn residents, days in advance, of the risk of excessive rainfall and hence the potential for surface runoff. Drinking-water wells, under the influence of surface water, would be particularly vulnerable during these rainfall alert events, requiring adaptive management actions.

Keywords: excessive rainfall, waterborne diseases, Walkerton.

1. Introduction

The global assessment by the Intergovernmental Panel on Climate Change (IPCC) indicated that the climate was becoming more variable both on global and regional scales. The General Circulation Models suggest scenarios over the next few decades in which the global climate will be characterized by increased temperatures, altered hydrologic cycles increased variability, and increased extreme events (Karl *et al.*, 1995). The major health effects under climate change include temperature-related morbidity and mortality; health impacts of extreme weather events (storms, hurricanes, and precipitation extremes); air-pollutionrelated health effects; and both water-borne and food-borne diseases (Patz, 2000). The impact of excessive rainfall on waterborne disease is addressed in this study.

Waterborne disease outbreaks are usually caused by contamination of drinking water systems by bacteria, viruses, or small parasites. Most of the cases of waterborne disease involve mild illness, but severe outbreaks, including mortality, have also occurred in North America. An earlier study indicated that heavy rainfall was one of the most important factors in triggering waterborne disease outbreaks (Frost *et al.* 1996). For example, the Milwaukee outbreak in 1993 that resulted in the death of 54 people and more than 403,000 ill, was related to heavy rainfall and associated run-off (Hoxie *et al.* 1997). Based on the analysis of 548 reported water-borne outbreaks in the United States, Curriero *et al.* (2001) found more than half of the waterborne disease outbreaks in the United States in the past 50 years were preceded by heavy precipitation above the 90 percentile threshold.

Waterborne disease outbreaks are considered one of the most severe health threats in Canada. Although most people in Canada have direct access to treated public water supply systems, more than 5000 annual cases of waterborne diseases have been estimated, and this figure is considered to be highly underestimated. In 2000 alone, there were over 4700 cases of giardiasis and 560 cases of cryptosporidiosis reported in Canada, most presumed to be waterborne (Maarouf and Chiotti, 2000). There have been few studies addressing the critical threshold relationship between excessive rainfall and waterborne disease outbreaks in Canada. The word excessive is used to define those rainfall events that exceed a critical threshold, either individually or cumulatively. Because of the Walkerton outbreak in May 2000 where 7 people died and thousands became ill, determining this relationship between excessive rainfall and waterborne disease outbreaks has become a priority for meteorology and public health research. This study also investigated the impact of excessive rainfall on other waterborne disease outbreaks in southern Ontario. For example, critical thresholds for rain on snow situations will require the development of runoff models and associated threshold conditions, a future research project.

2. Climate Data

Detailed information about the Walkerton waterborne disease outbreak was obtained from the Ontario Government's official report of the Walkerton inquiry (O'Connor, 2002). The daily rainfall database from the Meteorological Service of Canada (MSC) was supplemented by the hourly radar reflectivity from the

National Climatic Data Center (NCDC) to better analyze the variation in the rainfall events. Also the mosaic WSR_88D radar image from NCDC proved to be invaluable in helping to capture time and space continuity for this heavy rainfall. CLI-MAT system, a Matlab based climatology analysis software (Liu, 2002), was employed to process the 30-year rainfall (1972-2001) data set for the Walkerton area. The monthly-mean soil moisture profile calculated from CLI-MAT proved to be very useful in determining the runoff intensity associated with this heavy rainfall. Upper-air reanalysis data from the National Center for Environmental Prediction (NCEP), together with visible GOES satellite image, defined the sequence of synoptic situations that triggered and maintained this heavy rainfall.

3. Overview of the Walkerton Waterborne Disease Outbreak

Walkerton is a small town in southern Ontario. In May 2000, Walkerton's drinking water system was contaminated with deadly bacteria, primarily *Escherichia coli* O157. Through an environmental testing of 13 livestock farms within a four-kilometer radius of the groundwater source for Walkerton's water system, the contamination source of this outbreak, *E.coli* O157, was found in two farms, including a farm near Well 5, the main groundwater source for Walkerton's drinking water system. Further investigation proved that *E.coli* O157 had entered Well 5 and likely originated from cattle manure starting on or shortly after May 12th (O'Connor, 2002). The first illnesses were identified in the community on the 18th of May. The drainage simulation model in the vicinity of Well 5 suggested that with heavy rain and strong surface run-off in contact with the manure in the barnyard and adjacent fields, the water could have drained toward Well 5. This drainage would carry the bacteria entering the well through overland flow and through transport in groundwater (O'Connor, 2002).

4. Rainfall and Run-off Climatology

The daily rainfall variations (Figure1a), based on daily storage rain gauges during 8-17 May 2000, illustrate continuous rainfall occurred from the 8th to the 12th, with two rainfall peaks recorded daily at the 10th and the 12th, separately. The rainfall on the 10th exceeded the top 10% of the last 30-year precipitation records. The rainfall of the 12th far exceeded both the two standard deviation of the 30-year rainfall mean and the top 10 percentile (Figure1b). Understandably, the 70 mm rainfall on the 12th was the main contribution to the five-day accumulation of rainfall and run-off, whereas the preceding four days of rain acted as precursors, contributing to soil moisture saturation, but not in themselves unusual for this area. The return period of such a continuous intense rainfall in May is approximately 1 in 60 years (Auld *et al.,* 2001).

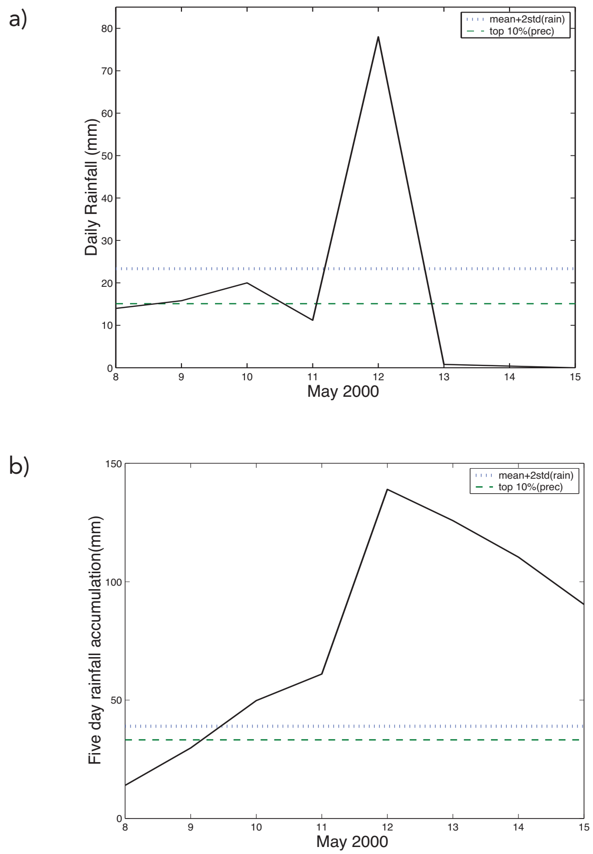


FIGURE 1

Time series of (a) daily rainfall and (b) five-day accumulated rainfall in Walkerton County during the outbreak period in May 2000.

A detailed rainfall variation profile was also extracted from three-hourly radar reflectivity data over the Walkerton area to better describe the variation of this rainfall process. The strong reflectivity from the 9th to the 12th confirmed intense rainfall occurred during this period with the two sharpest peaks occurring during the nights of the 9th and the 12th. The other two lesser intense rainfall periods, prior to these two peaks, were associated with rainfall in front of upper level troughs. The WSR-88D radar reflectivity image on the 10th (0315 UTC) showed a southwest to northeast oriented comma-shaped rainfall band extending from the low center located over southern Ontario. This corresponded to the intense rainfall over the Walkerton area during the night of the 9th (Figure 2a). The WSR-88D radar reflectivity image on the 13th (0100 UTC) shows a more intense and better-organized comma-shaped rainfall band. The southwest-northeast oriented rainfall band had a relatively small but very intense head over southern Ontario, which produced the heaviest rainfall over the Walkerton area during the night of the 12th (Figure 2b).

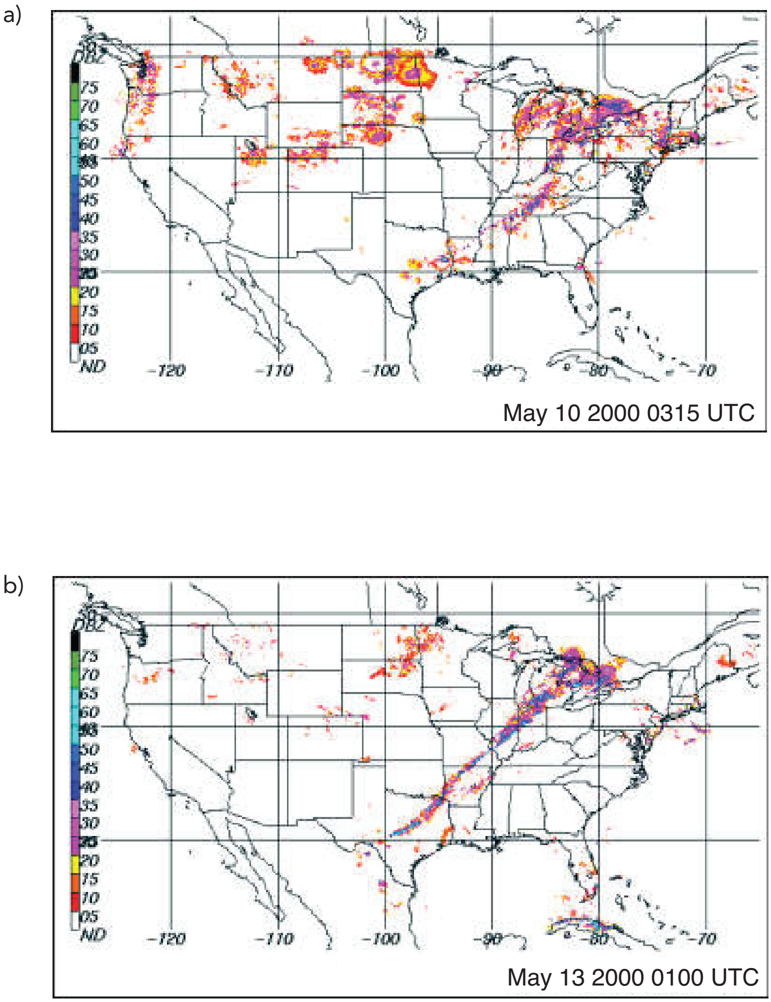
A soil moisture budget model was used to investigate the amount of run-off associated with such an intense rainfall. Since detailed data about soil layers, depth to groundwater, and vegetation were not available, a simple bucket model is used to model near-surface moisture conditions. The model can predict soil-water storage, evaporation, and water surplus. Water surplus is the fraction of precipitation that exceeds potential evapotranspiration and includes both surface and subsurface flows. The basic equation for calculating surplus is:

$$W = P + M - E - \frac{\Delta S}{\Delta t} \qquad (1)$$

In Equation (1), W is surplus, P is precipitation, M is snowmelt, E is evaporation, S is soil moisture, and t is time.

The budget parameters of snowmelt, potential evapotranspiration and precipitation are computed on a daily basis. As continuous intense rainfall occurred during this event, monthly mean output is sufficient to display surface run-off effects from this heavy rainfall.

The monthly mean water surplus calculated in Figure 4 showed a water surplus or run-off that far exceeds zero from January to May. This saturated soil status is also illustrated by comparing the distribution of the main water input (precipitation) and output (evapotranspiration) in Figure 5. The precipitation exceeds evapotranspiration from January to May with some precipitation stored on the surface as snow during the winter months, hence producing sufficient recharge amounts for soil saturation by the beginning of May. Subsequent rainfall amounts would continue to maintain saturation and produce substantial surface run-off during the intense rainfall period from May 8th to the 12th, especially the major rainfall event on the final day.



May 10 2000 0315 UTC

May 13 2000 0100 UTC

FIGURE 2

Radar reflectivity for the National Weather Service WSR-88 radar at (a) 0315 UTC, May 10, 2000, (b) 0100 UTC May 13,2000.

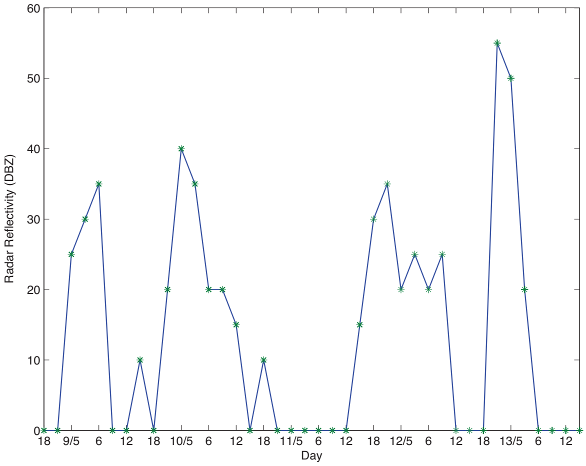


FIGURE 3

Rainfall intensity variation showed in three-hourly radar reflectivity data in Walkerton County during the outbreak period in May 2000.

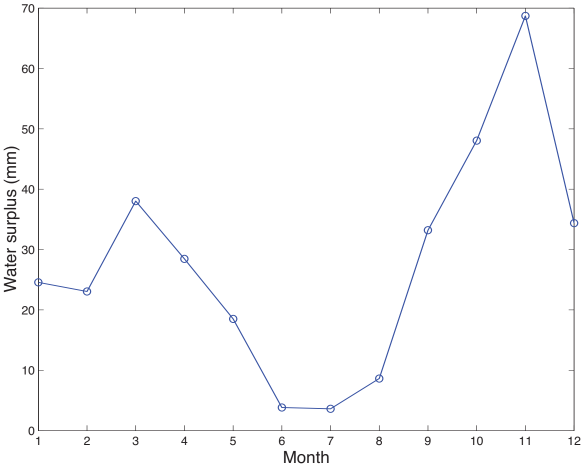


FIGURE 4

Monthly mean water surplus at Walkerton County in the year 2000.

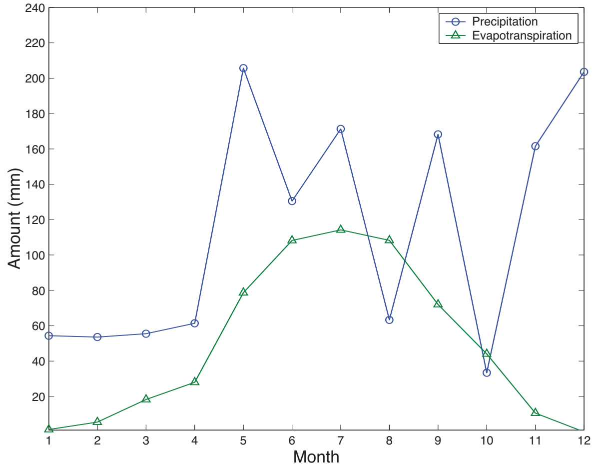


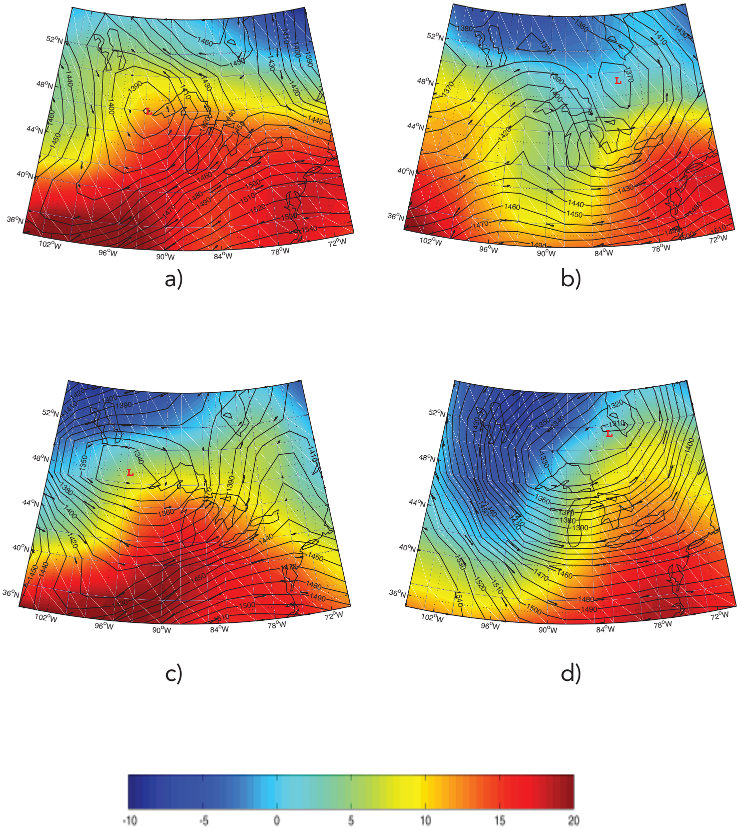
FIGURE 5

Monthly mean precipitation and evapotranspiration at Walkerton County in the year 2000.

5. Synoptic Situation

The synoptic situation associated with this continuous intense rainfall over the Walkerton area showed a unique pattern, as illustrated in the evolution of 850mb weather conditions over southern Ontario (Figure 6). On May 8, a synoptic-scale low centered west of the Great Lakes with a southwest to northeast orientated trough extending deep into the central United States. The cyclonic flow around the low resulted in the cold advection over Winnipeg, and the warm advection over south-western Great Lakes (Figure 6a). The low-pressure system moved east slowly. By May 10, the low-pressure center had reached western Quebec, with the upper level trough tracking over the eastern Great Lakes and southern Ontario (Figure 6b). The GOES-8 satellite image on the 10th shows a well-defined southwest-northeast-oriented comma cloud over eastern North America. Southern Ontario is located under the northeast segment of this cloud shield (Figure 7a). The brighter colour cloud over southern Ontario demonstrates a very cold cloud top temperature and strong vertical movement conducive for the potential of heavy rainfall.

After this initial system passed southern Ontario on the 11th , a second synoptic low system moved in, with the low-pressure center located west of the Great Lakes on the 12th (Figure 6c). This second low-pressure system was much deeper than the former one and intensified between May 12 and 13. The associated advection with this system brought relatively cold air from high latitudes into contact with lower level warm and moistening air from the southeastern coast, forming a very strong surface front over the Great Lakes region (Figure 6d). The surface front passed the Great Lakes during the night of the 12th. This intense



a)

b)

c)

d)

FIGURE 6

Evolution of synoptic situation on 850 mb field during 8-13 May 2000: (a) May 8, (b) May 10, (c) May 12, (d) May 13.

frontal system and the associated strong vertical motion produced the heaviest rainfall. A bright color comma-shaped cloud with strong convective cloud over southern Ontario in the GOES-8 Satellite image also indicates a favorable environment for excessive precipitation (Figure 7b).

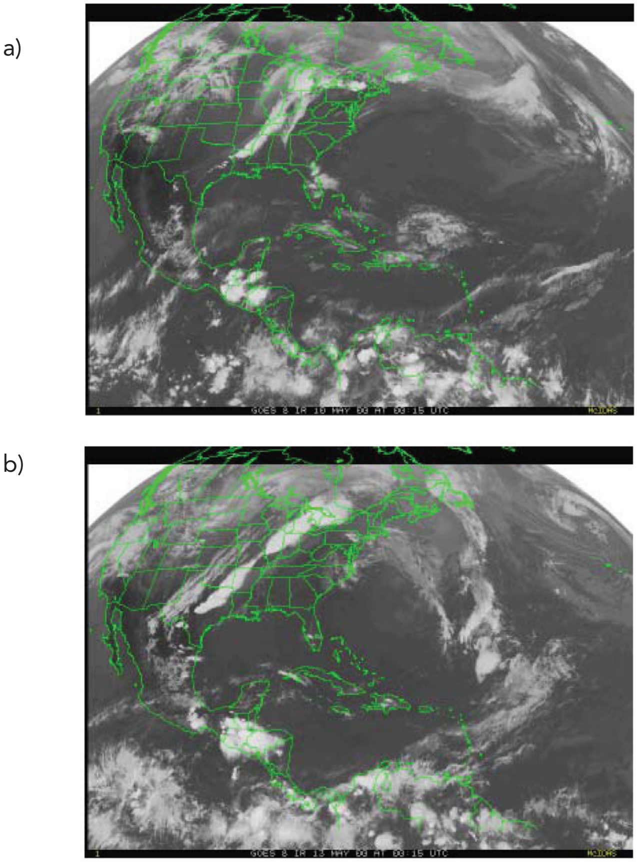


FIGURE 7

GOES-8 image at (a) 0015 UTC May 10 2000 and (b) 0015 UTC May 13 2000, showing comma shaped cloud associated with the surface front system.

6. Summary and Future Directions

By reconstructing one of the most severe waterborne disease outbreaks in Canada, the contributing role of excessive rainfall has been demonstrated, including the critical thresholds that directly affect the runoff and transport of contamination. Multiple factors are associated with run-off, such as, rainfall, soil moisture status, temperature and evapotranspiration. The special synoptic situations that triggered and maintained this continuous and heavy rainfall event; the night time timing of the rainfall events; and rainfall exceeding the 90 percentile threshold are all especially noteworthy.

Analyses of the daily rainfall database from the Meteorological Service of Canada, coupled with the hourly radar reflectivity from NCDC, demonstrated that continuous intense rainfall occurred between 8 – 12 May, 2000, with an extreme intense period at midnight on May 12th, that exceeded the 90th percentile and two standard deviations of the 30 year mean. The soil moisture budget analyses showed a saturated soil existed during this event that ensured a strong run-off, especially during the very intense precipitation period on midnight of May 12th. The upper-air reanalysis data and visible GOES satellite image showed a very special synoptic situation that triggered and maintained this heavy rainfall. Two slowly moving low-pressure systems passed through southern Ontario, centered on Walkerton, resulting in continuous intense precipitation. The first low seemed to act like a precursor by contributing to the recharge of soil moisture and increasing the run-off risk whereas the second low pressure system was much deeper as it passed Southern Ontario yielding excessive rainfall and strong run-off conditions.

The rainfall that triggered the Walkerton waterborne disease outbreak was above both the two standard deviation of the mean rainfall and the 90th percentile of the precipitation. The latter index has been demonstrated to be a critical value to define excessive rainfall and triggering waterborne disease outbreaks in the United States (Curriero, 2001). The same critical threshold criterion of over 90th percentile of the precipitation, confirmed in the case study of Walkerton, plus the Quantitative Precipitation Forecasts provided by the Meterological Service of Canada (MSC), could provide an operational WellHead Protection Alert System (WELLPAS) for Canada. More importantly, based on the radar data, it became apparent that most of the intense rainfall occurred during the night and it most probably escaped the attention of the community. The WellHead Protection Alert System would be designed to issue public advisories for exceedences above the 90% level, days in advance, thereby allowing for adaptive and preventative management actions. In return, WELLPAS could provide a meteorological-health service to Canadians for both municipal and private drinking-water systems. Additional research is on-going between the Meteorological Service of Canada and Health Canada to examine other waterborne disease outbreaks to further refine the critical threshold levels for precipitation and run-off, especially during rain on snow events, across Canada.

7. Acknowledgments

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