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Lessons learned from the 2013 Calgary flood: Assessing risk of drinking water well contamination

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A B S T R A C T

A devastating flood occurred in southern Alberta on June 19, 2013, from greater than normal snowfalls in the Rocky Mountains and excess precipitation during the early spring that left soils saturated and unable to absorb any additional precipitation. This flood was Canada's most costly natural disaster, with five to six billion Canadian dollars in damages. The first objective of this study was to determine if the flood caused an increase in private drinking water well contamination in the Calgary Health Zone by comparing contamination rates to previous years. The second objective was to determine which environmental factors were associated with contamination during this flood event. Test results of total coliforms (TC) and *Escherichia coli* (EC) of private water wells were used to determine contamination. A geographically weighted Poisson regression analysis suggested that TC contamination was not associated with this flood. The EC contamination is positively associated with floodways, flood fringe, farms, and negatively associated with intermittent water (sloughs). These results suggest that for the 2013 flood, individual well characteristics are more important than surrounding geographic features. Thus, it is recommended that homeowners who live in a high-risk area ensure their wells are properly maintained to reduce risk of water well contamination.

1. Introduction

The contamination of rural drinking water is a multifaceted problem because of a complex interaction of environmental factors that involve humans and livestock activity (Corvalan, Hales, & McMichael, 2005). As the intensity of agriculture increases in conjunction with the increase in population density, there is growing need to understand how environmental health is mediated by environmental factors (Zinsstag, Schelling, Waltner-Toews, & Tanner, 2011). This problem is exemplified by the flooding that occurred in southern Alberta on June 19, 2013. This flood was named Canada's most costly natural disaster, costing between five and six billion Canadian dollars in damage (Milrad, Gyakum, & Atallah, 2015). Factors that contributed to the flood included greater than normal snowfalls in the mountains, excess amount of precipitation during the early spring to the Bow and Elbow River watershed, and a wet spring that left soils saturated unable to absorb any additional precipitation (Milrad et al., 2015). At its peak discharge rate, it is estimated that the Bow River was flowing around 1700 m^3/sec (Milrad et al., 2015).

Water must test negative for both total coliforms (TC) and faecal coliforms to be considered drinking quality (World Health Organization, 2004). TC are widespread in the environment and can include the genera *Escherichia, Citrobacter, Klebsiella, Enterobacter, Serritia,* and *Hafnia* and are found in faecal environments such as the intestines of warm-blooded animals and non-animal sources in the environment including plants and soil. While the presence of total coliforms does not necessarily indicate the presence of harmful bacteria, it is a good indication of the water

Abbreviations: TC, Total Coliforms; EC, *Escherichia coli*; PGLM, Poisson generalized linear model; GW-PGLM, Geographically Weighted Poisson generalized linear model.

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cleanliness (World Health Organization, 2004). As a result, a count of TC is a widely used indicator of potable water quality in North America (Weiner, 2012).

There can be many different sources of TC that are not classified as faecal. TC are used as an indicator of water quality as a part of a multi-barrier approach to ensuring the safety of drinking water. Although there are no health-based risk assessments for TC in the absence of faecal coliforms, as TC are not considered a risk to human health, a positive TC test does warrant further investigation. When a water sample tests positive for TC but negative for *Escherichia coli* (EC), this indicates that the source is not faecal. As protected groundwater systems should contain zero TC, a positive TC test result indicates that there is likely contamination from within the distribution system (e.g. biofilms) or the surrounding environment (Canada Health, 2012).

Of more concern for drinking water is the presence of EC. EC is commonly found in both human and animal faecal matter. It is rare to find the presence of EC without also finding faecal contamination. Presence or absence of EC is considered the most reliable indicator of faecal contamination, and testing for this bacterium is regarded as the optimal choice for drinking water surveillance (World Health Organization, 2004).

A strong environmental link has been demonstrated between heavy rainfall events, outbreaks of waterborne disease and overland flooding, which is the most frequently occurring natural disaster (Hofstra, 2011; Hrudey, Payment, Huck, Gillham, & Hrudey, 2003). At a local scale, flooding is affected by the amount of rainfall received, topography, and surrounding geology (McMichael, Woodruff, & Hales, 2006). Regions where ground lithology permits the rapid transport of water from the surface into the groundwater system can negatively impact water quality. When lithology is coupled with environmental conditions, such as heavy periods of rainfall and flooding events, greater quantities of water is more quickly transferred from the surface to groundwater systems (Richardson, Nichols, Lane, Lake, & Hunter, 2009; Wallender, Ailes, Yoder, Roberts, & Brunkard, 2013).

Flood mediated water well contamination and resultant outbreak of gastroenteritis is well exemplified the tragedy of Walkerton, Ontario, Canada in 2000. Following a heavy rain event, where 70 mm of rain that fell within a few days, EC |strain 0157: H7| was responsible for causing over 2300 cases of gastroenteritis; 65 of these cases requiring hospitalization, and seven resulting in death (Hrudey et al., 2003). The rain event had carried EC into the groundwater supply used as drinking water for the town. Furthermore, the improper municipal management of the chlorine treatment facilitated this contamination (Hrudey et al., 2003).

Water well design and structure are known to affect the likelihood of contamination. Faecal matter most commonly enters a drinking water system because of improper well design or unsatisfactory upkeep of the well. Well placement is also important, as an inadequate setback from septic tanks, waste sites, and wells located in depressions can affect the probability of contamination (Richardson et al., 2009; Wallender et al., 2013). These issues are highlighted in the Walkerton tragedy, as the town is situated on a surface where the geologic conditions are considered very poor, having a large amount of highly fractured rock surrounding the water wells. These fractures allow for quick recharge between surface and groundwater. The problem was further exacerbated by the shallowness of one well that was also located near farms, and served as a potential point source for faecal contamination. The susceptibility of this well to surface water influence had been known previously known (Hrudey et al., 2003).

Previous models have explored the relationship between environmental conditions and the contamination of groundwater with bacteria through including the variables listed above (Hofstra, 2011; Hrudey et al., 2003; Richardson et al., 2009; Wallender et al., 2013). However, much of this research does not include surface factors such as flood events. It is important to examine water well contamination as a result of these events and determine risk factors that may contribute to the contamination of private drinking water wells as the frequency and magnitude of natural disasters such as flooding, heavy rainfalls, and hurricanes that are increasing (Few, 2003; Hofstra, 2011). The objectives of this study were to determine: 1) if the prevalence of well water samples testing positive for TC and EC increased as a result of the June 2013 southern Alberta flood; and 2) which environmental factors influenced contamination of private drinking water wells and drinking water safety in the Calgary Health Zone following the June 2013 flood.

2. Materials and methods

2.1. Study area

The extent of the study area is the Calgary Health Zone (Fig. 1). This zone contains one of Alberta's two metropolitan centers, the city of Calgary, as well as smaller municipalities, including Canmore, Banff, and High River. As of 2011, this health zone had a population slightly over 1.4 million people, making this the most populous health zone in Alberta. This is a geographically diverse health zone with the Rocky Mountains to the west, and prairie land to the east. Major rivers that run through the Calgary Health Zone are the Spray River, Elbow River, and Bow River.

2.2. Data

Coliform test results of private water wells were obtained from Alberta's Provincial Laboratory for Public Health (ProvLab; Calgary, AB, Canada), where well owners submitted samples to ProvLab on a voluntary basis. For analysis, the laboratory used a Colilert Enzyme Substrate to produce a binary positive or negative result for TC and EC. Historical results for TC and EC were obtained from ProvLab for the study period (June 19 - September 30) dating back to 2005. For the 2013 risk mapping assessment, 66.3% of the obtained data were geolocated. Sample results with no spatial information were excluded from this analysis, leaving 470 quarter sections for analysis after aggregation. There are a total of 60,811 quarter sections in the Calgary Health Zone, each with an area of 0.65 km^2.

The independent variables used in the analysis include hydrology variables including minor and major streams, rivers, intermittent water, and water bodies, aquifer depth, hydraulic connectivity, and flood hazard classifications. Flood hazard product was created based on a 100-year flood. The *floodway* is part of the river channel where water is the deepest, has the fastest flow and is most destructive. Beyond is the *flood fringe* where overland flooding occurs. Water moves at a slower pace, and usually less than one meter deep. Within the dataset, flood fringe and overland flooding were classified separately, as overland flooding is considered to be a special case of flood fringe by the developers (Alberta Environment and Parks, 2013). Additional variable collected for analysis were land cover data, abandoned well data, population and dwelling density and farm number and number of farms and hectares of farmland. Precipitation data was data obtained for June 2013 to capture the overland water burden due to precipitation around the time of the flood. A raster digital elevation model (DEM) was obtained at a 30-m pixel resolution. Vector layers used for zonation and mapping include boundary shapefiles of the Calgary Health Zone, Alberta Township Sections, City of Calgary. See supplemental data for a detailed outline of data sources, scale, accuracy, and last update.