Using Geographical Information Systems to Identify the Source of a Waterborne Gastrointestinal Outbreak in Walkerton, Ontario, Canada, May-June, 2000

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ABSTRACT

An outbreak of *E.coli 0157:H7 and Campylobacter* occurred in the town of Walkerton, Ontario, Canada during the spring of 2000. The outbreak resulted in 7 deaths and 2300 people becoming infected. It was determined that the outbreak was waterborne in origin. The cases and controls were geocoded using street network files and a digital telephone directory. A dynamic computer model of the towns drinking water system was built and the events leading up to the outbreak were recreated using several possible scenarios. Water from each of the town's 3 wells was traced to individual households on an hourly basis over a period of 3 weeks and exposure measured using statistical software. The analysis enabled the implication of one well as the source of the outbreak.

1.0 INTRODUCTION

In May 2000 the town of Walkerton, Ontario experienced a waterborne gastrointestinal outbreak that infected 2 300 people and resulted in 7 deaths. The pathogens involved in this outbreak were predominantly *E.coli 0157:H7* and *Campylobacter*. The town's drinking water was supplied by ground water from 3 different wells, all of which were in service during the time of the outbreak. As part of the epidemiological investigation a number of geomatic and hydraulic modeling tools were utilized to determine the source of the outbreak. In this instance we were able to use GIS and other spatially based software to trace contamination from the source to the household and prove statistically the source of the outbreak.

2.0 METHODOLOGY

ArcView GIS was used to plot the cases and controls within the town in order to visualize the incidence of illness throughout the town. The cases and controls were digitized using street network files; in addition an electronic telephone directory was used to provide the background population. Much of this data needed to be enhanced to work effectively at a household level. The results were as expected for a waterborne outbreak with what appeared to be random cases distributed throughout the entire town and beyond. The point data was then transformed to a case density raster grid and a pattern emerged suggesting that the distribution of cases may not in fact be uniform across the town. A hydraulic model of the town's water system was created using WaterCad software to replicate the events leading up to the outbreak. The objective of the water modeling exercise was to re-create the pattern of water flow throughout the town's distribution system immediately before, and during the outbreak period.

Modeling of the Walkerton water system involved inputting the following parameters into an appropriate software application, in this case, WaterCAD: exact size, location, elevation, age, and composition of all water pipes; size, storage capacity, and active volumes of the two stand-pipes (water towers); well pump specifications (including pump curves); and pipe friction (Cesario 1995, Clark 1998). The software views the system as a network of nodes, which can be source (well), storage (tanks) or demands (customer) locations, connected by links (pipes and pumps). Each metered commercial user was questioned about water use during the critical period and an individualized temporal water demand pattern was assigned to each *commercial node*. Residential users in Walkerton were not metered and were assigned to the nearest *residential node*. Well pump controls were added to the model and pump *on* and *off* times were set in accordance with the historical pump records. Computerized data from the Supervisory Control and Data Acquisition (SCADA) system was available and contained 15 minute pumpage rates for all three wells. Hourly residential demand was estimated using the daily volume of water supplied to the system after accounting for commercial users, and literature based hourly demand patterns (Dziegielewski 2000, Kindler and Russell 1984, Protopapas et al. 2000, RMOW 1999).

As flushing of the distribution system commenced on May 19 as a result of contamination suspicions, the water flow model was not considered reliable after May 18. Because of this, all analyses in the present investigation only considered exposure dates up to midnight of May 18.

Exposure scenarios (see Table 1) were created by adding hypothetical inert contaminates to each well at predetermined times and concentrations. WaterCAD provides the ability to follow the movement and relative concentrations of contaminates through a distribution system. Considering the shape of the epidemic curve, the computerized well pumpage data, and the hypothesized importance of the May 12-14 rain event, six contamination scenarios were considered. For each scenario, WaterCAD provided the hourly hypothetical contaminant concentration at each residential node. Diagrams and graphs were generated using S-Plus , Excel and Arcview, to visualize the temporal-spatial pattern of contaminants among the exposure scenarios investigated. This data was then exported to SAS for further analysis.

Prior to the outbreak there had been heavy rainfall in the area. As a result we were aware of the possibility that surface runoff might be impacting on the wells (Curriero et al. 2001). We also used raster based hydrologic modeling in ArcView with Spatial Analyst to look at runoff from farms near the wells to see if surface runoff from any of the farms could be possibly influencing the wells. Using aerial photography (30cm resolution) superimposed on a digital elevation model it was possible to run a simple surface runoff model on particular locations (Maidment and Djokic 2000). Cattle were clearly visible at a 30cm resolution and by running a drainage simulation using cattle as a source, runoff from one particular group of cattle was directly upstream from the implicated well. While this was a simplified surface runoff model it was extremely easy and quick to use and provided immediate, if somewhat superficial answers. The results from this simulation were later verified by an independent hydro-geologic survey of the area, physical inspections of the water system and microbiological evidence from the lab.

3.0 CONCLUSIONS

Results from the water distribution system modeling indicate that Well 5 appears to have disproportionally serviced the southern regions of the town during the period of interest. Except for variations in the absolute range of contaminants, Scenario [5a] (average node contaminant range: 0.0 - 73.4 units) and Scenario [5c] (average node contaminant range: 0.0 – 16.1) resulted in similar distribution patterns. Scenario [7a] (average contaminant range: 0.0 –84.2 units) resulted in a similar spatial contaminant concentration pattern to that of Scenario [7b]. Well 6 and Well 7 appeared to have disproportionally supplied the northern areas of the town.

TABLE 1 Exposure scenarios evaluated in the Walkerton waterborne outbreak

Scenario/ Exposure	Well	Contamination Pattern	Hypothesis Tested
[5a]	5	100% contaminated from 12:00 AM May 9, and continuing.	Well 5 heavily contaminated when it started up on May 9.
[5b]	5	25% contaminated from 12:00 AM May 9 to 12:00 AM May 12, then 100%.	Well 5 slightly contaminated when it started up on May 9; the contamination was augmented by heavy rainfall on the 12th and the 13th.
[5c]	5	100% contaminated from 12:00 AM May 9 to 12:00 AM May 11.	Well 5 heavily contaminated when it started up on May 9 but the contamination only lasted for 3 days.
[6]	6	100% contaminated from 12:00 AM May 9, and continuing.	Well 6 heavily contaminated when it started up on May 9.
[7a]	7	100% contaminated from 12:00 AM May 8, and continuing	Well 7 heavily contaminated the day before it shut off prior to the outbreak peak.
[7b]	7	100% contaminated from 12:00 AM May 1, and continuing	This scenario allowed the testing of whether or not Well 7 water was protective.

The average daily node contaminant concentrations associated with each exposure scenario were compared with the epidemic curve of the cases. It appeared that the epidemic curve most closely resembled the pattern of exposure levels associated with Scenario [5b]. A total of 367 persons met the control definition, 204 females, and 163 males. The median age of controls was 42.0 years (mean: 40.7 years, range <1 to 94 years). In general, it appeared that cases were associated with higher levels of Well 5 water than controls (Scenarios 5a, 5b, and 5c), and controls were associated with higher levels of Well 6 and 7 water than cases (Scenarios 6, 7a, and 7b).

4.0 DISCUSSION

The results of this study support the hypothesis that Well 5 was the primary, if not the only, well involved in the Walkerton *E.coli* / *Campylobacter* waterborne outbreak. Moreover, the results suggest that the extreme rainfall event, which occurred just prior to the peak in the outbreak, may have played a significant role. Using water system modeling software it is possible to recreate events leading up to outbreak events. This type of modeling can be used to test a variety of hypotheses in order to establish a most likely scenario.

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