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Consequence Evaluation of Liquid Hazardous Material Release using GIS Flow Modeling

Jesus Aguilar Serrano, M. Rapik Saat, Ph.D. (mohdsaat@illinois.edu)
Rail Transportation and Engineering Center, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA

Increasing petroleum crude oil traffic by rail in North America and several recent severe release incidents highlight the need to further improve railroad transportation safety. Accurate estimation of the consequence of a release incident is key element in risk assessment. Previous methodologies may be overly simplistic or not appropriate to model liquid hazardous material releases. This research aims to address this gap and provide a specific methodology for evaluating the consequence of liquid hazardous material releases.

Background

The consequence of a liquid hazardous material release is mainly governed by the topography at the area of release. Using the digital elevation model (DEM), the methodology developed in this study considers the terrain to accurately estimate the potential area affected by the release.

A DEM is an image where the value contained in each pixel corresponds to the elevation in that location (Figure 1). The image resolution determines the size of the pixel and therefore the size of the area represented by each pixel.

The methodology is based on the basic assumption that overland flow moves downhill by the steepest path. This is a commonly used assumption in hydrology and other overland flow models. The steepest path calculation is based on the 8-neighbors method. Although there are other methods to calculate the steepest path, this is the one already implemented in ArcMap. With this method, the flow will move from one pixel to the pixel with the steepest downward slope in the neighborhood of the original pixel. At maximum, each pixel may have eight neighbors and therefore eight possible paths downhill.

Currently the methodology does not consider any specific released volume. It is assumed that there is enough quantity released to go from the point of release to the closest water body following the steepest path. The point of contact between the steepest path and the other water bodies represents the end of the overland flow. The ultimate goal is to identify the potential affected area in the worst case scenario, which would correspond to the assumption.

61	58	57	51	47	45	44	37	34	31
58	55	53	49	45	44	43	35	33	30
57	52	47	45	44	41	39	33	31	27
51	46	44	37	37	36	34	30	29	26
47	45	40	37	37	33	28	26	24	21
42	41	37	31	32	24	24	22	21	19
43	39	36	28	30	24	23	19	18	16
37	34	31	27	24	22	20	18	17	12
34	30	27	23	20	17	15	12	12	12
30	26	24	20	19	15	12	12	12	12

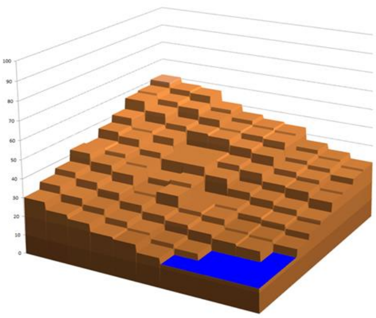

Figure 1. Matrix of pixels and 3D representation of a Digital Elevation Model (DEM)

Case Study

To illustrate the methodology and demonstrate its applicability to a real consequence estimation analysis, a case study of the Lac-Mégantic accident was performed.

The required spatial data was downloaded from the Natural Resources Canada website for the specific area of Lac-Mégantic, Quebec. The vector data consists of the railroads, the streets, and the lake shoreline. The raster data includes the DEM and the satellite image of the area. The DEM has a resolution of roughly 20 meters.

Once the data had been loaded within ArcMap (Figure 2), the next step was to set the points of release. In this example, the points of release were estimated based on the approximate location of the tank-car pile from the pictures taken after the accident. Given that the pile occupies an extensive area, four points of release were set and analyzed.

The two output rasters obtained from the Flow Direction and Flow Accumulation tools were combined into one layer of points (Figure 3). Each pixel is represented by one arrow which indicates the flow direction and the relative accumulation in the pixel – the heavier the color the higher the accumulation. The final paths and area affected are shown in Figure 4.

The results in Figure 4 can be compared to the accident picture in Figure 5. The model accurately predicts which area of the city would be more damaged, and the point of entry of the hazmat into the lake.

Although in the actual photo, it seems like the area affected is wider, this model was able to identify two main different flow paths after the accident: a path through the city and another path toward the rail tracks. The wider area affected compared to the model could be the consequence of the violent fire ignited immediately after the accident.

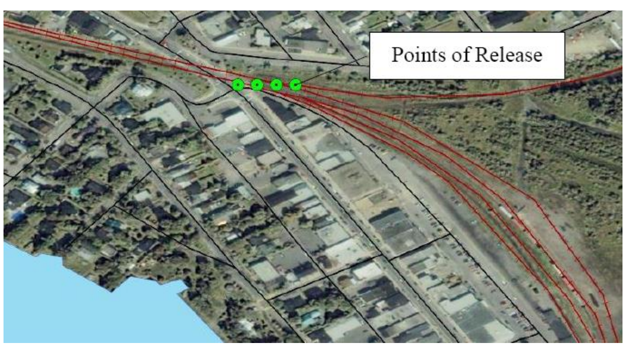

Figure 2. General area of study

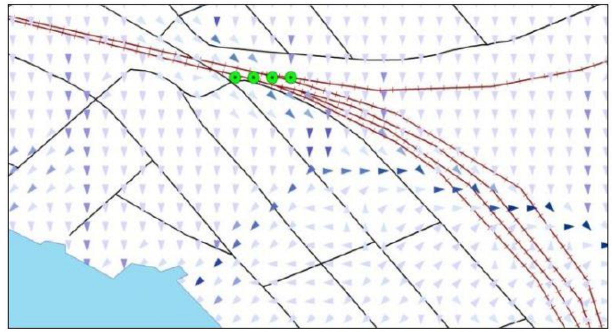

Figure 3. Flow direction and flow accumulation results

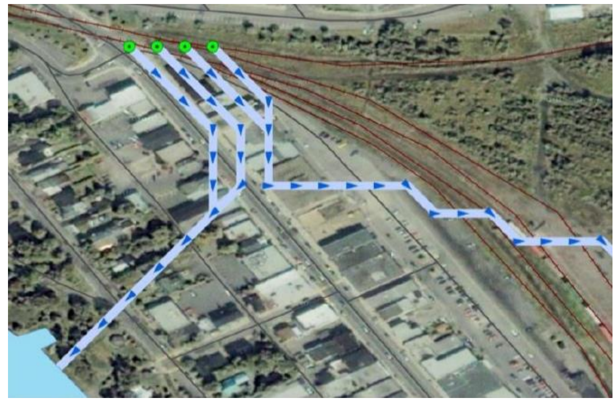

Figure 4. Flow paths estimated from the analysis

Figure 5. Actual picture to compare to the model results

Conclusion

This study presents a methodology to estimate the potential consequence of accidental release of liquid hazardous materials that can be used for emergency respond prioritization and risk-mitigation planning.