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A case study of chlorine transport and fate following a large accidental release

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HIGHLIGHTS

► A case study on a large accidental release of chlorine.
► This paper examines atmospheric transport and deposition onto nearby surfaces.
► The mass of chlorine transferred into nearby water bodies was estimated.
► Simulated dose compares well with available health effects and vegetative damage.
► Model-estimated chlorine concentrations compare well with available fish kill data.

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ABSTRACT

A train derailment that occurred in Graniteville, South Carolina during the early morning hours of 06 January, 2005 resulted in the prompt release of approximately 60 tons of chlorine to the environment. Comprehensive modeling of the transport and fate of this release was performed including the characterization of the initial three-phased chlorine release, a detailed determination of the local atmospheric conditions acting to generate, disperse, and deplete the chlorine vapor cloud, the establishment of physical exchange mechanisms between the airborne vapor and local surface waters, and local aquatic dilution and mixing.

Previous studies of large chlorine releases have concluded that depletion of the resulting vapor cloud through physical and chemical reactions with sunlight, atmospheric constituents, and local surfaces can significantly reduce the areal extent over which the vapor poses a toxicological hazard. For Graniteville, modeling results were the most consistent with available data on human health effects, animal and fish mortality, and vegetation damage when an effective deposition velocity in the lower end of a range of values commonly cited in other studies (1 cm s^{-1}) was applied. This relatively small deposition is attributed to a lack of sunlight, a limited uptake in vegetation due to rapid stomatal damage, and the limited presence of nearby man-made structures. Explicit simulations of chlorine deposition into adjacent surface waters were based on a modified Henry's Law approach and resulted in the transfer of an estimated 21 kg of chlorine into these waters.

1. Introduction

The collision of two trains at a rail spur in the town of Graniteville, South Carolina in the early morning hours of 6 January, 2005 caused a catastrophic breach to a railcar containing chlorine. The sudden depressurization of the railcar's inner tank resulted in the rapid discharge of approximately two-thirds of the total contents (60 tons) of chlorine into the environment within a few minutes (NTSB, 2005). The discharged mixture of liquid and aerosols quickly vaporized and formed a dense cloud of chlorine vapor that settled toward the west and southwest into a shallow valley bisected by Horse Creek, which bounds Graniteville to the west. Over the next 3 h, this dense chlorine cloud spread through gravitational settling, diffused into the ambient atmosphere, and was subsequently transported out of the area by the prevailing south-southwesterly wind. The resulting statistics on mortality, morbidity, and environmental damage included 9 fatalities and 71

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hospitalizations, several hundred deaths of animal and fish, and a severe bleaching of vegetation within a radius of approximately 1 km of the accident scene (Allen and Thomason, 2005; Buckley et al., 2007; Wenck et al., 2007). A previous modeling study (Buckley et al., 2007) examined the release of chlorine from an emergency response perspective and provides further background information.

Graniteville is located in southwestern South Carolina in a region of gently sloping terrain. The derailment site lies in a shallow valley formed by Horse Creek which is oriented from north to south (Fig. 1). Land use in the area is generally suburban, with a textile mill and supporting facilities and parking lots adjacent to the derailment site. The prevailing south-southwesterly wind at the time of the collision was the result of clockwise circulation around a surface high pressure system centered off the southeast United States coast ahead of an advancing cold front (Fig. 2).

A modeling study was conducted to characterize in detail the transport and fate of this chlorine release through the air and surface waters in the immediate vicinity of Graniteville. All calculations for this study were based on a rapid discharge of 60 tons of the total inventory of 90 tons of product from the railcar (NTSB, 2005). Modeling studies of similar large chlorine releases, notably in Festus, Missouri and Macedonia, Texas, are summarized by Hanna et al. (2008a). To account for the effects of local topography, fine scale meteorological conditions were generated with the Regional Atmospheric Modeling System (RAMS, Pielke et al., 1992). The SRNL has many years of experience with RAMS in both operational and research applications. Particular attention was placed on accurately characterizing the near-surface conditions that affected the initial generation of a large, dense cloud of chlorine vapor and the subsequent dispersion and depletion of this toxic cloud as it was transported over the study area. The calculations were run for 3 h after the railcar was breached, a period that bounds the eventual dissipation of the release and subsequent transport out of the affected Graniteville area. The airborne transport and diffusion calculations were based on the Second-Order Closure Integrated Puff (SCIPUFF, Sykes et al., 1993, 1995) module of the Hazard Prediction Assessment Capability (HPAC, Sykes et al., 1998, 2004) code, using the detailed local meteorological conditions generated with RAMS. The HPAC-SCIPUFF suite was chosen for its proven ability to simulate dense gas releases, its effective widespread use by numerous other investigators, as well as its extensive benchmarking (e.g., Sykes et al., 1993; Cox et al., 1998, 2003; Chang et al., 2003; Hanna et al., 2007, 2008a, 2008b).

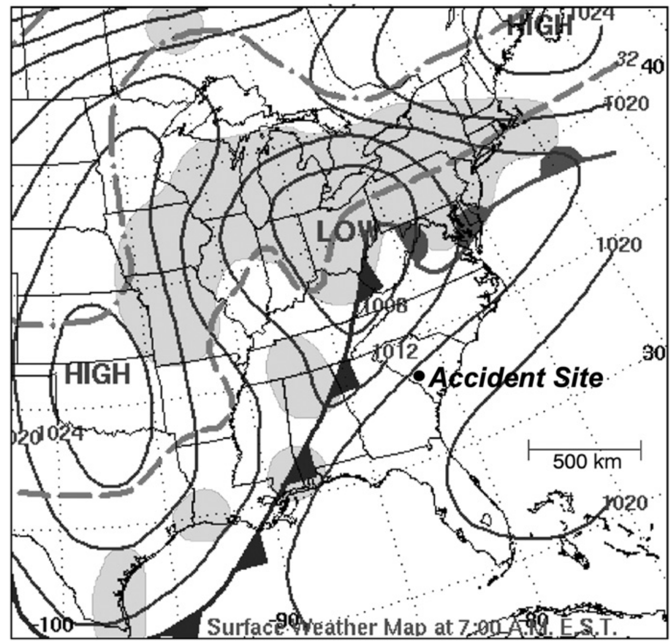

Fig. 2. Synoptic conditions at 1200 UTC (7:00 a.m. local time) January 6, 2005 (This figure is reproduced from Fig. 5 of Buckley et al., 2007).

A unique aspect of the Graniteville release was the close proximity of navigable surface waters, including the Flat Rock and Bridge Creek ponds north of the derailment site, and Horse Creek. Absorption of the chlorine vapor by these waters, and the subsequent dilution and transport of the absorbed chlorine (as hydrochloric acid) were modeled with the Savannah River National Laboratory's ALGE model (Garrett et al., 2005; Blanton et al., 2009). Chlorine absorption rates were calculated using a Henry's Law approach modified for reactive chemicals.

In addition, published data on human health and environmental effects collected after the release provided considerable opportunity for evaluating model results, particularly with respect to important physical processes associated with reactive chemicals that are not explicitly simulated by current atmospheric dispersion models. For example, recent investigations have noted that the depletion of chlorine vapor through interactions with man-made structures can significantly reduce the distance over which the release poses an airborne human health hazard (Hanna and Chang, 2008; Dillon, 2009). The associated uncertainties are of significant concern to agencies responsible for transportation emergency planning (Goodwin and Donaho, 2010). For this study, a site specific characterization of chlorine vapor depletion was performed by evaluating a bounding range of values for the domain-averaged

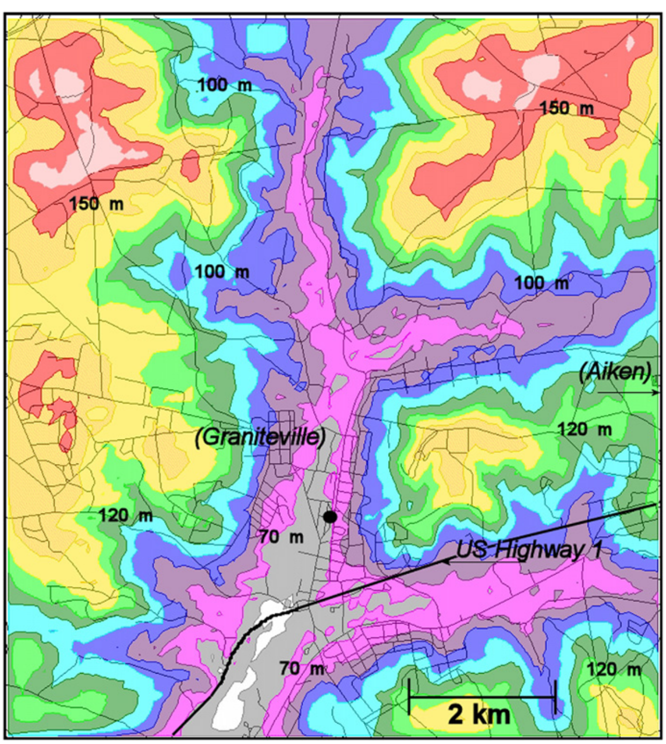

Fig. 1. Terrain in the area with contour intervals of 10 m. Gray and purple shading denotes the lowest elevations, while red and pink shading indicates the highest elevations. Light gray shading indicates topographic elevation exceeding 50 m but less than 60 m AGL while light pink shading indicates topographic elevation exceeding 160 m AGL. The large black circle denotes the derailment site, while lighter lines indicate local roads.