Exposure and Risk Assessment of a Hazardous Urban Release Using the QUIC Dispersion Model

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Introduction

- Chemical, biological, radiological, or nuclear (CBRN) releases pose significant environmental and human exposure risks, especially in densely populated urban areas.
- Toxic industrial chemicals (TICs) such as chlorine gas, are often transported via train or semi-truck near or through cities for the use in various industrial and consumer products. While most TICs are important commodities, the transport is not without inherent risks.
- An accidental or intentional spill could become deadly within a matter of minutes, requiring emergency responders to be prepared for various scenarios.
- Atmospheric dispersion modeling is a critical component of efficient and precise emergency preparation and response to minimize civilian exposure.
- Guidance information for evacuation and sampling is typically needed within 30 minutes after the release, which is generally too short to set up and run a dispersion model.
- Research and testing of models under potential real-life scenarios or case studies helps gauge model effectiveness and inform local stakeholders of preparedness measures.
- The **Quick Urban and Industrial Complex (QUIC) Model**, developed by Los Alamos National Laboratory, is one option that is relatively fast-response and can compute pollutant dispersal on the building-to-neighborhood scale throughout the 3D urban canopy.

Project Objective and Justification

- **Objective**: Run QUIC for a hypothetical scenario to analyze local meteorological effects associated with an intentional or accidental chlorine gas release in downtown Los Angeles.
- **Goal:** Use the modeled concentration plumes for a basic exposure and risk assessment by overlaying data on US Census Bureau census tract demographics.
- **Justification:** Wind direction and speed are two important parameters that influence pollutant transport. Los Angeles is influenced by a strong and predictable land-sea breeze circulation that dominates local flow. This concept was implemented into the model runs.
  - During daylight hours, sun heats the land surface and causes air to rise and then subside over the ocean. The pressure differential causes a breeze to blow inland, which tends to reverse in the evening hours.
  - Chlorine gas is a well-researched, toxic gas that affects breathing-level concentrations due to its density. Several deadly spills have occurred.

QUIC Model Simulation Parameters

Model Parameter	Implemented Parameter
Domain Location	Downtown Los Angeles, CA, roughly centered on Pershing Square, rotated 38˚ from north
Domain Size (dx, dy, dz)	3500 m x 3500 m x 1000 m
Domain Resolution (dx, dy, dz)	10 m x 10 m x 2 m (surface only, parabolic)
Number of Buildings	4297
Time Step	2 seconds
Run Duration	1 hour, concentration plume exported every 5 minutes
Wind Speed and Direction Scenarios	**1) Sea breeze: 5 m/s from WSW, 260˚** **2) Land breeze: 2 m/s from SSE, 150˚**
Boundary Layer Profile	Logarithmic, neutral stability
Release Agent	Dense Gas (Chlorine)
Release Amount	15,000 kg
Release Instant	Instantaneous
Gas Density	3.214 kg/m^3
Source Geometry	Cylinder
Height and Radius of Release	5 m x 17 m (model adjusts based on release amount)
Ambient Temperature, Pressure, RH	295K (~70˚ F), 1 atm, 30%
Dense Gas Module	Two-Phase Thermodynamic Module

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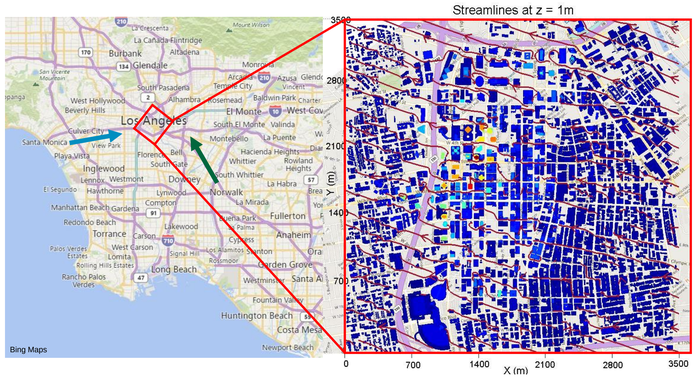
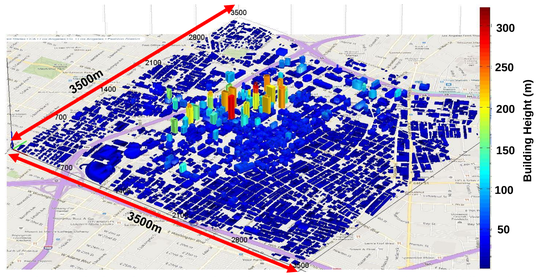
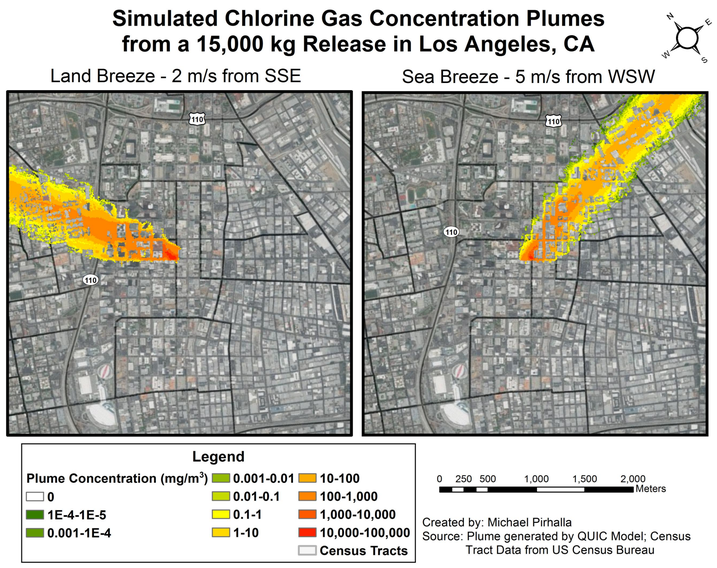
QUIC Model Domain and Chlorine Plume



Map of the Los Angeles vicinity with the QUIC model domain symbolized by the red polygon. The domain is rotated 38˚ clockwise. Prevailing land (green) and sea (blue) breeze wind directions are denoted by the colored arrows (left). An example of the wind flow streamlines on the X-Y plane is shown on the right after running the urban wind model, QUIC-URB, for the land breeze case. The buildings cause significant redirection of the flow (right).



A 3D view of the inner model domain portraying the building height profiles in central Los Angeles. Taller buildings exceed 250-300 m while outlying buildings range from 40-80 m.



Average 30 minute QUIC model simulated chlorine gas concentration plumes for the land and sea breeze cases. The values were averaged to show the potential 30 minute breathing level (~1 m) concentrations for exposed individuals.

Exposure Analysis

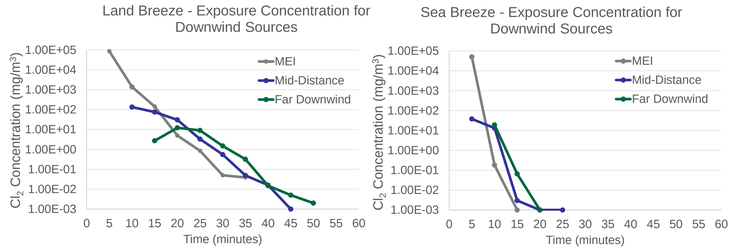
Various inhalation exposure limits and guidelines for chlorine gas from accepted literature.

Description	Value (ppm)	Value (mg/m^3)	Source
NIOSH REL and NOAEL	0.5	0.6	NIOSH (2005)
NIOSH IDLH	10	12	-
OSHA PEL	1	1.2	OSHA (2006)
California OEHHA Acute REL	0.072	0.086	OEHHA (2008)
Acute MRL based on NOAEL	0.06	0.072	ATSDR (2010)
Short Term (Acute) Human Exposure Effects			
Odor Detection	0.2-3.5	0.24-4.2	Ellenhorn and Barceloux (1988)
Mild mucous membrane irritation tolerated up to 1 hr	1-3	1.2-3.6	-
Moderate irritation w/ chest pain, cough	5-30	6-36	-
10, 30 min LC_{50} for average population	364, 210	437, 252	Withers and Lees (1985)
Death in 30 minutes	430 400	516 480	- Prater (1990)
Death within minutes/immediate	1,000-1,200	1,200-1,440	-

ATSDR = Agency for Toxic Substances and Disease Registry; **IDLH** = Immediately Dangerous to Life and Health; **LC_{50}** = Lethal Concentration for 50% of test subjects; **MRL** = Minimal Risk Level; **NIOSH** = National Institute for Occupational Safety and Health; **NOAEL** = no-observed-adverse-effect-level; **OEHHA** = Office of Environmental Health Hazard Assessment; **OSHA** = Occupational Safety and Health Administration; **PEL** = Permissible Exposure Limits; **REL** = Recommended Exposure Limits

Number of individuals potentially affected by the modeled land and sea breeze chlorine plumes. Those individuals receiving a potentially deadly dose are restricted to concentrations > 500 mg/m^3.

	Number of Affected Individuals			
	Land Breeze		Sea Breeze	
Category	Any Conc.	Receiving Deadly Dose	Any Conc.	Receiving Deadly Dose
Total Number Affected	6317	213	7395	161
Male	3844	129	3765	85
Female	2473	84	3630	76
Population < 10	162	4	910	5
Population > 60	1210	37	914	39
White	2723	98	2648	92
African American	1293	43	443	18
Asian	1289	37	1441	62
Hispanic	1368	43	4582	28
2+ Races	327	13	365	7
Median Age	43	36	34	41
Avg. Size Household	1.7	1.3	2.6	1.6



Five-minute average concentrations for representative "receptor" locations: near the release for a maximally exposed individual (MEI), 1 km downwind (mid-distance), and 2 km downwind (far downwind).

Conclusions

- The faster sea breeze scenario diffused the chlorine plume in < 30 minutes while the land breeze took upwards of 40-50 minutes.
- Approximately 6300-7400 people would be impacted by the chlorine plumes to some degree, while 2.2-3.4% (161-210 people) of those affected would receive a potentially deadly exposure concentration of ≥ 500 mg/m^3.
- The slower land breeze scenario affected more people due to the width of the plume, but the faster sea breeze directly impacted more neighborhoods with deadly concentrations.
- Demographic data indicated some disparities among settled neighborhoods, especially for Hispanic and African American communities.
- Lots of competing factors influence results → release methodology, continuously varying wind, sensitivity of various populations, residents would seek cover, building infiltration effects, census tract assumptions, need for continuous release.
- The method of release, if intentional, could create a homeland security concern.
- The QUIC model is not necessarily suitable for "real time" operations due to its complexity and runtime. Each simulation took ~45 minutes to complete.