FATE AND TRANSPORT MODELING OF URBAN RADIOLOGICAL CONTAMINATION

Jonathan Shireman (Jonathan.Shireman@Aptim.com) APTIM Federal Services, Knoxville Tennessee, USA

Katherine Ratliff (ratliff.katherine@epa.gov), Anne Mikelonis (Mikelonis.Anne@epa.gov) United States Environmental Protection Agency, Durham, North Carolina, USA

Case Study Description

Objective:

Develop data driven strategies and methods for containing, monitoring, and remediating radioisotopes following detonation of a dirty bomb.

Data Requirements and Sources:

Ground deposition plume	Measured by survey
High resolution elevation data	Lidar
Surface permeability map	NLCD 2016
Meteorological data	NOAA data tools
Building footprint	City/Metro Planning
Transportation features	City/Metro Planning
Storm Sewer Features	City/Metro Planning
Drainage Control	City/Metro Planning

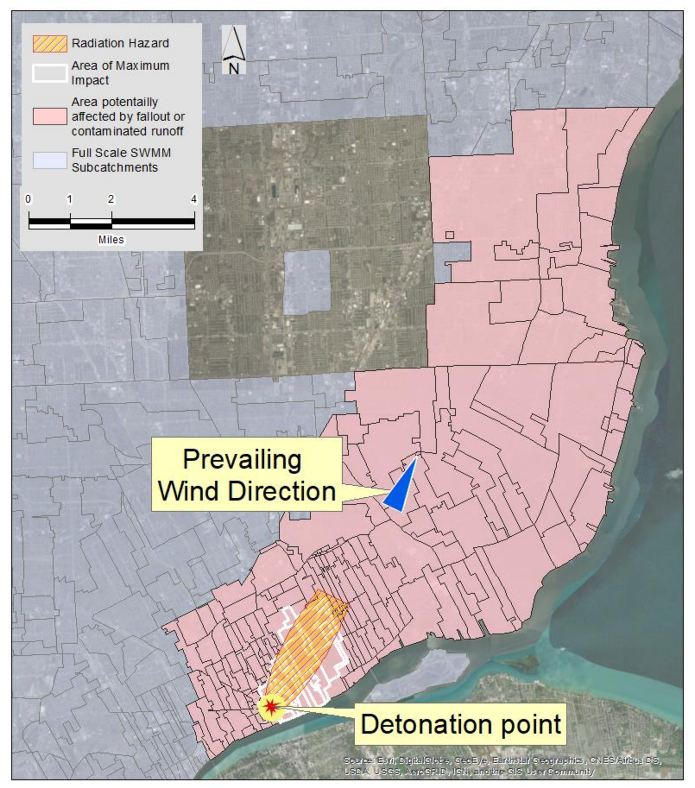
Methods:

Use hypothetical event in a known setting and historical meteorological conditions to simulate overland transport into a stormwater management runoff control system.

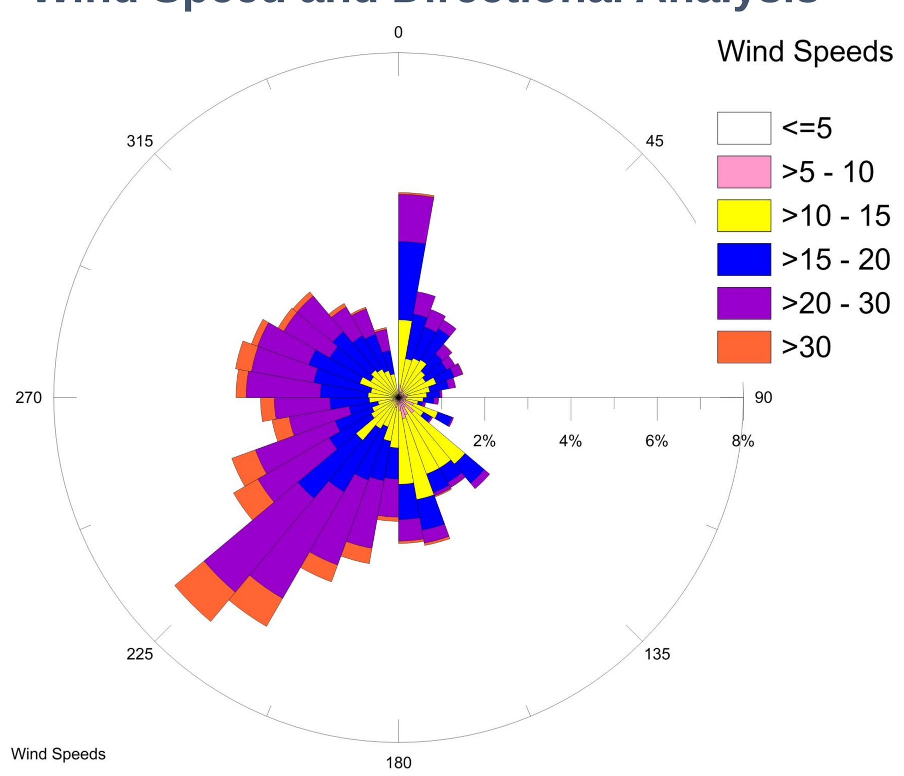
- Historical prevailing wind direction and speed
- Develop storm intensity and return frequency
- Compare to design storm characteristics
- Use existing outfall locations and hydrologic controls
- Create 2D model, surface gradient, obstructions, grid layout, and land use types
- Model a range of contaminant transport properties

Under actual incident conditions the ground plume geometry would be obtained by empirical measurements.
For the case study model (CSM) a hypothetical ground deposition plume was modeled using data from NOAA National Center for Environmental Information > Data Access > Land Based Stations > State and County, 20 years of climate observations for stations near the hypothetical incident.

Wind Speed and Directional Analysis

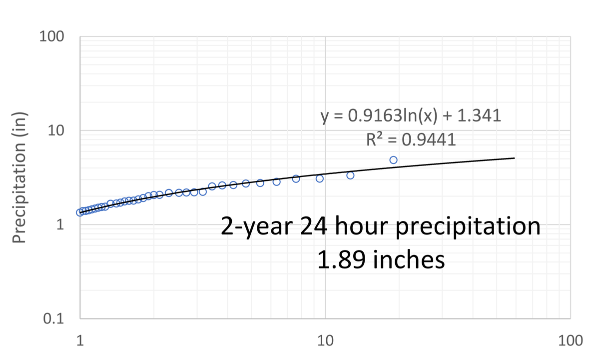


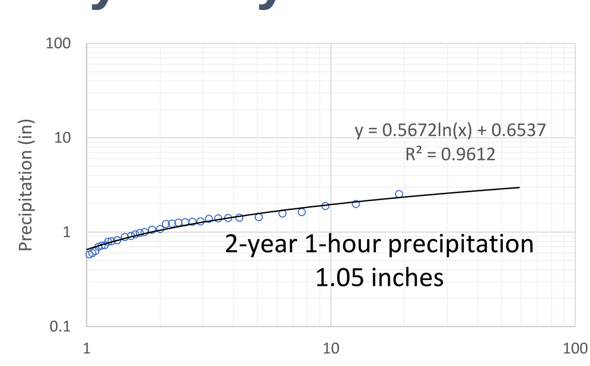
Stormwater subcatchments potentially affected by air dispersion of radiological contamination



Sustained Winds 1990 – 2017
Dominant sustained Winds from SW at 20 to 30 mph

Storm Return Frequency Analysis





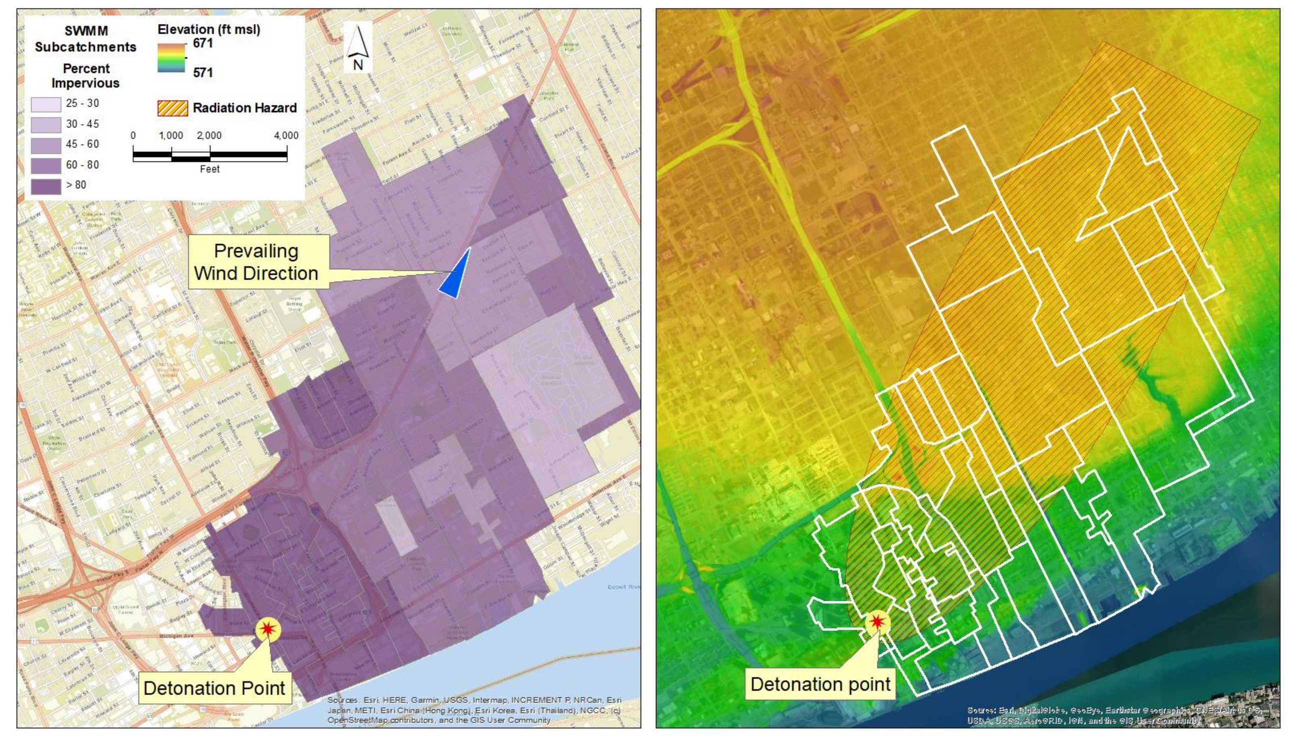
Identify Potentially Affected Subcatchments

- Prevailing wind direction indicates potential contamination dispersal to north-north east
- Initially 215 subcatchments were identified as potentially directly impacted or receiving contaminated runoff
- Air dispersal modeling showed the footprint of the ground deposition plume representing a potential health hazard was restricted to an area near the detonation point
- Mesh generation using all 215 subcatchments and building obstructions required over 24 hours of computational time on standard desktop processor.
- By focusing on the area where high level hazards (orange cross hatch overlay) are anticipated and removing small buildings (< 200 ft2) mesh generation could be accomplished in abut 1 hour.

The areas selected for inclusion in the 2D overland flow model are outlined in white above.

EPA's Storm Water Management Model (SWMM) was used and implemented through PCSWMM® to model 2D overland flow.

2D Overland Flow Boundary Layer Construction



SWMM Subcatchments and Digital Elevation Raster for Radiological Contamination Transport Case Study Model

Case Study Model Boundary Layer Created in ArcMAP

Features within and downgradient of the radiologic hazard area:

- Select subcatchments intersecting the plume and down gradient to the nearest outfalls
- Clip roads to subcatchments and create polygons using ArcGIS buffer tool
- Clip buildings to subcatchments
- Merge SWMM subcatchment and road layers into 2D boundary layer

Import 2D Boundary Layer into PCSWMM®

- 2D Boundary Layer enforces node spacing, cell geometry
- Tag attribute used to differentiate land use types
- SWMM subcatchment sublayer set to hexagonal geometry with 80 foot resolution (center to center spacings)
- Road Sublayer set to rectangle geometry with 40 resolution

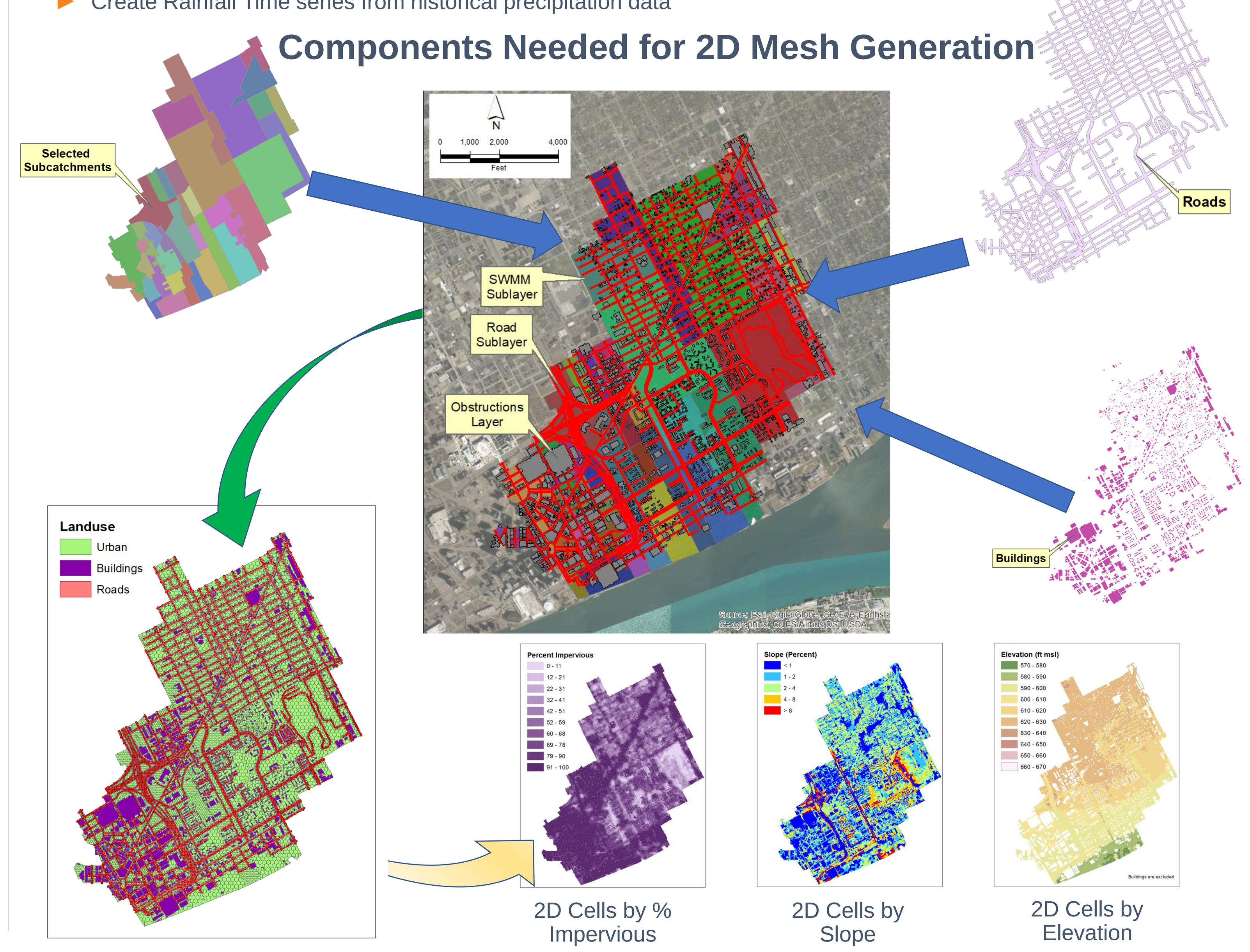
Generate 2D Mesh PCSWMM®

- 2D mesh generates 2D cells, and SWMM conduits and junctions

Import 2D cells and Buildings as SWMM Subcatchments and Build Runoff Model

- Import 2D Cells into subcatchment layer
- Merge buildings into subcatchment layer and assign outlets using PCSWMM® tools
- SWMM IMPERV, SLOPE and ELEV Attributes populated using PCSWMM® Area Weighting Tool and NLCD or DEM raster files
- Assign outlet nodes for buildings using PCSWMM® tools
- Create outlets and connecting conduits
- Create Rainfall Time series from historical precipitation data

Components Needed for 2D Mesh Generation



2D Cells by % Impervious

2D Cells by Slope

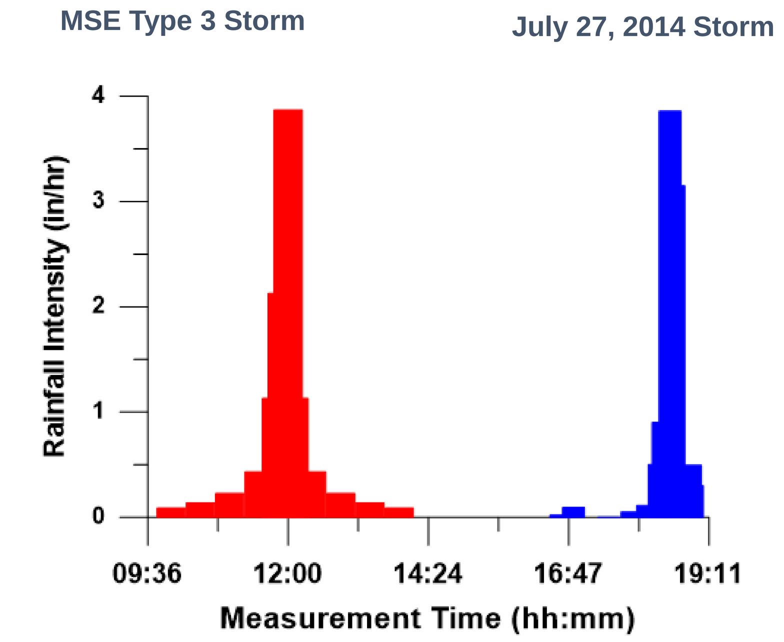
2D Cells by Elevation

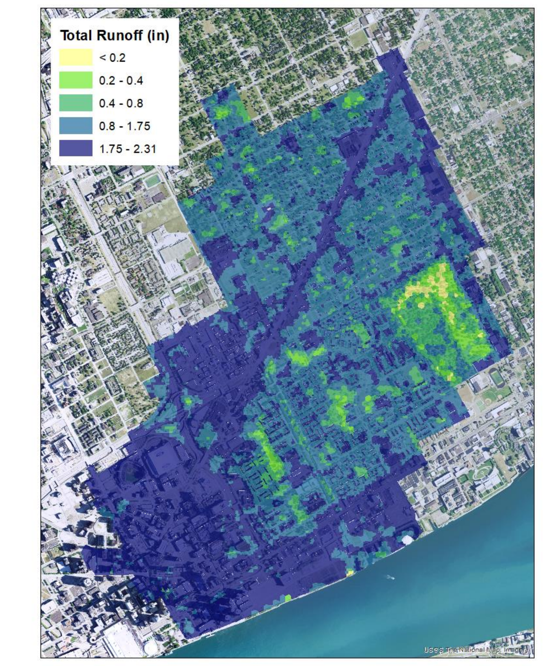
SWMM Model Storm and Washoff Inputs and Run Results

2-Year 1-Hour Peak Rain Fall events

- Range 0.996 – 2.08 inches total precipitation
- 8 storms between 2004 - 2017 meet criteria
- Median Rainfall Storm - July 27, 2014
- Duration 1hr 3 min
- Sustained Winds from SE

Storm Type	Real Storm July 27, 2014
Duration	1.03 hr.
Total Precipitation	0.96 in
Max Rate	3.86 in/hr
Storm Type	**MSE Type3 Design**
Duration	24 hr.
Total Precipitation	2.35 in
Max Rate	3.86 in/hr





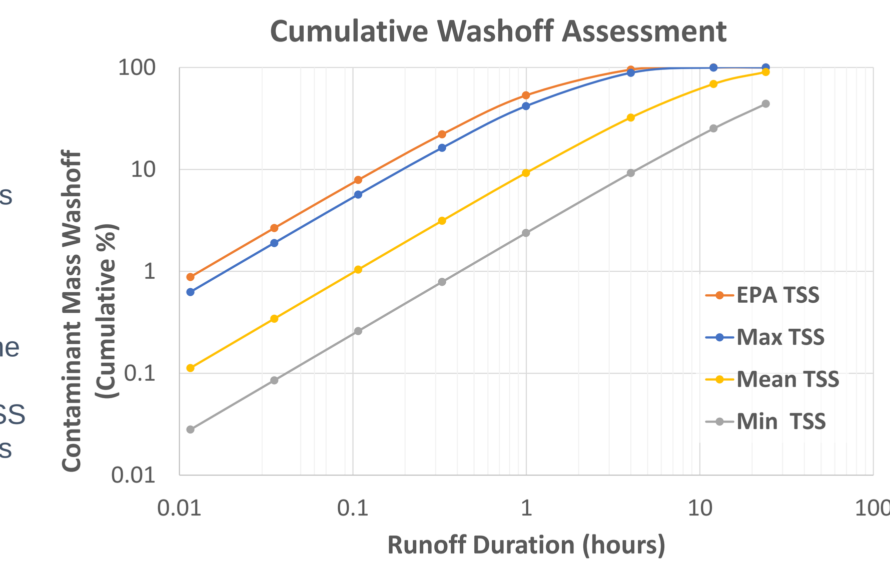
Estimate of Washoff Parameters for Modeling Radiological Contaminant Behavior

Literature Review of Contamination Transport

- Primary fallout contaminant is Cs-137, also most likely isotope to be used in a dirty bomb
- Most studies of Cs-137 soil contamination focus on rural or agricultural areas, findings indicated about 0.1 % of watershed inventory lost per year
- Studies of other pollutants (e.g. suspended solids or total nitrogen) focus on urban settings
- Cesium adsorbs strongly to clay and organic matter; primary components of suspended sediment (TSS).

Managing Uncertainty: Range of TSS washoff parameters is wide and location specific. Washoff assessments assuming standard exponential function illustrates behavior used for the case study model. Peak runoff depth (q) used for sensitivity analysis.

Conclusion: Cesium in the deposition plume is expected to adsorb to sediment, therefore TSS can be used as a surrogate. However, the low loss of cesium inventory of studied watersheds indicates lower end of washoff factors apply.



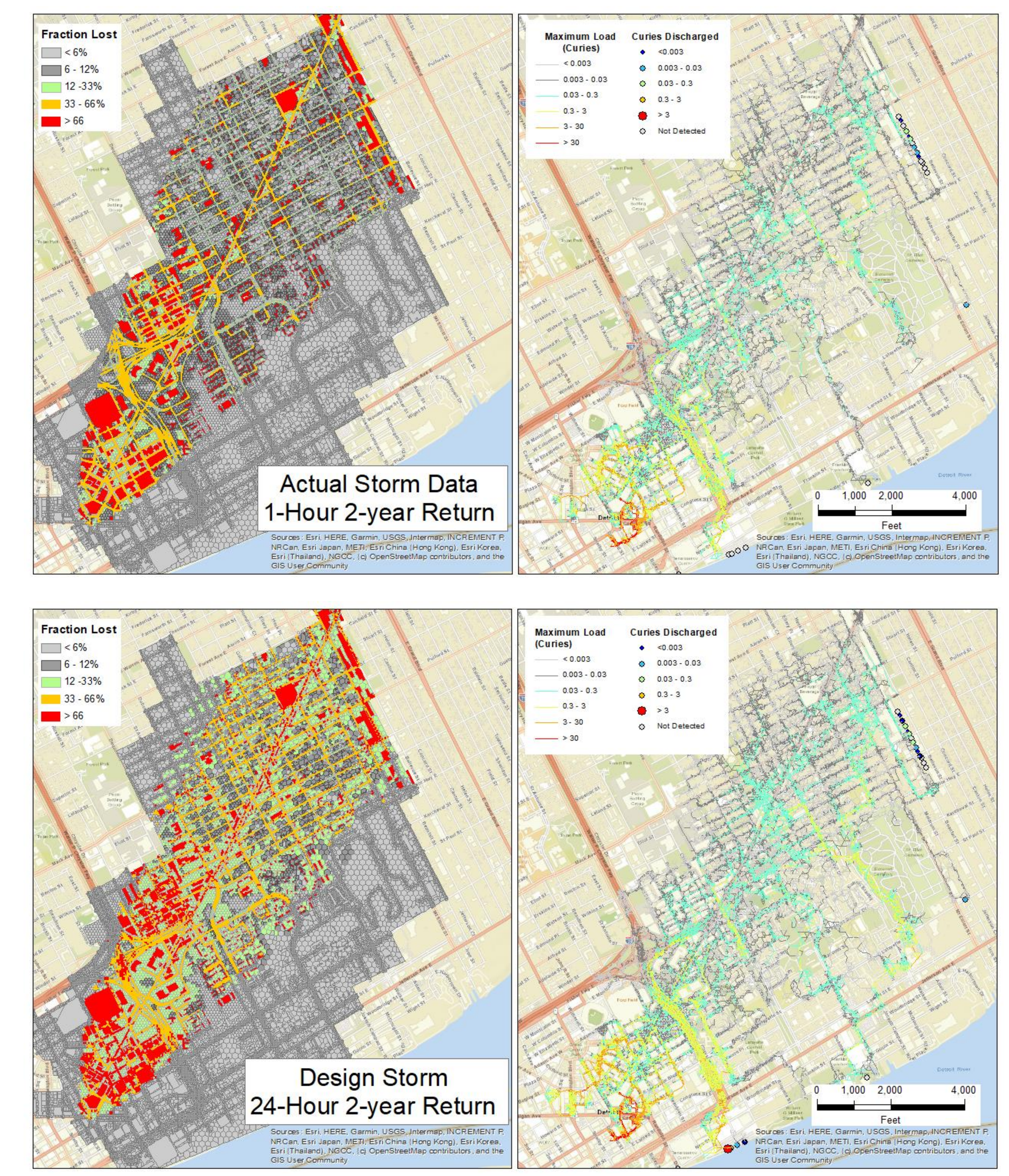
Washoff Estimates for Three Land Uses

Parameter	Land Use Types		
	Building	Road	Urban
K_w	2.45	0.56	0.13
N_w	1.25	1.23	1.20
k	0.61	0.14	0.03
q, in/hr	0.33	0.25	0.25

Buildings Rapidly flushing; value near high end of parameter range of values applied

Roads Roads and pavement flush more slowly due to greater roughness and lower slope; geometric mean of parameter values used

Urban Mixture of open and high-density development; low end of parameter range of values used



Model Washoff Results

2-year Return Frequency Storms

- Building first flush primary contribution to initial runoff;
- With increasing duration greater fractions of initial inventory removed from roads and eventually from urban areas
- Primary transport is along roadways
- Contamination does not reach outfalls during short duration storm, contamination discharges during 24-hour Storm

Conclusion:

A 2D overland flow model based on available urban planning data and a hypothetical ground deposition plume is an effective method to identify likely overland transport pathways and to visualize mass flux of contaminants in response to high return frequency rain events.

This method allows rapid identification of infrastructure features that have a high potential for impact, provides insight for planning response actions and supports development of long-term monitoring programs.