ICWMM 2025 – Toronto, Canada

A hazard-vulnerability-risk approach to estimate losses produced by water distribution pipe breaks

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Introduction

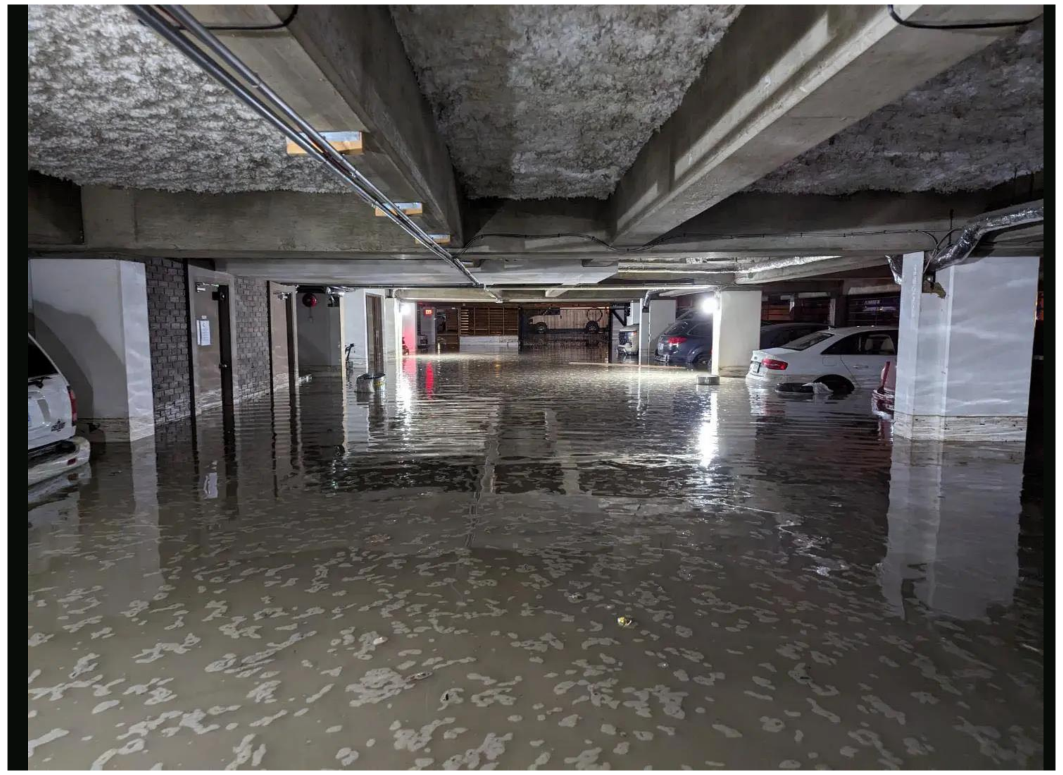
Montreal, QC (2023)

https://globalnews.ca/news/9863421/montreal-water-main-break-flooding-sinkhole/

- 900mm (36in) pipe burst at 4 am.
- Over 18 buildings evacuated.
- Basements, crawlspaces and first floors with economic losses.
- Damages to several cars, and a sinkhole on the road.

Introduction

Kelowna, BC (2023)



https://globalnews.ca/news/9614407/residents-flooded-kelowna-bc-apartment-building-still-without-power/

- 250mm (10in) pipe burst.
- One main 32-unit apartment building affected.
- Several cars compromised in basement and other losses on the first floor.
- Building's electrical system damaged, resulting in no power for over 4 days.

Introduction

Halifax, NS (2023)

https://globalnews.ca/news/9612812/armdale-roundabout-halifax-flooded/

- Diameter not reported. Pipe break caused by construction in the area.
- Flooding in roads and damages to some cars.
- Affected access to two university facilities.

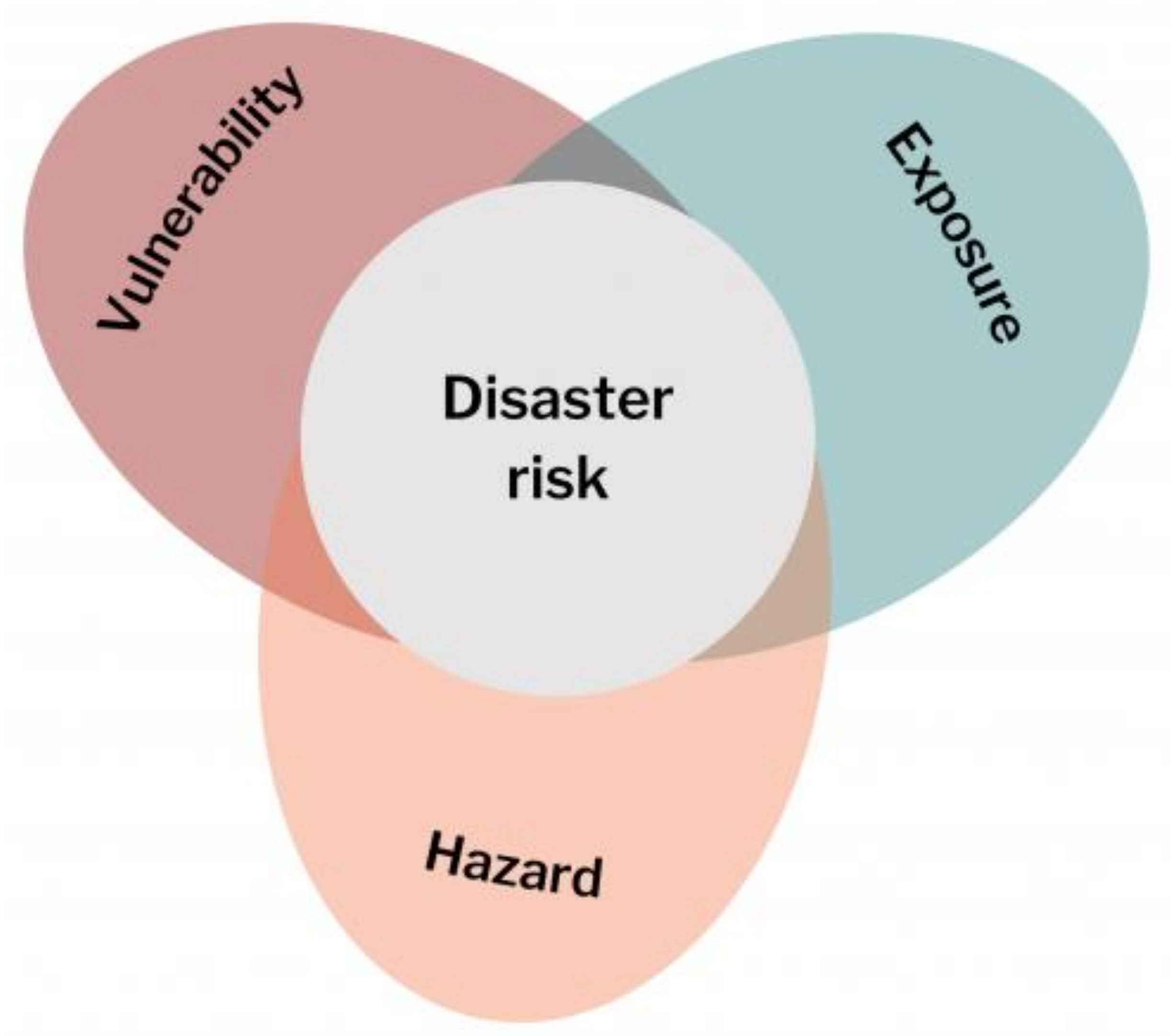
Hamilton, ON (2023)

https://www.thespec.com/news/hamilton-region/it-was-just-torrential-water-main-break-floods-parts-of-kirkendall-neighbourhood/article_63870dae-44f5-5272-80d2-6c09cc746595.html

- Diameter not reported. ~3-4pm.
- Flooding in road, damages to some cars, sinkhole at intersection.
- Damages to yards and driveways.

Methodology

FLOODING RISK ASSESSMENT GENERATED BY PIPE BURSTS



https://haznet.ca/understanding-disaster-risk-canada-introduction/

- Hazard: Flooding from pipe bursts (probability of occurrence and associated intensity).

- Exposure: Urban infrastructure (spatially distributed).

- Vulnerability: Flood damage curves (relate loss/damages of infrastructure with the intensity of a hazard scenario).

Methodology

1. Computation of hazards

- Annual Rate of Occurrence (ARO): Probability of pipe burst

  Different models for pipe break probability calculation. E.g.:

Cullinane et al. (1992):

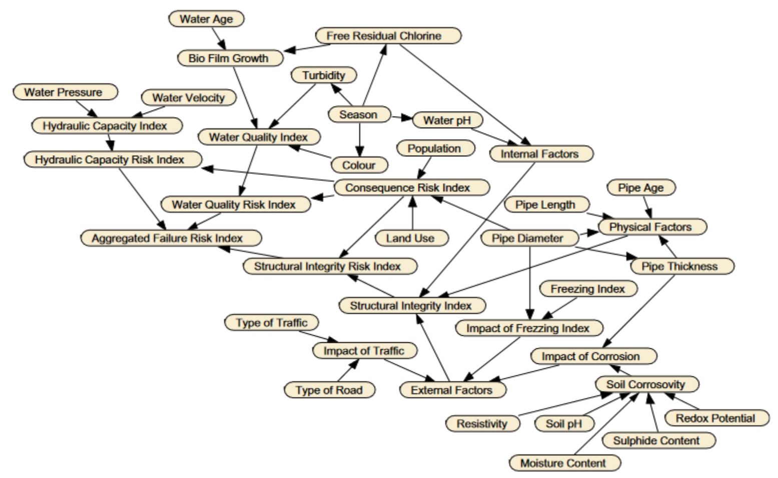
$$\Pr(i) = 1 - A_i$$

$$A_i = \frac{0.21218 D_i^{1.462131}}{0.00074 D_i^{0.285} + 0.21218 D_i^{1.462131}}$$

Kleiner et al. (2002):

Static	Dynamic	Operational
material	age	replacement rates
diameter	temperatures (soil, water)	cathodic protection
wall thickness	soil moisture	water pressure
soil (backfill) characteristics	soil electrical resistivity	
installation	bedding condition	
	dynamic loadings	

Kabir et al. (2015):

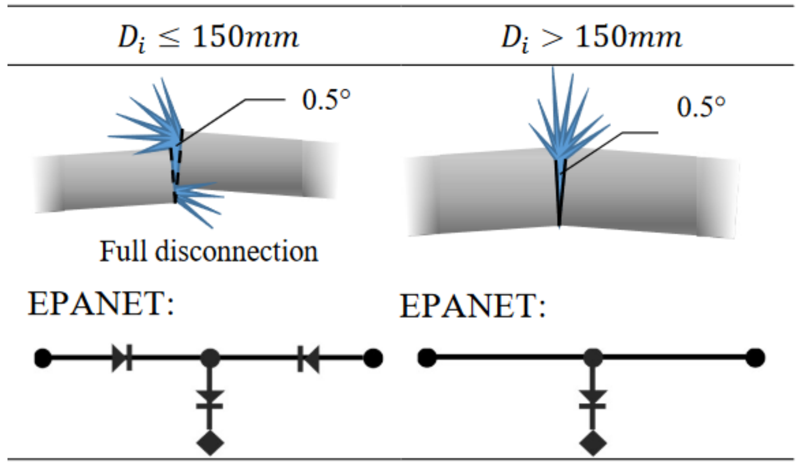


- Outflows from a broken pipe

  Assumed type of failure 0.5° round crack at the midpoint.
  Full disconnection for small-diameter pipes.
  No disconnection for large-diameter pipes

Requires an EPANET simulation for each pipe breakage scenario

Paez et al. (2018):



$$Q_i(t) = K_i \cdot \left(h_i(t)\right)^{0.5}$$

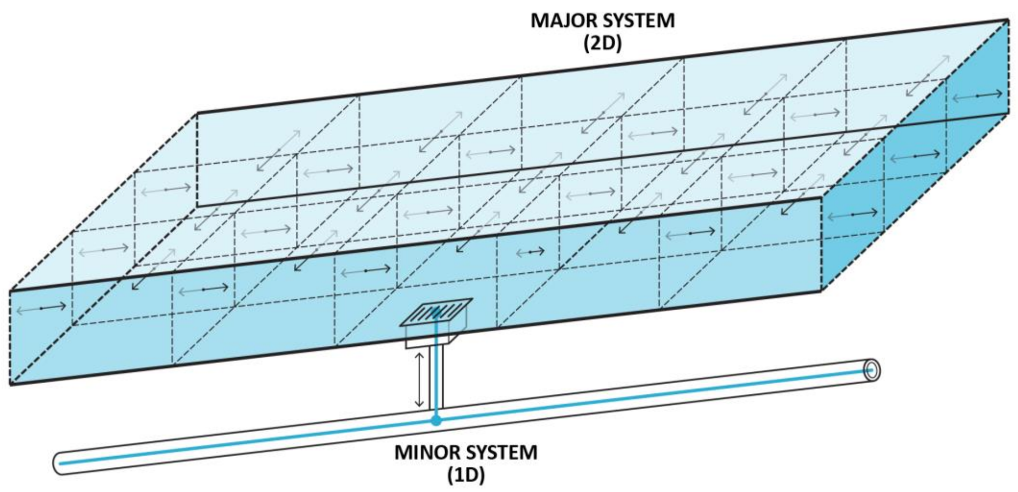
$$K_i = \frac{\pi}{2} \cdot 0.5° \cdot D_i^2 \cdot \sqrt{2g}$$

Methodology

1. Computation of hazards

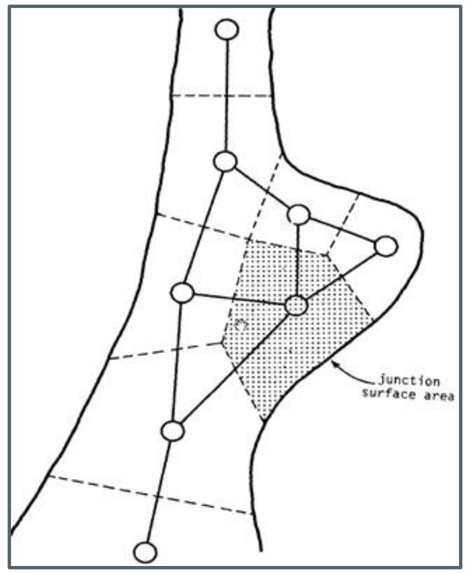
- Urban flood modelling

  Use of integrated 1D-2D model in SWMM

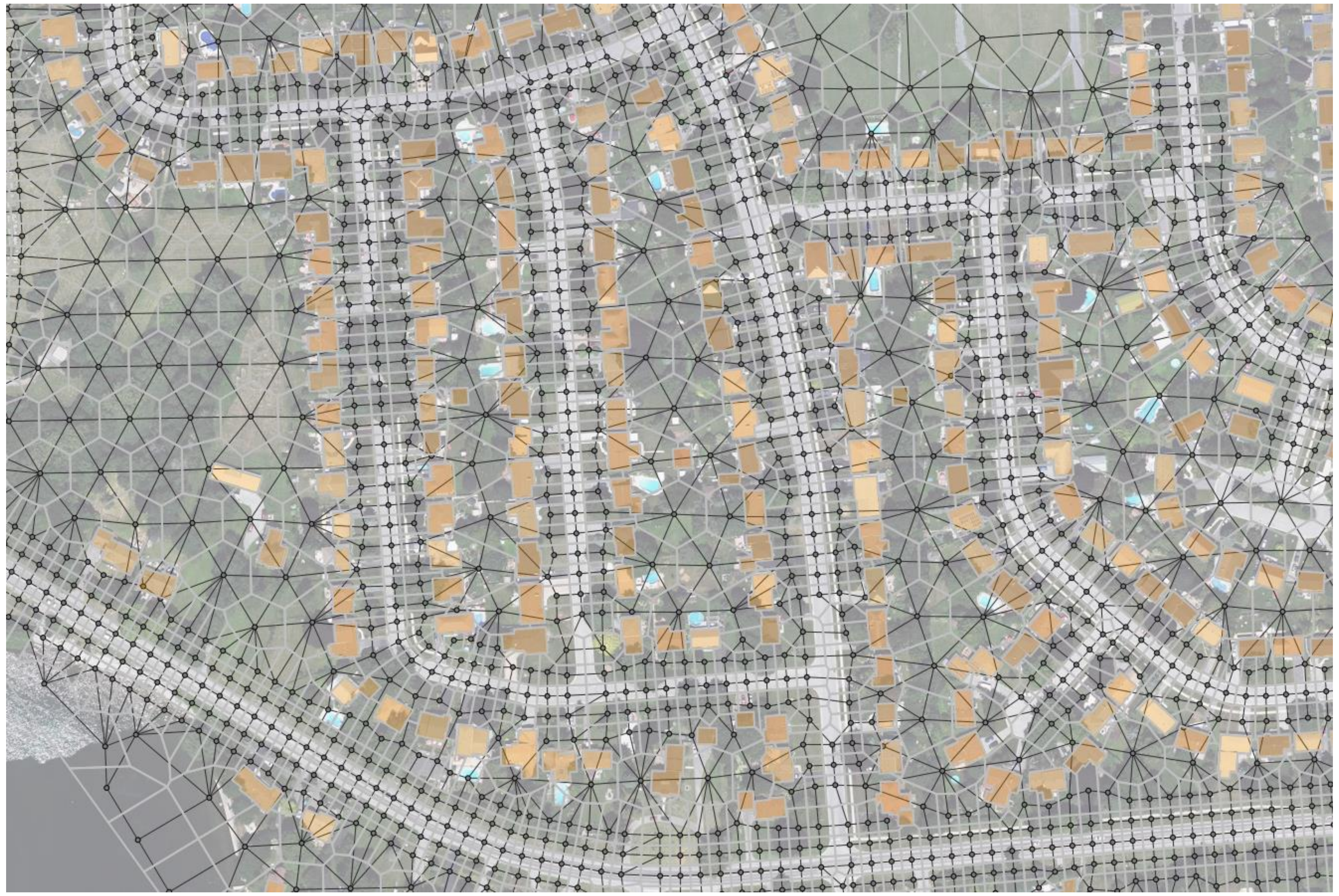


2D component based on Dynamic Estuary Model:

Ambrose (1980) – Shubinski & Orlob (1965)



Requires a SWMM simulation for each pipe breakage scenario



Different types of mesh used to model roads, buildings, yards, open surfaces, etc.

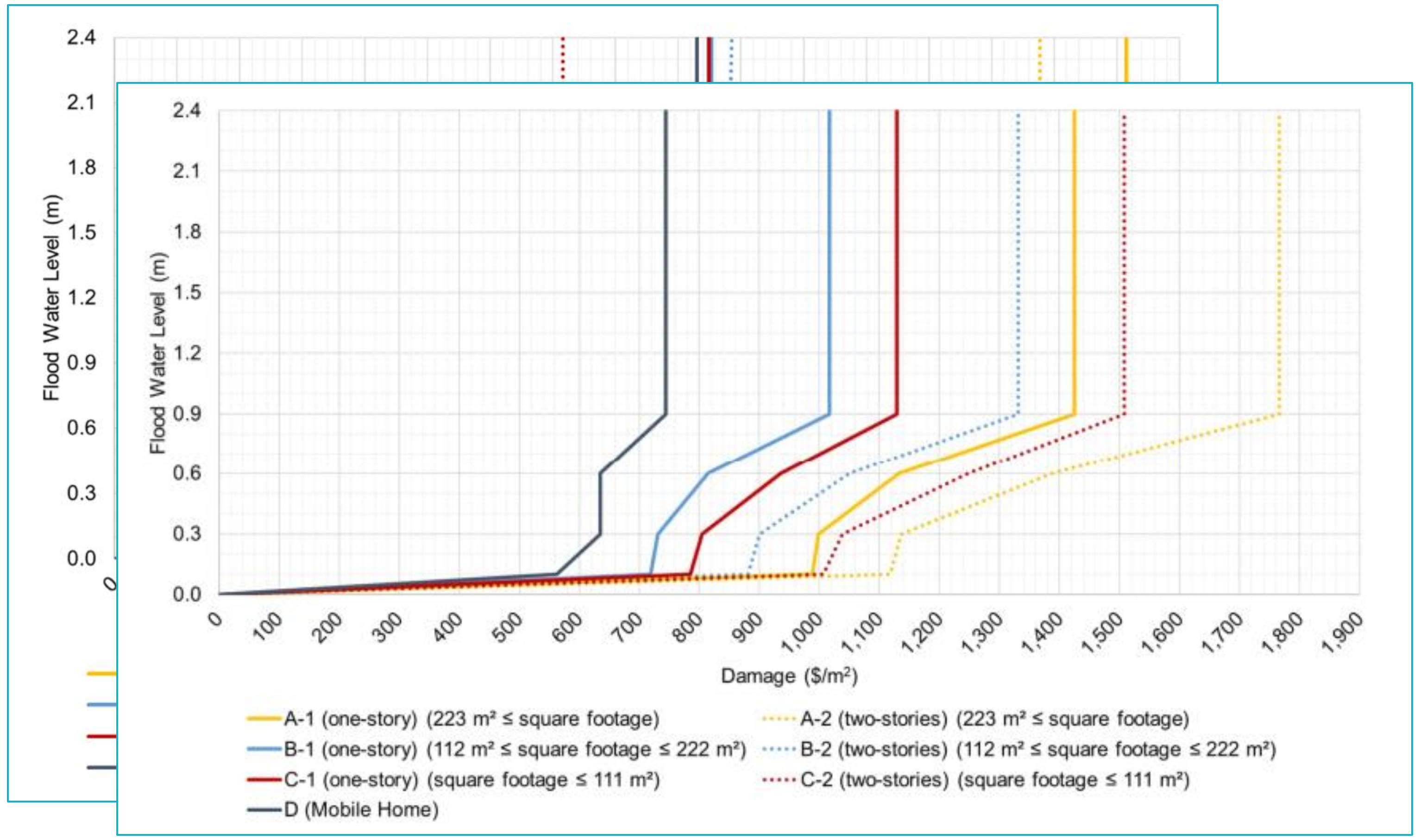
*Pipe break outflows assigned to cell above midpoint of broken water main

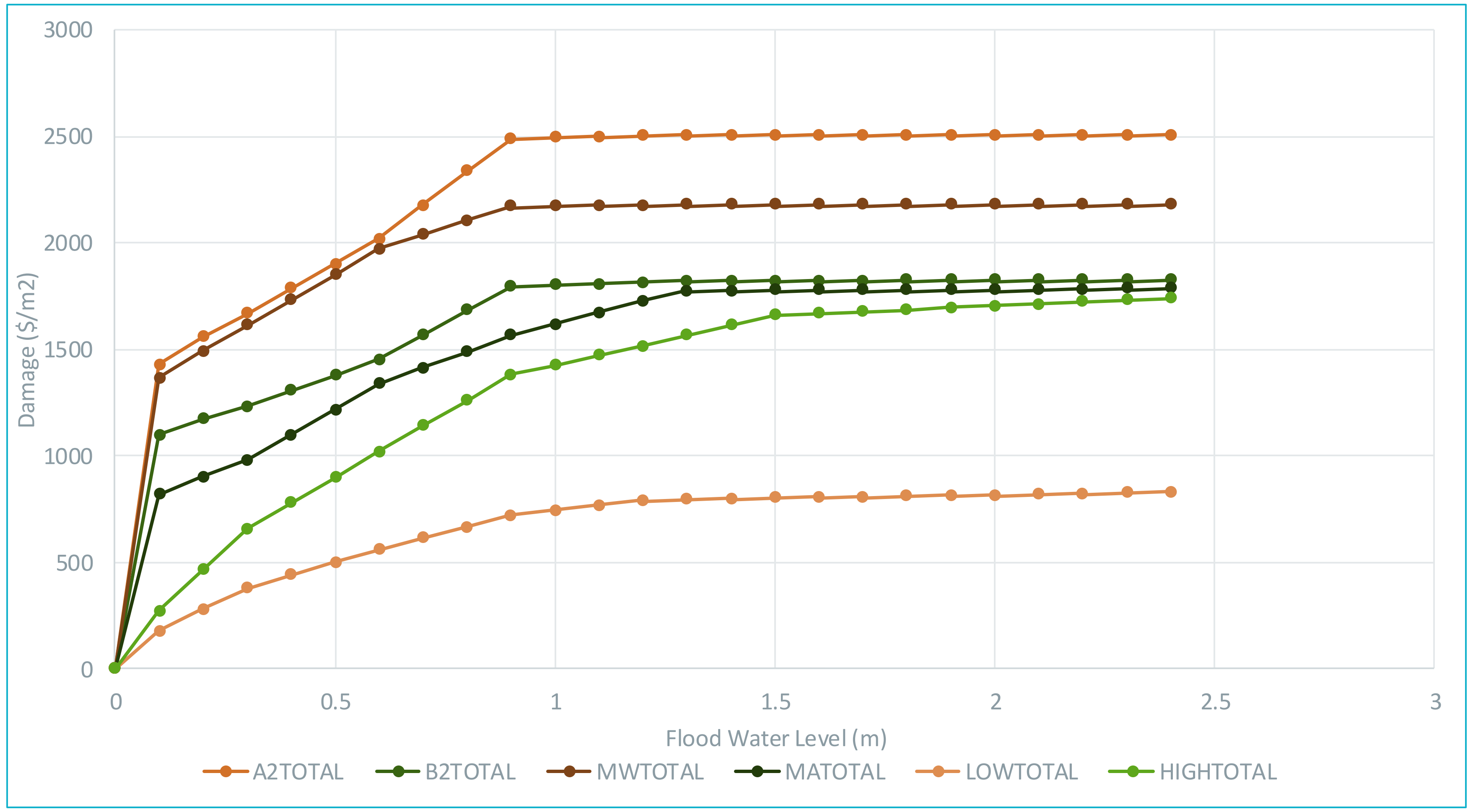
Methodology

2. Vulnerability

- Damage/loss curves associated with each building

HATCH (2023)





Damage curves can come as:

- %Loss vs. Water Depth
- Loss per unit area vs. Water Depth
- Total Loss $ vs. Water Depth

*Sometimes split between Structural and Content for buildings.

Methodology

3. Risk

- Different risk indicators

Single Loss Expectancy (SLE): Totalized damages across all exposed assets for a single event

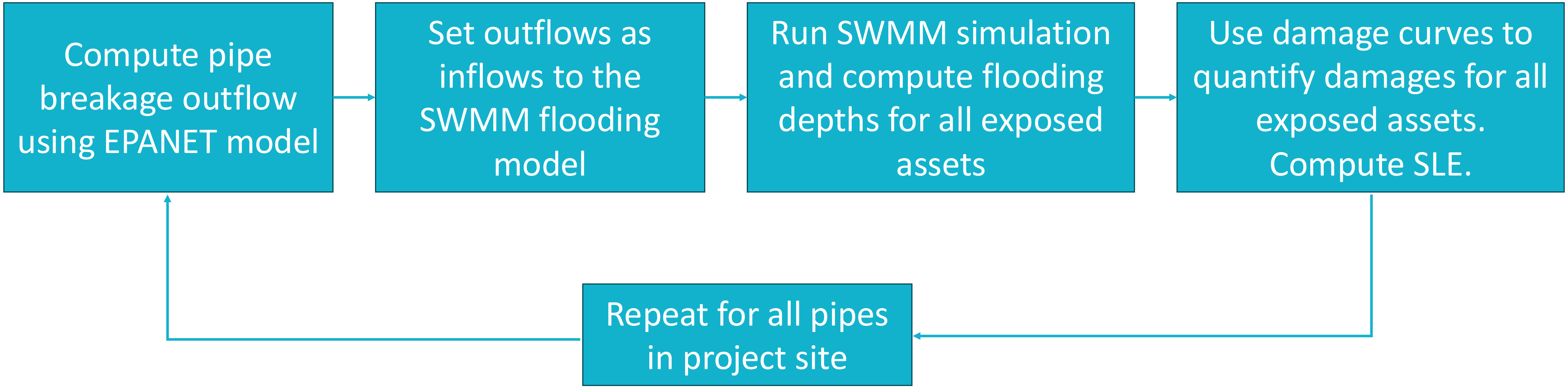
Annualized Loss Expectancy (ALE): Weighted sum of SLEs using their probability or occurrence (Annual Rate of Occurrence)

$$ALE = \sum SLE \cdot ARO$$

Map of impacted assets and damages per scenario:

Methodology

Overview

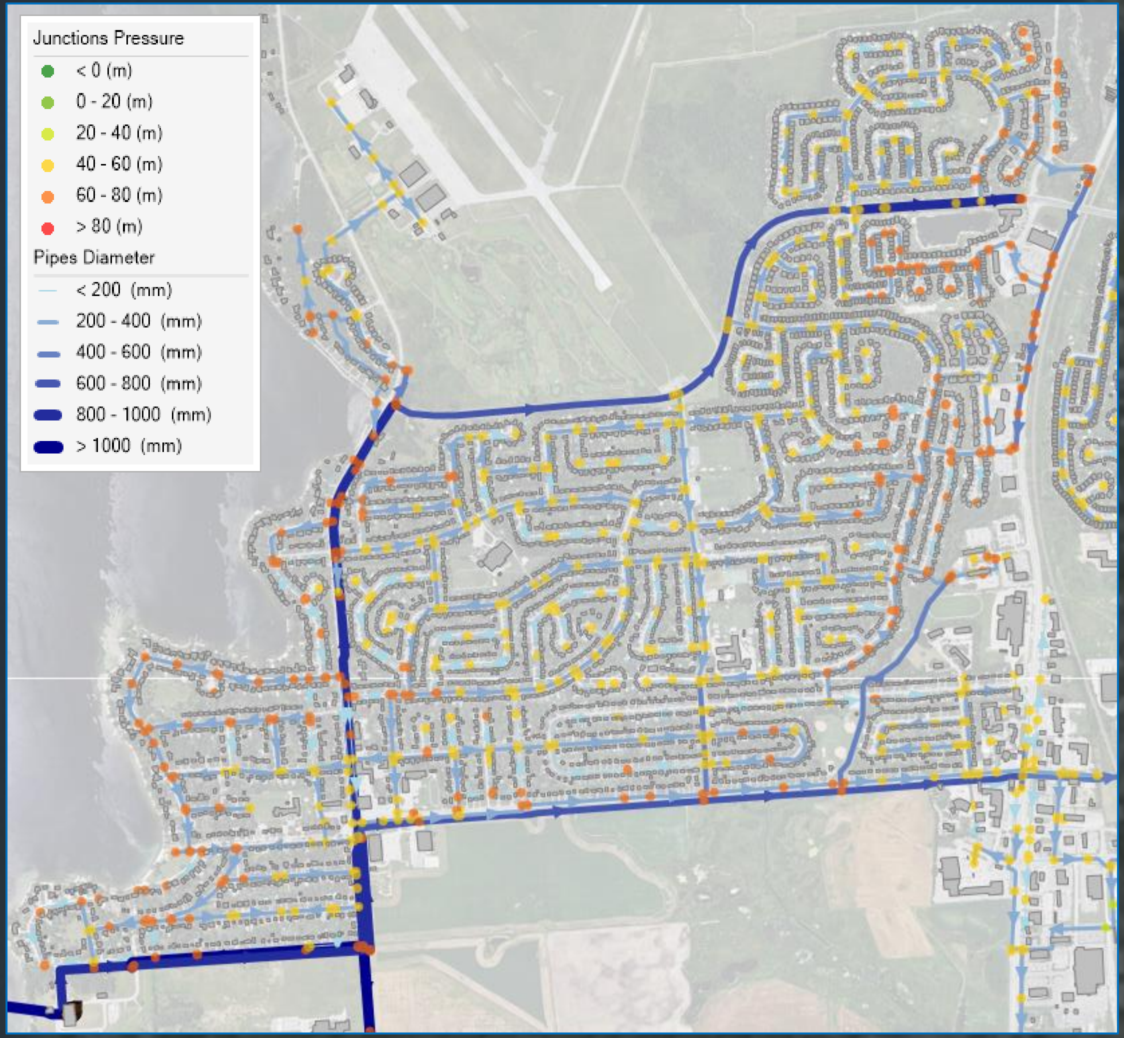


Case Study

CHI

StormCity

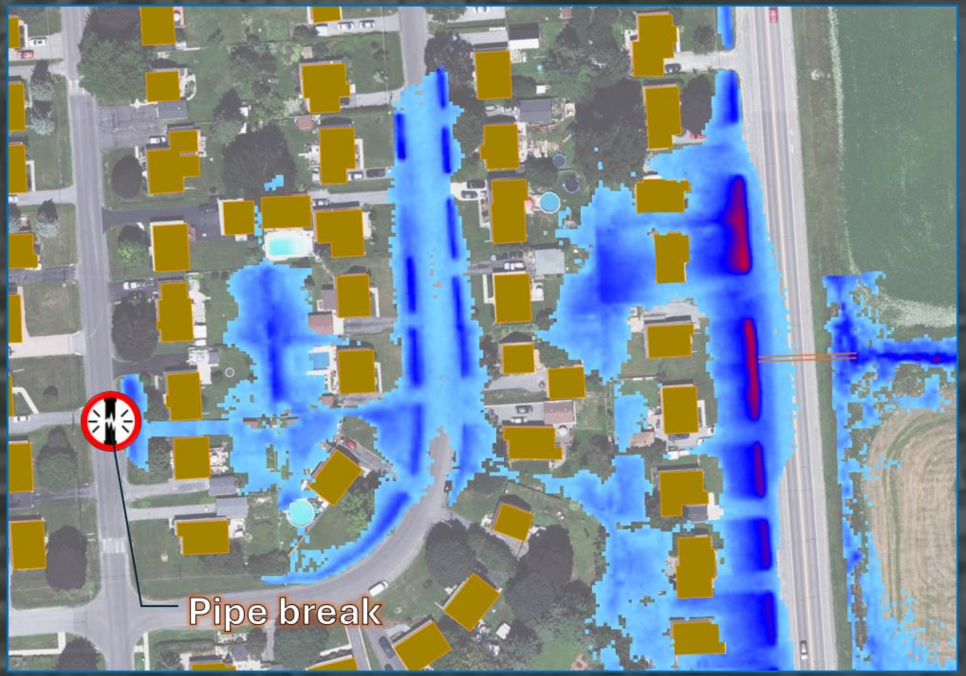
Residential neighborhood in small city (ON):



- EPANET model provided by municipality.

- Minimum Hour demand scenario selected.
- 438 water mains analyzed for pipe breakage (i.e., 438 EPANET simulations for pipe outflow computation and 438 SWMM simulations for flooding extent computation)
- Pipe break duration assumed to be 2 hours based on estimations discussed with operations professionals.

- Probability of pipe breakage computed using Cullinane et al. (1992) – only using pipe diameter.
- 2D model developed with ~30k cells.



Case Study

PIPE:

Diameter: 150mm

Computed break outflow: 153.6 L/s

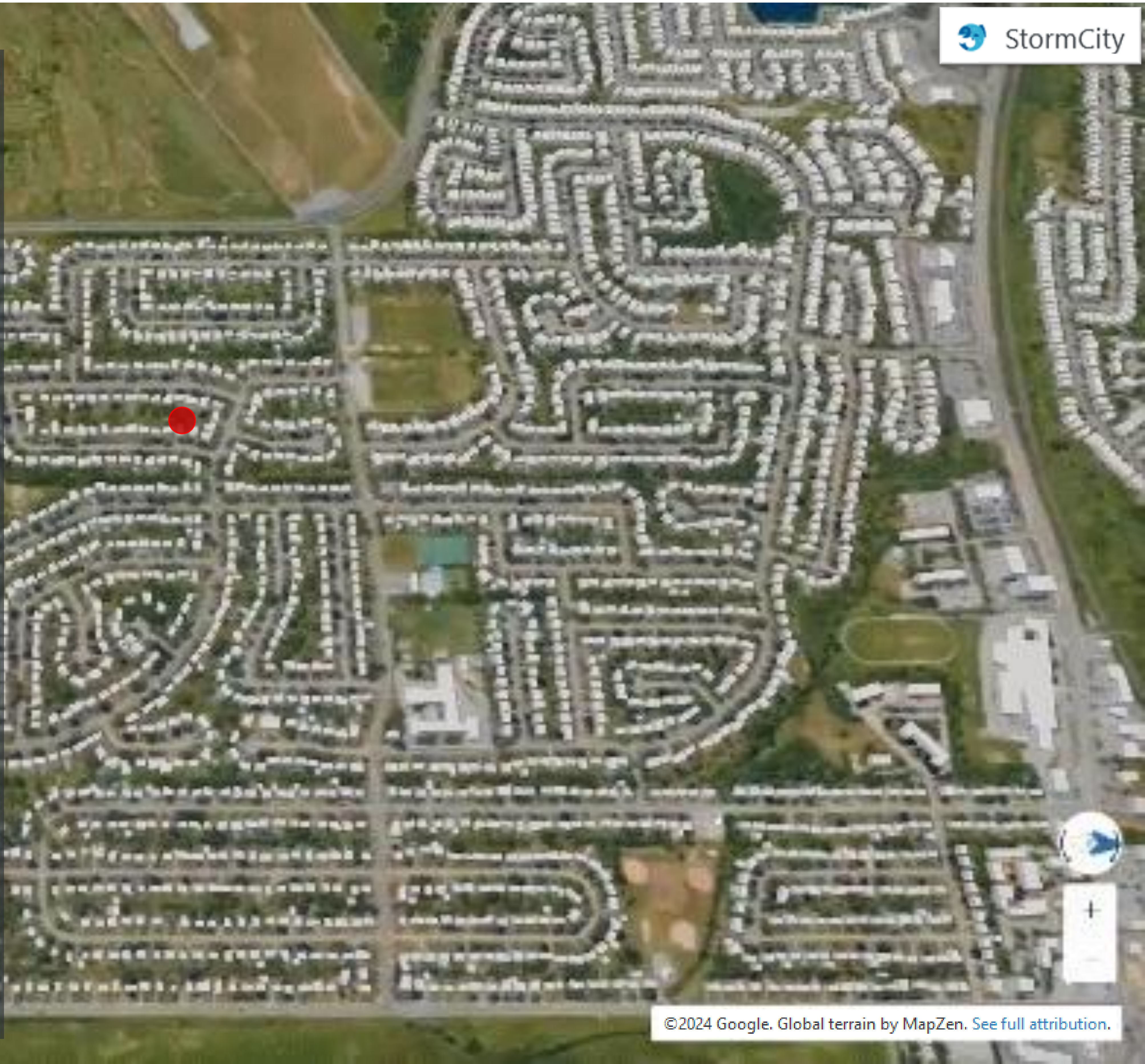
LOCATION:

Small local road

Adjacent to some residential units, a sports park and a local creek.

IMPACT:

Negligible. Flows directed to the creek. Might have small affectation to parking lot of park.



Case Study

PIPE:

Diameter: 600mm

Computed break outflow: 1032.9 L/s

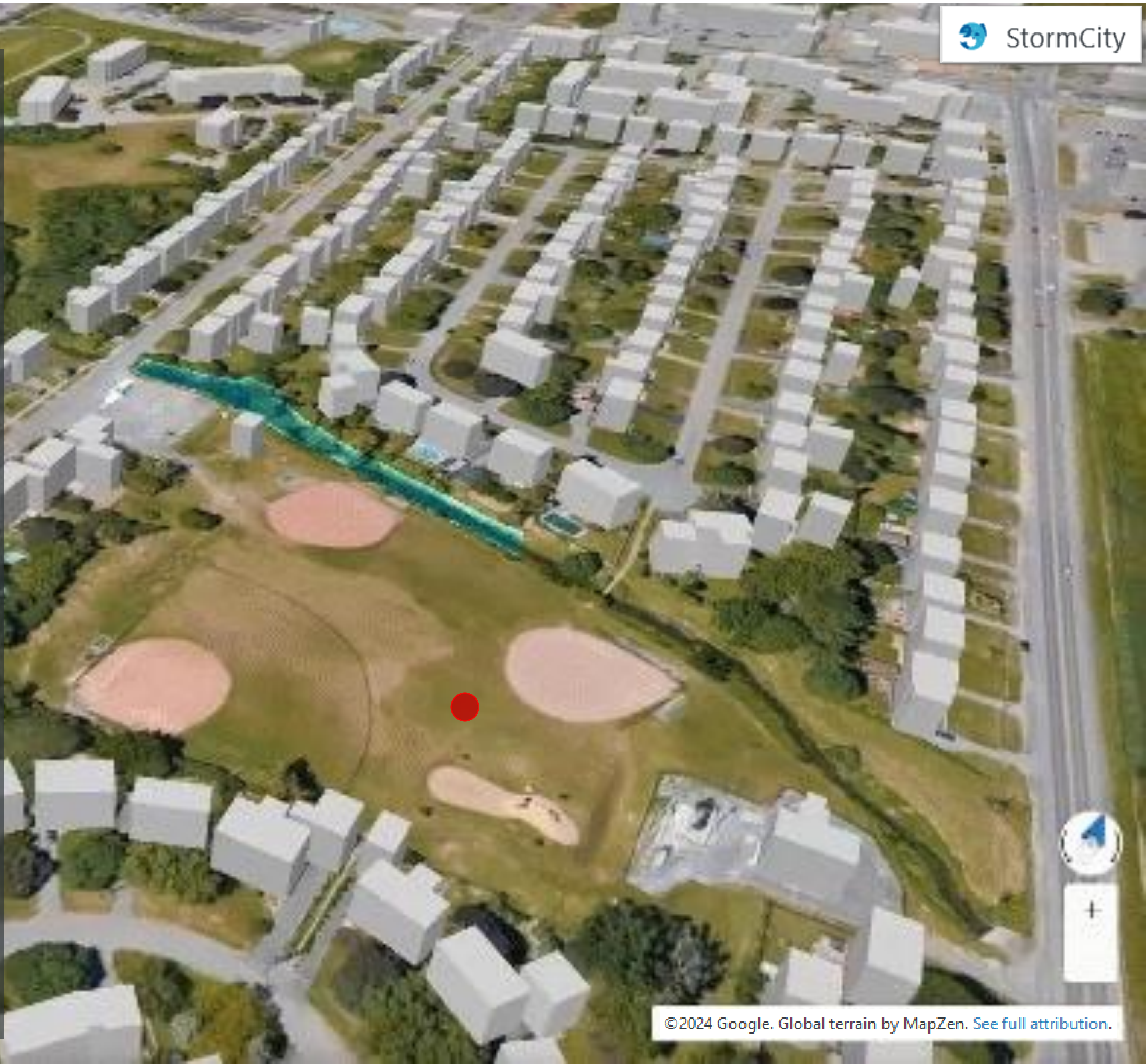
LOCATION:

Arterial road

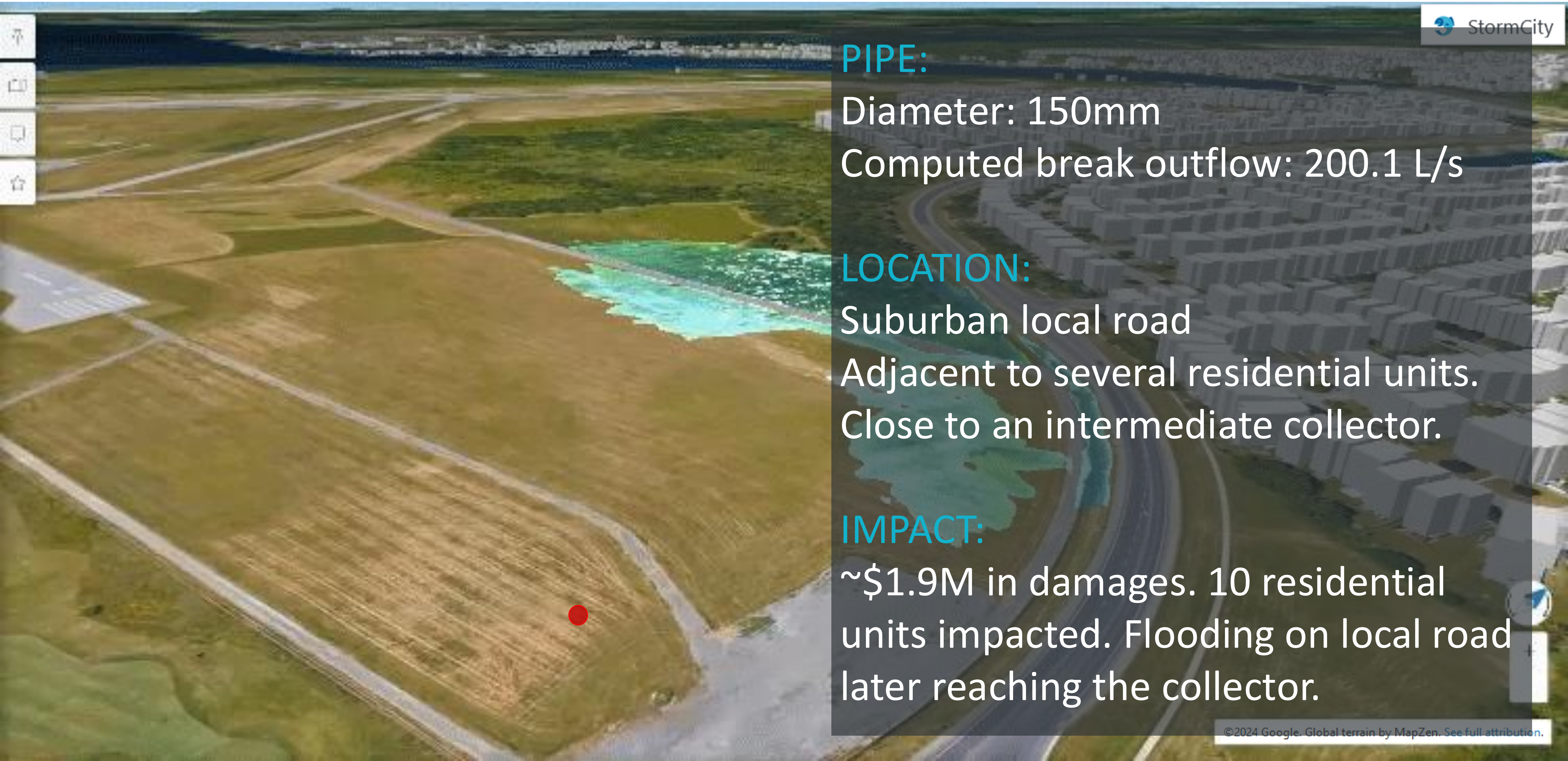
Adjacent to airport facilities (over 400m away from runway)

IMPACT:

Negligible. Flooding on green areas of airport and small internal driveway.



Case Study



PIPE:

Diameter: 150mm

Computed break outflow: 200.1 L/s

LOCATION:

Suburban local road

Adjacent to several residential units.

Close to an intermediate collector.

IMPACT:

~$1.9M in damages. 10 residential units impacted. Flooding on local road later reaching the collector.

Case Study

PIPE:

Diameter: 300mm

Computed break outflow: 664.7 L/s

LOCATION:

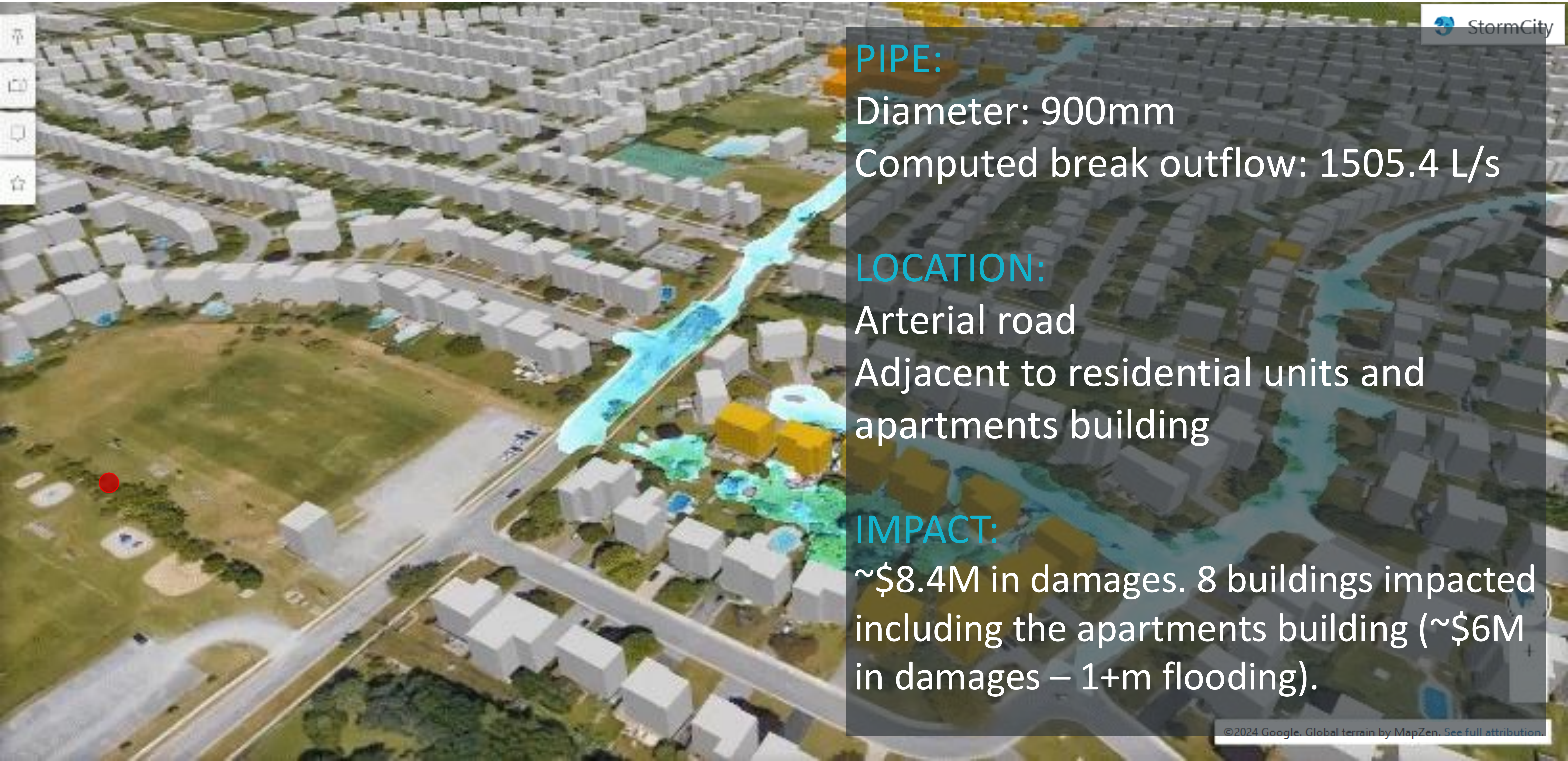
Intermediate collector road

Adjacent to several residential units and uphill of a public school.

IMPACT:

~$14.7M in damages. 28 buildings impacted including a public school (~$10M in damages).

Case Study



PIPE:

Diameter: 900mm

Computed break outflow: 1505.4 L/s

LOCATION:

Arterial road

Adjacent to residential units and apartments building

IMPACT:

~$8.4M in damages. 8 buildings impacted including the apartments building (~$6M in damages – 1+m flooding).

Case Study

PIPE:

Diameter: 900mm

Computed break outflow: 904.0 L/s

LOCATION:

Arterial road

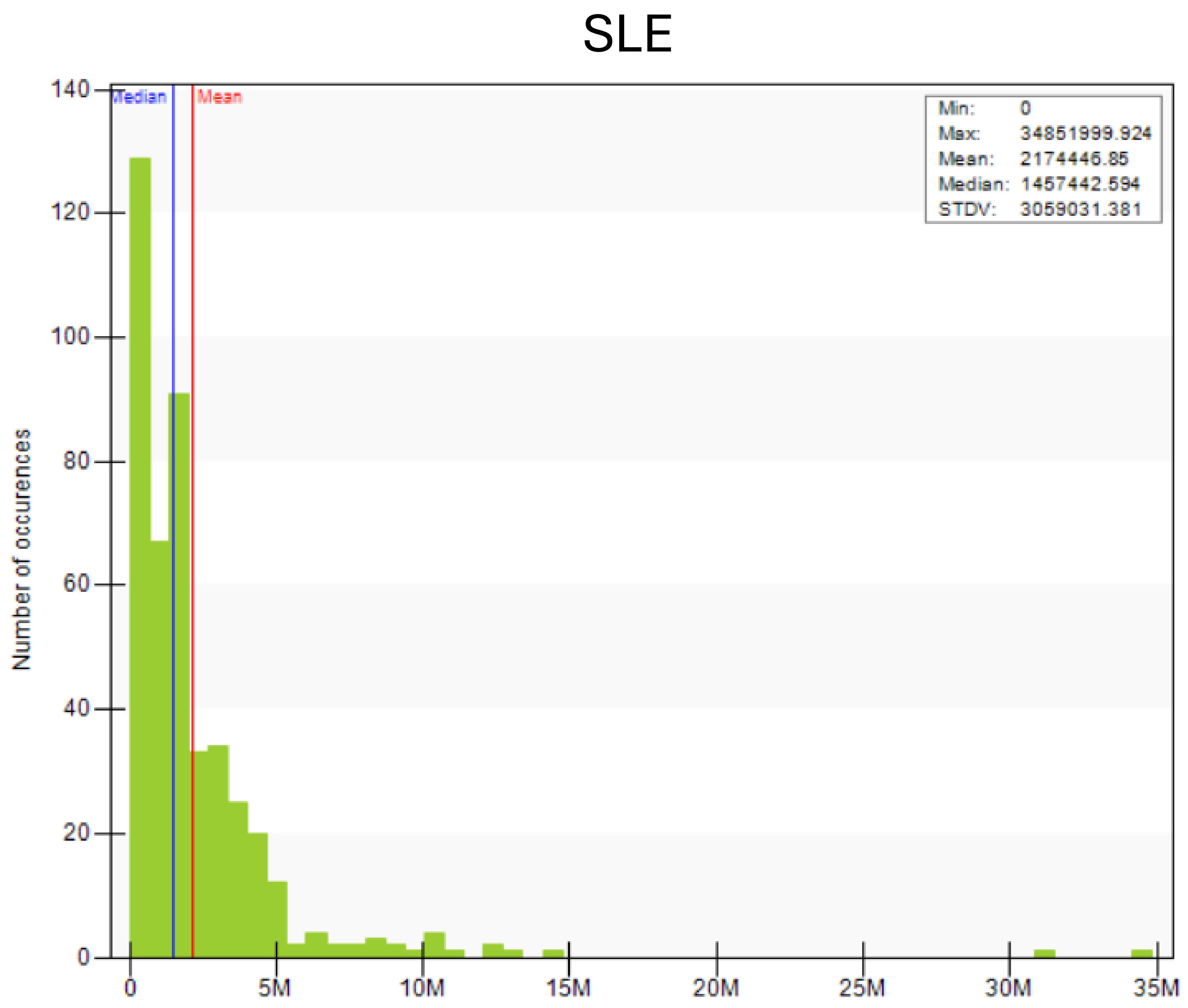
Adjacent to several residential units

IMPACT:

~$9.2M in damages. 27 residential units (5 units with more than 1m flooding). Affectation to suburban local roads. Water reaches close to highway at limit of project area.

Results

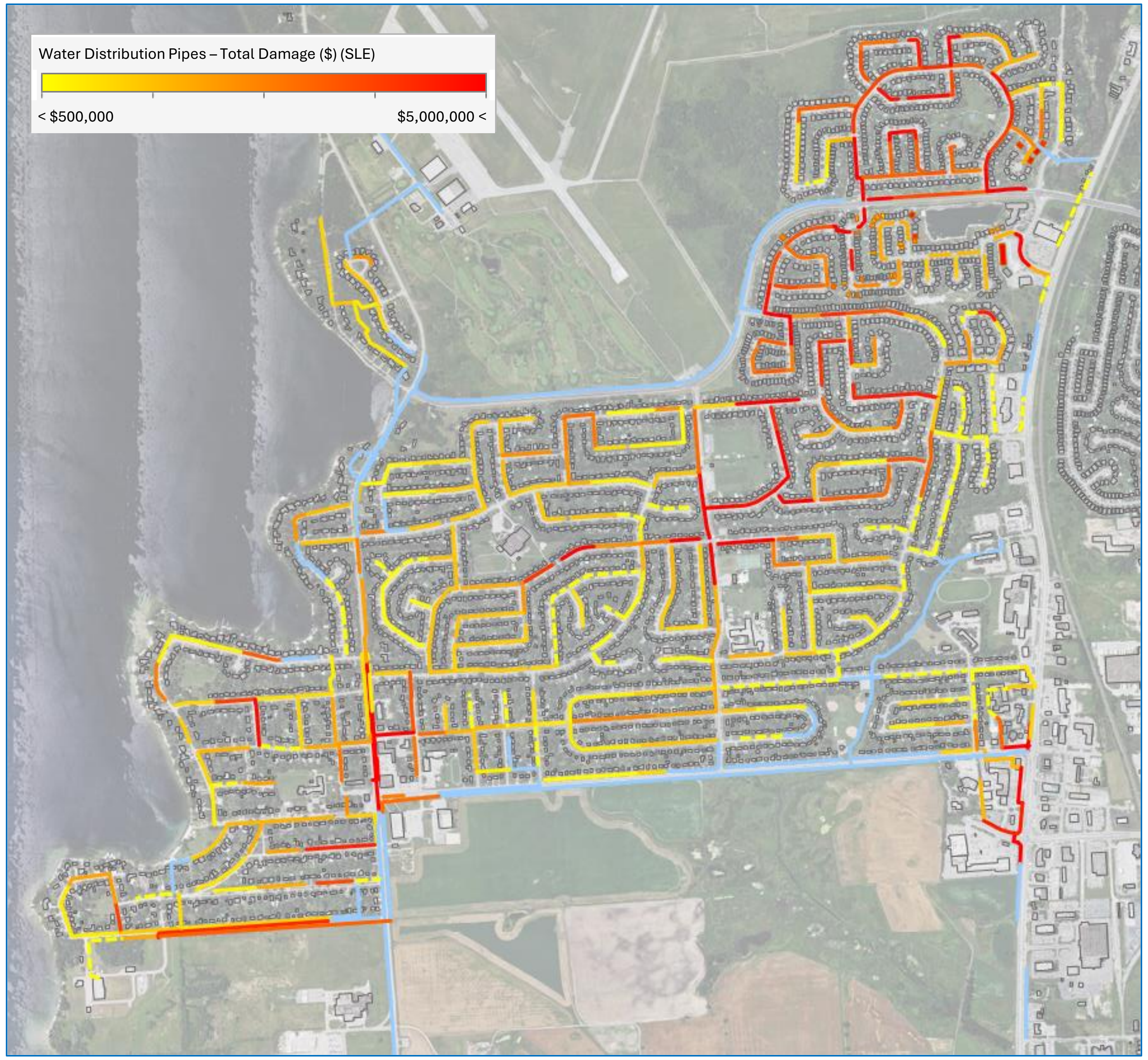
Risk metrics



- SLE ranging from **$0** (mostly for pipes that produced flooding only along **streets, near agricultural/green areas** not characterized with damage curves, or near the shoreline) to **~$10M** (for large or medium pipes producing flooding near **highly vulnerable buildings**, or flat areas where **several single detached homes** got partially affected)

Results

Risk metrics



- SLE ranging from **$0** (mostly for pipes that produced flooding only along **streets, near agricultural/green areas** not characterized with damage curves, or near the shoreline) to **~$10M** (for large or medium pipes producing flooding near **highly vulnerable buildings**, or flat areas where **several single detached homes** got partially affected)

Results

Risk metrics

- The computed ALE for the study area was **$262,679/year**.

- This value gives a first indication of the yearly value worth investing in mitigating these risks and should be compared with estimated costs to do so.

- ALE metric is highly dependent on the probability of pipe breakage. Having a more specific model to estimate probabilities of occurrence would change this value.

Conclusions

Conclusions

- The proposed methodology allows for que quantification of flooding risk associated with water main bursts.

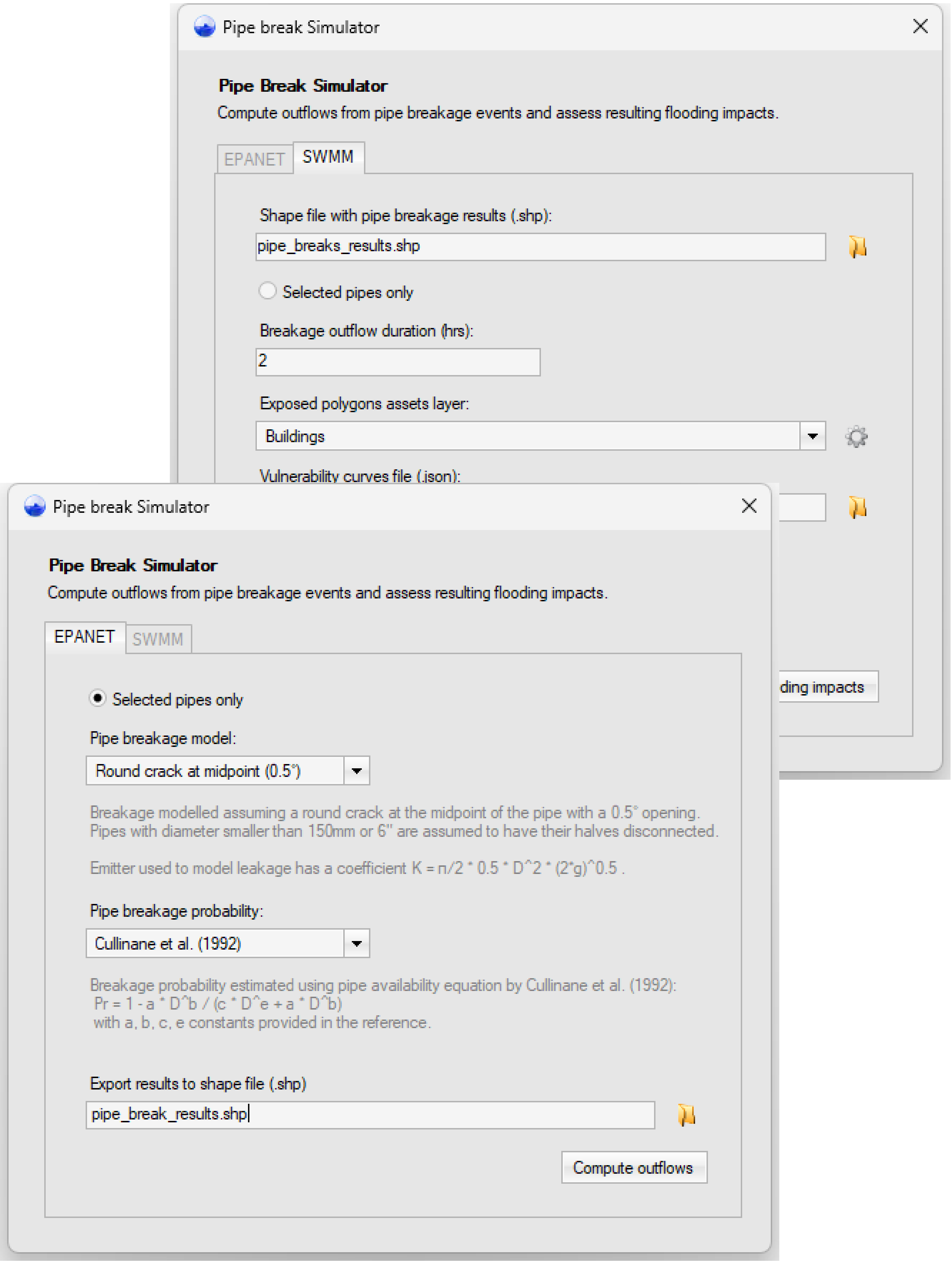
- The implementation of the methodology in PCSWMM is convenient as it allows for an easy transition between the part of the methodology completed in an EPANET project and the part of the methodology completed in a SWMM project.

- The ALE is a useful decision-making tool that can aid in deciding if a mitigation strategy is required, worth it, and better than other alternatives.

Recommendations

- Explore ways to include impacts to roads and other urban, nonstructural infrastructure.

- Explore ways of speeding flooding simulations. For this project, each simulation took ~5 minutes.



Thank you

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