Developing an integrated urban inundation flood model for extreme rainfall events for Metro Manila, Philippines

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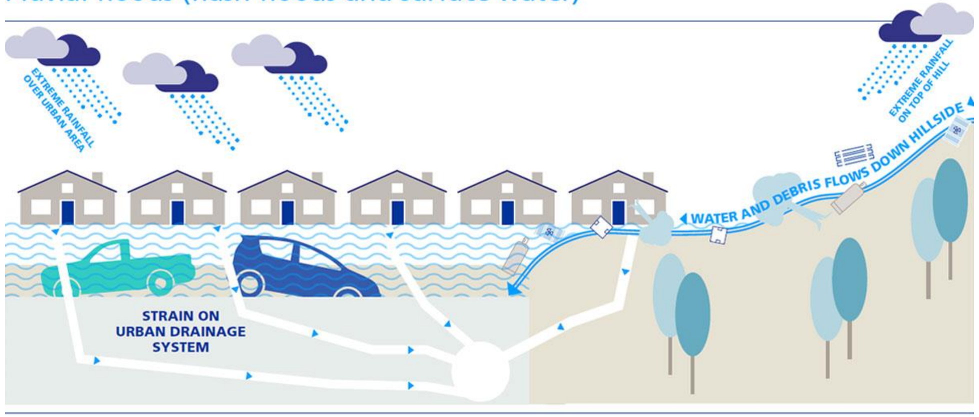
Research outline

- Research background
    (Urban flood modeling)
- Objectives
- SSI model theory
- Results and analysis
- Conclusion

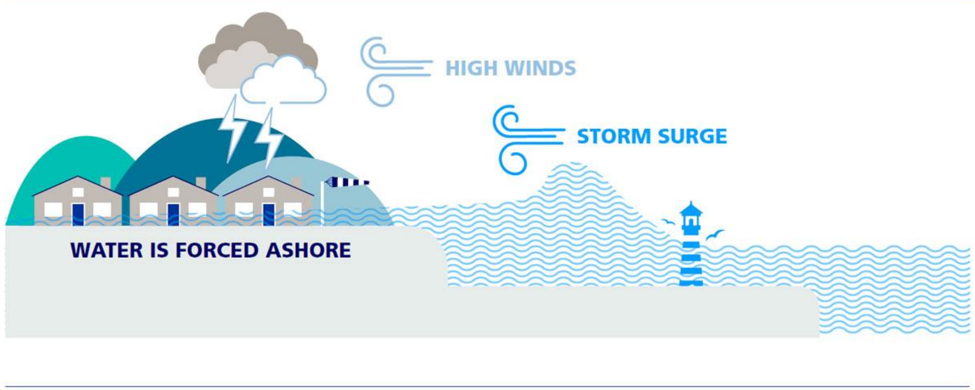
What is flooding?

An overflow of water (caused by rainfall, dam break, storm surge) that submerges land that is usually dry.

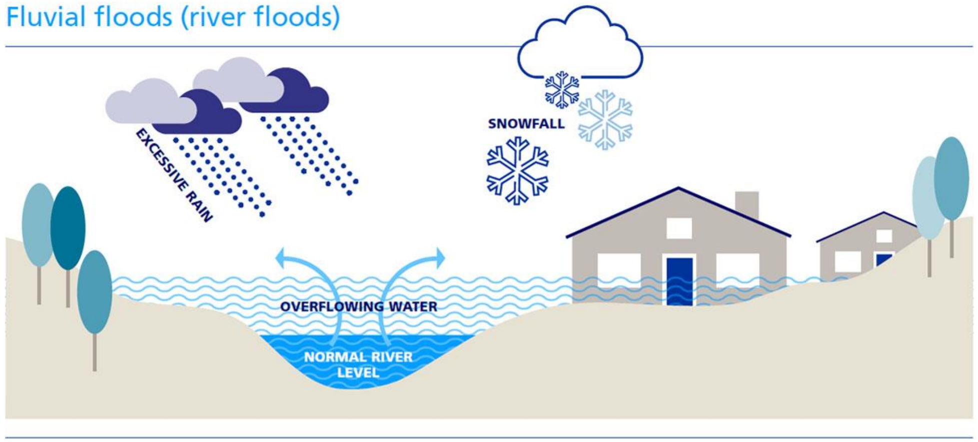
Pluvial floods (flash floods and surface water)



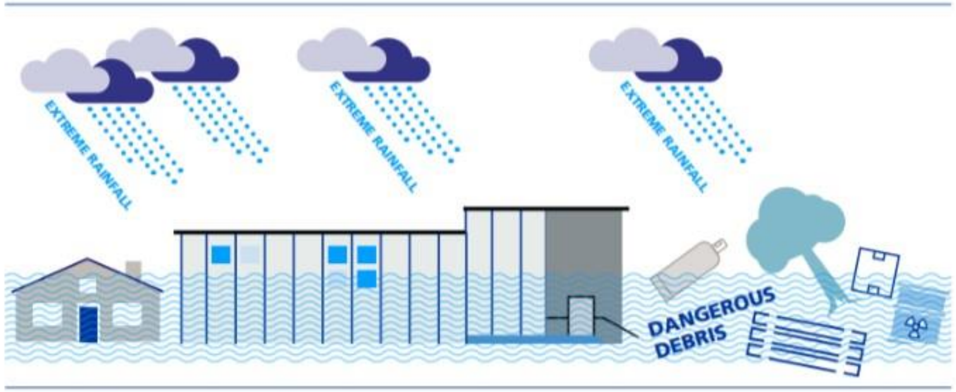
Coastal flood (storm surge)



Fluvial floods (river floods)

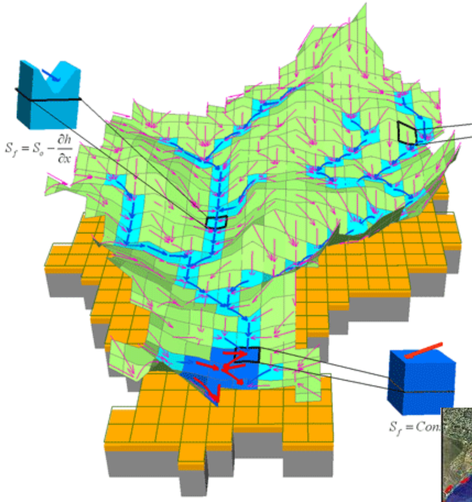


Flash flooding



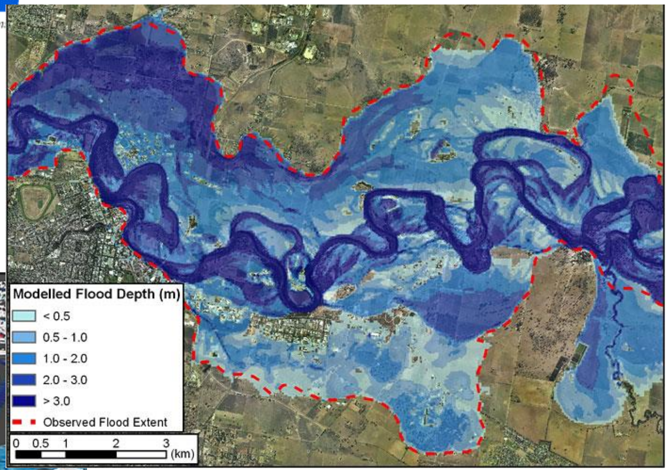
FLOOD MODELING TECHNIQUES

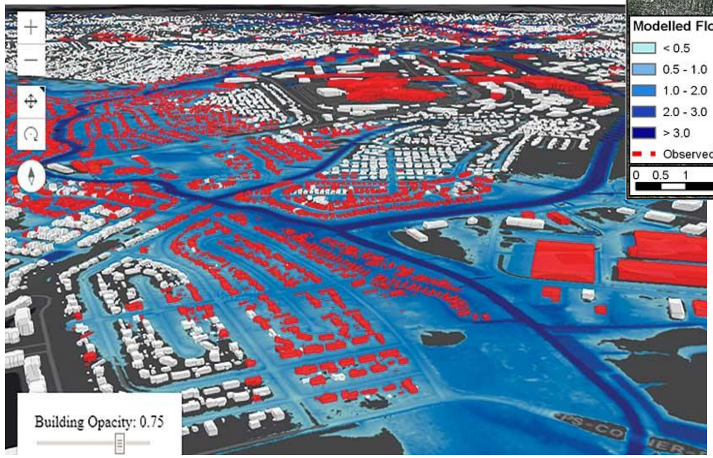
- Spatial Extent
- Dimensionality
- Mathematical complexity
  - Kinematic
  - Inertial
  - Diffusive
  - Dynamic
  - Coupled



Watershed
~1,000,000,000 m^2

Inundation
<50,000,000 m^2

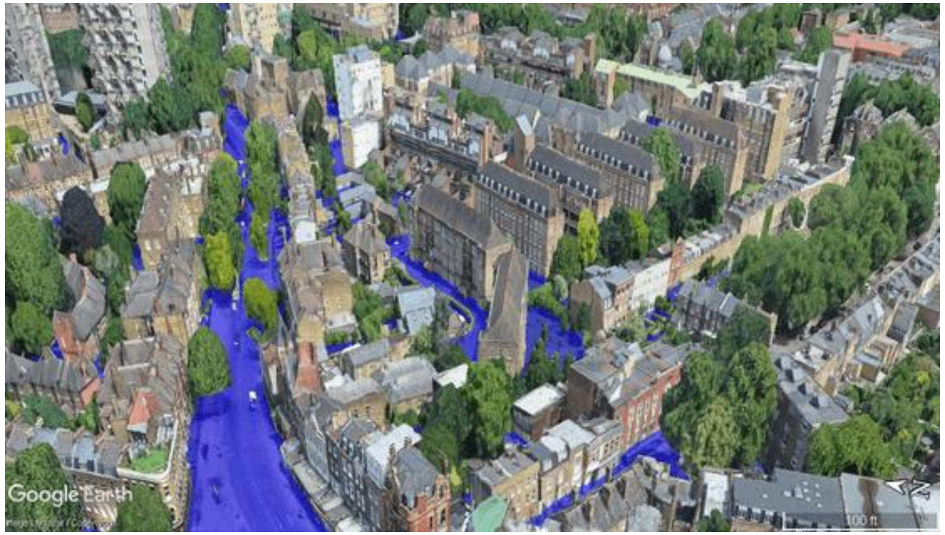




Sewer pipe cell grid

<100 m^2

Urban flood modeling



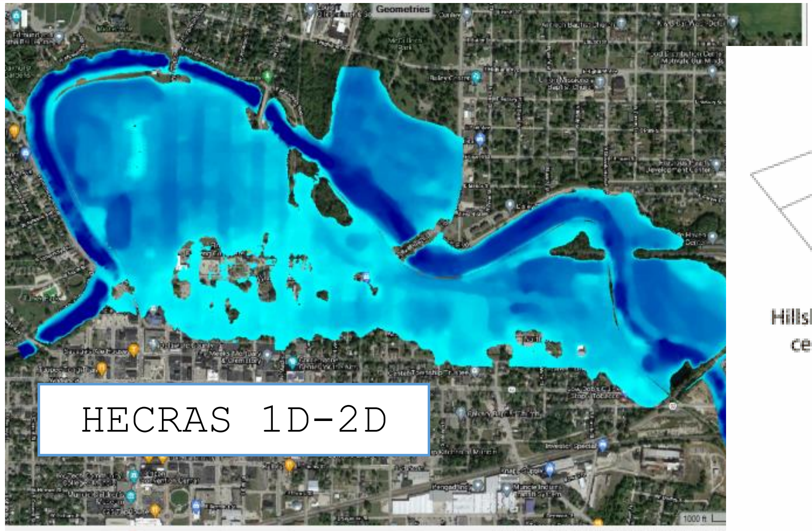
Inundation modeling	Urban flood modeling
2D overland flow	More complex dynamics (building, artificial barriers)
Soil type based infiltration	More impervious surfaces, more runoff
	Integration of surface and sewer pipe system
Generalized DEM	Requires higher resolution DEM
Scale (~50km^2)	Scale (<100m^2)
	More densely populated areas

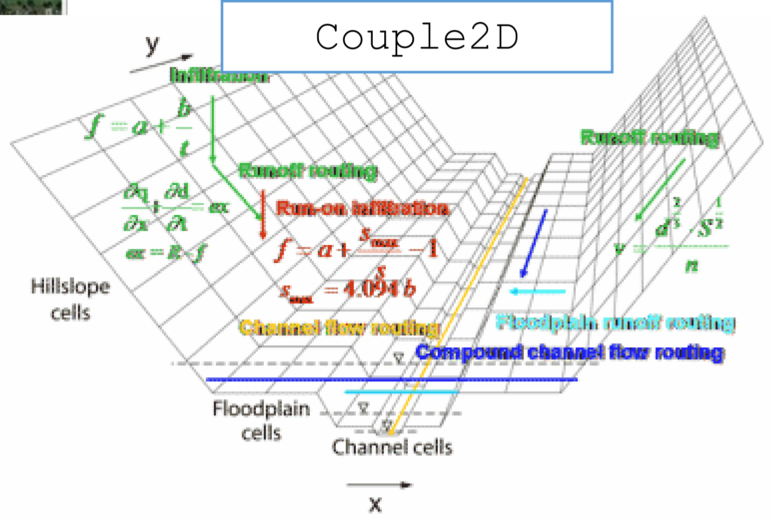
RESEARCH GAPS

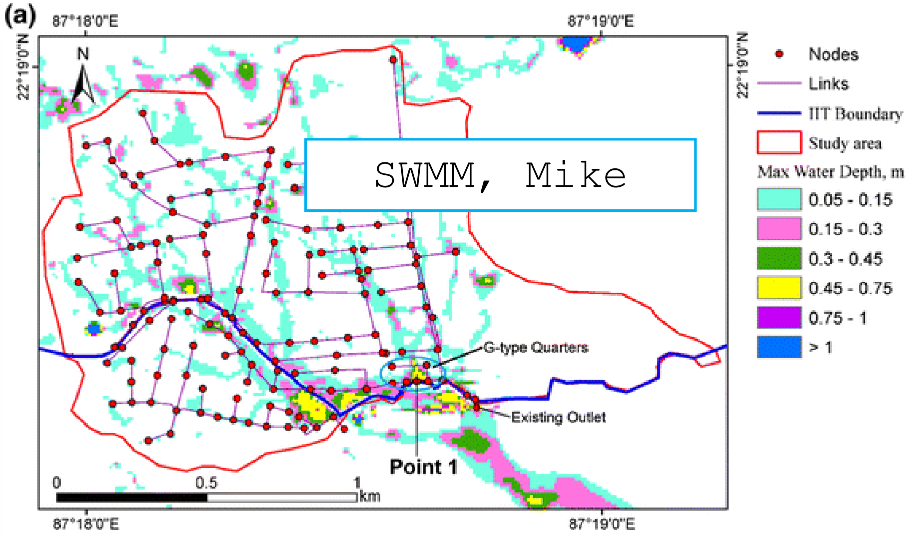
- **Flood modeling:**
  - Separate computations of large scale runoff, urban domain-scale inundation and sewer pipe interaction
  - Long simulation time for high-resolution data
  - Incompatibility and complexity in integration

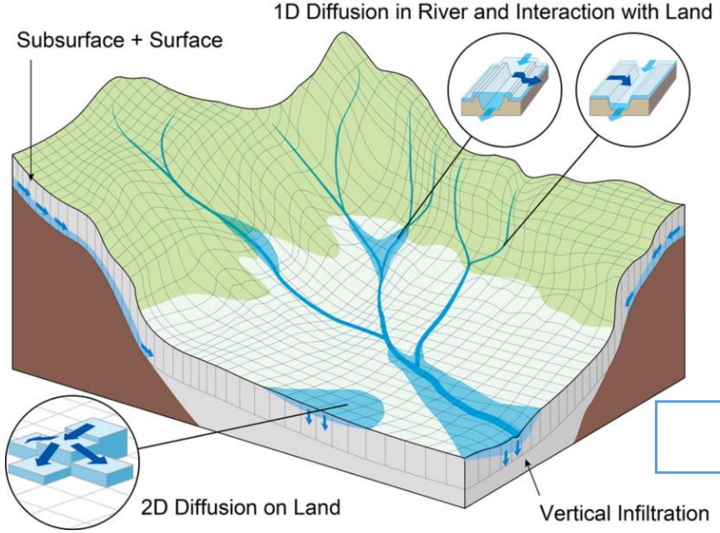
- **Issues for developing countries:**
  - Limited availability of adequate resolution elevation data
  - Lack of systematized drainage network data
  - Scarce researches on flood modeling/mitigation

Recent flood modeling advances:

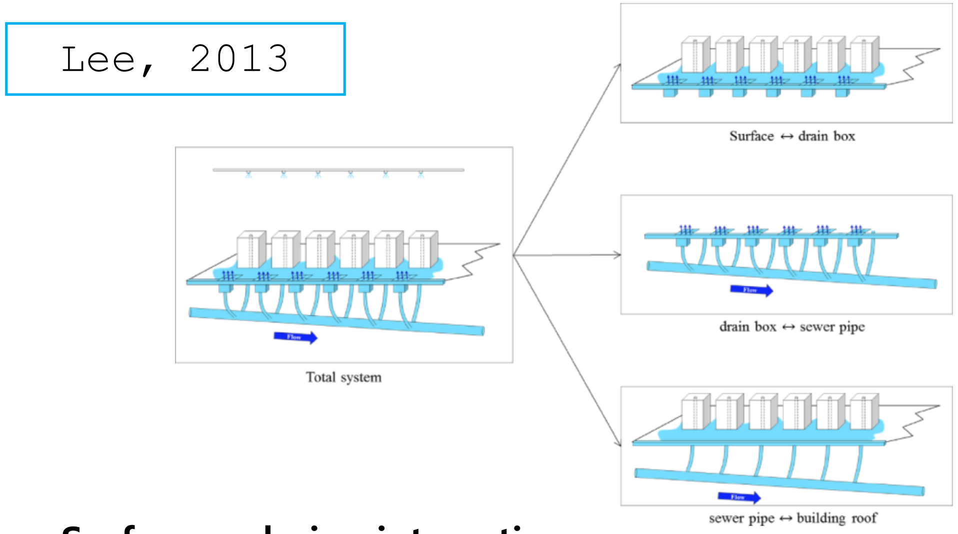






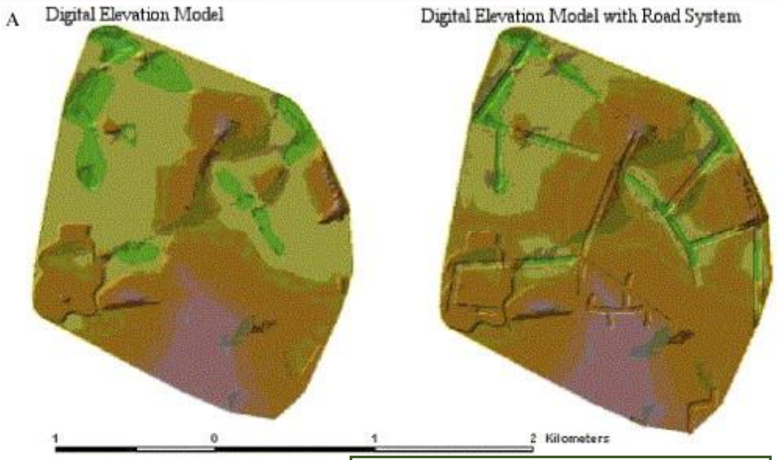


Coupling or integration scheme



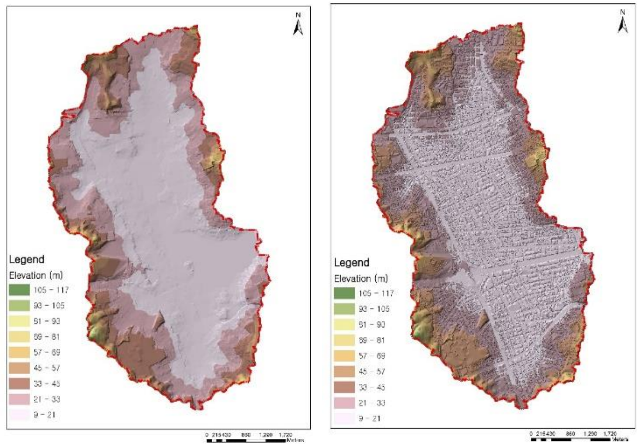
Surface and pipe interaction

Recent flood modeling advances:



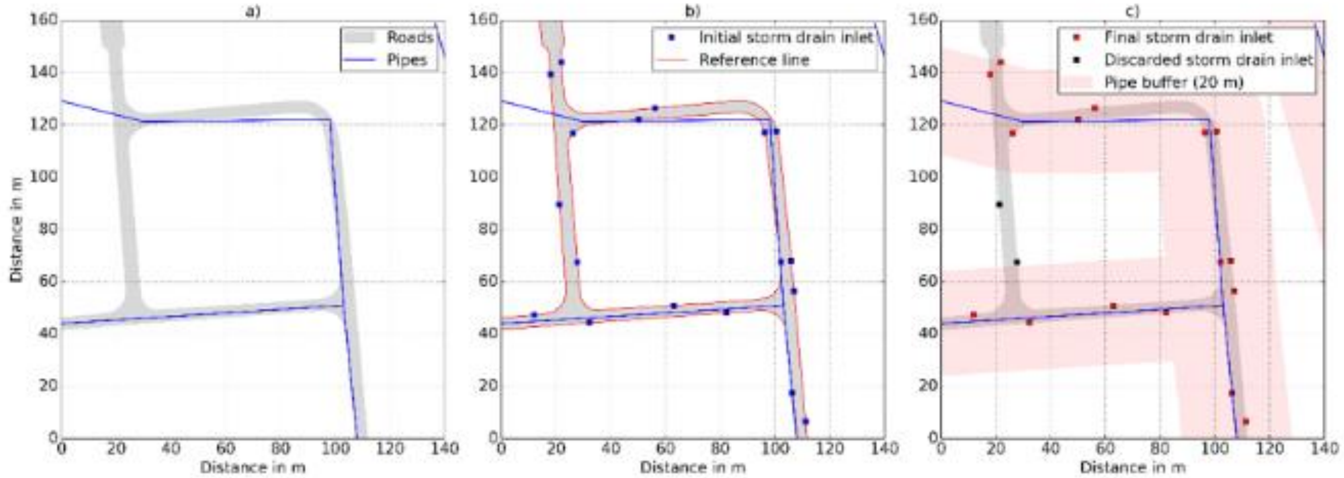
Mark et al.,2004

Lee et al.,2016

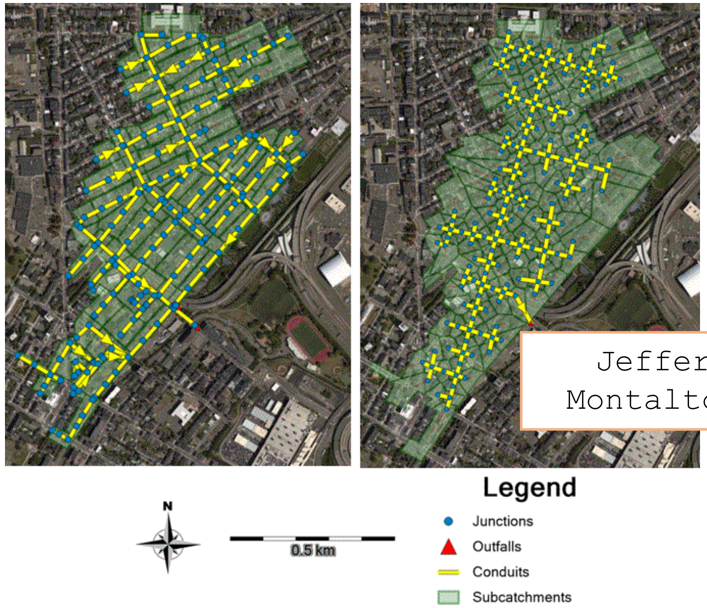


Lee ,2021

DEM modification

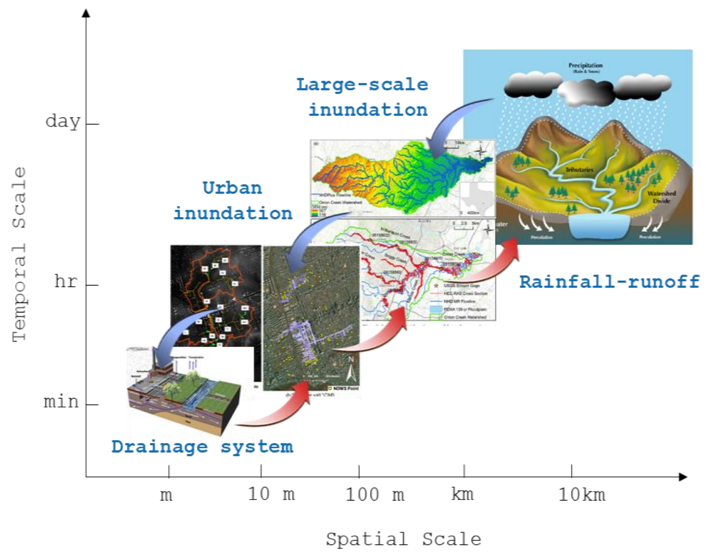


Bertsch et al., 2017

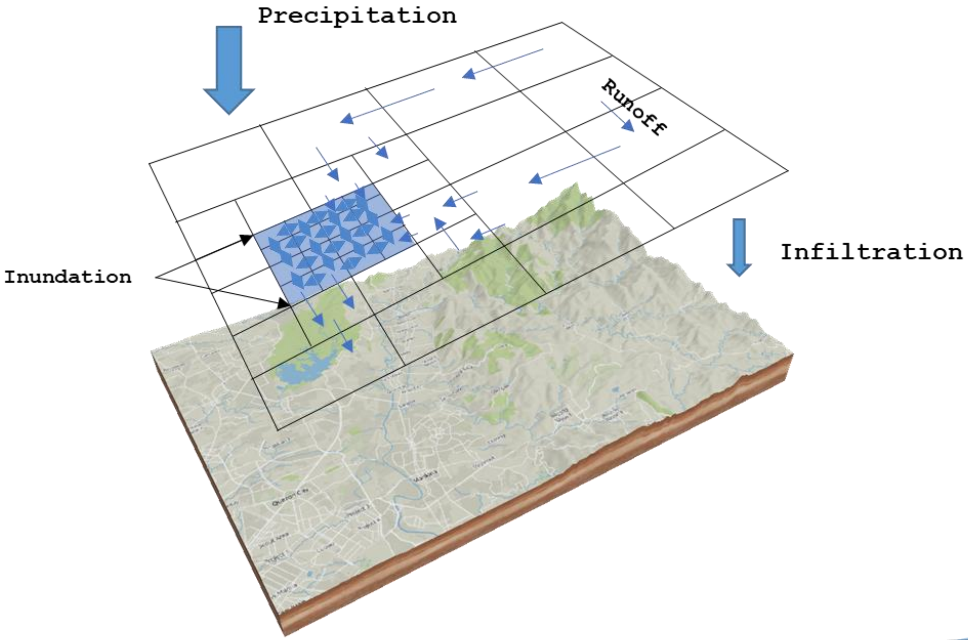


Jeffers and Montalto, 2018

Synthetic sewer system



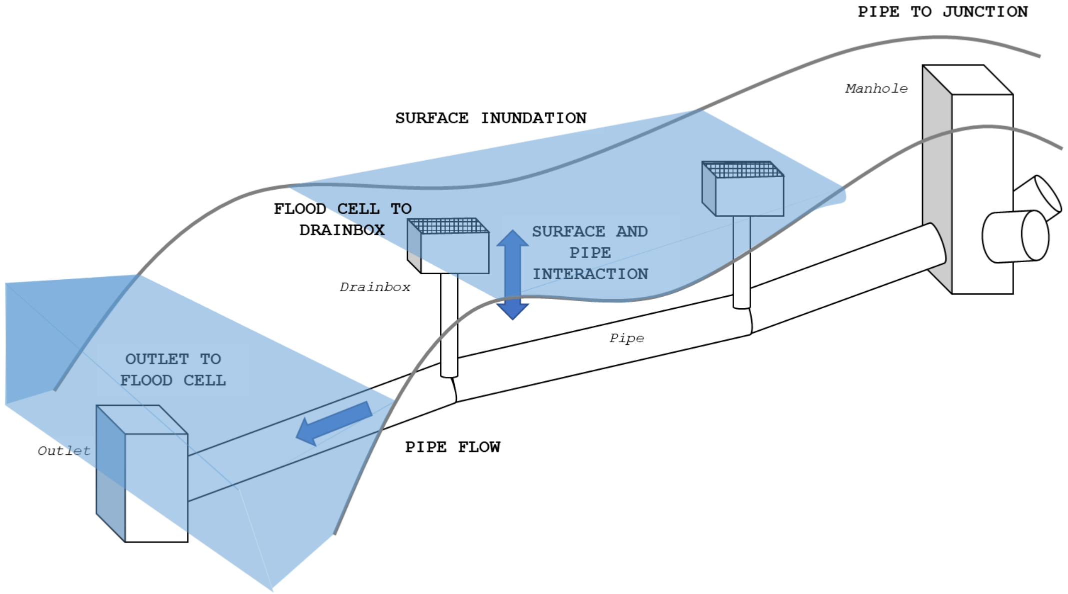
Flood inundation by different spatial scale



Watershed
~1,000,000,000 m^2

Urban domain
<50,000,000 m^2

Surface and sewer pipe interaction model



Sewer pipe cell grid
<100 m^2

Model Integration overview

Surface and drainbox interaction

Surface to drainbox discharge Q_{sd} is calculated by:

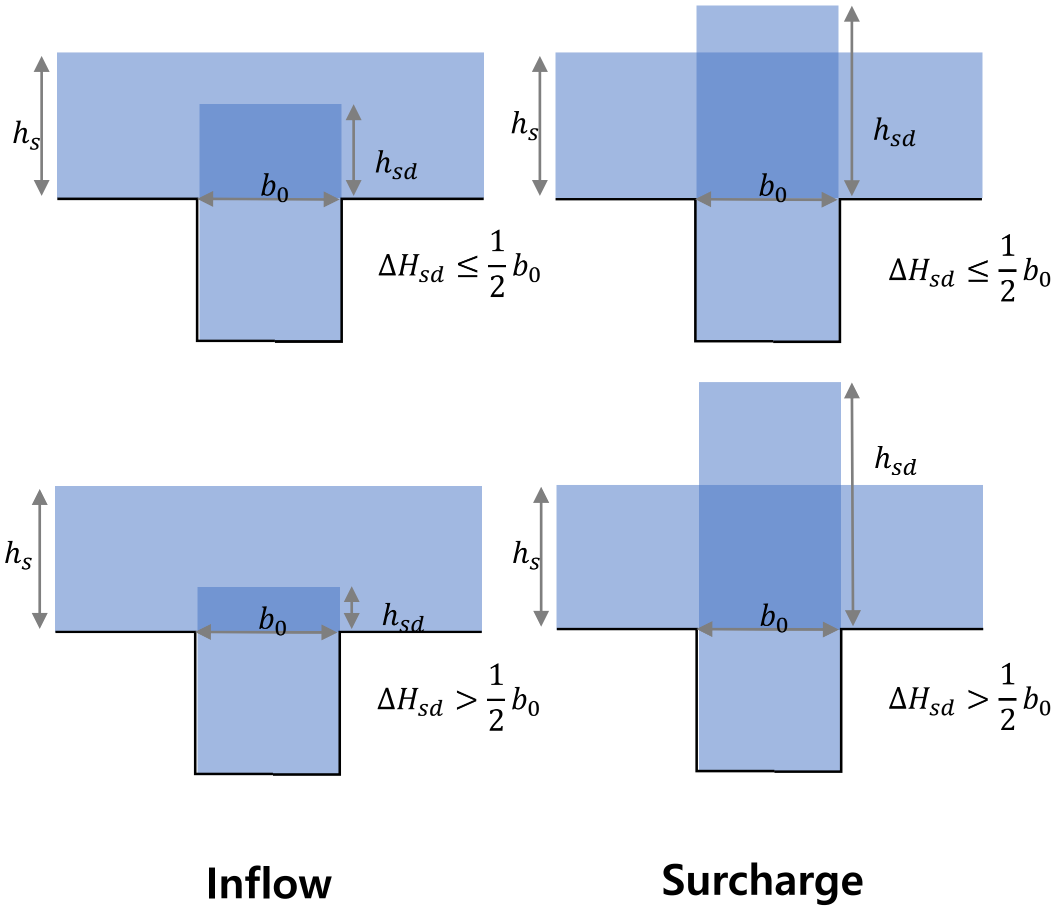
$$\Delta H_{sd} = max(h_s, h_{sd}) - min(h_s, h_{sd})$$

Weir equation

$$Q = \begin{cases} C_w A\sqrt{2g(\Delta H_{sd})} & : h_s > h_{sd} \\ -C_w A\sqrt{2g(\Delta H_{sd})} & : h_s < h_{sd} \end{cases}$$

Orifice equation

$$Q = \begin{cases} C_o L \frac{2}{3}\sqrt{2g}\,(\Delta H_{sd})^{\frac{3}{2}} & : h_s > h_{sd} \\ -C_o L \frac{2}{3}\sqrt{2g}\,(\Delta H_{sd})^{\frac{3}{2}} & : h_s < h_{sd} \end{cases}$$



Drainbox to sewer pipe discharge Q_{dp} is calculated by:

$$\Delta H_{dp} = max(h_d, h_{dp}) - min(h_d, h_{dp})$$

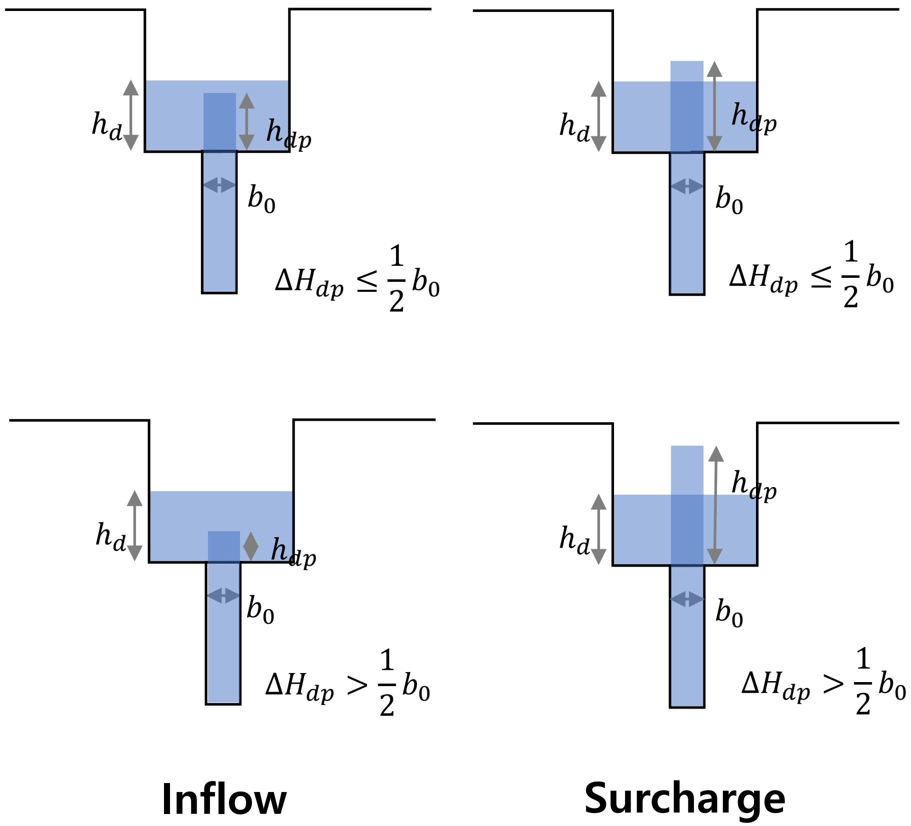
Drainbox and sewer pipe interaction

Weir equation

$$Q = \begin{cases} C_w A\sqrt{2g(\Delta H_{dp})} & : h_d > h_{dp} \\ -C_w A\sqrt{2g(\Delta H_{dp})} & : h_d < h_{dp} \end{cases}$$

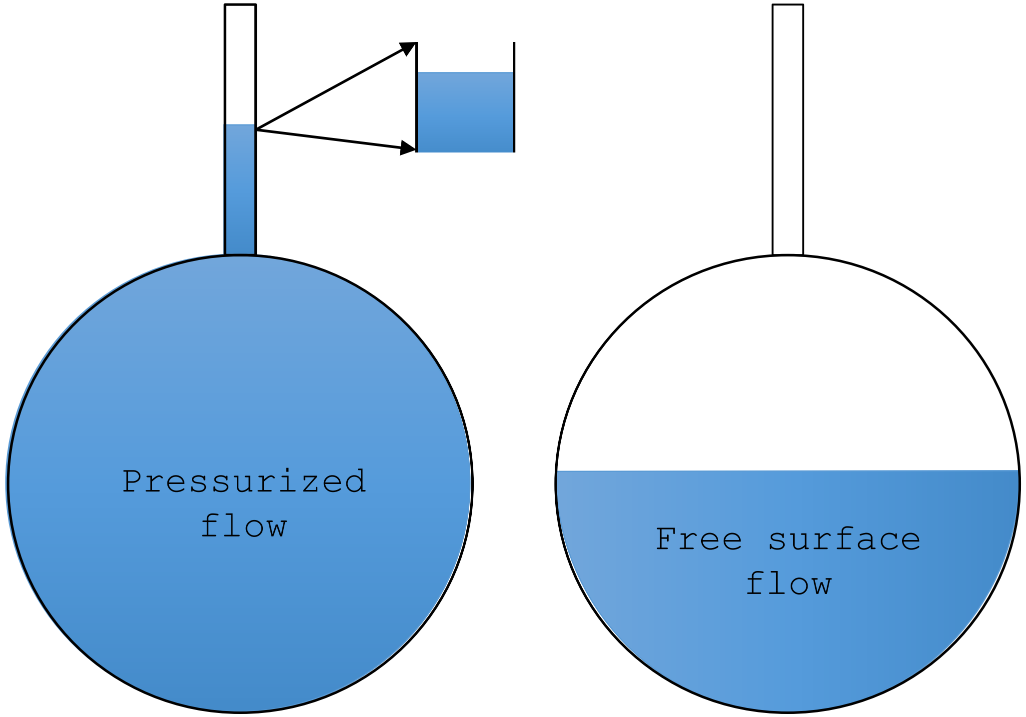
Orifice equation

$$Q = \begin{cases} C_o L \frac{2}{3}\sqrt{2g}\,(\Delta H_{dp})^{\frac{3}{2}} & : h_d > h_{dp} \\ -C_o L \frac{2}{3}\sqrt{2g}\,(\Delta H_{dp})^{\frac{3}{2}} & : h_d < h_{dp} \end{cases}$$



Pipe flow

Hyperbolic conservative form for free surface flow



$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{S}$$

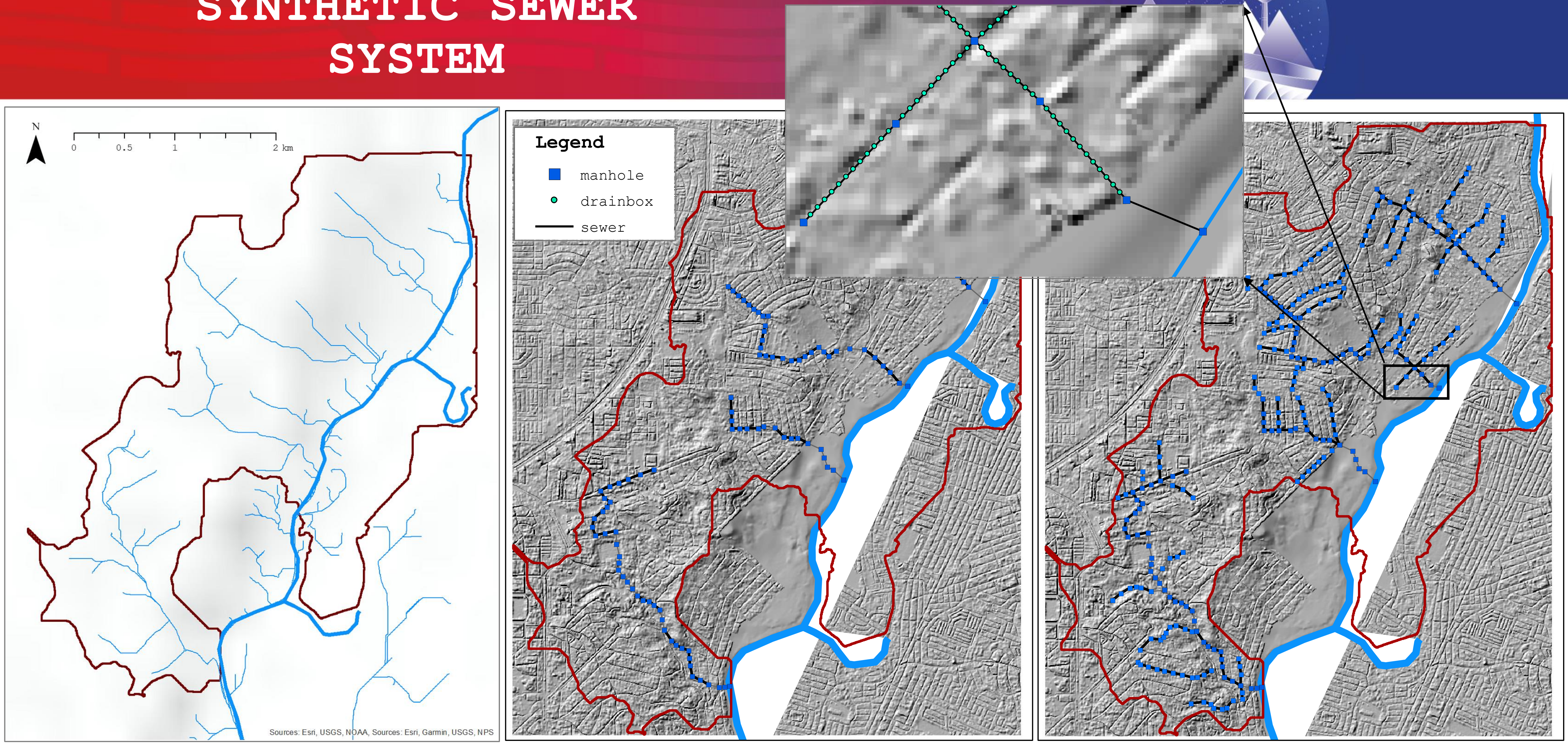
$$\mathbf{U} = \begin{bmatrix} A \\ Q \end{bmatrix}, \mathbf{F} = \begin{bmatrix} Q \\ \frac{Q^2}{A} + \frac{A\bar{p}}{\rho} \end{bmatrix}, \mathbf{S} = \begin{bmatrix} 0 \\ gA(S_0 - S_f) \end{bmatrix}$$

Discretized form:

$$U_i^{n+1} = U_i^n - \frac{\Delta t}{\Delta x}\left(\boldsymbol{F}^n_{i+\frac{1}{2}} - \boldsymbol{F}^n_{i-\frac{1}{2}}\right) + \Delta t S^n$$

1D flow simulation with Preissmann slot model is conducted to simulate the flow within pipe channel

SYNTHETIC SEWER SYSTEM

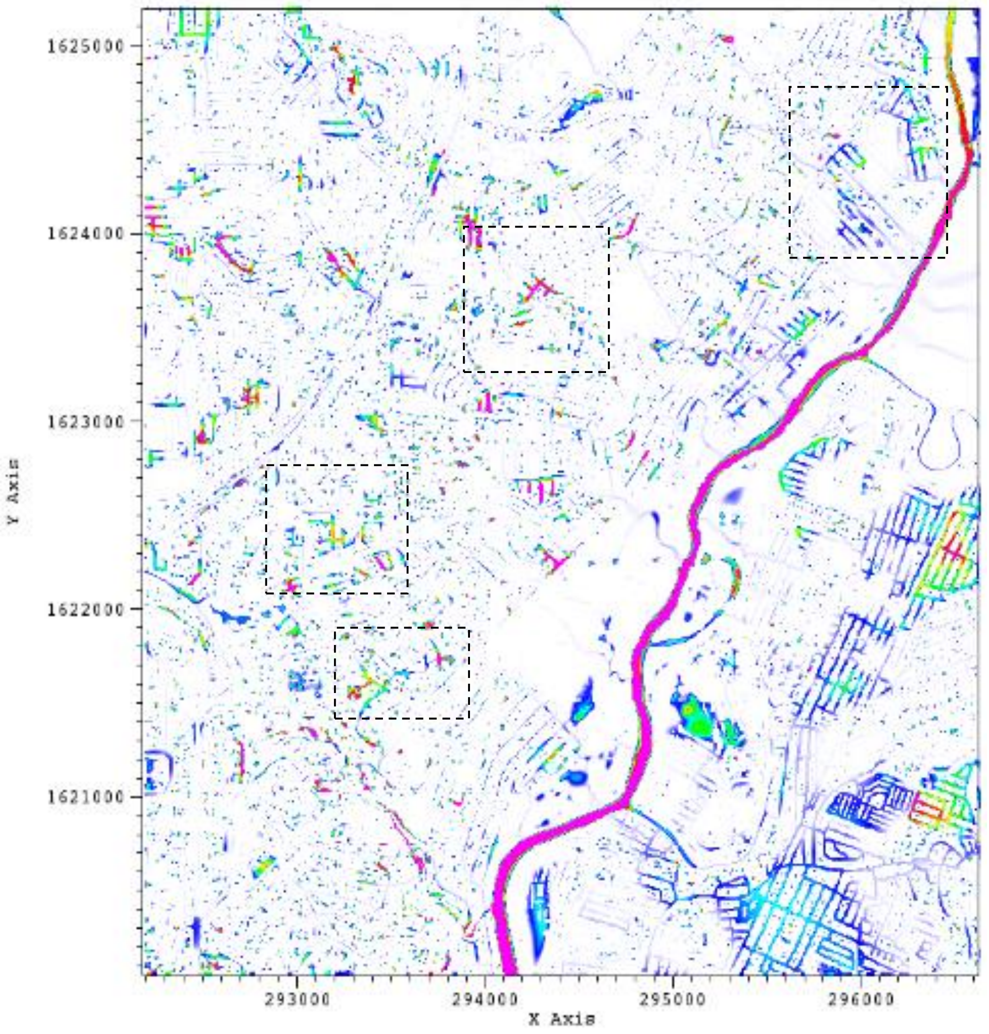


Stream channel

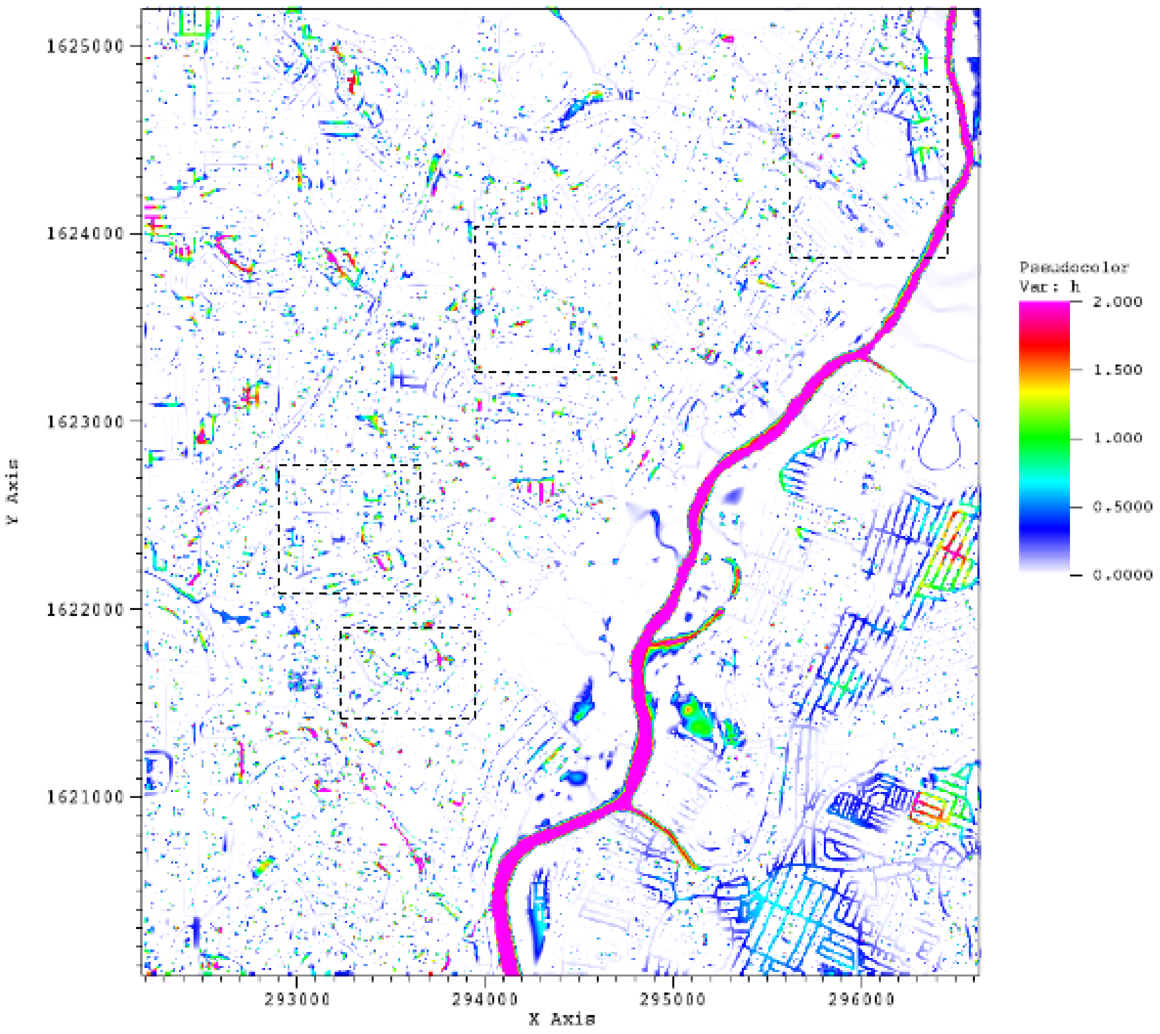
Synthetic sewer system:
1st order

Synthetic sewer system:
2nd order

SIMULATION RESULTS: FLOOD DEPTH (M)

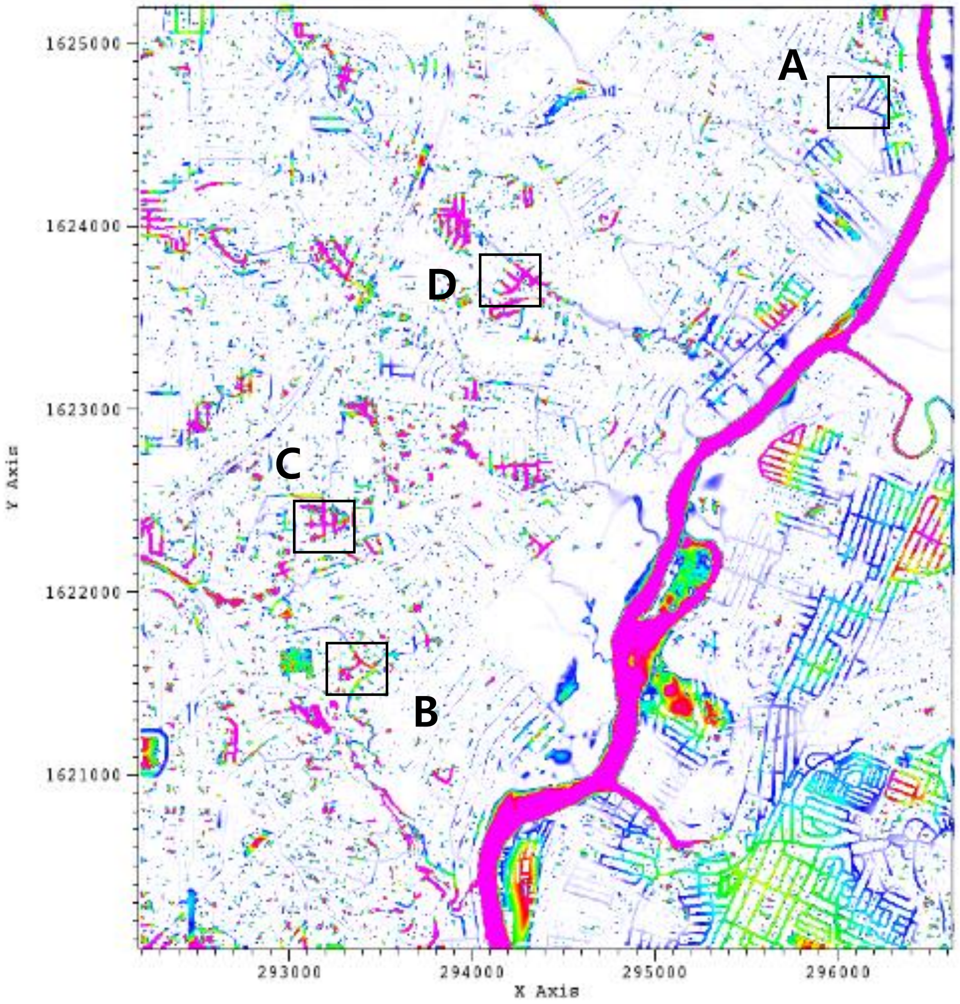


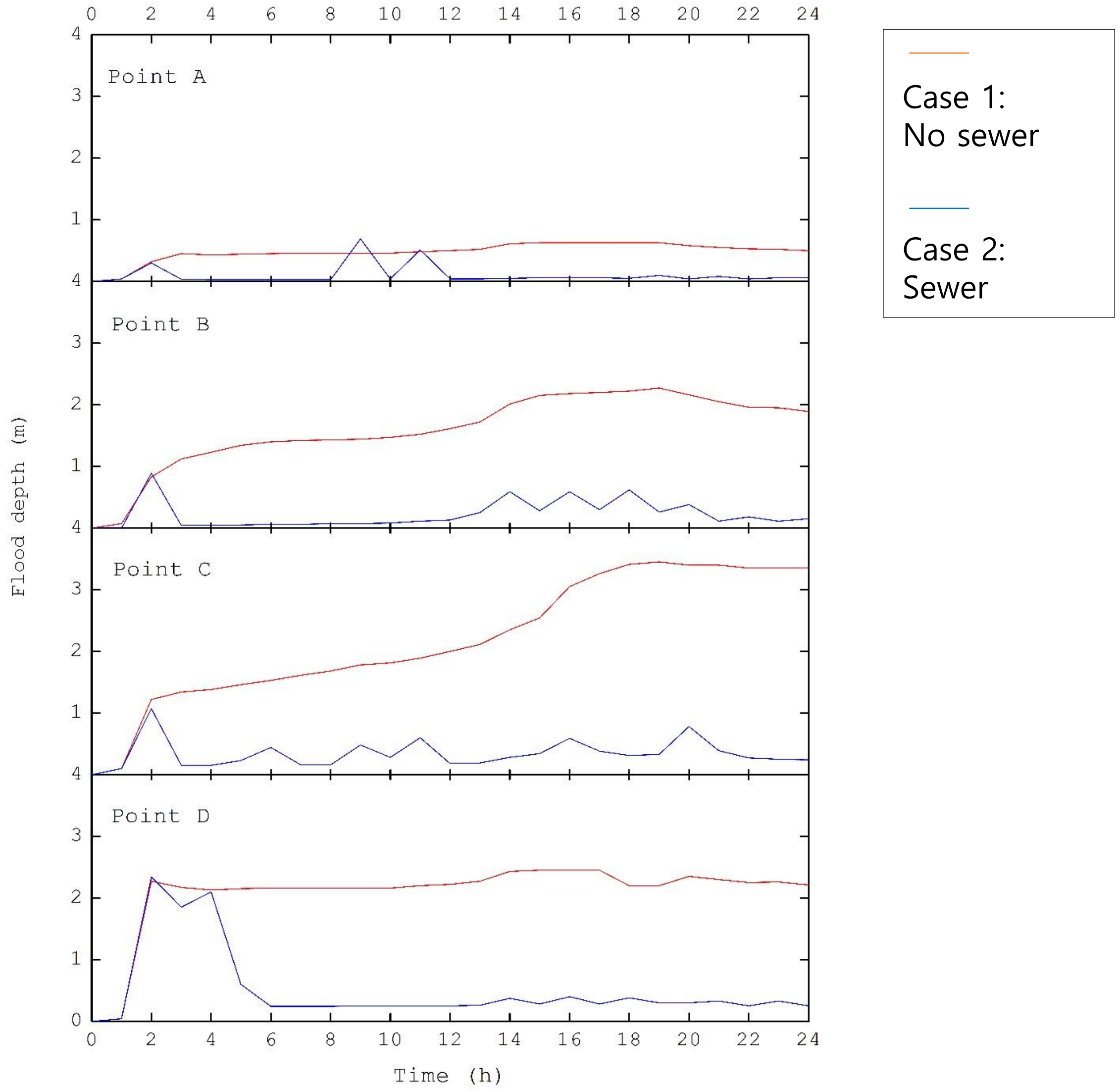
No Sewer: t = 06h

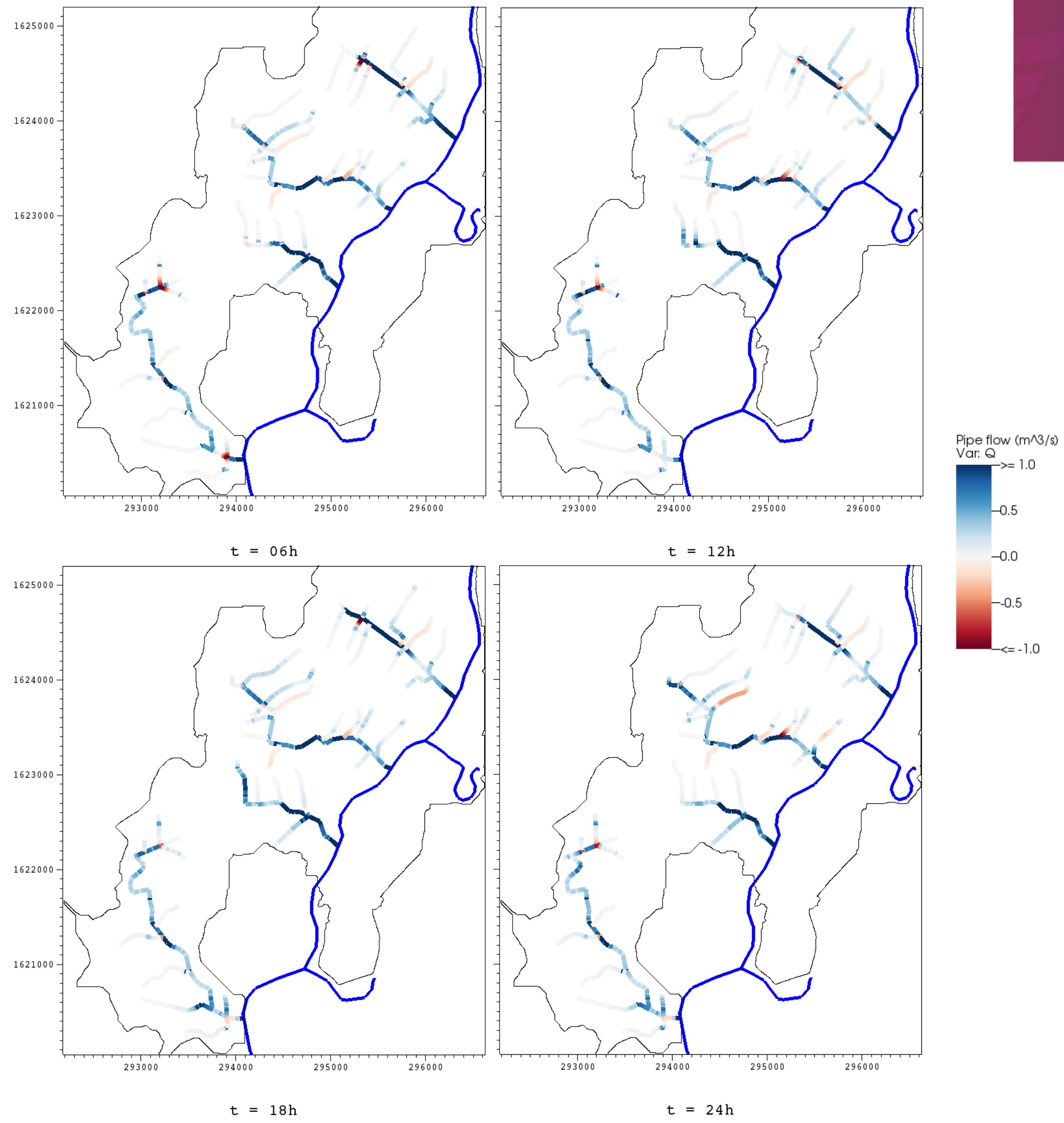


2nd Order Sewer: t = 06h

Flood depth comparison: Case 1 and Case 2



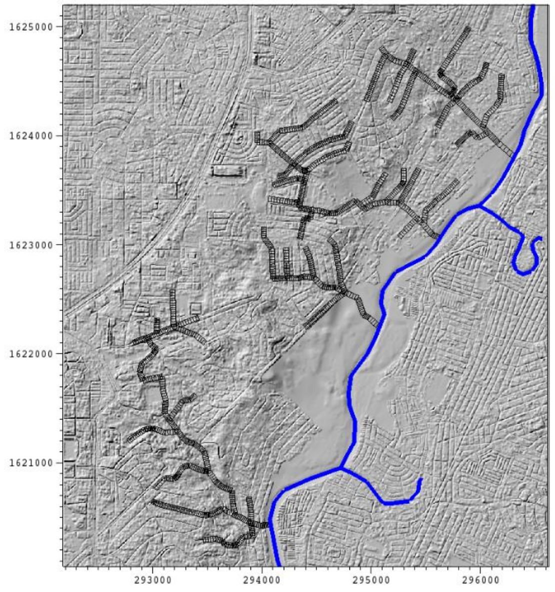


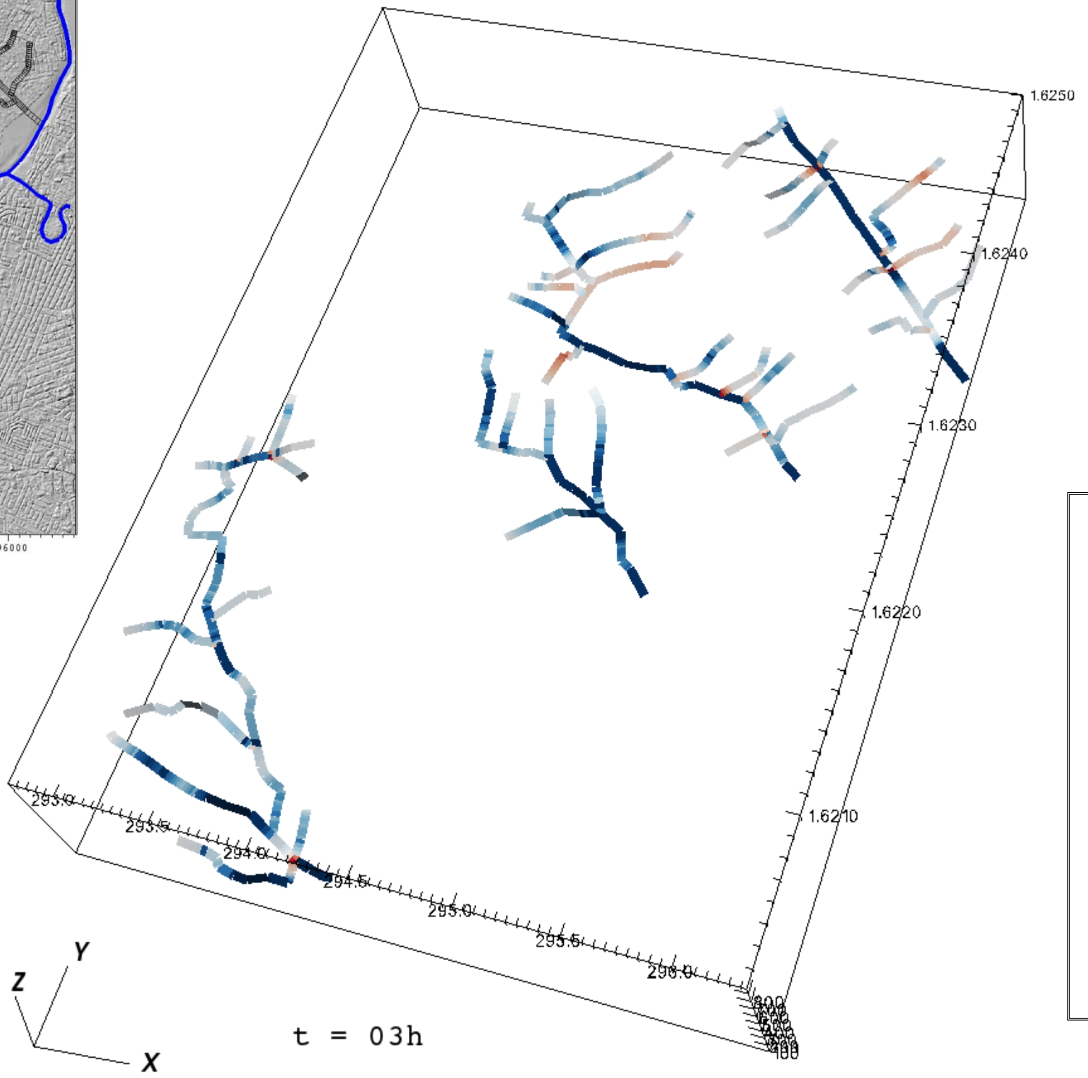


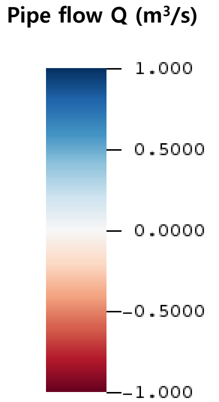
Pipe flow results

- Maximum flow observed in the principal pipe
- Weakened/backflows are observed in:
  - Pipes with less steeper slope
  - Bottleneck pipes
  - Upstream connecting pipe is perpendicular to the receiving pipe

Sewer pipe flow

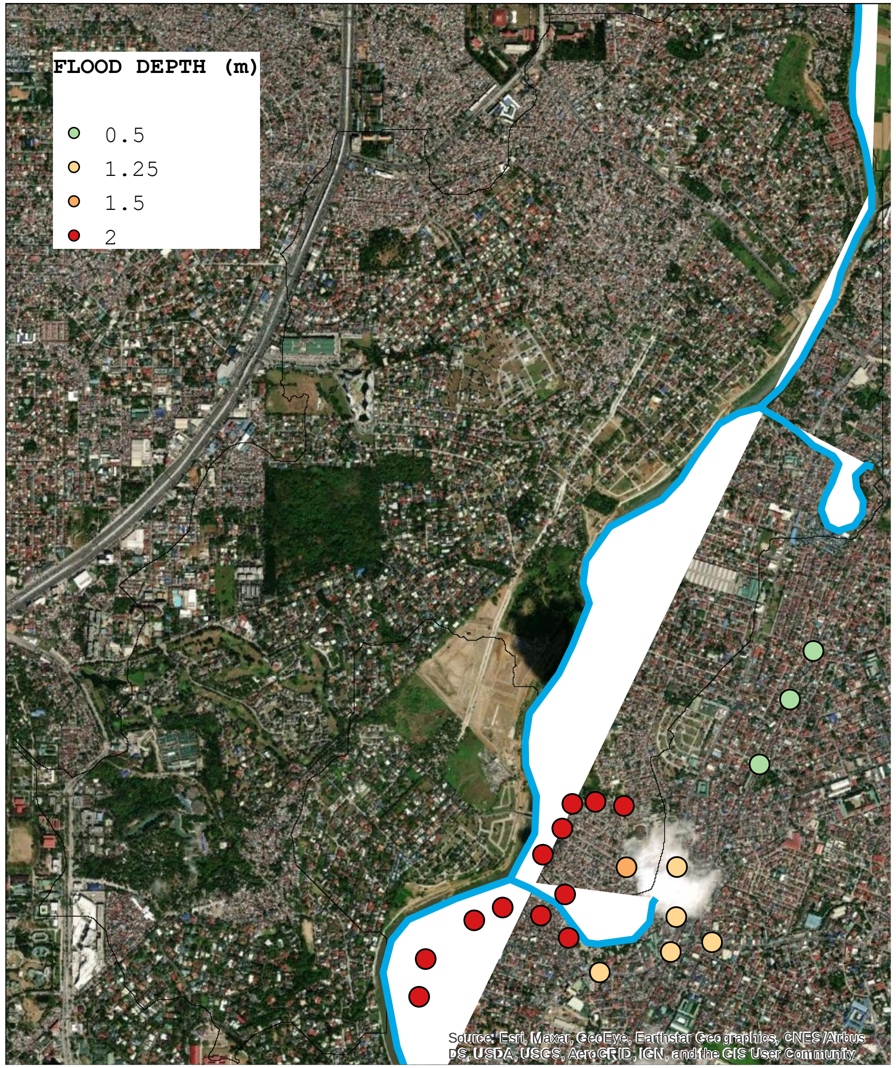






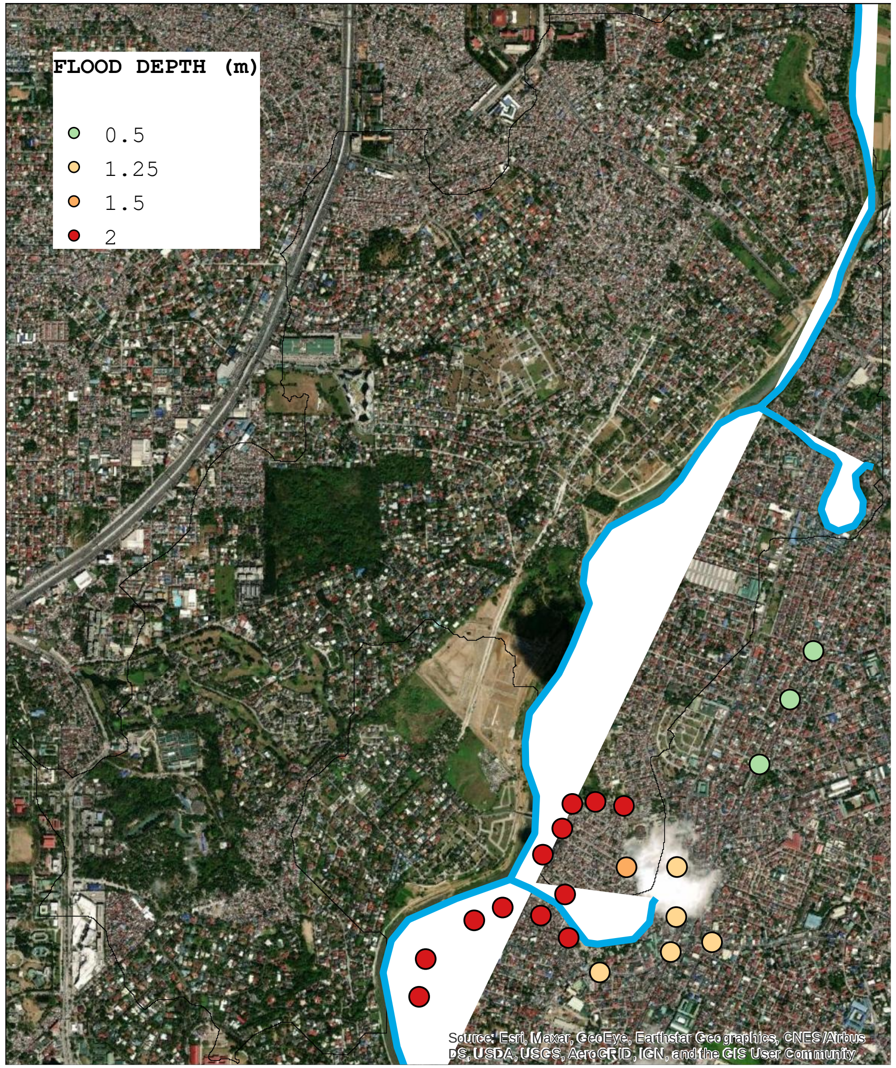
- Predominant flow is observed within the principal pipe
- Weakened/backflows are observed in:
  - Chokepoint pipe junctions
  - Pipes with lesser steep slope
  - Upstream connecting pipe is perpendicular to the receiving pipe

Flood validation 2020 Case event



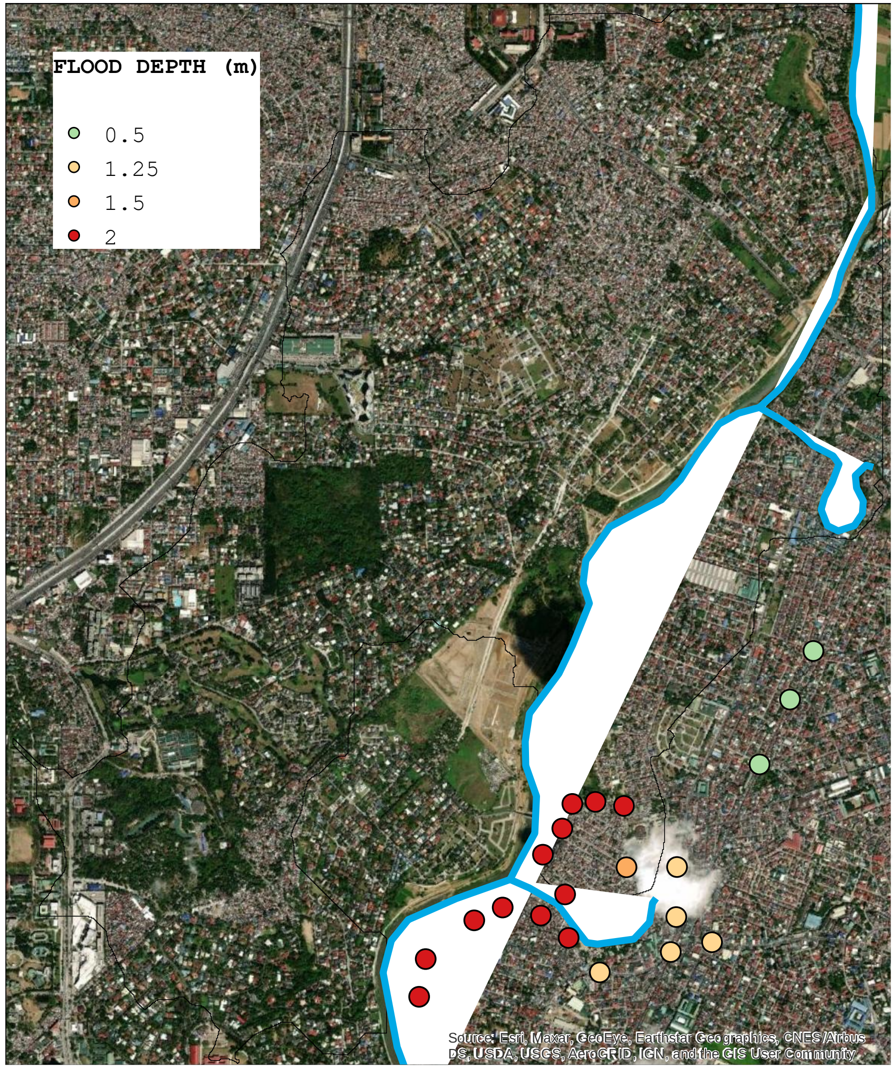
	District		Street	Maximum height	Peak	Flood time	Image
1	Bench	Tumana	Pipino, Mais	tuhod sa 2nd floor			
2		Tanong	Manggahan st	dibdib			Image 1
3	Paula	Tanong	Providence village, Anne st.	20 ft	10-11am		Image 2
4		Malanday	Malaya st	2nd floor	6am		
5		Tumana	Dona Petra	2nd floor			Image 3
6		Conception Uno	Shoe avenue	gutter deep	10:30 AM		
7		Conception Uno	Libis	balikat			
8		San roque	Midtown subd, dragon st	dibdib			
9		Malanday	Purok 4	bewang second floor			
10		Malanday	Bouganvilla	bubong			Image 4
11		Tumana	Bagong Farmers 1	step 1 from 2nd floor			
12	Robert	Dela Pena	Flores st	leeg	noon		Image 7
13			Providence, Austin St	bewang second floor			
14			Providence	bewang second floor			
15		Calumpang	Roxas st	bewang	noon		
16	Gema	Sto nino	sto nino highschool, agriculture st	bewang			
17	Airam	San roque	Munding ave, ignacio st, dela paz highway	dibdib			
18		Sto. Nino	Pla pla st.	1 step to 2nd floor			
19		Tanong	Providence	5m	4am		
20	Emelita	TAnong	Tuazonville, Road 3 and road 4	tuhod			
21	Ultimo	Tanong	Lopez jaena	lampas tuhod			
22	Luciano	San roque	New Marikina subd, flamingo, eagle, paralle, bacolod st.	dibdib			
23	Luciano		lark st	5ft	12nn		
24	Judea	Parang	Kaolin st. Calcite st	2 ft			
25	Shiela	Malanday	Purok 7, Dahlia st	2nd floor			
26		Barangka		lubog ang 1st floor	7am		Image 5
27	Johnardie	Tumana	singkamas	lampas 2nd floor	10-11am		
28	Janina	Conception Uno	Libis, jp rizal	dibdib. Lampas tao	10-11am	subside 3-4pm	Image 6
29	Elsa	Tumana	Ampalaya	2nd floor			
30	Janice	San Roque	eagle st, new marikina	4ft			

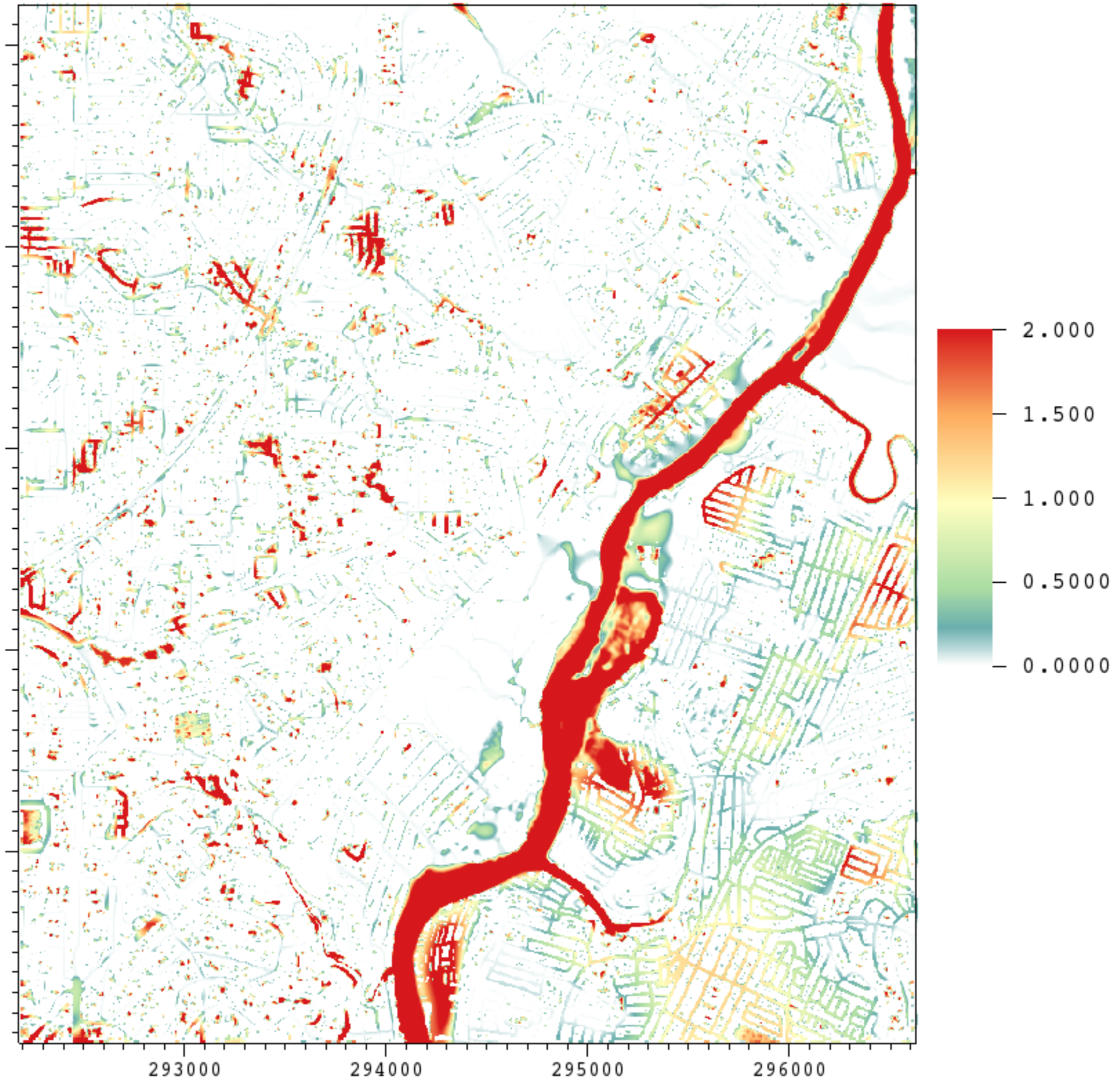
Flood validation
2020 Case event



Flood validation 2020 Case event

Simulated maximum flood depth





ANALYSIS:

1. Simulations with sewer integration generates more realistic inundation
2. Simulated flood depth is sensitive to changes in DEM
3. Higher order sewer network is recommended

Sewer pipe model: Analysis summary

- Model can simulate recession of flood in surfaces connected to the sewer pipes
- Increase in river extent is observed when applying sewer simulation
- Surcharge is expected for bottleneck pipes, slope with smaller values and when upstream pipe is perpendicular to the receiving pipe
- Accuracy of flood is sensitive to small changes in DEM

Thank you for listening.

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