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Overview of the Stormwater Management Model

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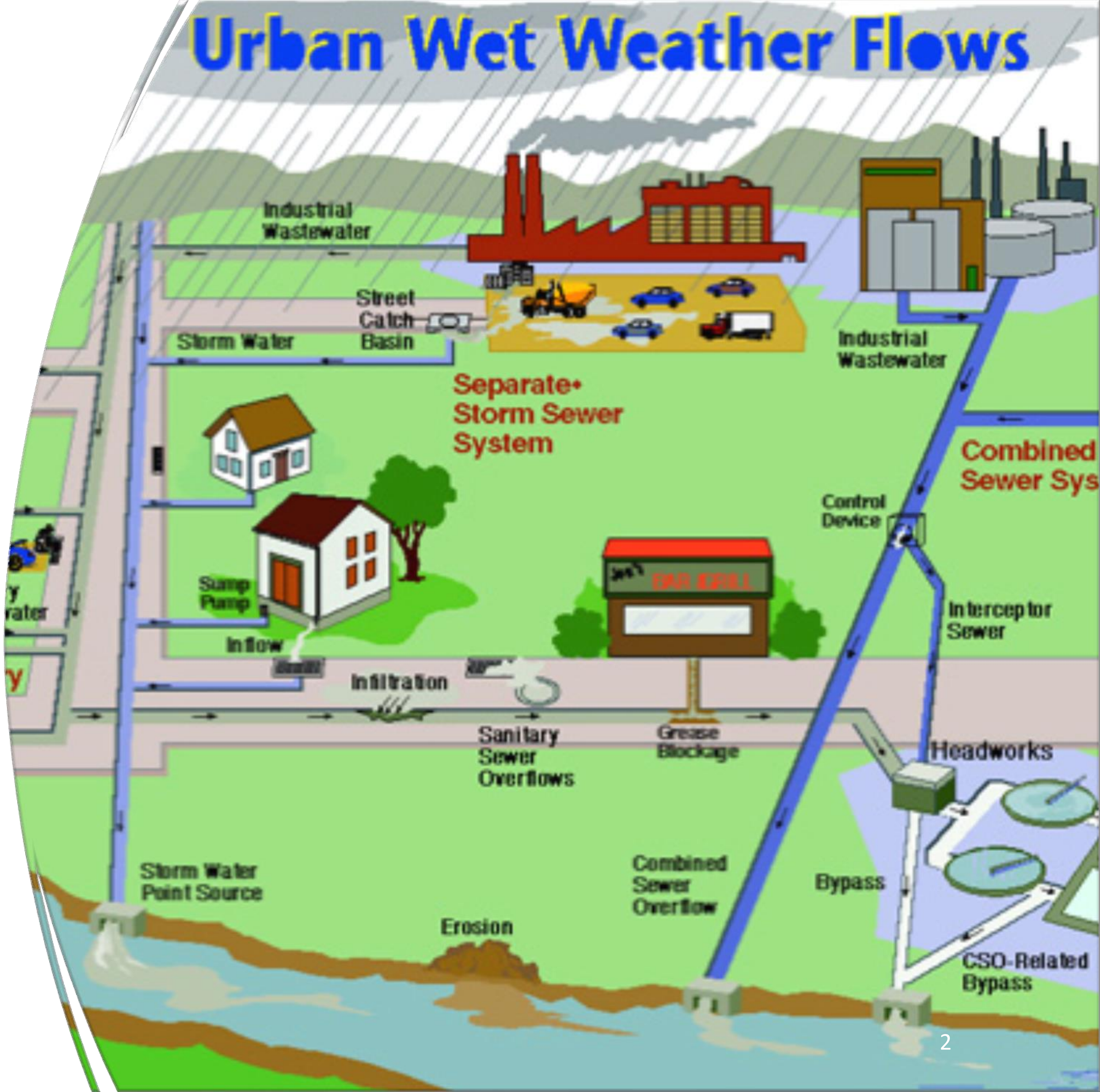
What is the EPA Stormwater Management Model (SWMM)?

- Dynamic rainfall-runoff simulation model
  - Event or continuous simulation
  - Runoff quantity and quality
- Hydrologic components of sub-catchments and groundwater modules receive precipitation (other meteorologic inputs) and estimate runoff quantity and quality
- Runoff can be routed through built collection infrastructure (e.g., pipes, storage/treatment assets, pumps, and control structures) and open channels







What can SWMM be used for?

- Design, sizing, and placement of draining system infrastructure
  - Both traditional gray infrastructure
  - As well green /nature-based infrastructure/ low impact development and best management solutions
- Modeling inflow and infiltration
- Nonpoint and point source pollutant loadings for load allocation studies
- Control of combined and sanitary sewer overflows and other stormwater pollutants
- Flood inundation modeling studies
- Digital twins of collection systems for real time decision support applications

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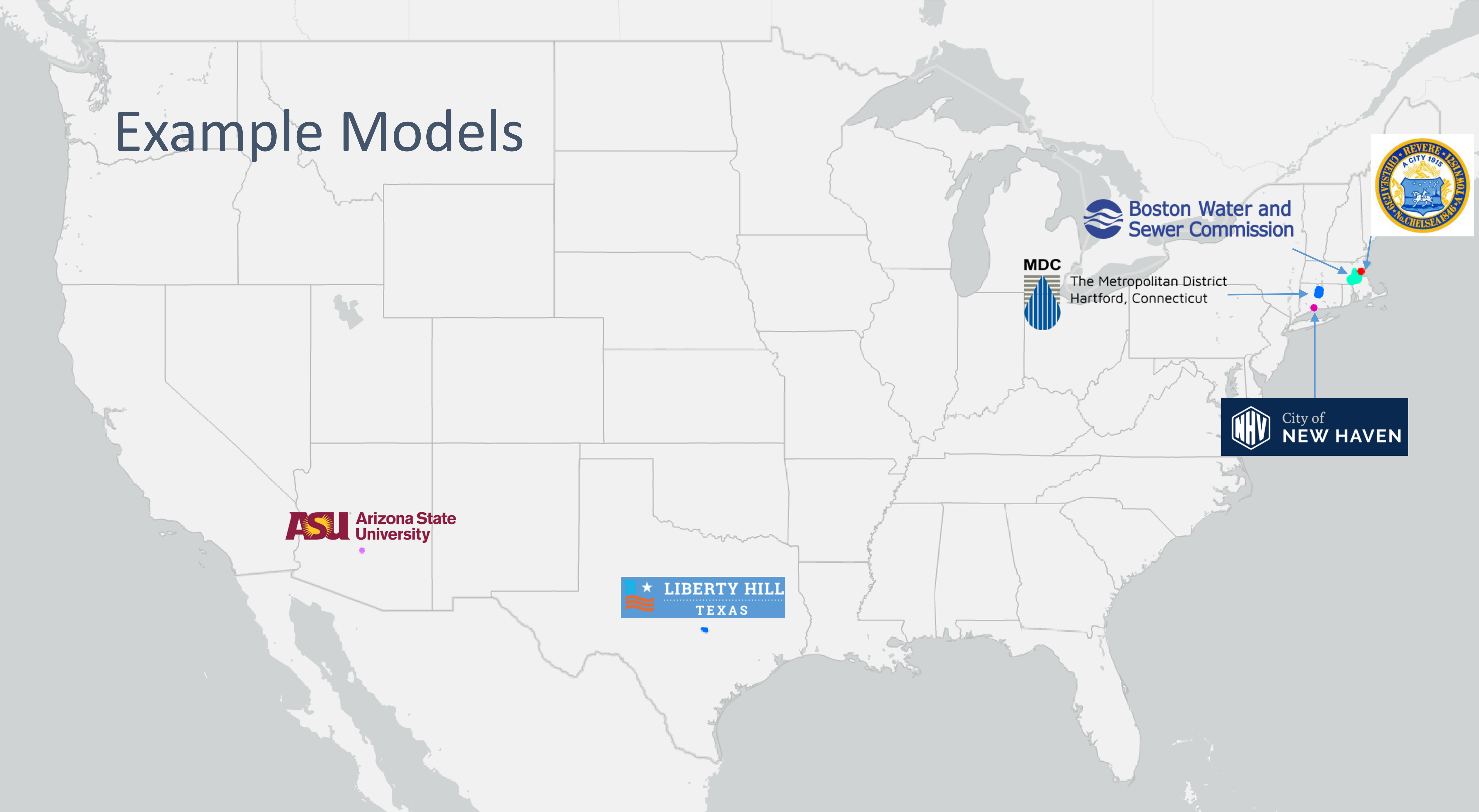
What does SWMM currently not do well very well?

- Watershed level studies including irrigated agricultural
- Subsurface and LID water quality routing
- Feedback between built and overland flow
- Sediment routing
- Explicit water quality routing with multi-species reactions
- No in-built tools for parameter estimation, uncertainty assessment, sensitivity analysis, etc
- No in-built tools for infrastructure and operational optimization

Case Studies

Example Models



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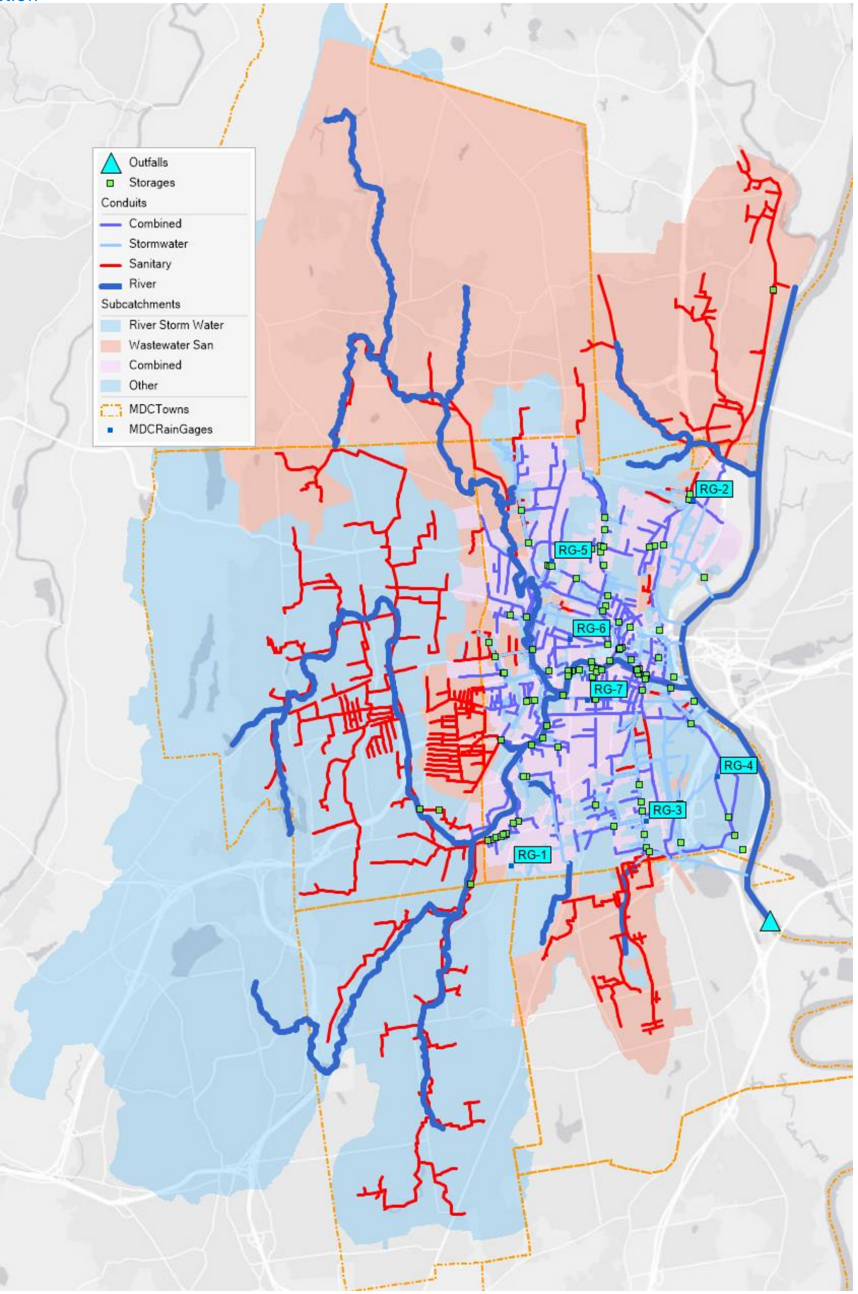
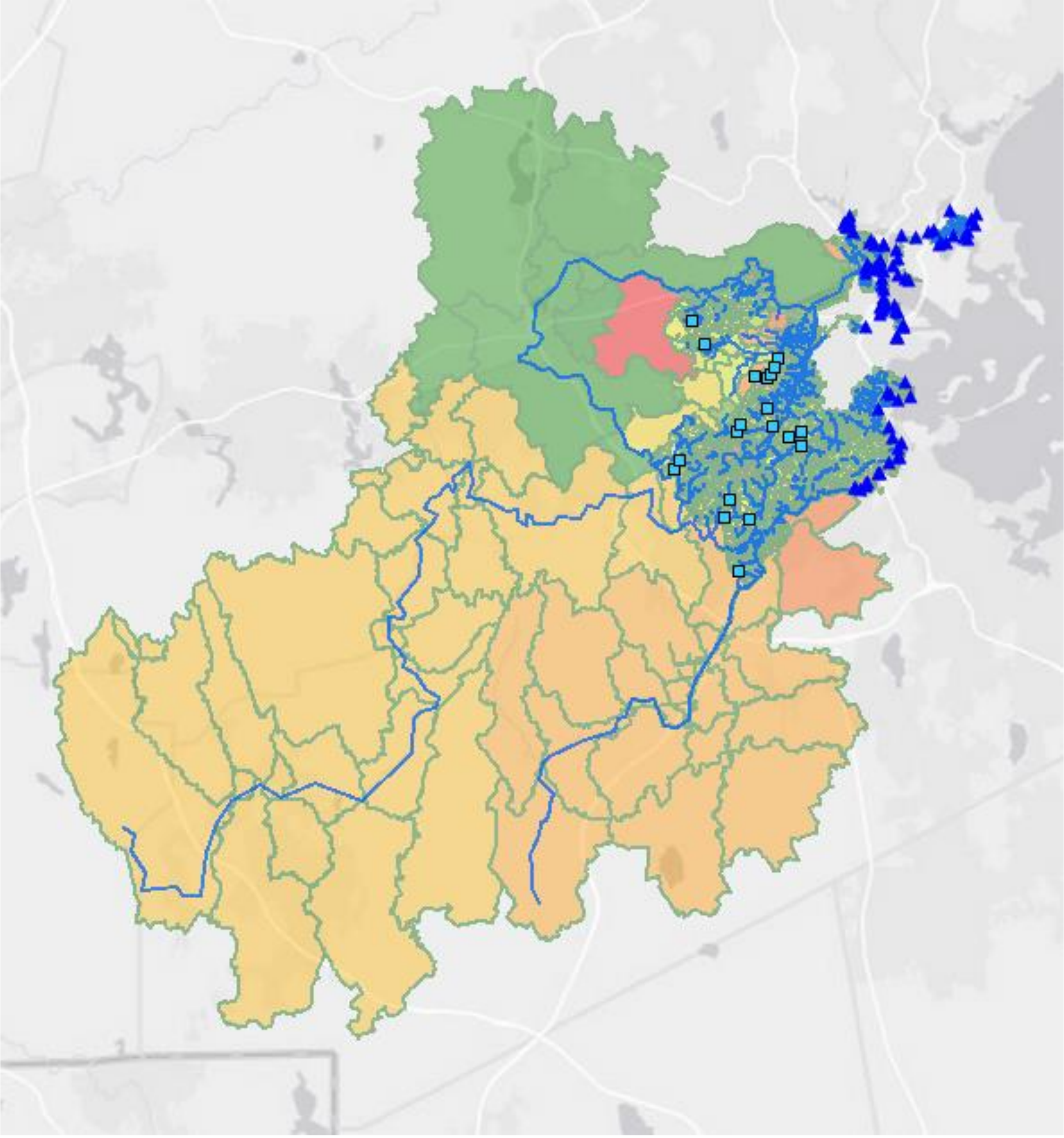
CSO/SSO: Hartford, Conn.



Water quality: Boston



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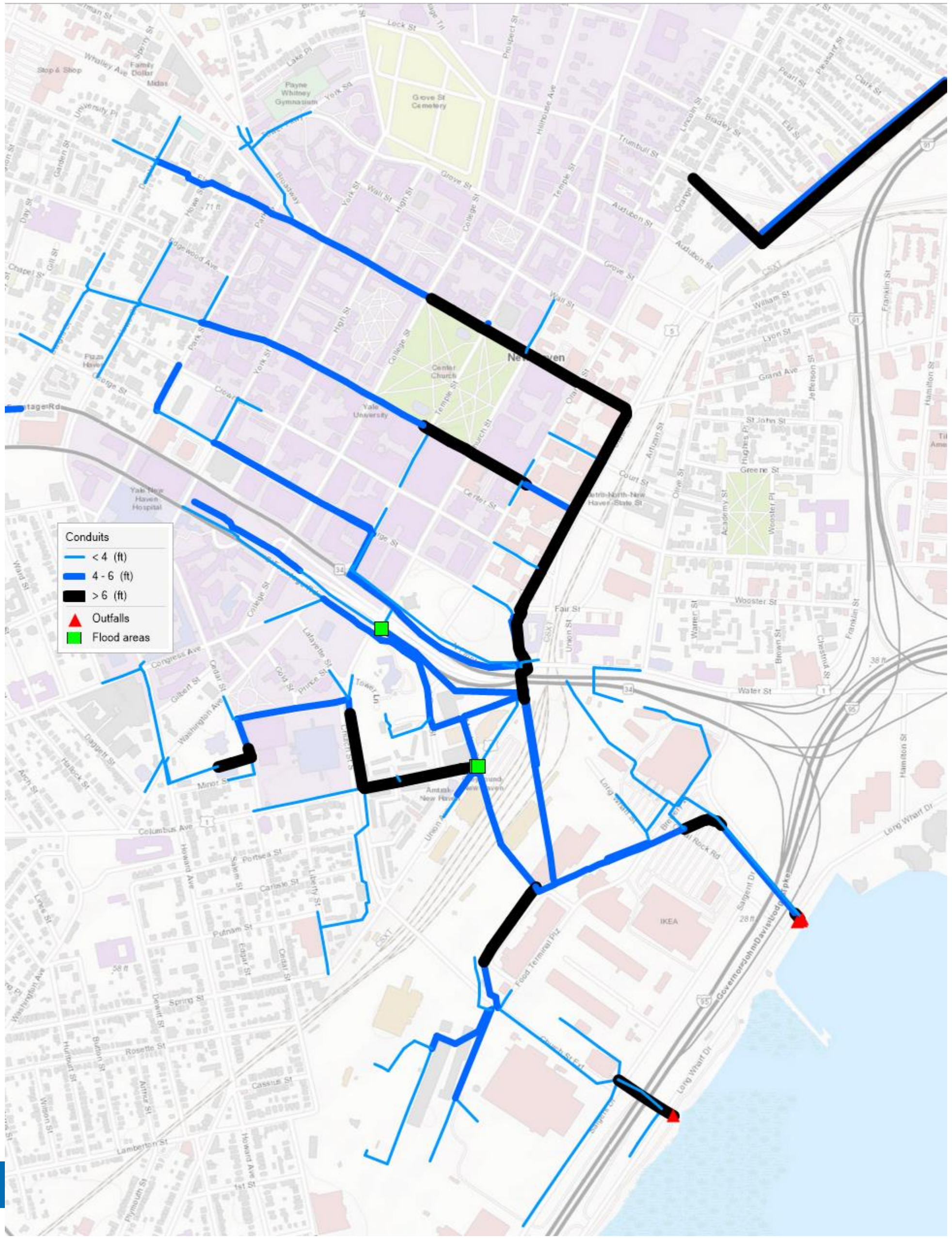
Flood control: New Haven, Conn.



Drainage design: Revere, Mass.

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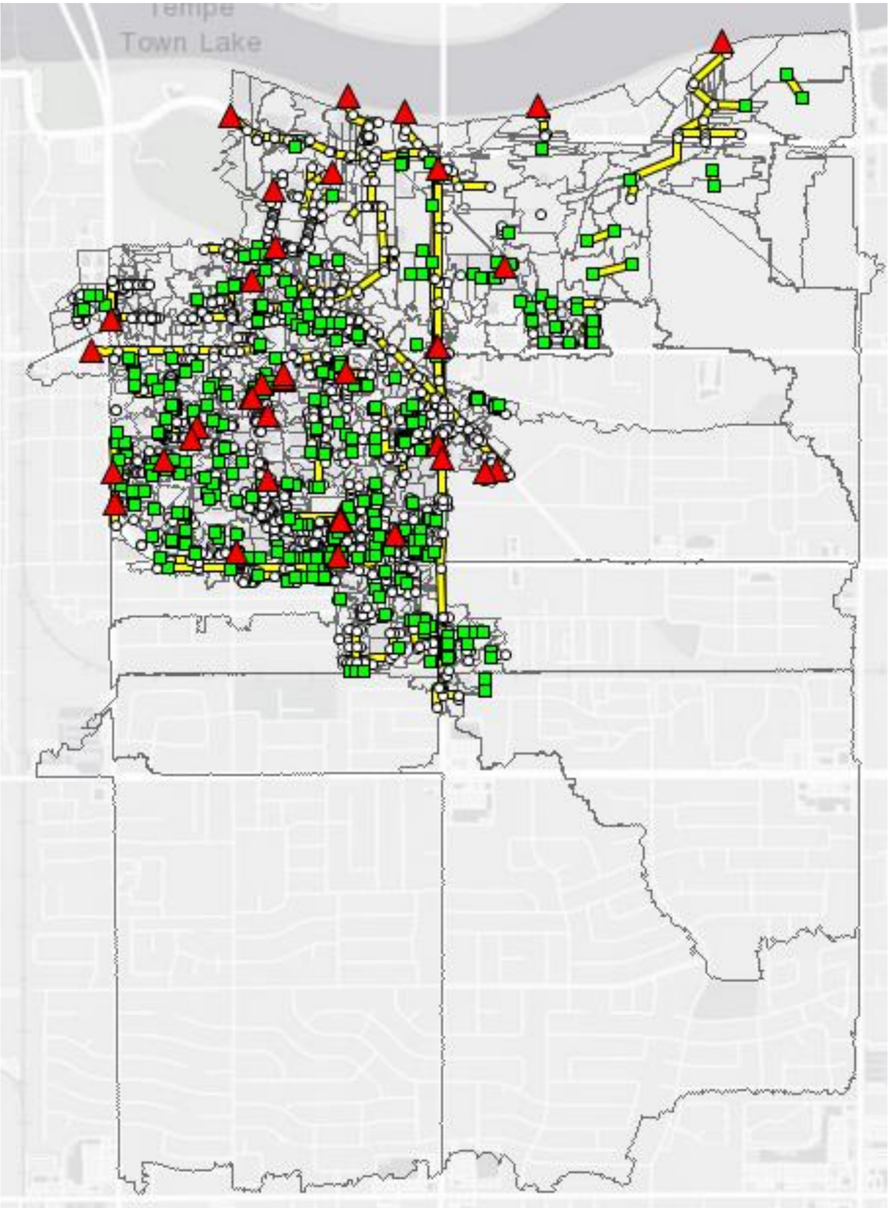
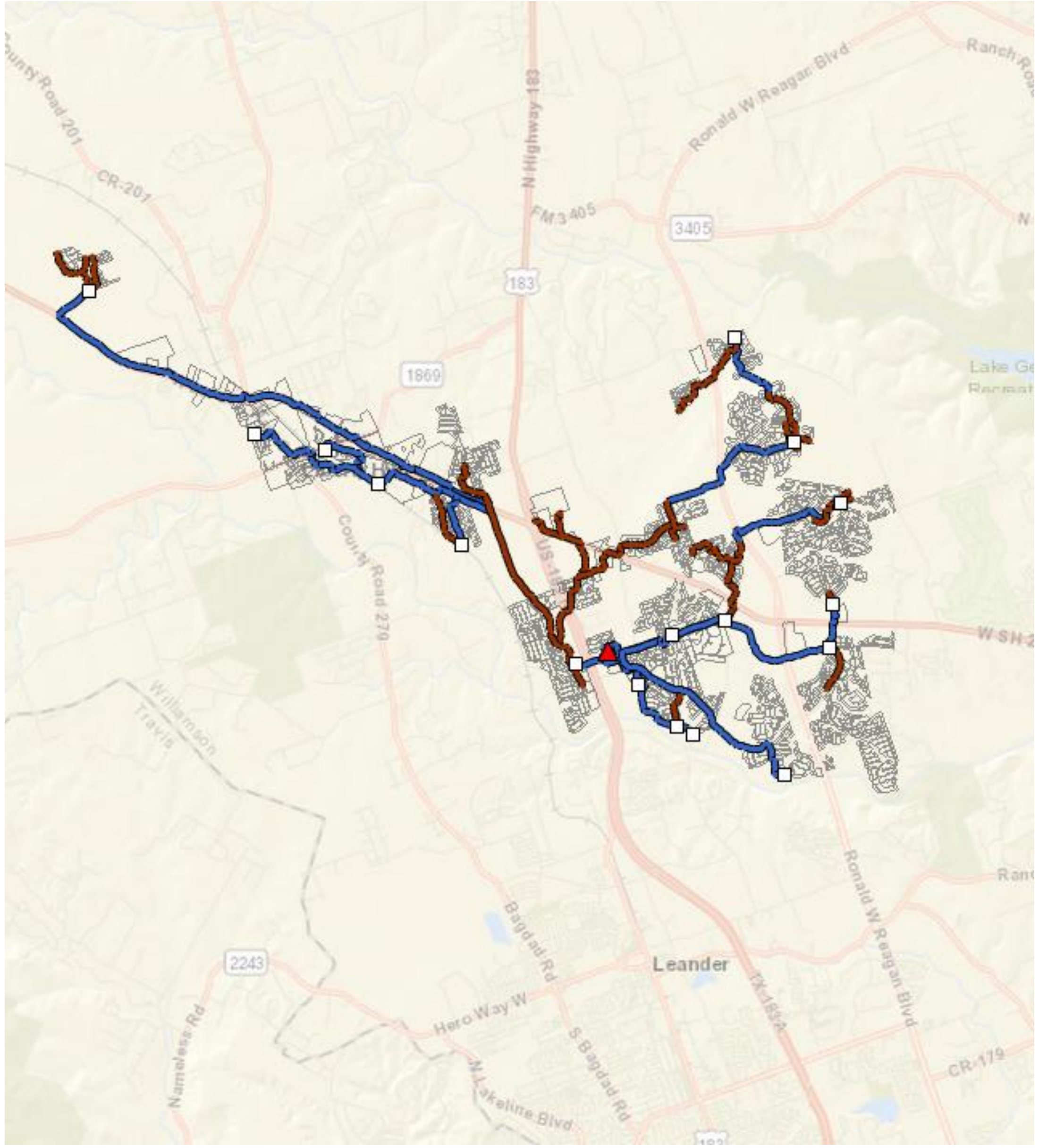
Drainage design: Arizona State U.



Sanitary sewer planning: Liberty Hill, Texas



Feature	Arizona State U.	Liberty Hill	New Haven	Hartford	Boston	Revere
Purpose	Drainage design	Sanitary sewer planning	Flood control	CSO / SSO / Flood control	Water quality	Drainage design
Design condition	10-yr & 100-yr	2-yr	10-yr / 1-yr tide	various	annual	10-yr
Model domain (ha)	1,100	1,700	400	18,000	110,000	8
Subcatchments	1,400	170	1,500	4,000	3,700	130
Nodes	2,100	800	500	5,200	4,400	70
Outfalls	40	1	18	1	80	2
Real-time control				✓	✓	
Streets/inlets						✓
Open channel flow				✓	✓	
Groundwater				✓	✓	
Infiltration/inflow		✓		✓		
Low impact development			✓			
Infiltration galleries	✓					
Water quality					✓	
Long-term simulation				✓	✓	
Climate change			✓			

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Fundamentals of SWMM5 Hydraulic Routing Formulations

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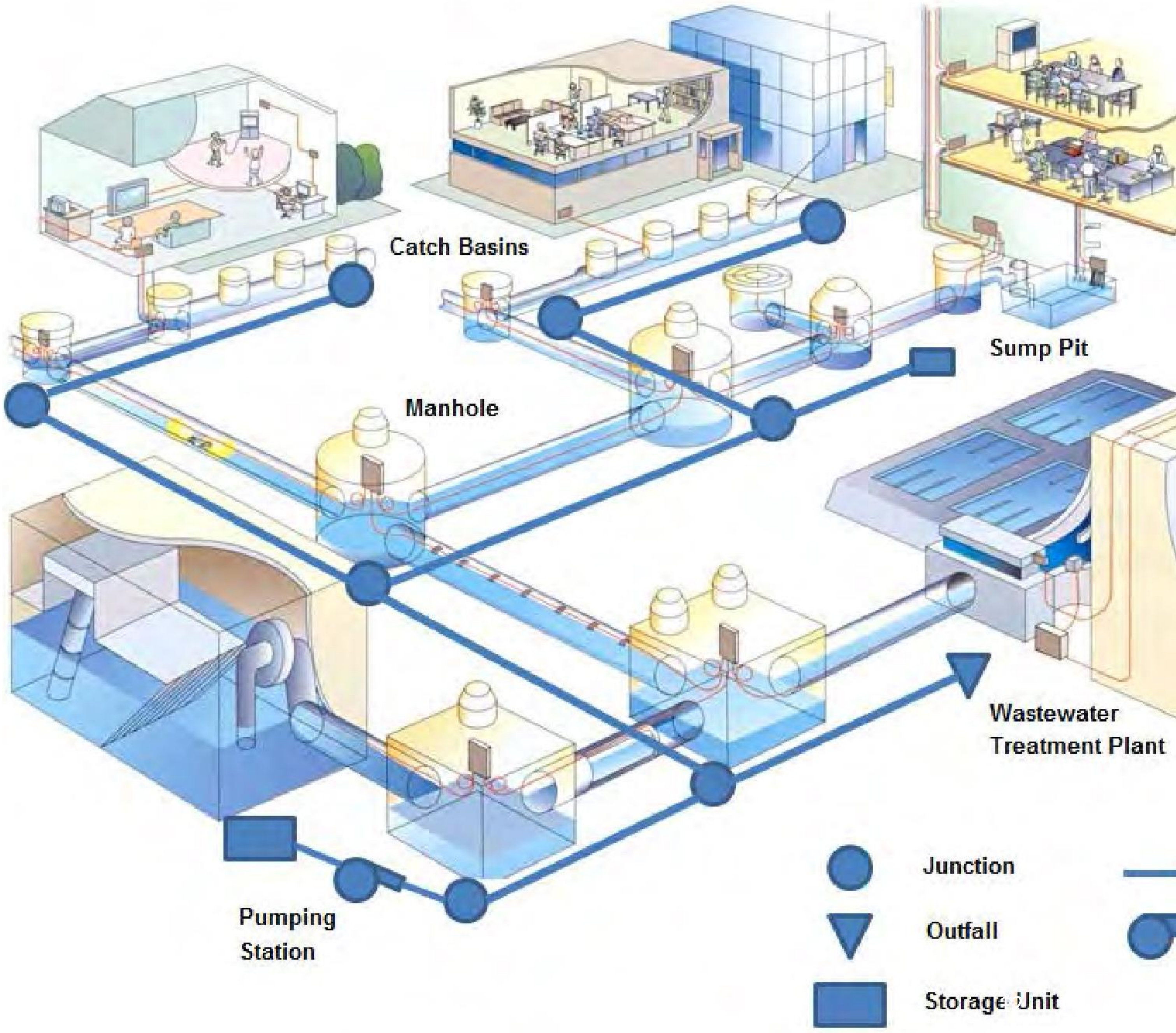
Center for Environmental Solutions and Emergency Response

Water Infrastructure Division

SWMM Hydraulic Routing Conceptualization

- Node-link network representation of built component of collection system infrastructure
- Nodes:
  - Junctions (maintenance holes)
  - Outfalls
  - Flow divider
  - Storage units
- Links
  - Conduits
  - Channels with irregular and regular cross-sections
  - Pumps
  - Orifices
  - Weirs
  - Outlets



Governing Equations

Continuity

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

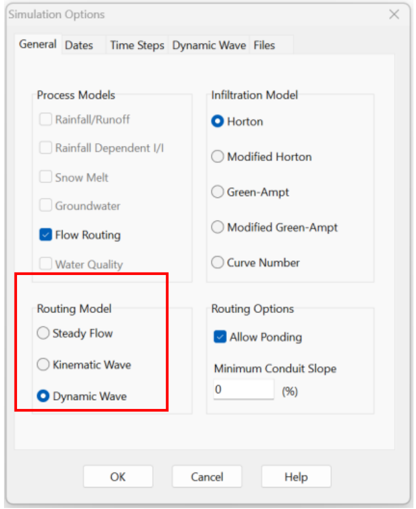
Momentum

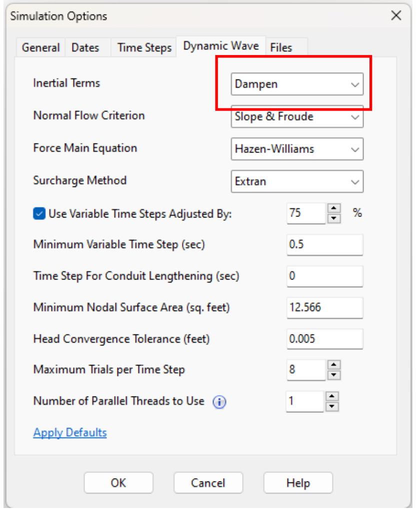
$$\underbrace{\alpha\left(\overbrace{\frac{\partial Q}{\partial t}}^{\text{Local acceleration}} + \overbrace{\frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x}}^{\text{Convective acceleration}}\right)}_{\text{Inertial component}} + \overbrace{gA\frac{\partial h}{\partial x}}^{\text{Pressure}} + gA\left(\overbrace{S_f}^{\text{Friction}} - \overbrace{\frac{\partial Z}{\partial x}}^{\text{Gravity}}\right) = 0$$

Dynamic Wave

Diffusive Wave

Kinematic Wave





- One-dimensional flow
- Hydrostatic pressure dominates with negligible vertical acceleration
- Bottom slope of channel/pipe is small
- Mannings equation describes resistance effects
- Incompressible flow

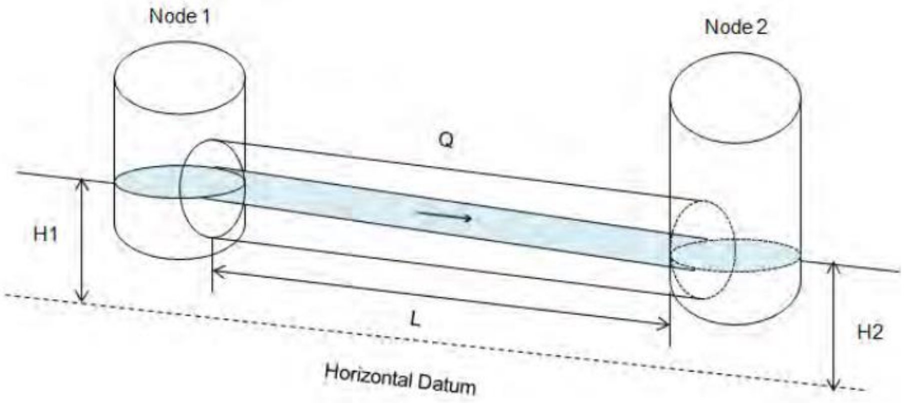
Numerical Approximations – Spatial Derivatives

- First order upwind differencing used for spatial derivates

$$\frac{\partial A}{\partial x} = \frac{A_{Upstream} - A_{Downstream}}{L}$$

$$\frac{\partial H}{\partial x} = \frac{H_{Upstream} - H_{Downstream}}{L}$$

- Very long conduits induce errors



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Numerical Approximations – Time Integration

Explicit

$$U_{n+1} = U_n + \Delta t . f(U_n, t_n)$$

- Simple and fast to implement
- Conditionally stable

Implicit

$$U_{n+1} = U_n + \Delta t . f(U_{n+1}, t_{n+1})$$

- Unconditionally stable
- Requires solving a system of equations at each timestep

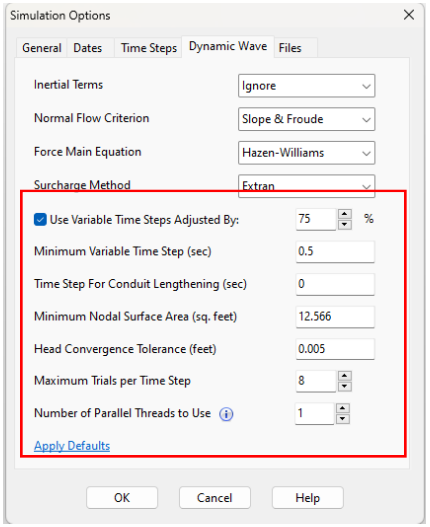
SWMM Semi-implicit

$$U_{n+1} = U_n + \Delta t . f(U_n, t_n) + \Delta t . f(U_{n+1}, t_{n+1})$$

- Splitting the difference
- Improved stability than fully explicit methods
- Stability considerations for SWMM:
  - Time step can be no longer than the time it takes for wave to travel length of conduit

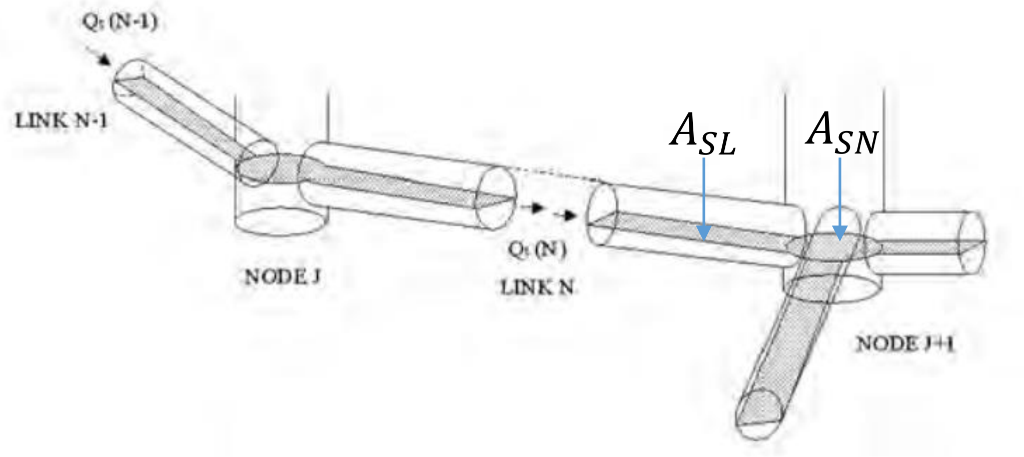
$$\Delta t \leq \frac{L}{|\overline{U} + c|}$$

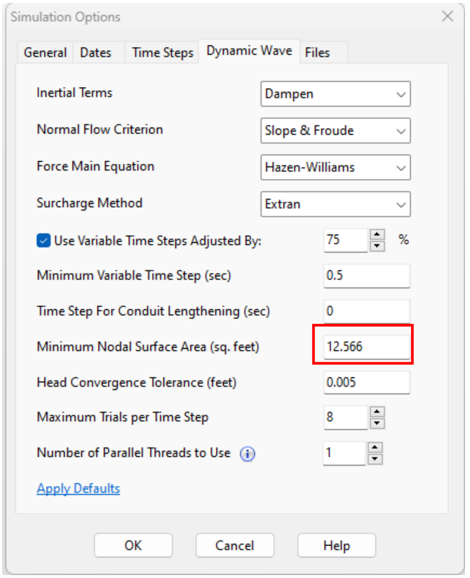
```
*************************
Routing Time Step Summary
*************************
Minimum Time Step           :     20.00 sec
Average Time Step           :     20.00 sec
Maximum Time Step           :     20.00 sec
% of Time in Steady State   :      0.00
Average Iterations per Step :      2.43
% of Steps Not Converging   :      2.99

*****************************
Highest Flow Instability Indexes
*****************************
Link 8060 (2)
Link 8040 (1)

*********************************
Most Frequent Nonconverging Nodes
*********************************
Node 10208 (2.99%)
Node 82309 (1.94%)
Node 80608 (1.81%)
Node 80408 (0.62%)
```



Continuity at Nodes

- For non-storage nodes minimum nodal storage area specified is applied to prevent division by zero:
  - Default = 12.566 ft^2

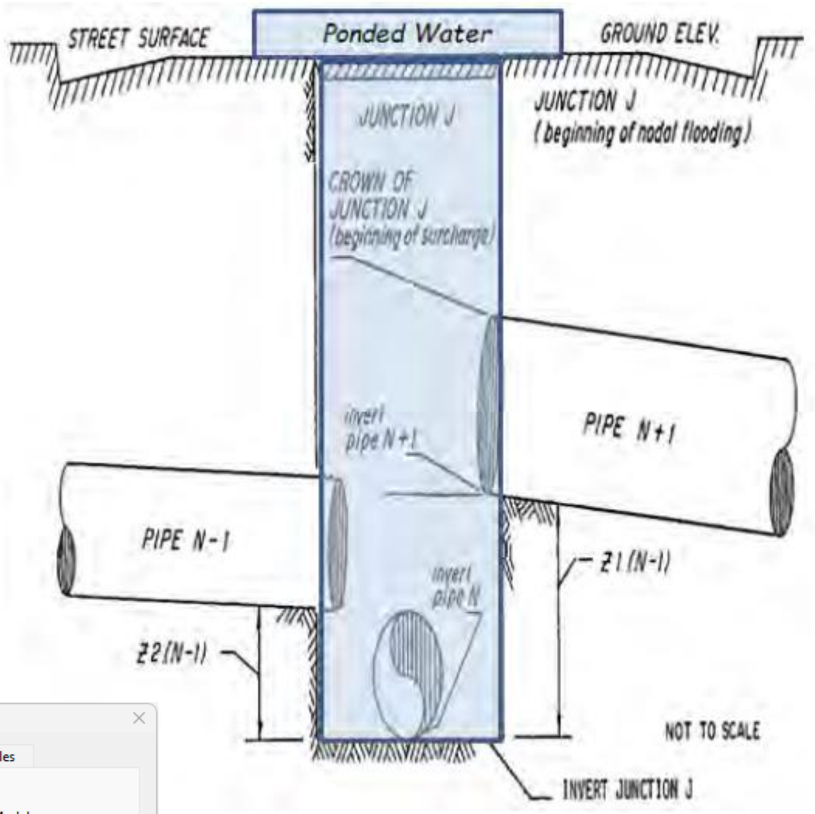


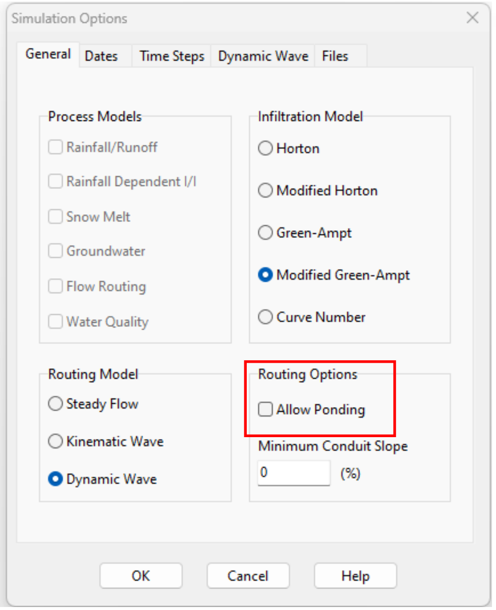


$$\frac{\partial H}{\partial t} = \frac{\sum Q}{A_{SN} + \sum A_{SL}}$$

Nodal Flooding

- Nodal surcharging - all conduits connected are full or water level exceeds the crown of the highest conduit
- Flooding can be either be configured as:
  - Loss to the system
  - Ponding over user specified area to mimic overland flooding.
    - Flows reintroduced back into the system when capacity is available





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Convergence - Continuity

$$\Delta V = V_{final} - V_{initial}$$

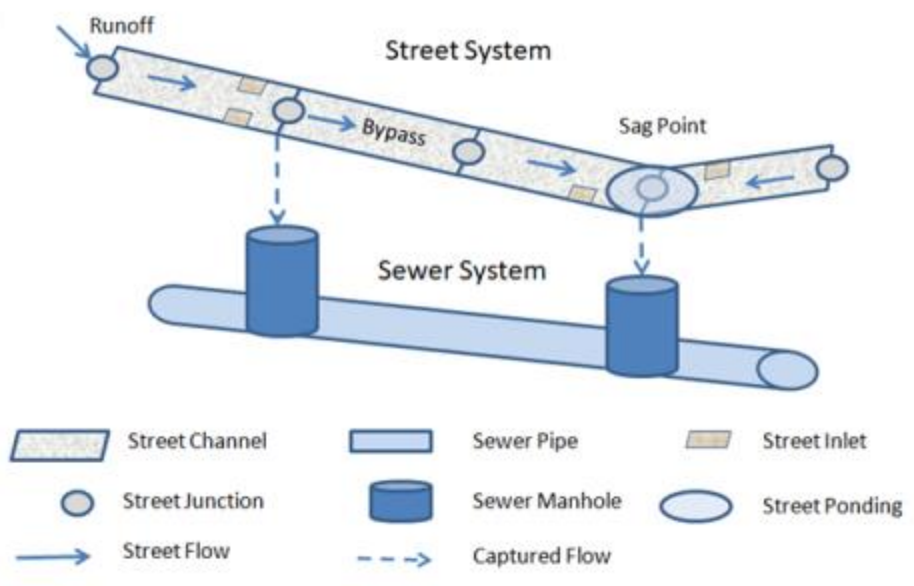
$$Continuity\ Error = \frac{\left(Q_{Inflow} - \left(Q_{Outflow} + \Delta V\right)\right)}{Q_{Inflow}} \times 100$$

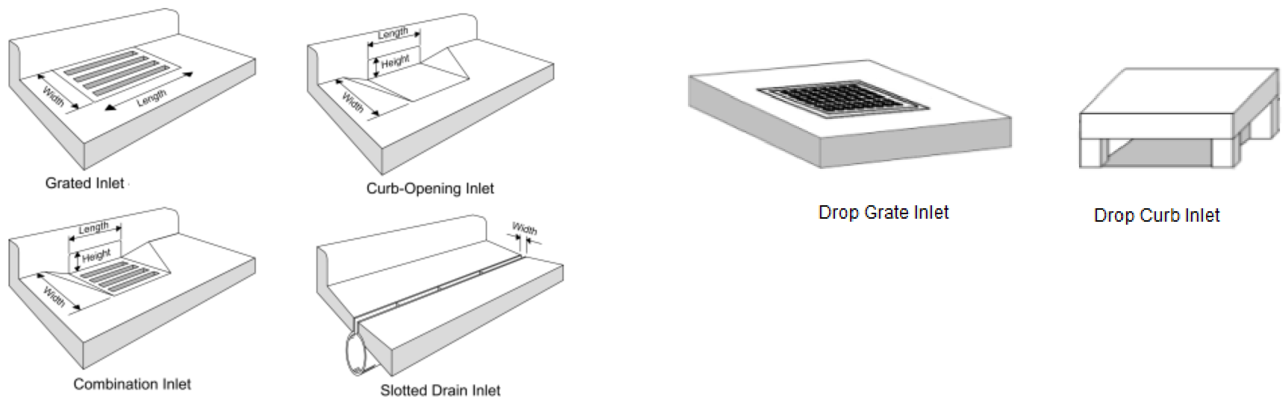
```
**************************        Volume        Volume
Flow Routing Continuity       acre-feet      10^6 gal
**************************     ---------     ---------
Dry Weather Inflow .......         0.000         0.000
Wet Weather Inflow .......         0.000         0.000
Groundwater Inflow .......         0.000         0.000
RDII Inflow ..............         0.000         0.000
External Inflow ..........        33.470        10.907
External Outflow .........        33.344        10.866
Flooding Loss ............         0.000         0.000
Evaporation Loss .........         0.000         0.000
Exfiltration Loss ........         0.000         0.000
Initial Stored Volume ....         0.000         0.000
Final Stored Volume ......         0.119         0.039
Continuity Error (%) .....         0.020


*************************
Highest Continuity Errors
*************************
Node 80608 (1.52%)
```

Advanced Features

- Evaporation from open channels and storage units
- Minor losses
- Force mains
- Culverts
- Control rules for hydraulic elements
- HEC-22 Inlet Analysis





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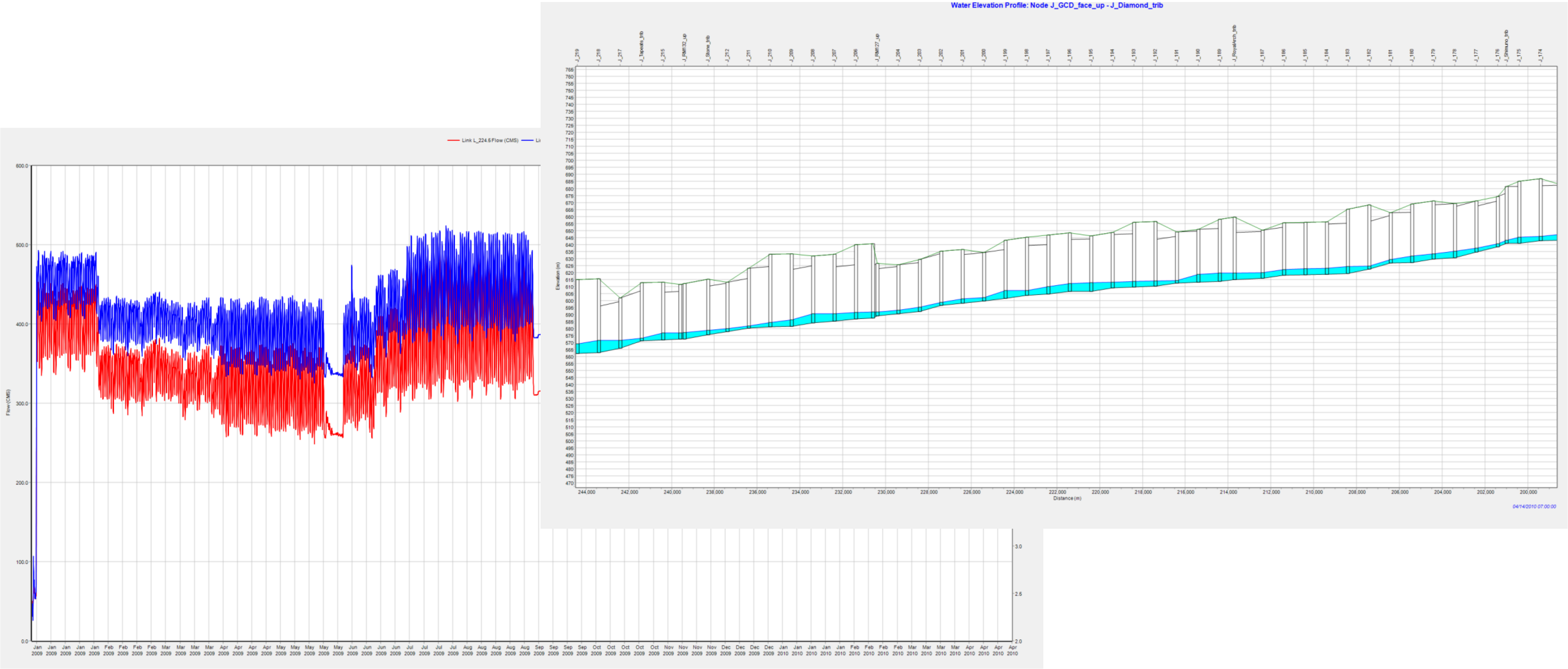
Visualizing Results



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Report Summary

Always review the report file for potential errors!

Summary Results

Topic: Node Depth — Click a column header to sort the column.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J_GCD_face_up	JUNCTION	5.47	6.76	933.76	372	19:00	6.76
J_GCD_face_down	JUNCTION	7.07	8.36	933.76	372	19:01	8.36
J_-24.5	JUNCTION						
J_-23.5	JUNCTION						
J_-22.5	JUNCTION						
J_-21.5	JUNCTION						
J_-20.5	JUNCTION						
J_-19.5	JUNCTION						
J_-18.5	JUNCTION						
J_-17.5	JUNCTION						
J_-16.5	JUNCTION						
J_-15.5	JUNCTION						
J_-14.5	JUNCTION						
J_-13.5	JUNCTION						
J_-12.5	JUNCTION						

Summary Results

Topic: Node Inflow — Click a column header to sort the column.

Node	Type	Maximum Lateral Inflow CMS	Maximum Total Inflow CMS	Day of Maximum Inflow	Hour of Maximum Inflow	Lateral Inflow Volume 10^6 ltr	Total Inflow Volume 10^6 ltr	Flow Balance Error %
J_GCD_face_up	JUNCTION	549	549	369	07:00	1.32e+07	1.32e+07	0.001
J_GCD_face_down	JUNCTION	0.335	548	369	07:00	7.56e+03	1.32e+07	0.001
J_-24.5	JUNCTION	0.478	545	369	07:03	1.08e+04	1.32e+07	0.002
J_-23.5	JUNCTION							
J_-22.5	JUNCTION							
J_-21.5	JUNCTION							
J_-20.5	JUNCTION							
J_-19.5	JUNCTION							
J_-18.5	JUNCTION							
J_-17.5	JUNCTION							
J_-16.5	JUNCTION							
J_-15.5	JUNCTION							
J_-14.5	JUNCTION							
J_-13.5	JUNCTION							
J_-12.5	JUNCTION							

Summary Results

Topic: Link Flow — Click a column header to sort the column.

Link	Type	Maximum |Flow| CMS	Day of Maximum Flow	Hour of Maximum Flow	Maximum |Velocity| m/sec	Max / Full Flow	Max / Full Depth
BR1	CHANNEL	548	369	07:00	5.64	0.00	0.03
L_-24.85	CHANNEL	544	369	07:03	5.34	0.00	0.03
L_-24	CHANNEL						
L_-23	CHANNEL						
L_-22	CHANNEL						
L_-21	CHANNEL						
L_-20	CHANNEL						
L_-19	CHANNEL						
L_-18	CHANNEL						
L_-17	CHANNEL						
L_-16	CHANNEL						
L_-15	CHANNEL						
L_-14	CHANNEL						

Summary Results

Topic: Flow Classification — Click a column header to sort the column. Flow class frequencies are fraction of all time steps.

Conduit	Adjusted/ Actual Length	Fully Dry	Upstrm Dry	Dnstrm Dry	Sub Critical	Super Critical	Upstrm Critical	Dnstrm Critical	Normal Flow Limited	Inlet Control
BR1	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-24.85	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-24	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-23	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-22	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-21	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-20	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-19	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-18	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-17	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-16	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-15	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-14	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-13	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-12	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
L_-11	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

```
Analysis Options
****************
Flow Units ............... CMS
Process Models:
  Rainfall/Runoff ........ NO
  RDII ................... NO
  Snowmelt ............... NO
  Groundwater ............ NO
  Flow Routing ........... YES
  Ponding Allowed ........ YES
  Water Quality .......... NO
Flow Routing Method ...... DYNWAVE
Surcharge Method ......... EXTRAN
Starting Date ............ 01/01/2009 00:00:00
Ending Date .............. 12/31/2018 00:00:00
Antecedent Dry Days ...... 0.0
Report Time Step ......... 01:00:00
Routing Time Step ........ 30.00 sec
Variable Time Step ....... YES
Maximum Trials ........... 8
Number of Threads ........ 12
Head Tolerance ........... 0.000100 m

**************************        Volume         Volume
Flow Routing Continuity        hectare-m       10^6 ltr
**************************     ---------      ---------
Dry Weather Inflow .......         0.000          0.000
Wet Weather Inflow .......         0.000          0.000
Groundwater Inflow .......         0.000          0.000
RDII Inflow ..............         0.000          0.000
External Inflow ..........   1519618.200   15196340.435
External Outflow .........   1512181.528   15121972.942
Flooding Loss ............         0.000          0.000
Evaporation Loss .........         0.000          0.000
Exfiltration Loss ........         0.000          0.000
Initial Stored Volume ....      2424.512      24245.369
Final Stored Volume ......     10047.401     100475.053
Continuity Error (%) .....        -0.012

*************************
Time-Step Critical Elements
*************************
Link L_214.1 (63.98%)
Link L_362 (35.69%)

********************************
Highest Flow Instability Indexes
********************************
All links are stable.

*********************************
Most Frequent Nonconverging Nodes
*********************************
Convergence obtained at all time steps.

*************************
Routing Time Step Summary
*************************
Minimum Time Step           :    11.19 sec
Average Time Step           :    19.09 sec
Maximum Time Step           :    25.05 sec
% of Time in Steady State   :     0.00
Average Iterations per Step :     2.21
% of Steps Not Converging   :     0.00
Time Step Frequencies       :
   30.000 - 13.228 sec      :   100.00 %
   13.228 -  5.833 sec      :     0.00 %
    5.833 -  2.572 sec      :     0.00 %
    2.572 -  1.134 sec      :     0.00 %
    1.134 -  0.500 sec      :     0.00 %

*****************
Analysis begun on:  Thu May 15 16:10:26 2025
Analysis ended on:  Thu May 15 16:15:50 2025
Total elapsed time: 00:05:24
```

Learning Resources

- SWMM User Manuals
  - https://www.epa.gov/water-research/storm-water-management-model-swmm
- CHI openswmm
  - https://www.openswmm.org/
- http://www.dynsystem.com/NetSTORM
- UWRI, 2023, "SWMM PowerPoint course“
  - https://doi.org/10.18738/T8/S5PU4Q
- EPA SWMM GitHub
  - https://github.com/USEPA/Stormwater-Management-Model

Contact

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GitHub

https://github.com/USEPA/Stormwater-Management-Model
https://github.com/USEPA/SWMM-GUI