Modeling for Urban Drainage Mitigation

Connecticut Association of Flood Managers
Annual Meeting – October 30, 2019

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Presentation Purpose, Goal, & Outline

Purpose:

The Question: “What model do you use for Urban Flood Mitigation Modeling”

Goal:

Provide some detail around my standard answer “It Depends”

Presentation Outline:

- Major Challenges & Complexities of Urban Flooding
- What is Modeling & why do we do it.
- Definitions and Concepts
- Models – As Tools, Applications, Limitations, and Examples
- Final Thoughts

Urban Flooding

How do you end up with a lot of water where you don't want it?

Urban flooding occurs due to:

- Insufficient collection inlets
- Insufficient pipe capacity
- Uncontained overland flow
- Storm surge
- High tides
- All the above

Major Challenges & Complexities

On June 18, 2018, Norwalk saw 2.52 inches of rainfall in 40 minutes, which aligns with a 1-2% annual chance event.

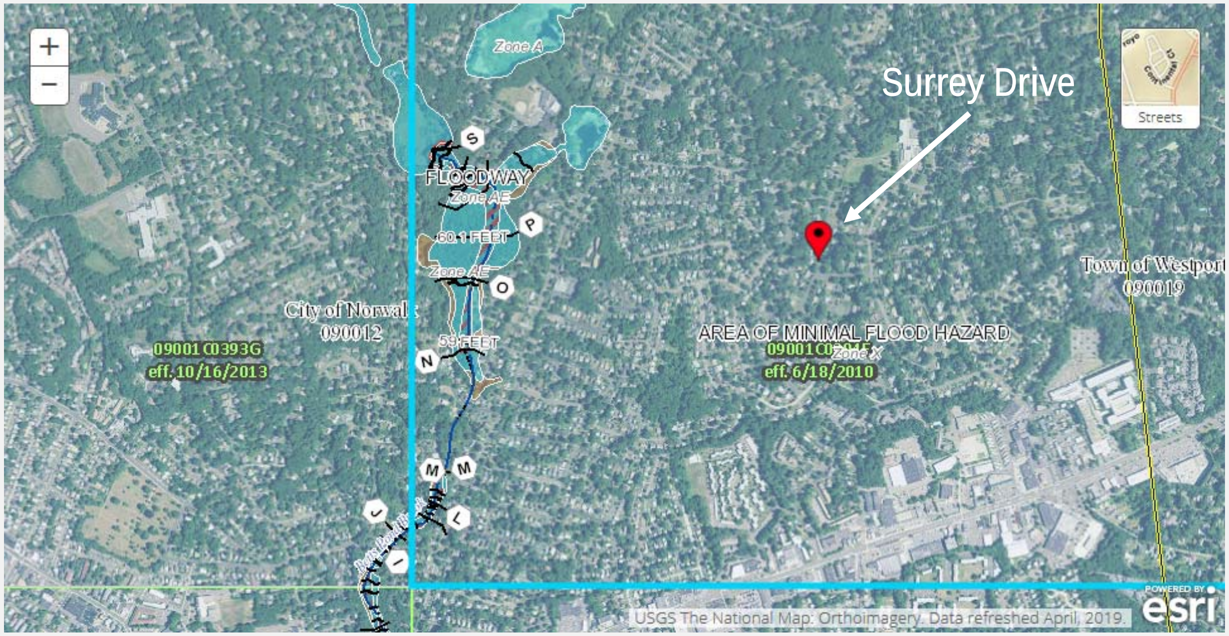
Extreme Precipitation Estimates

	5min	10min	15min	30min	60min	120min
1yr	0.33	0.51	0.63	0.83	1.04	1.30
2yr	0.41	0.63	0.78	1.01	1.27	1.58
5yr	0.47	0.73	0.91	1.22	1.57	1.98
10yr	0.52	0.82	1.04	1.41	1.84	2.34
25yr	0.61	0.97	1.23	1.71	2.27	2.93
50yr	0.69	1.11	1.42	1.98	2.67	3.46
100yr	0.78	1.26	1.63	2.31	3.14	4.11
200yr	0.88	1.44	1.87	2.68	3.70	4.87
500yr	1.06	1.74	2.27	3.29	4.61	6.10

NRCC Extreme Precipitation Estimates for Norwalk, CT

Major Challenges & Complexities

Existing flood maps are not comprehensive



We know the problem areas, but they aren't mapped.
How do we assess and address this pervasive issue?

Major Challenges & Complexities

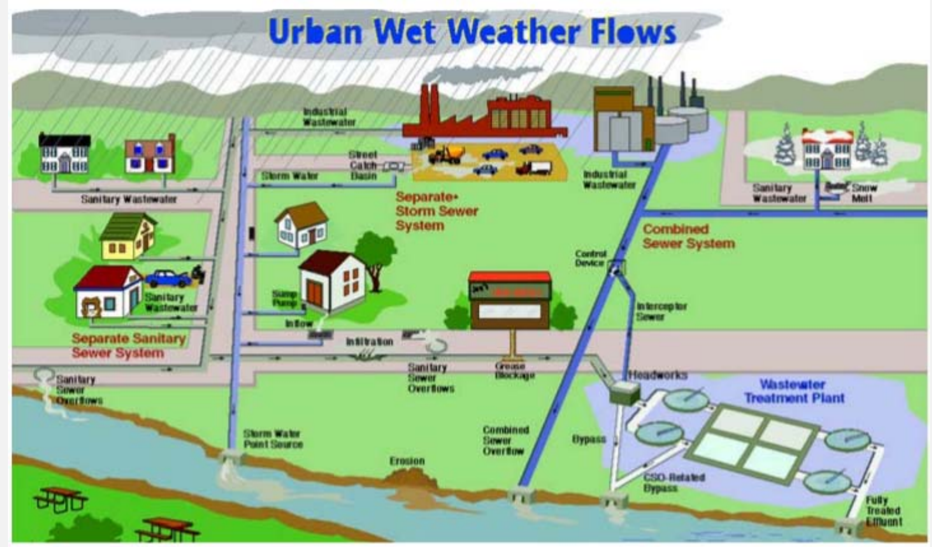
Many Urban Municipalities struggle with:

- Regular maintenance & Condition assessments
- Reliable data collection on system
- Haphazard historical approach
- Increasing storm intensity
- Sea level rise
- Public perception

What do we mean by Modeling?

Hydrology & Hydraulics (H&H) modeling is performed by **simulating real world processes** with **accounting methods and mathematic models** to **predict where, when and how water will flow.** The processes we try to simulate are: precipitation, infiltration, runoff, open channel flow, pipe flow, etc. Simulations are developed with different methods and tools that can differ in levels of complexity and sophistication. Common tools used for urban modeling are:

- HydroCAD
- HEC-RAS (Oveland)
- SWMM (Basic EPA, XPSWMM, PCSWMM, SSA, etc.) (Pipe)
- XPSWMM, InfoWorks ICM (Overland & Pipe)



WHY Model?

1. Understand Problem – The problem may be obvious, but the source is not

2. Identify Solutions – Hopefully without shifting the problem up or downstream

Different Approaches for Hydrology

- Lumped Hydrology
  - Traditional drainage catchment areas with composite runoff & infiltration parameters
- Distributed Hydrology
  - Discrete, high resolution finite elements with direct runoff & infiltration parameters
  - Routing defined by terrain
- Rainfall
  - Synthetic "design" storms or observed precipitation events

Definitions for this presentation

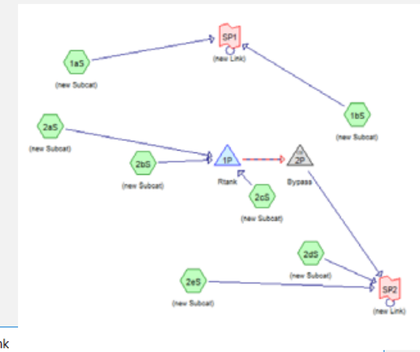
- Static or Dynamic
  - Static models are solved to an equilibrium state, solving once per time step in one direction (downstream or upstream).
  - Dynamic models are solved iteratively upstream and downstream at each time step, account for momentum and changes in flow direction
- Steady or Unsteady
  - Constant Flow
  - Varying Flow, typically achieved with hydrograph.
- 1D or 2D
  - 1D: movement is possible on 1 axis, or in only 2 directions.
  - 2D: movement is possible on 2 axes, or in infinite number of directions on a single plane for each finite element.

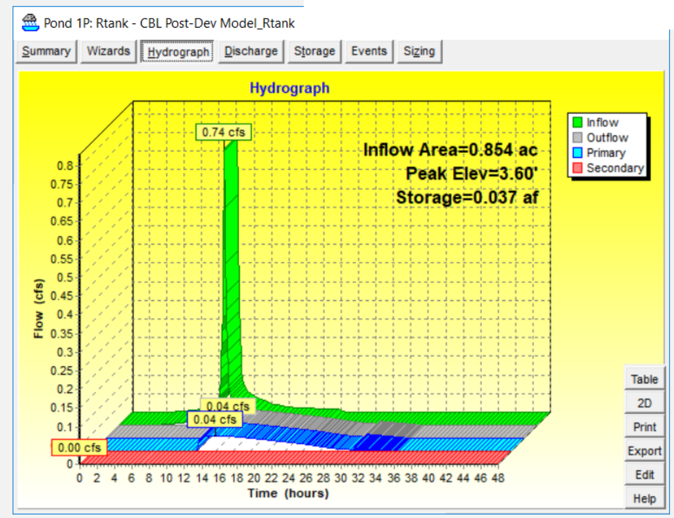
Hydraulic Mathematical Models

- Navier-Stokes Equations
  - 3D equations of motion for fluids, accounting for momentum, Coriolis effect, viscosity
- Shallow-Water Equations
  - 2D (depth integrated) equations of motion for fluids derived from Navier-Stokes Equations, accounting for momentum, Coriolis effect, viscosity
- 1D St. Venant Equations
  - Based on conservation of mass & energy
  - One dimension only assuming uniform velocity over entire cross-section
- Manning's Equation
  - Empirical open-channel flow equation relating friction, velocity, and slope, assuming fluid surface is parallel to the conduit slope

HydroCAD (H&H, 1D, One Direction, Static)

- Basis
  - Developing TR-55/TR-20 analysis using synthetic storms for hydrology
  - Uses Manning's, weir, and orifice equations for hydraulics
- Applications
  - Pre & post-development analysis for land use & bmp selection
  - Several great built-in tools for stormwater treatment bmp selection, detention systems.
  - Pump station design in simplified hydrology areas (natural depressions, polders)
- Limitations
  - Solution is not dynamic
  - Not intended for surcharged pipe or high tailwater conditions
  - Not intended for reverse flow



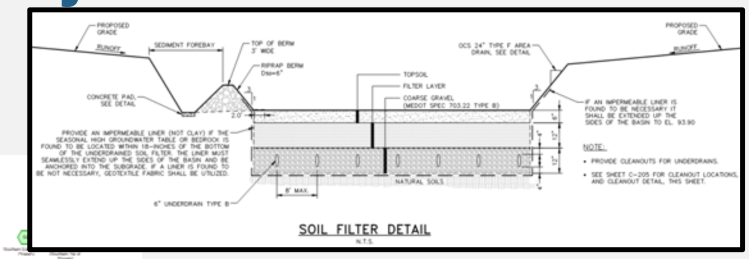


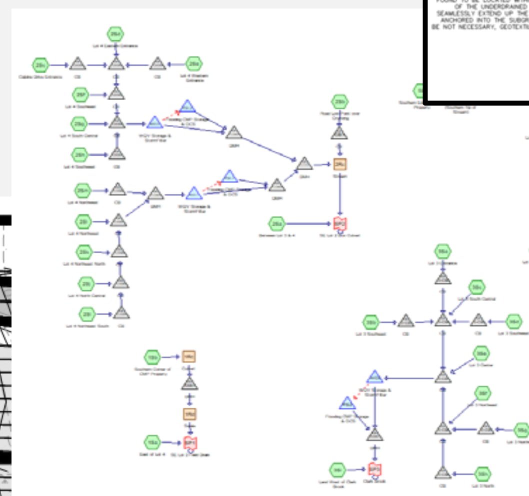
HydroCAD: Development Projects

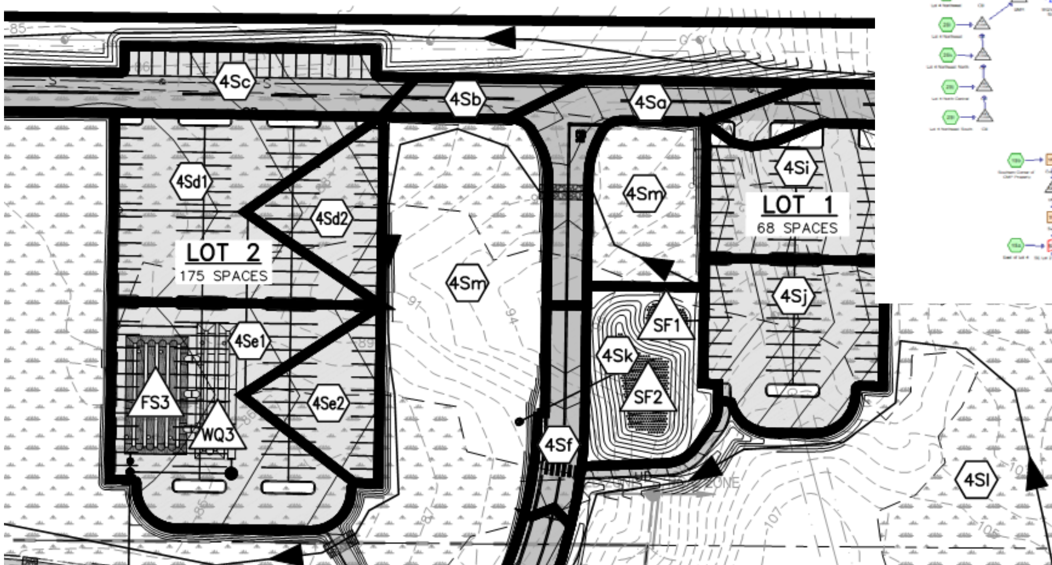
Pre & Post Development Stormwater Analysis

Site-specific Infrastructure

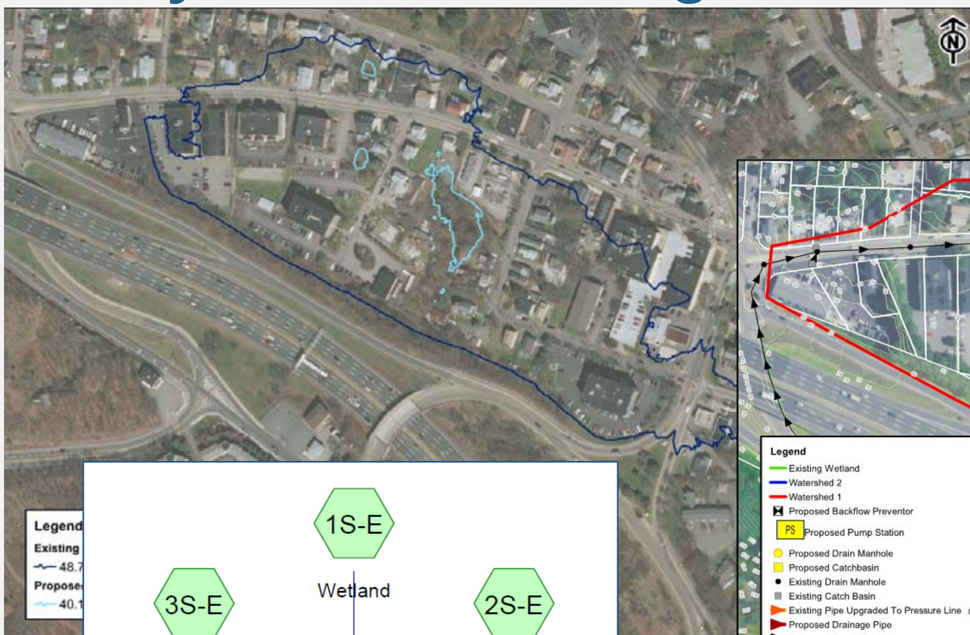
BMP Sizing

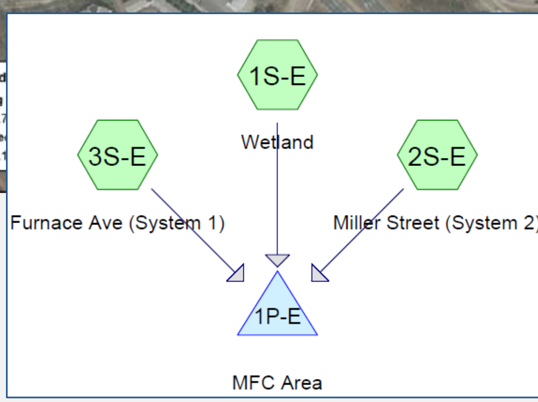


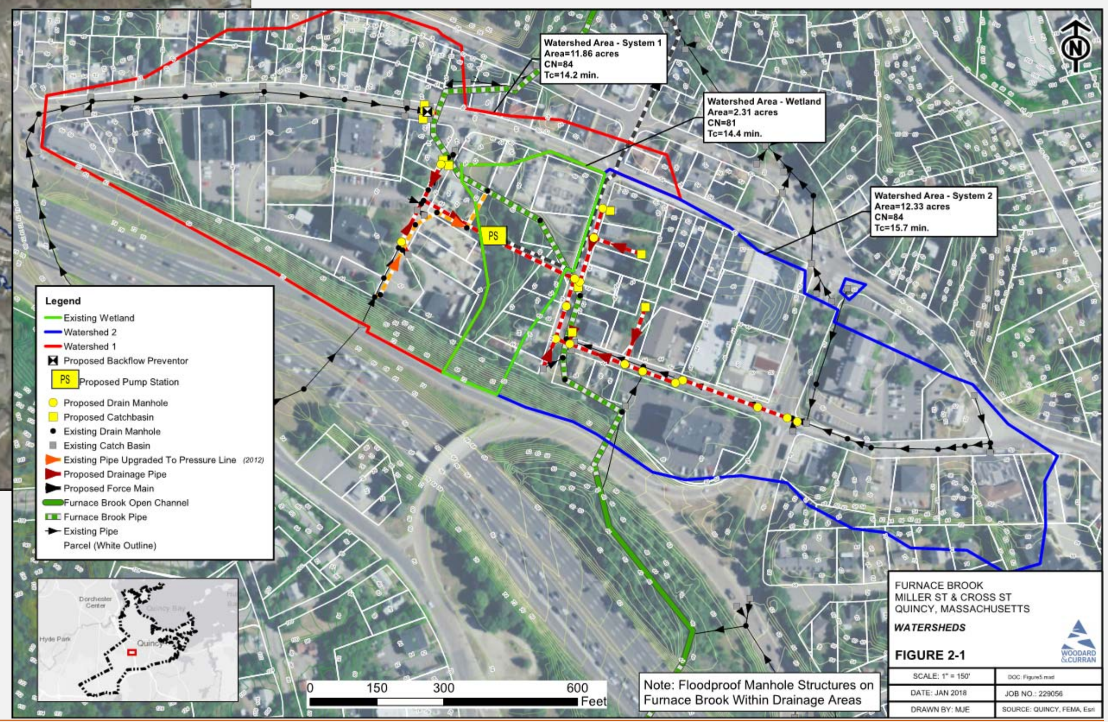




HydroCAD: Mitigation Projects

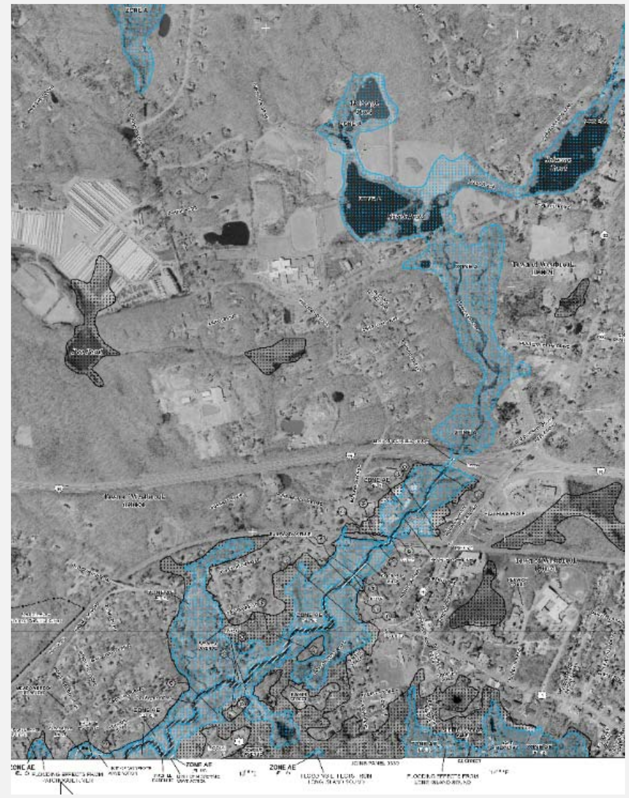






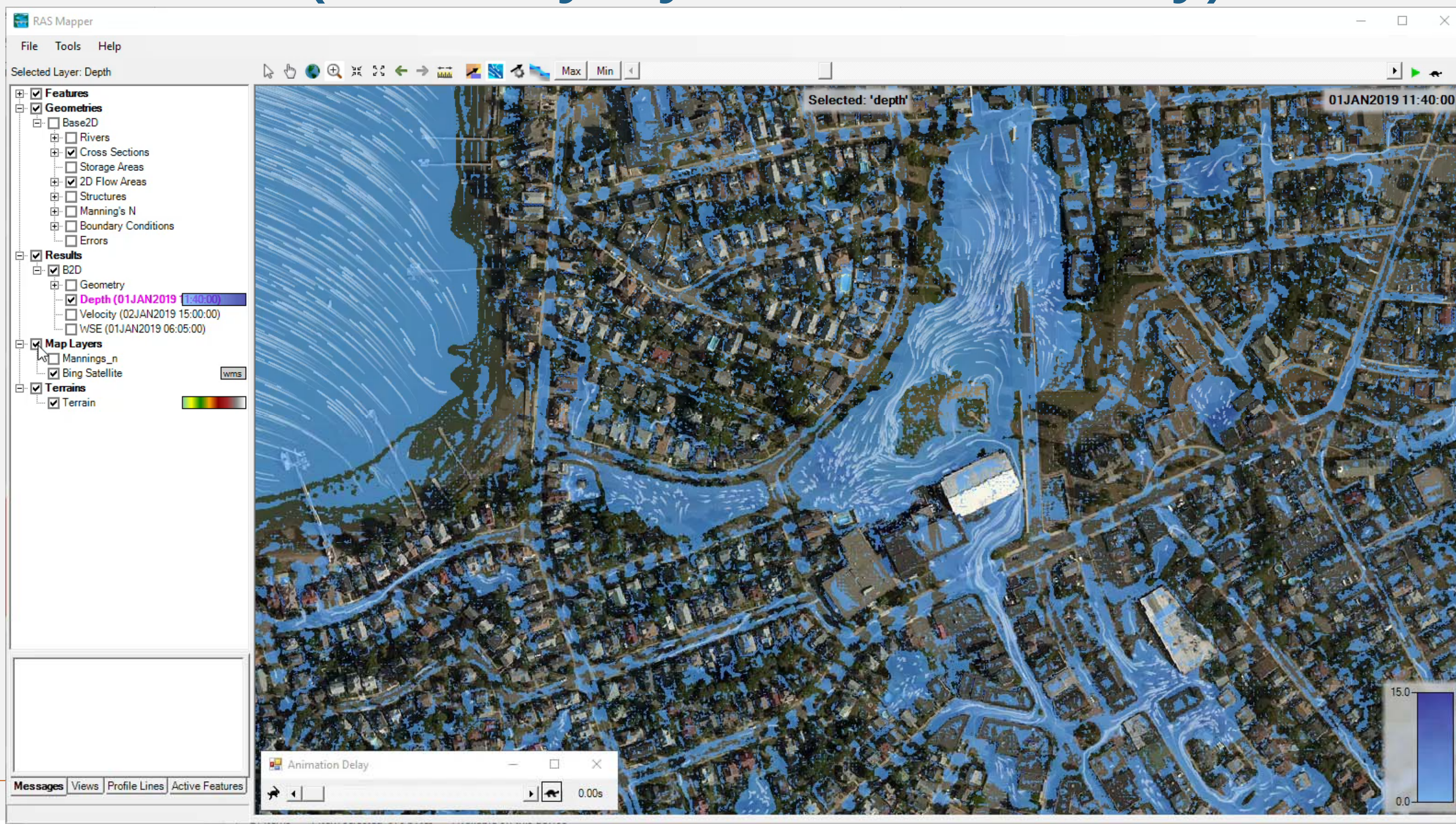
HEC-RAS (Hydraulics, Static or Dynamic, 1D/2D)

- Basis (1D)
  - 1D energy equation (St. Venant Equations)
  - Manning's equation (for friction losses)
  - Contraction/expansion losses based on velocity changes
  - Conservation of momentum for mixed regime flow (hydraulic jumps, obstructions, etc.)
- Basis (2D)
  - Finite volume analysis
  - Depth-integrated 2D energy equation (Shallow 2D Equations)
- Applications
  - River channel & floodplain mapping
  - Overland flood mapping
  - Risk mapping (inundation, depth/velocity mapping)
  - Dam breach analysis
- Limitations
  - Not coupled with hydrology model
  - Not build to simulate complex closed conduit networks, limited to simple systems and culverts



Patchogue River, Westbrook, CT
Steady State, Static, 1D, HEC-RAS

HEC-RAS (2D, Fully Dynamic, Unsteady)

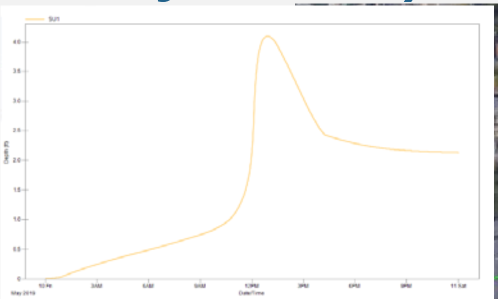


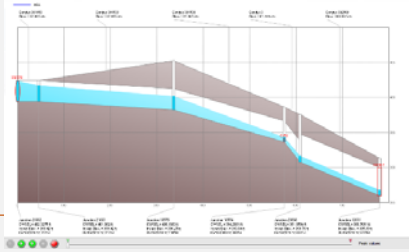
Ingleside Park – Winthrop, Massachusetts

- Extensive flooding
- Challenging topography
- Tidally influenced

EPA SWMM (H&H, 1D, Dynamic)

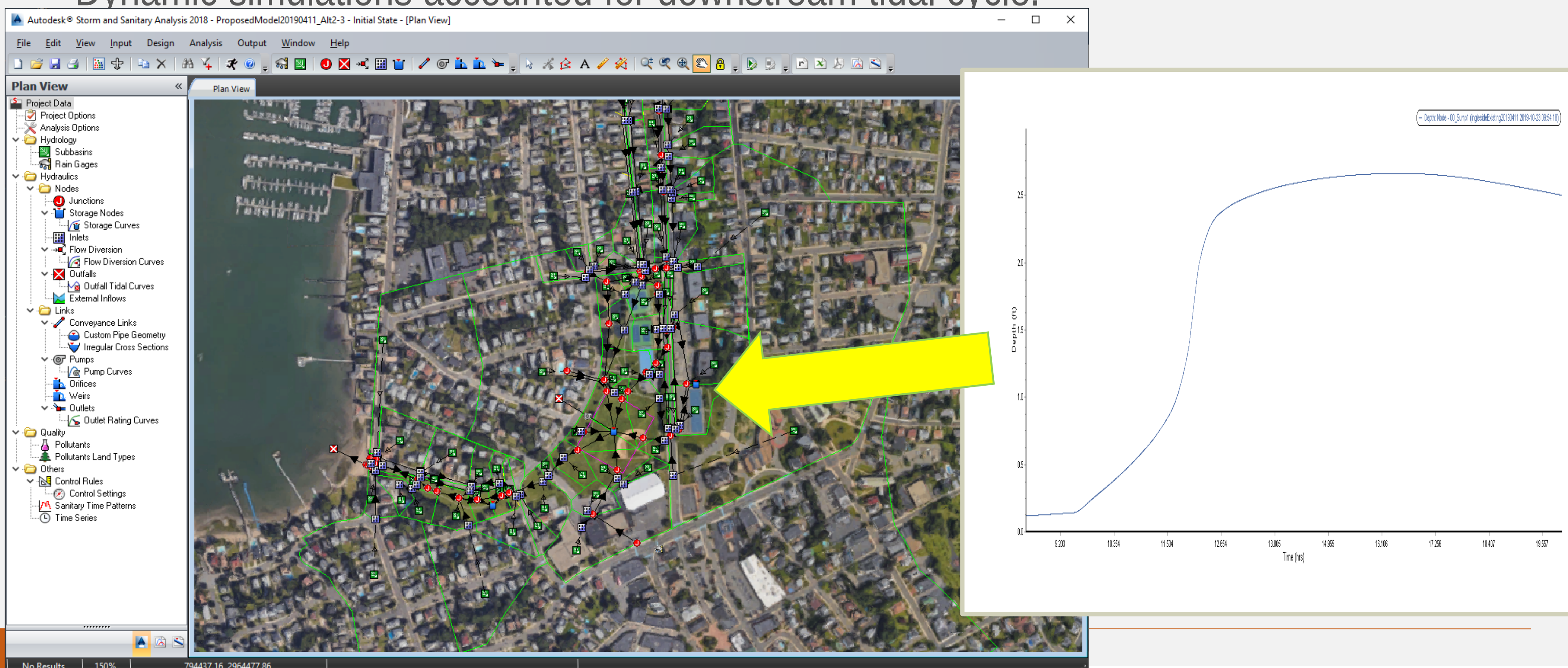
- Basis
  - Lumped hydrology (EPA nonlinear reservoir, SCS, CN runoff methods)
  - 1D St Venant Equations hydraulics for open and closed channel (fully dynamic, diffusive wave, and kinematic routing options)
- Applications
  - River channel & floodplain mapping
  - Closed system capacity analysis
  - Risk mapping (inundation)
- Limitations
  - No 2D overland capability – routing must be defined by user in pipes or channels
  - Better suited when flooding area/problem well defined and documented prior to analysis





AutoCAD Storm & Sanitary (SWMM)

Storm & Sanitary Analysis (SWMM) was used to characterize existing flooding in Ingleside Park and identify and evaluate subsurface storage and pumping alternatives. Dynamic simulations accounted for downstream tidal cycle.



XPSWMM, InfoWorks ICM, PCSWMM (Quasi 2D) H&H, Fully Dynamic, Integrated 2D & 1D:

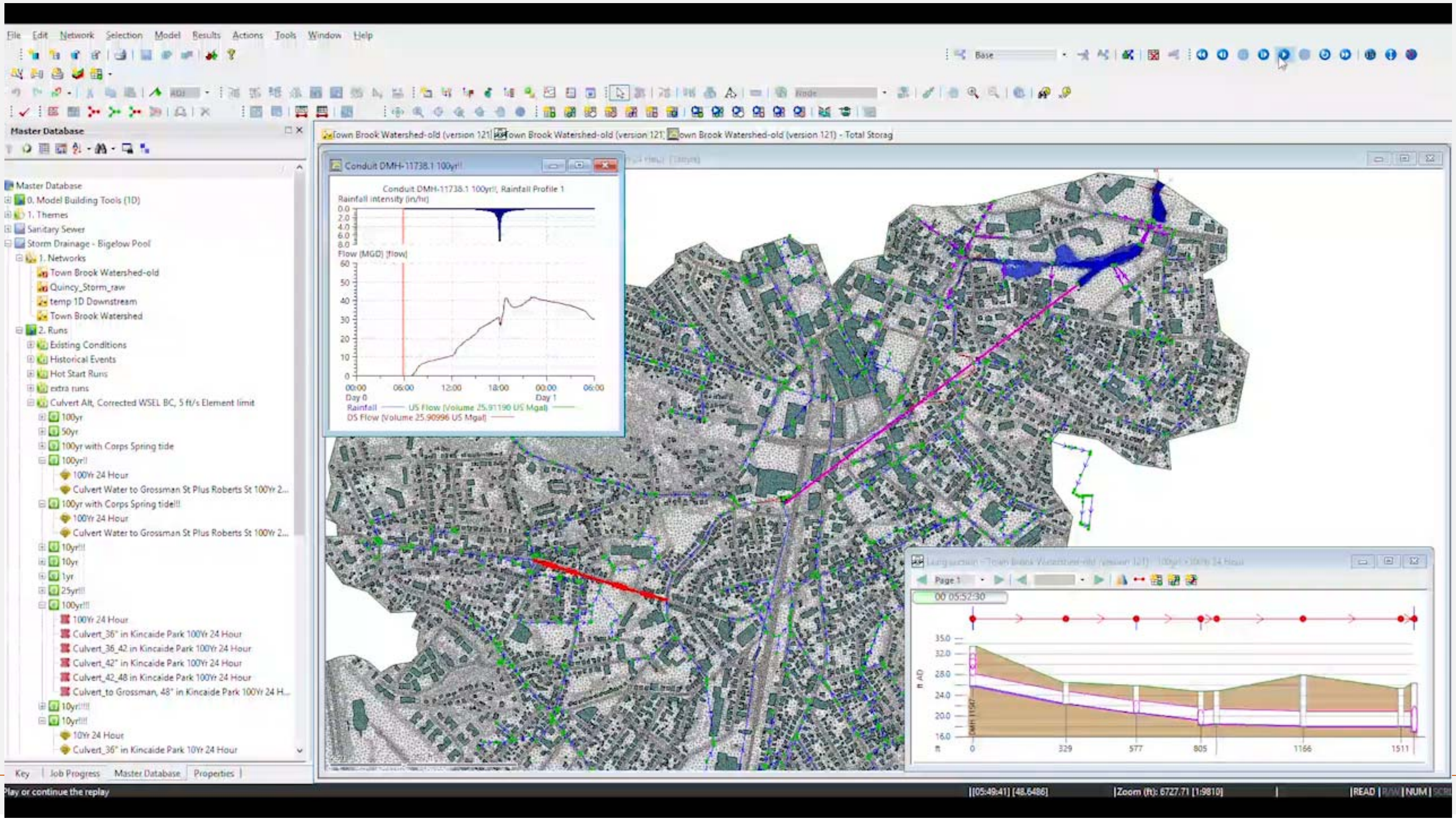
- Basis
  - Finite element discretization for study area (resolution based on project need)
  - Distributed hydrology over elements
  - 2D Shallow Water Equations for overland flow
  - 1D St Venant Equations for pipe flow
  - Weir/orifice/rating curve connection of 1D & 2D for storm drain inlets/outfalls
- Applications
  - Visualize complex urban drainage systems
  - Closed system and Overland flood mapping
  - Inundation and risk (depth/velocity) mapping
- Limitations
  - Significant data & processing requirements
  - Steep learning curve

PCSWMM, Lexington, MA – H&H, Dynamic, Integrated 2D/1D

Integrated 1D/2D Hydrology with Focused 2D Area and Pipe Network

- Proposed Solution
  - Increased conveyance pipe size;
  - Regrading at curb line and driveway entrances; or
  - Construct new outfall based on natural flow paths.

InfoWorks ICM, Quincy, MA
Integrated 2D/1D, Large urban environment



XPSWMM, Norwalk, CT
H&H, Integrated 2D/1D, Understand Problem

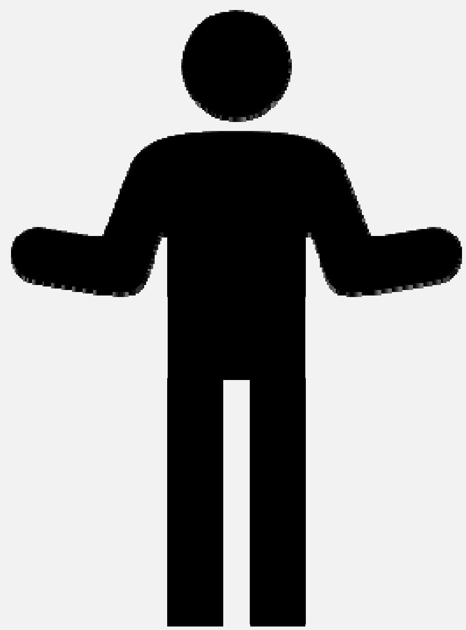
Final Thoughts

- HydroCAD
  - Great design tool
  - Simple to teach & use
- HEC-RAS
  - Good analysis tool
  - Can be as simple or as complicated as you want to make it.
  - Best for overland flow
- EPA SWMM
  - Good analysis tool
  - Simple interface
  - Best for closed system analysis
- AutoCAD Storm & Sanitary
  - Functionality of SWMM
  - Good if Also designing in Civil3D
- PCSWMM
  - Best SWMM model builder we have found.
  - Simple interface and great tools
  - Best for small to medium size jobs, But full 2D is coming (so they say).
  - Enterprise functionality (Distributed Computing) with/out Enterprise price.
- InfoWorks ICM
  - Great for large area analysis with integrated 1D/2D
  - Enterprise functionality (GPU capable) with Enterprise price.
- XPSWMM
  - Functionality as InfoWorks ICM +
  - Older and more mature
  - Best overall tool, most flexible

Earn that PDH/CEU

Which of these models are approved by FEMA?

- HydroCAD
- HEC-RAS
- SWMM
- AutoCAD Strom & Sanitary
- PCSWMM
- InfoWorks ICM
- XPSWMM



Questions