Introduction to US EPA's Stormwater Management Model (SWMM)

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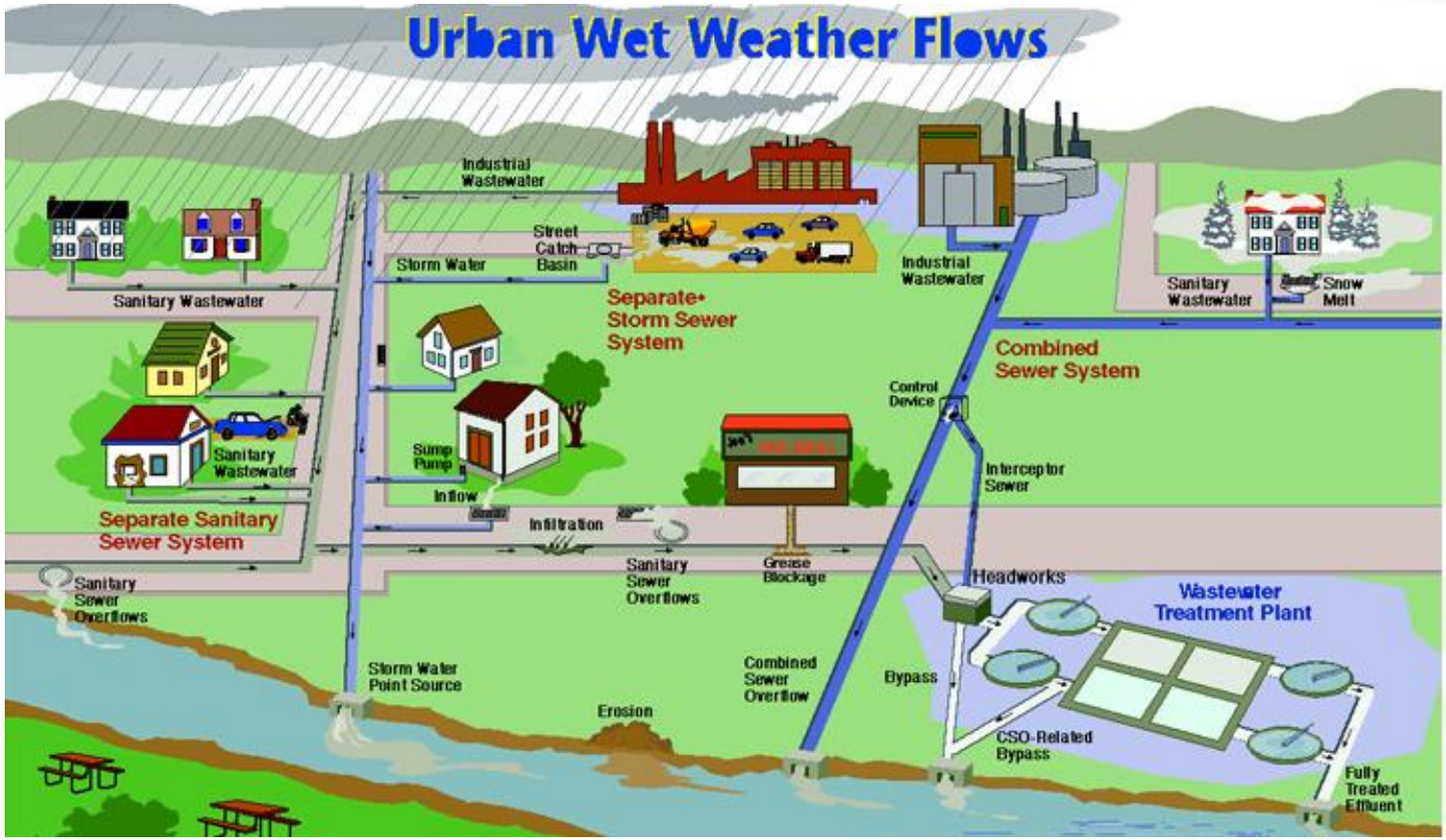
What is SWMM?

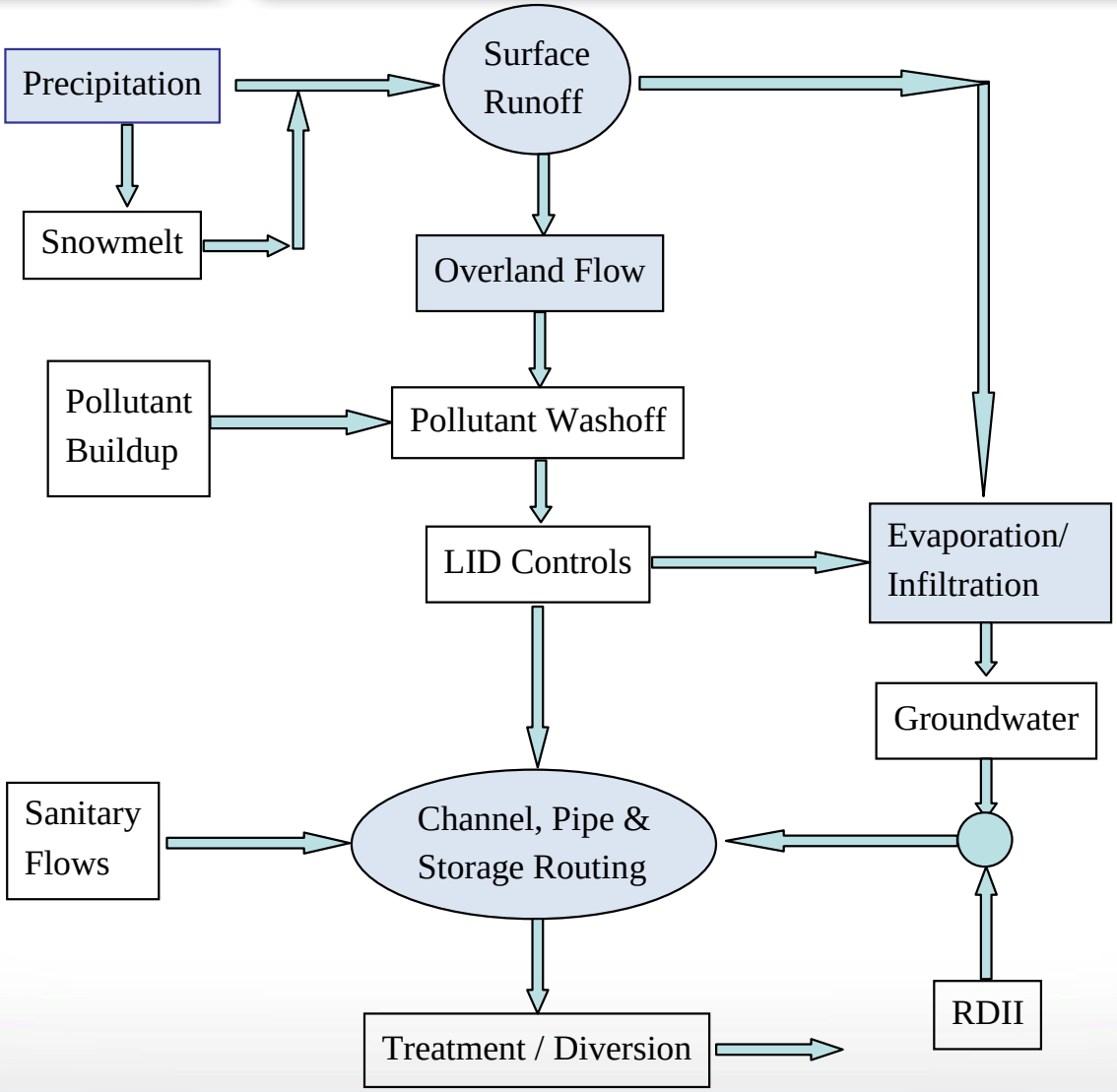


The EPA Storm Water Management Model (SWMM) is a dynamic **rainfall-runoff** simulation model used for **single event** or long-term (**continuous**) simulation of **runoff quantity** and **quality** from **primarily urban areas**.

Development Chronology

Version	Year	Contributors	Comments
SWMM I	1971	Metcalf & Eddy, Inc. Water Resources Engineers University of Florida	First version of SWMM; focus was CSO modeling; few of its methods are still used today.
SWMM II	1975	University of Florida	First widely distributed version of SWMM.
SWMM 3	1981	University of Florida Camp Dresser & McKee	Full dynamic wave flow routing, Green-Ampt infiltration, snow melt, and continuous simulation added.
SWMM 3.3	1983	EPA	First PC version of SWMM.
SWMM 4	1988	Oregon State University Camp Dresser & McKee	Groundwater, RDII, irregular channel cross-sections and other refinements added over a series of updates throughout the 1990's.
SWMM 5	2005	EPA CDM	Complete re-write of the SWMM engine in C; graphical user interface added; improved algorithms and new features provided.
SWMM 5 - LID	2010	EPA	Explicit modeling of LID controls added.

SWMM's Process Models



Hydrologic Modeling Features

- Spatially and time-varying rainfall
- Evaporation of standing surface water
- Snow accumulation and melting
- Rainfall interception from depression storage
- Infiltration into soil layers
- Interflow between groundwater and drainage system
- Nonlinear reservoir routing of overland flow
- Capture and retention rainfall/runoff with various types of low impact development (LID) practices

Hydraulic Modeling Features

- Can handle drainages networks of unlimited size
- Use a wide variety of standard conduit shapes as well as natural channels
- Model special elements such as pumps, weirs, flow dividers, orifices, storage/treatment units
- Apply external user-defined time series of water quality, runoff, groundwater, RDII, dry weather sanitary flow, etc.
- Use rule-based scripts for controlling pumps and regulators
- Model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding

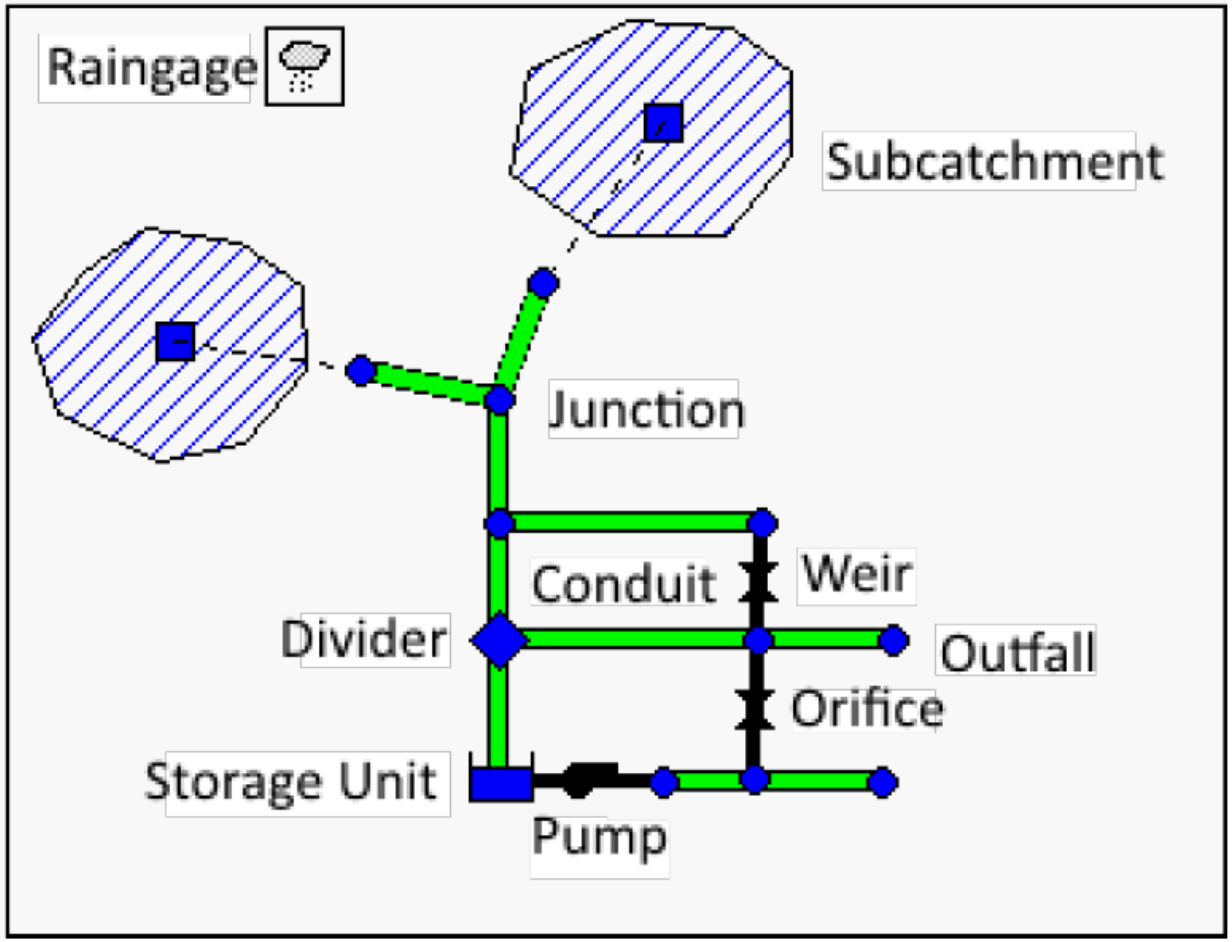
Water Quality Modeling Features

- Pollutant buildup over different land uses
- Pollutant washoff during storm events
- Direct contribution of pollutants from rainfall deposition
- Reduction in buildup due to street cleaning
- Reduction in washoff load from BMPs
- Inflows from user-defined sources and sanitary flows
- Water quality routing through the drainage network
- User-defined treatment functions

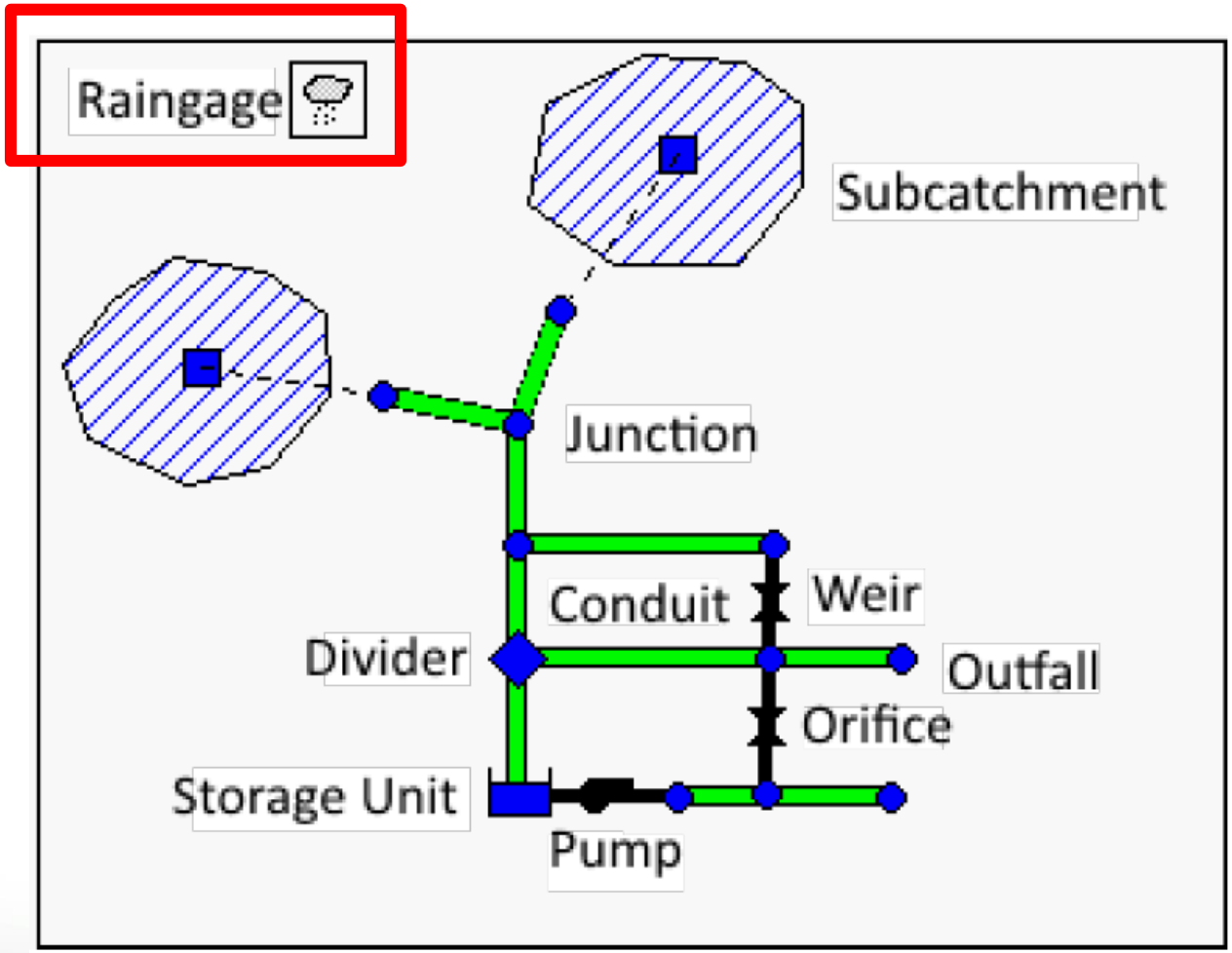
Typical SWMM Applications

- Design and sizing of drainage system components
- Control of combined and sanitary sewer overflows
- Modeling Inflow & infiltration in sanitary sewer systems
- Generating non-point source pollutant loadings for load allocation studies
- Evaluating green infrastructure for sustainability goals
- Floodplain mapping of natural channel systems

SWMM's Conceptual Model



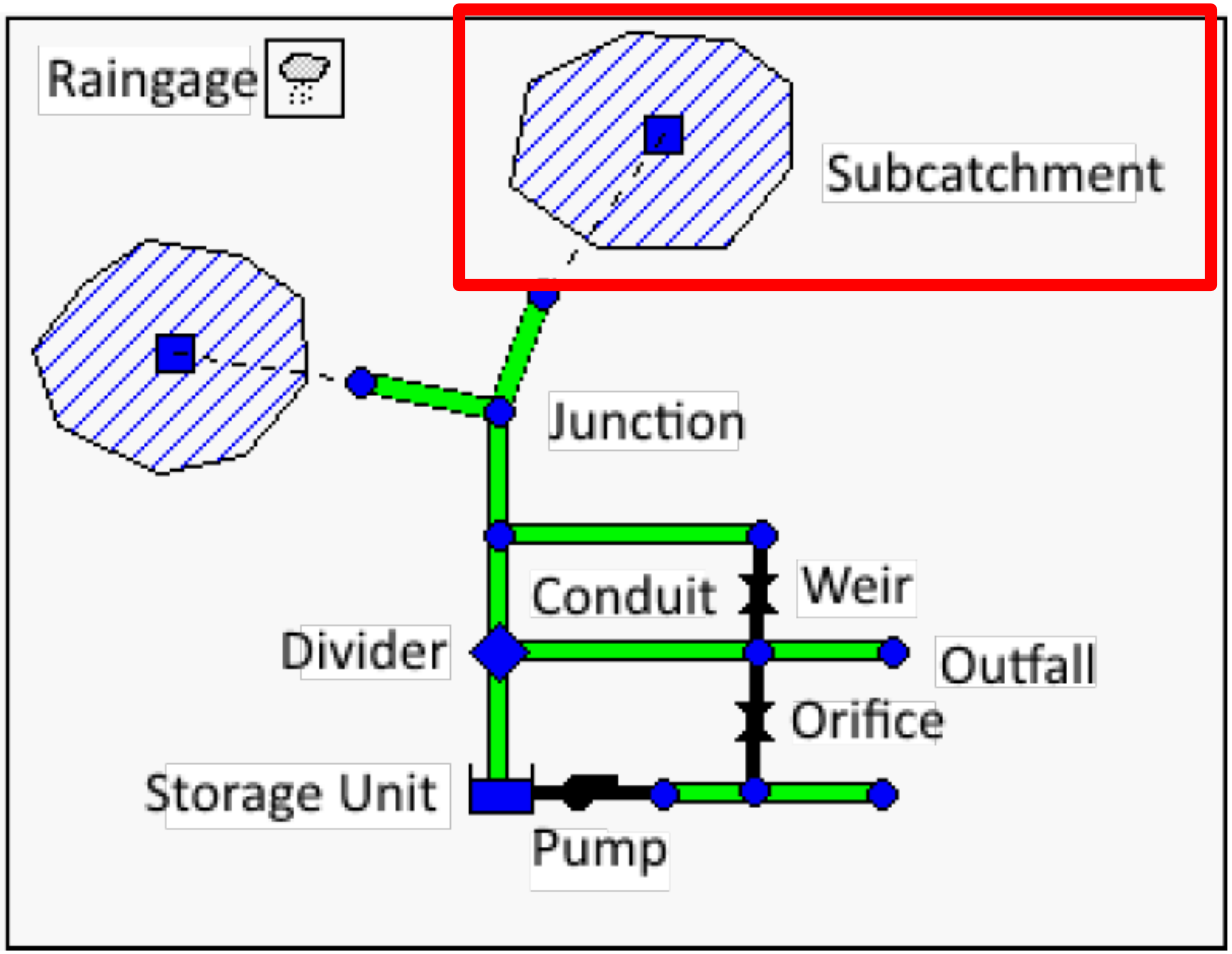
SWMM's Conceptual Model



Rain Gage Objects

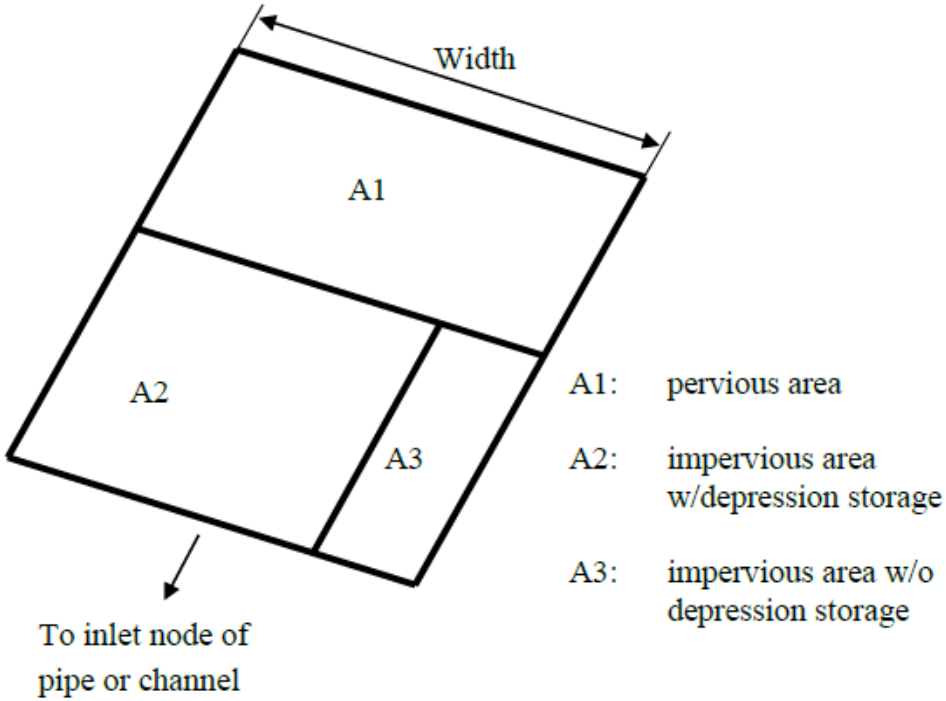
- Supply precipitation data for subcatchments
- User-defined time series or external file
- Single event vs. continuous simulation
- Principal input properties
  - Rainfall data type (e.g., intensity, volume, or cumulative volume)
  - Recording time interval (e.g., hourly, 15-minute)
  - Source of rainfall data
  - Name of rainfall data source
- Snowfall determined by user-defined dividing temperature
  - Temperature data from user-defined time series or climate file

SWMM's Conceptual Model



Subcatchment Object

- **Hydrologic units of land whose topography and drainage system elements direct surface runoff to a single discharge point**
- **Pervious and impervious subareas**



Subcatchment Object

- **Hydrologic units of land whose topography and drainage system elements direct surface runoff to a single discharge point**
- **Pervious and impervious subareas**
- **Calculate infiltration into unsaturated upper soil zone:**
  - **Horton infiltration**
  - **Modified Horton infiltration**
  - **Green-Ampt Infiltration**
  - **Modified Green-Ampt infiltration**
  - **Curve Number infiltration**

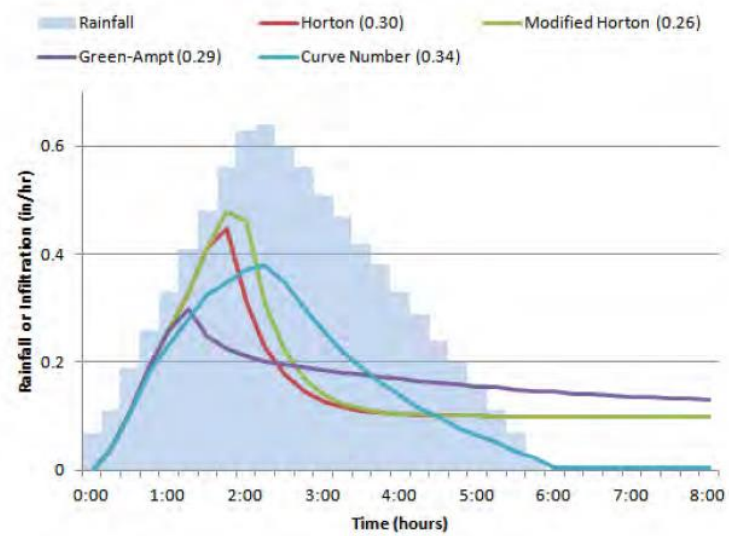
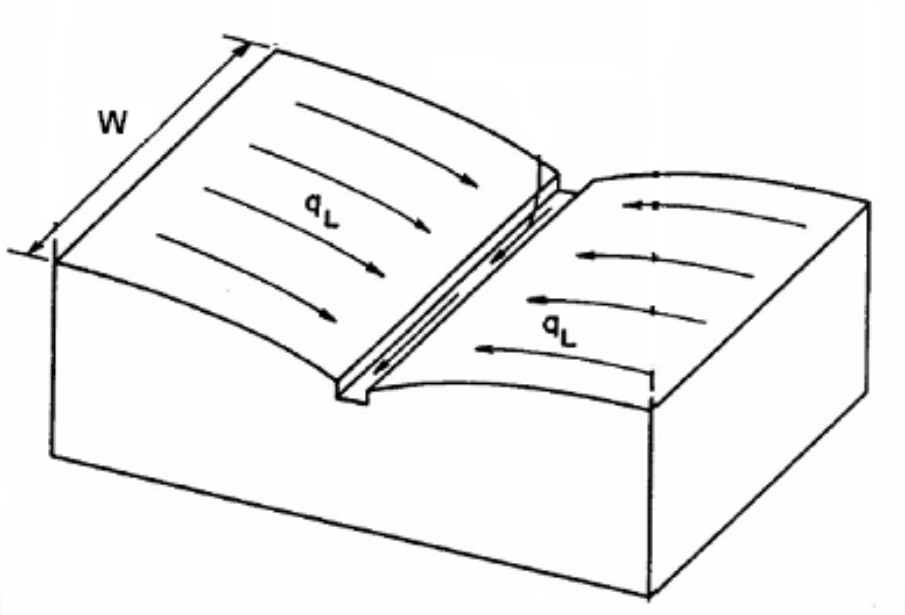


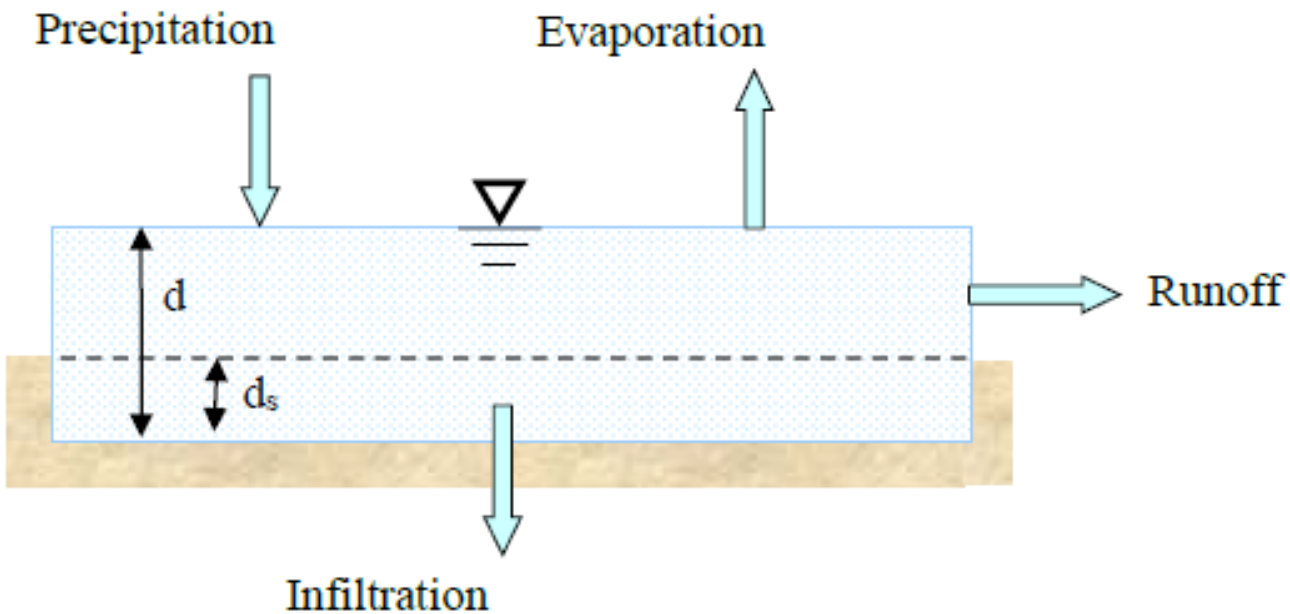
Figure 4-8 Infiltration rates produced by different methods for a 2-inch rainfall event.
(Numbers in parentheses are the fraction of rainfall that becomes runoff.)

Subcatchment Object

- **Conceptualize subcatchment as a rectangular surface with uniform slope *S* and width *W* that drains to a single outlet**
- **Parameters can be averaged over a coarse number of subcatchments or sub-divided into a finer number**



Nonlinear Reservoir Model



$$\frac{\partial d}{\partial t} = i - e - f - q$$

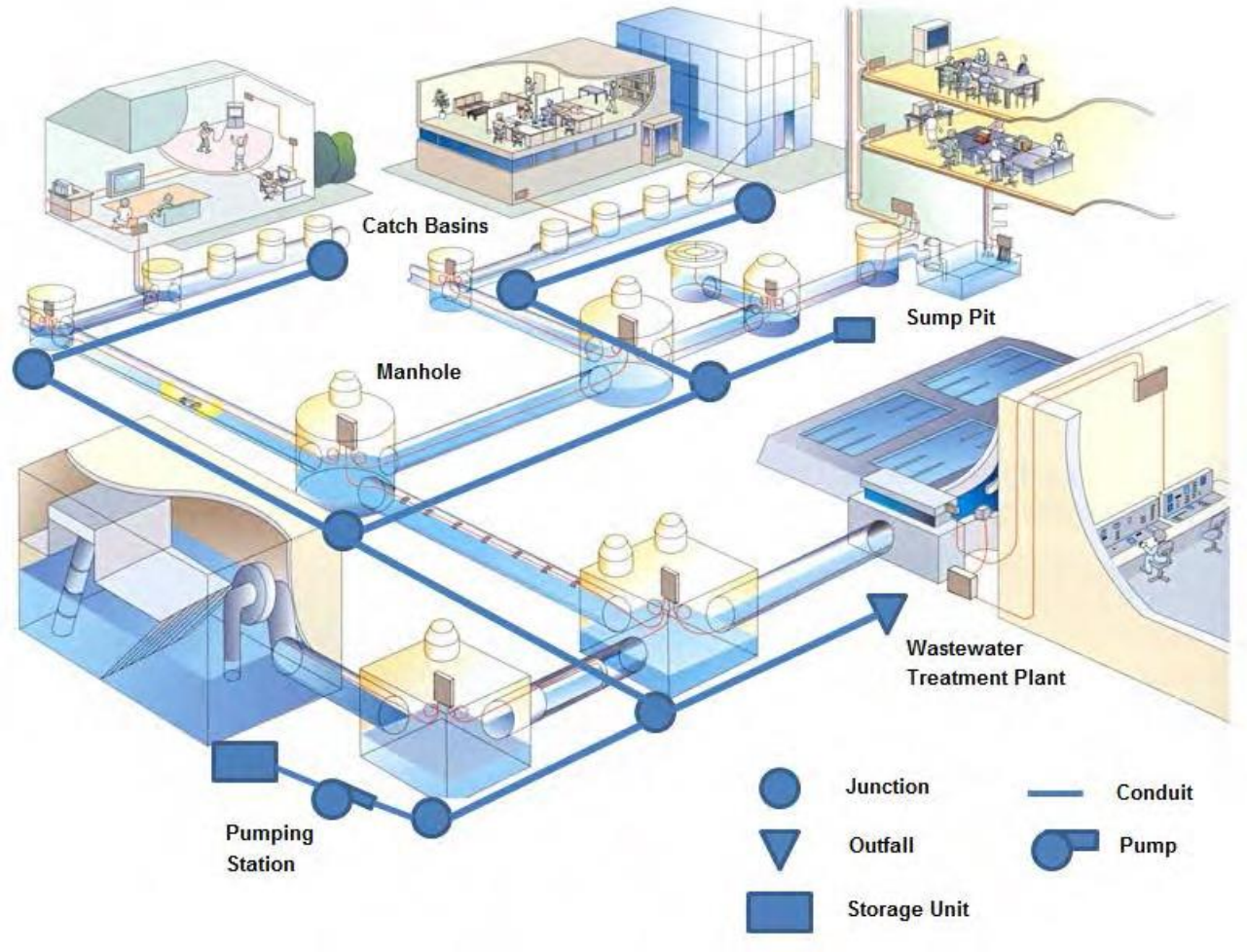
i = rate of rainfall + snowmelt (ft/s)
e = surface evaporation rate (ft/s)
f = infiltration rate (ft/s)
q = runoff rate (ft/s).

Hydrology Reference Manual Equation 3-1

Subcatchment Parameters

- assigned rain gage
- outlet node or subcatchment
- assigned land uses
- tributary surface area
- imperviousness
- slope
- characteristic width of overland flow
- Manning's n for overland flow on both pervious and impervious areas
- depression storage in both pervious and impervious areas
- percent of impervious area with no depression storage

SWMM's Hydraulic Model



Hydraulic Flow Routing

- **Governed by conservation of mass and momentum equations for gradually varied, unsteady free surface flow *(the Saint Venant flow equations)***
- **User chooses level of sophistication for routing:**
  - **Steady Flow Routing**
  - **Kinematic Wave Routing**
  - **Dynamic Wave Routing**

Continuity

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

x	=	distance (ft)
t	=	time (sec)
A	=	flow cross-sectional area (ft^2)
Q	=	flow rate (cfs)

Momentum

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA\frac{\partial H}{\partial x} + gAS_f = 0$$

H	=	hydraulic head of water in the conduit ($Z + Y$) (ft)
Z	=	conduit invert elevation (ft)
Y	=	conduit water depth (ft)
S_f	=	friction slope (head loss per unit length)
g	=	acceleration of gravity (ft/sec^2)

Steady Flow Routing

- Simplest type
- Assumes flow at each time step is uniform and steady
- Translates inflow hydrographs downstream
- Cannot account for
  - Channel storage
  - Backwater effects
  - Entrance/exit losses
  - Flow reversal
  - Pressurized flow
- Can only be used with branching conveyance networks

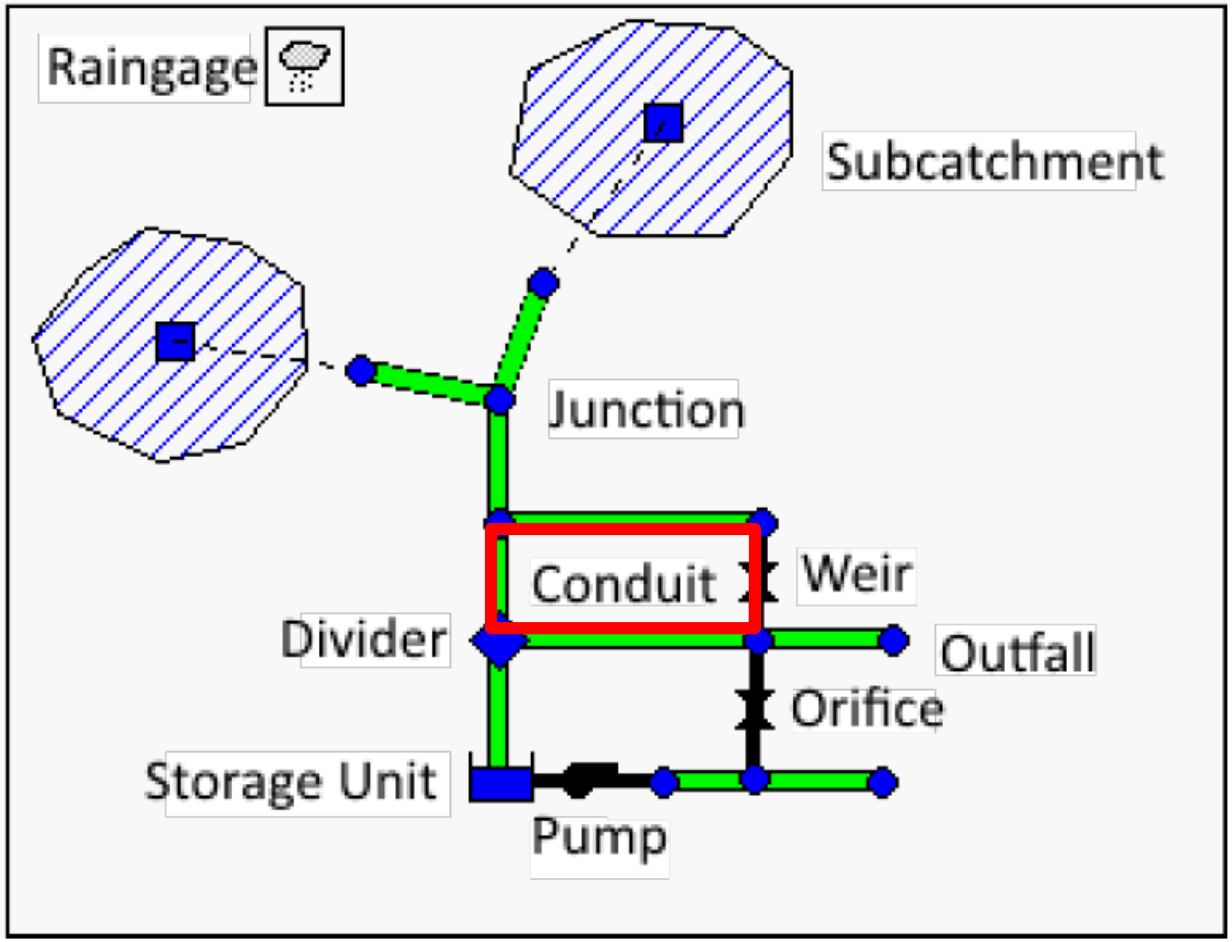
Kinematic Wave Routing

- Solves continuity equation and simplified momentum equation in each conduit (assumes gravity balanced by friction force)
- Channel storage leads to attenuated and delayed outflow
- Cannot account for
  - Backwater effects
  - Entrance/exit losses
  - Flow reversal
  - Pressurized flow
- Can only be used with branching network layouts
- Advantage: more stable at larger time steps

Dynamic Wave Routing

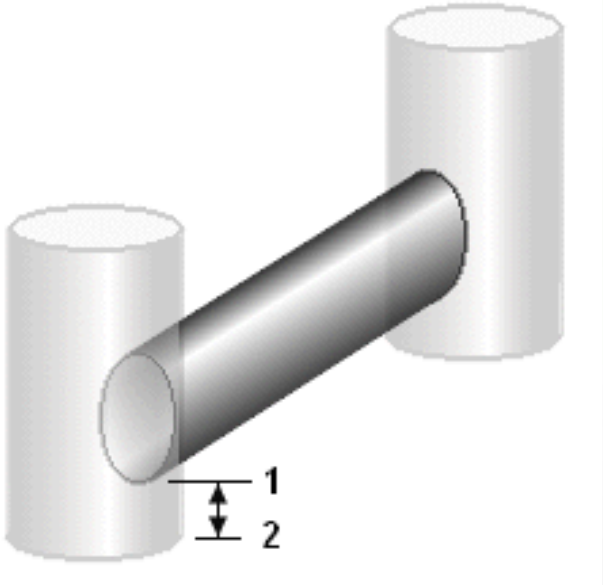
- Solves full 1-D St. Venant flow equations for non-uniform, unsteady flow
- Accounts for channel storage, backwater effects, pressurized flow, reverse flow
- Free surface or pressurized/surcharging flow
- Applicable to any network layout (including looped networks and those with significant flow restrictions)
- Requires a smaller time step

SWMM's Conceptual Model



Conduit Objects

- Pipes or channels that move water from one node to another in the conveyance system
- Variety of open/closed cross-sectional geometries
- Required parameters:
  - Identities of inlet/outlet nodes
  - Offset height (elevation above inlet and outlet node inverts)
  - Conduit length
  - Manning's roughness coefficient
  - Cross-section shape/dimensions
- Optional parameters: flap gate, entrance/exit loss, seepage rate



Junction Nodes

- **Drainage system nodes where links join together**
- **Examples:**
  - **Confluence of natural channels**
  - **Manholes in sewer system**
  - **Pipe connection fittings**
- **Can add external inflows**
- **Excess water → partially pressurized**
  - **Connecting conduits surcharged**
  - **Water loss vs. ponding**

http://soc.sty.nu/2013/04/confluence-2/

https://en.wiktionary.org/wiki/manhole#/media/File:DSCF0545_Manhole_cover,_Fortescue_Avenue.jpg

Junction Parameters

- Invert (channel or manhole) elevation
- Height to ground surface
- Ponded surface area when flooded (optional)
- External inflow data (optional)

https://www.thestar.com/news/city_hall/2017/05/16/toronto-flushes-plan-for-stormwater-fee.html

Outfall Node Objects

- Terminal nodes of drainage system
- Boundary condition options:
  - Critical or normal flow depth in connecting conduit
  - Fixed stage elevation
  - Tidal stage
  - User-defined time series of stage over time
- Principal input parameters:
  - Invert elevation
  - Boundary condition type and stage description
  - Flap gate presence

https://pubs.usgs.gov/sir/2012/5068/section6.html

Flow Divider Nodes

- Divert inflows into a specific conduit in a prescribed manner
- Four types:
  1. Cutoff Divider (diverts all inflow above a defined cutoff value)
  2. Overflow Divider (diverts all inflow above flow capacity of the non-diverted conduit)
  3. Tabular Divider (uses table of diverted flows)
  4. Weir Divider (uses weir equation to compute diverted flow)
- Principal input parameters:
  - Junction parameters
  - Name of link receiving diverted flow
  - Method used for computing amount of diverted flow

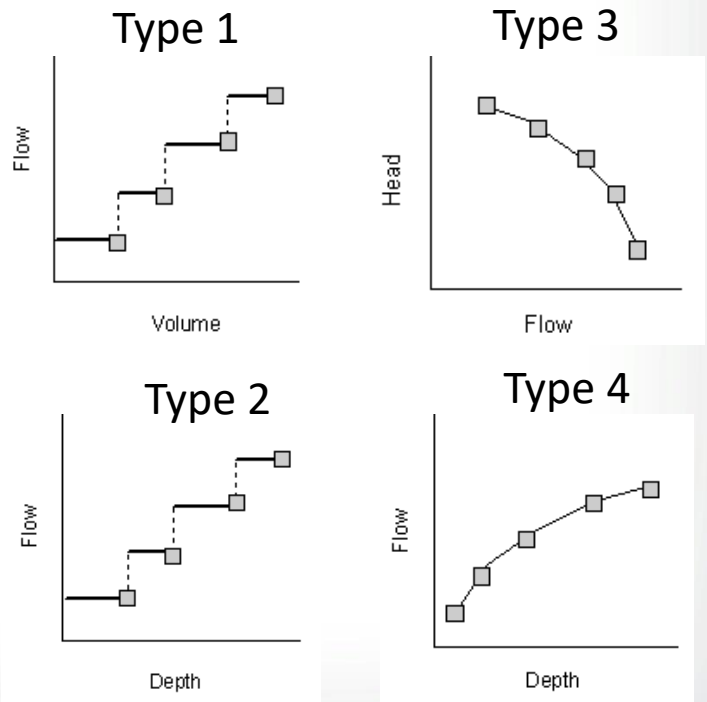
Storage Units

- Drainage system nodes that provide storage volume
- Volumetric properties described by a function or table of surface area vs. height
- Evaporation & seepage
- Principal parameters:
  - Invert (bottom) elevation
  - Maximum depth
  - Depth-surface area data
  - Evaporation potential
  - Seepage parameters
  - External inflow data

https://www.water-technology.net/wp-content/uploads/static-progressive/nri/water/floridaresproj.jpg

Pumps

- Links used to lift water to higher elevations
- Pump flow rate and head at inlet and outlet nodes controlled by a pump curve (5 types supported)
- Principal input parameters:
  - Inlet/outlet nodes
  - Pump curve data
  - Initial on/off status
  - Startup and shutoff depths
- No reverse flow
- Control rules can be used for startup and shutoff and modulate pump flow



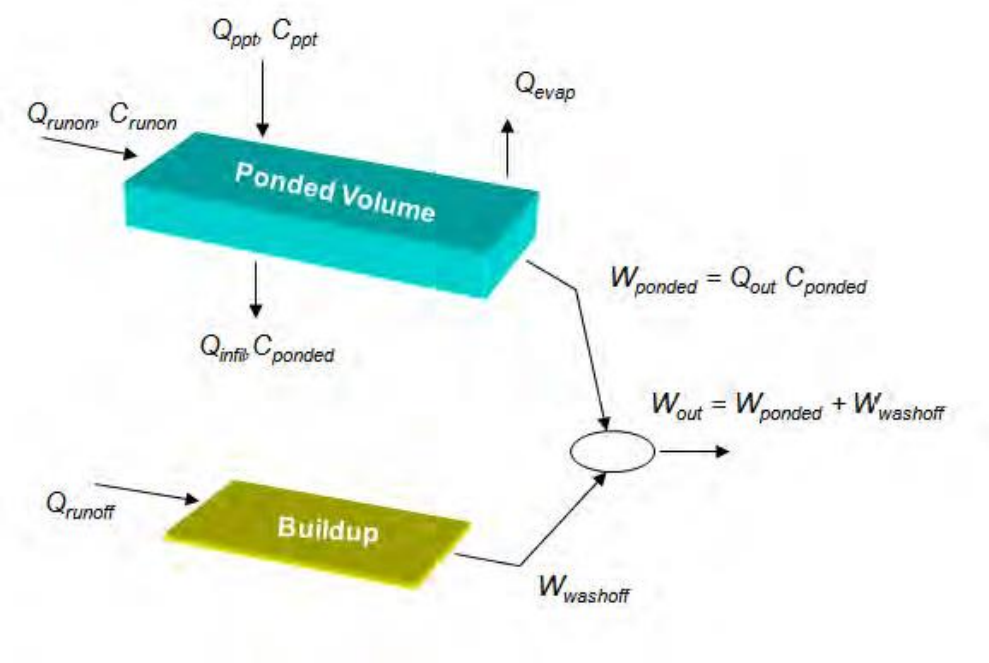
Flow Regulators

- Structures/devices used to control and divert flow
- Typical uses:
  - Control releases from storage facilities
  - Prevent unacceptable surcharging
  - Divert flow to treatment facilities and interceptors
- Orifices
- Weirs
- Outlets
- Control rules for size of orifice opening, weir crest height, etc.

https://www.ricecreek.org/?SEC=12347ED8-C790-4609-92F1-BD092D854E6B

Pollutants and Water Quality

- **Land use categories assigned to subcatchment (e.g., residential, commercial, industrial, undeveloped)**
- **Pollutant buildup, washoff, and street cleaning can then be defined for each land use**



Pollutant Buildup

- **Normalized by either mass per unit subcatchment area or unit curb length**
- **Amount of buildup a function of the number of preceding dry weather days calculated by one of these functions:**

Power Function

$$B = Min\left(C_1, C_2 t^{C_3}\right)$$

Exponential Function

$$B = C_1\left(1 - e^{-C_2 t}\right)$$

External Time Series

Saturation Function

$$B = \frac{C_1 t}{C_2 + t}$$

B – pollutant buildup
t – time
C_1 – maximum buildup possible
C_2 – buildup rate constant
C_3 – time exponent

Pollutant Washoff

- **Occurs during wet weather periods**

Exponential Washoff

$$W = C_1 q^{C_2} B$$

Rating Curve Washoff

$$W = C_1 Q^{C_2}$$

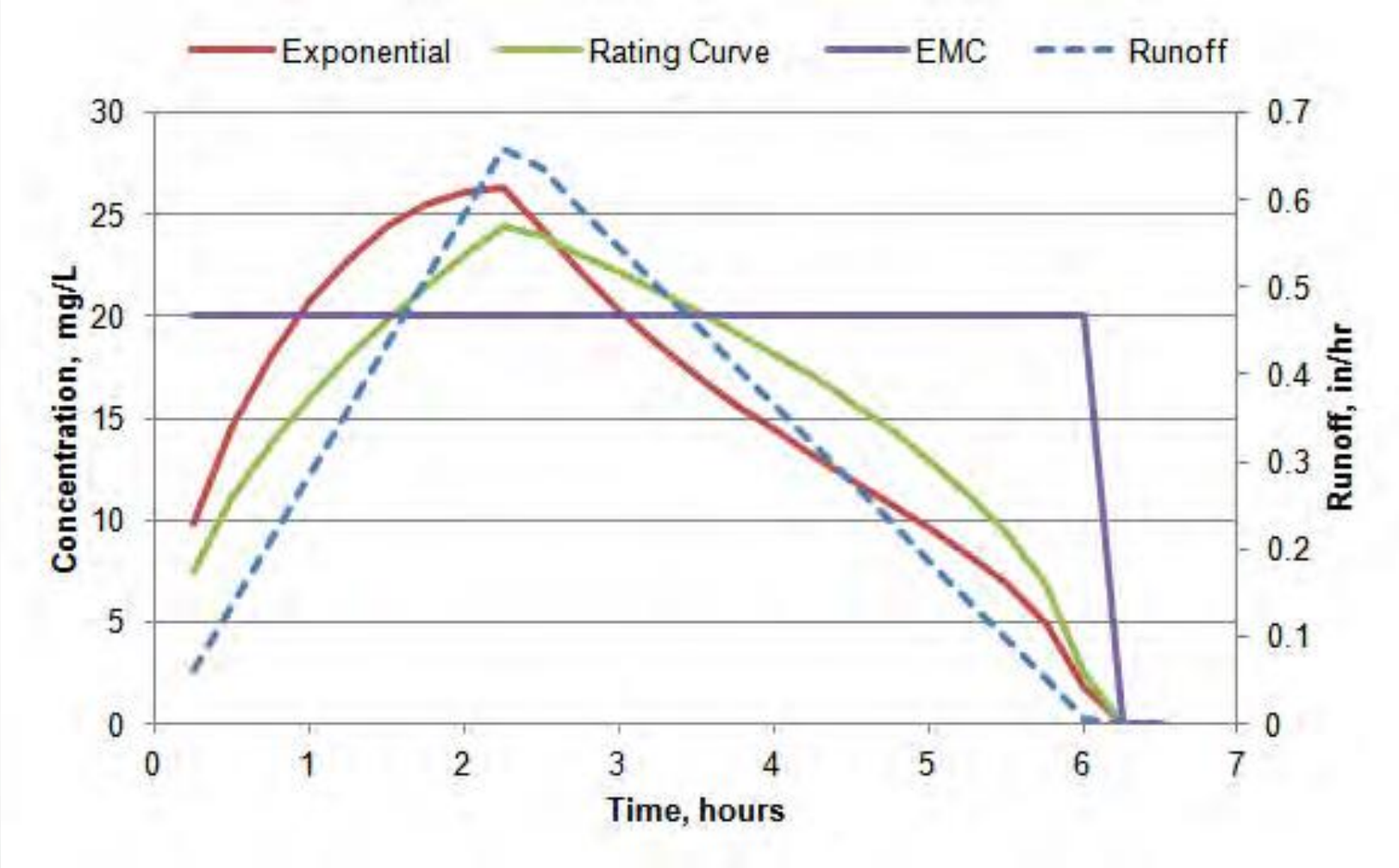
Event Mean Concentration

$$W = C_1 Q$$

W – washoff load
C_1 – Washoff coefficient
C_2 – Washoff exponent
q – runoff rate per unit area
B – pollutant buildup
Q – runoff rate

(also user-defined street sweeping and treatment functions at nodes)

Pollutant Washoff



LIDs in SWMM

Disconnection

Infiltration Basin

Rain Garden

Cistern

Infiltration Trench

Green Roof

Porous Pavement

Vegetative Swale

Street Planter

Limitations of SWMM

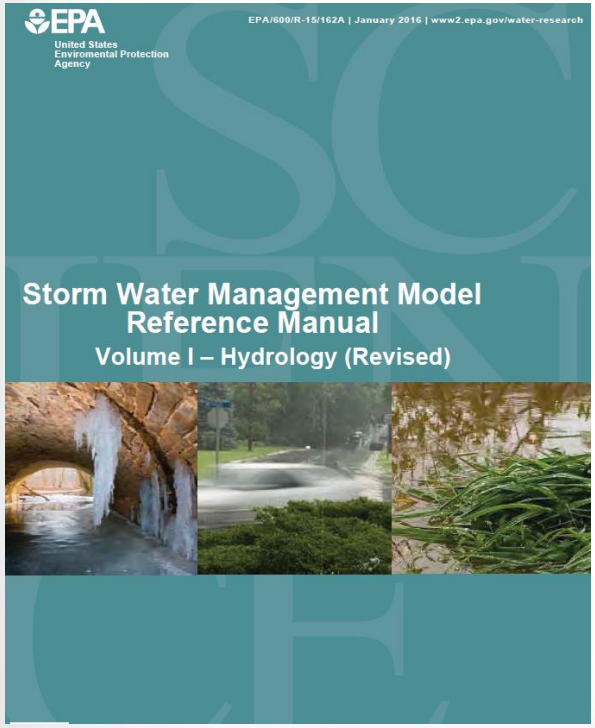
- Not designed to model to large-scale, non-urban watersheds
- Not applicable to forested areas or irrigated cropland
- Pollutant transformation modeling is rudimentary
- Cannot be used with highly aggregated (e.g., daily) rainfall data
- It is an analysis tool, not an automated design tool
- No official EPA release with a direct GIS interface (third party software wrappers available)

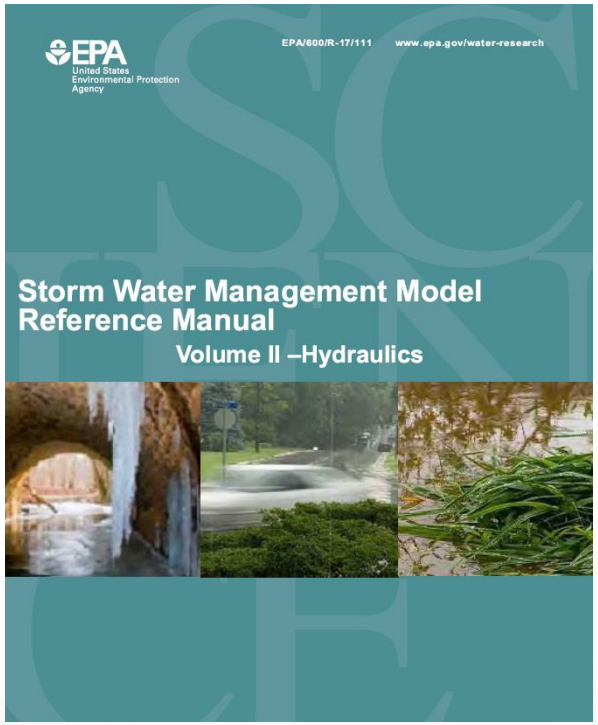
SWMM-Related Products

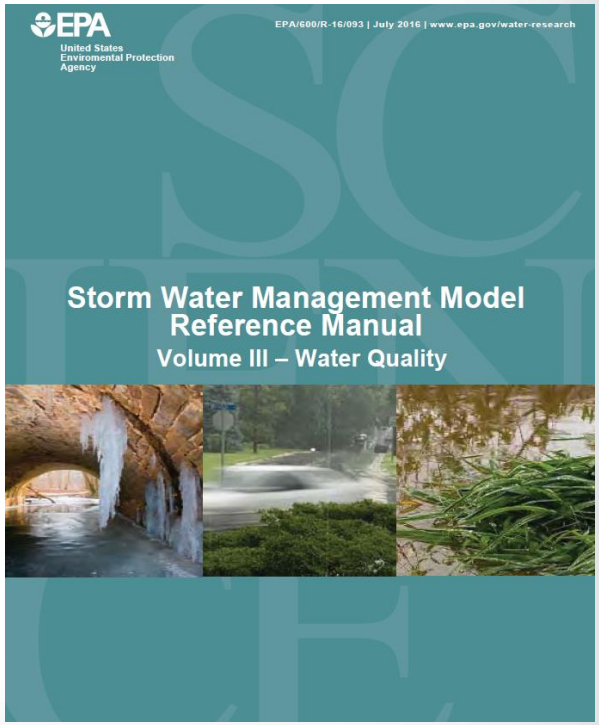
- **PCSWMM – CHI (https://www.pcswmm.com/)**
- **InfoSWMM – Innovyze (https://www.innovyze.com/en-us/products/infoswmm)**
- **XPSWMM – Innovyze (https://www.innovyze.com/en-us/products/xpswmm)**
- **MIKE URBAN – DHI (https://www.mikepoweredbydhi.com/products/mike-urban)**

Additional Resources

- https://www.epa.gov/water-research/storm-water-management-model-swmm
  - **SWMM Reference Manuals**







Additional Resources

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  - **SWMM Reference Manuals**
  - **Tutorials**

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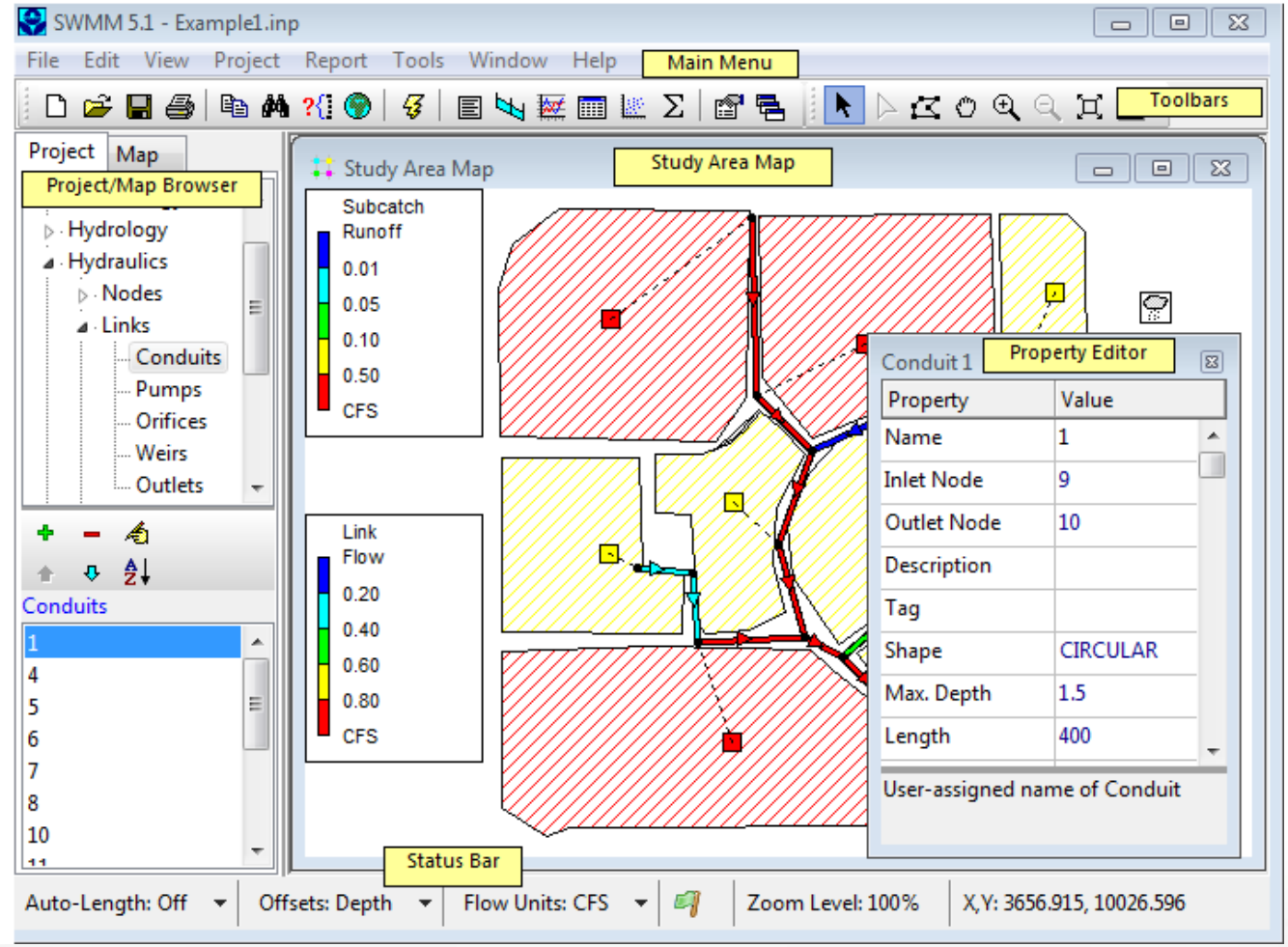
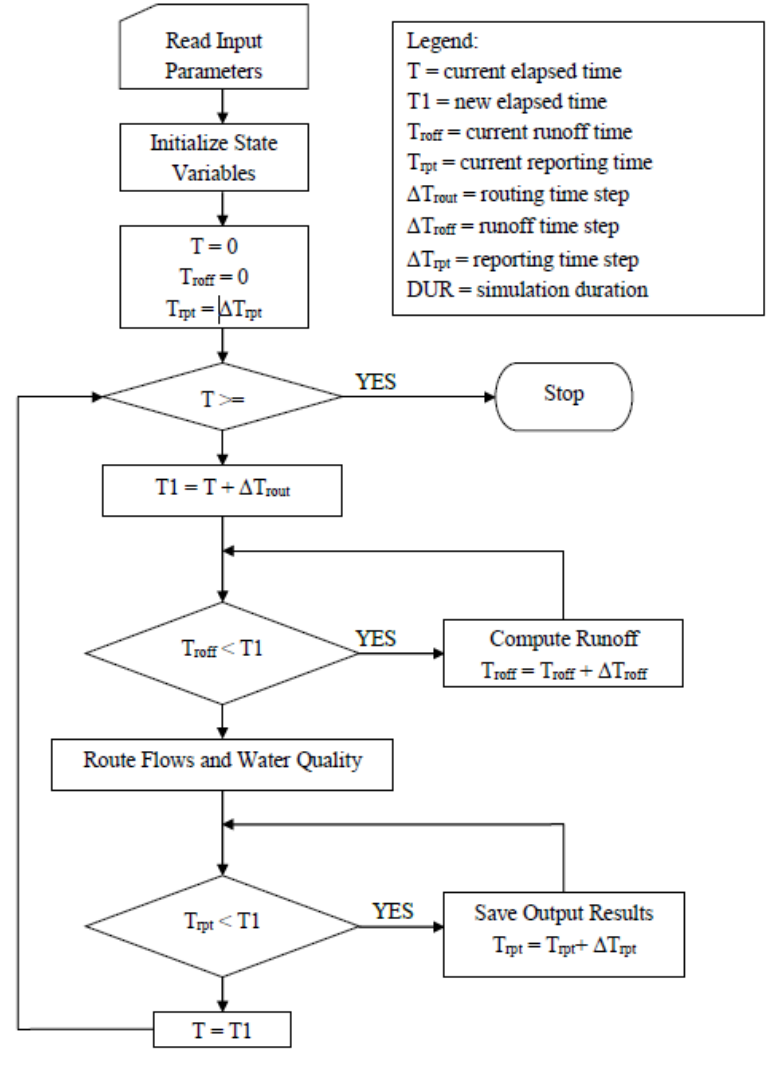
  - SWMM Reference Manuals
  - Tutorials
- https://www.openswmm.org
  - Code viewer, knowledge base, example models
  - SWMM-USERS list serv
- https://github.com/OpenWaterAnalytics
  - OWA SWMM Toolkit API
  - PySWMM

Bechtold Model Demo

Quick Start Tutorial



SWMM Simulation Procedure



Manning Equation

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Q = flow rate
A = cross sectional area
R = hydraulic radius
S = slope
n = Manning roughness coefficient

Force Main Equations

Hazen-Williams

$$Q = 1.318\, C\, A R^{0.63} S^{0.54}$$

Q = flow rate

C = Hazen Williams C-factor

A = cross sectional area

R = hydraulic radius

S = slope

Darcy-Weisbach

$$Q = \sqrt{\frac{8g}{f}} A R^{1/2} S^{1/2}$$

Q = flow rate

g = gravity acceleration

f = Darcy-Weisbach friction factor

A = cross sectional area

R = hydraulic radius

S = slope