An Introduction to the USEPA Storm Water Management Model (SWMM)

Michelle Simon

August 29-31, 2022

Udon Thani, Thailand

Disclaimer

The U.S. Environmental Protections Agency through its Office of Research and Development funded and managed the research described in this presentation. It has been subjected to the Agency's review and has been approved for release. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

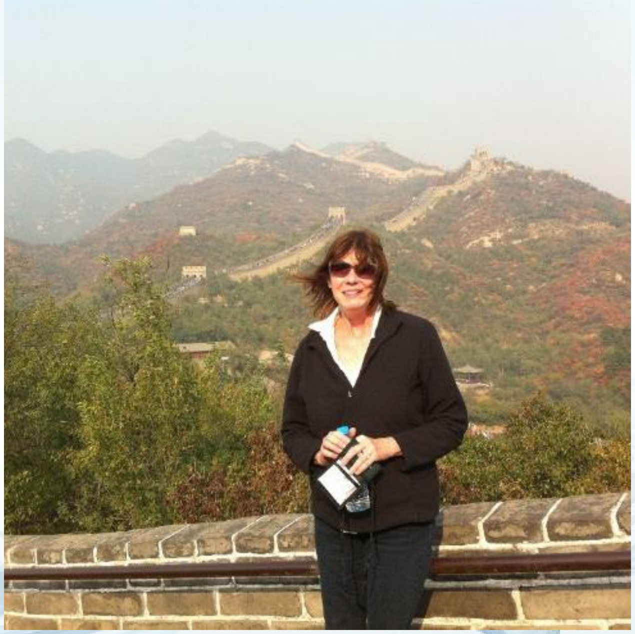
Speaker Introduction

Michelle Simon, Ph.D., P.E. Chemical Engineer, Office of Research and Development
Cincinnati, OH

20 Years Superfund Site Technical Support

Became EPA Technical POC for SWMM
(after the retirement of Lew Rossman
April 2017)

Ph.D. The University of Arizona
M.S. Colorado School of Mines
B.S. Notre Dame University



EPA United States Environmental Protection Agency

Presentation Outline

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Hydraulic Features to SWMM
5. Building the Hydrologic Model
6. History of SWMM
7. Using SWMM for Low Impact Development
8. Building LID Model
9. Demonstration of EPA Stormwater Calculator
10. Ground-truthing SWMM
11. Interpreting More Complicated SWMM Results
12. Where to get Data
13. SWMM Climate Adjust Tool
14. Conclusions

Day 1

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Features in SWMM
5. Building the Hydrologic Model
6. Day One wrap-up

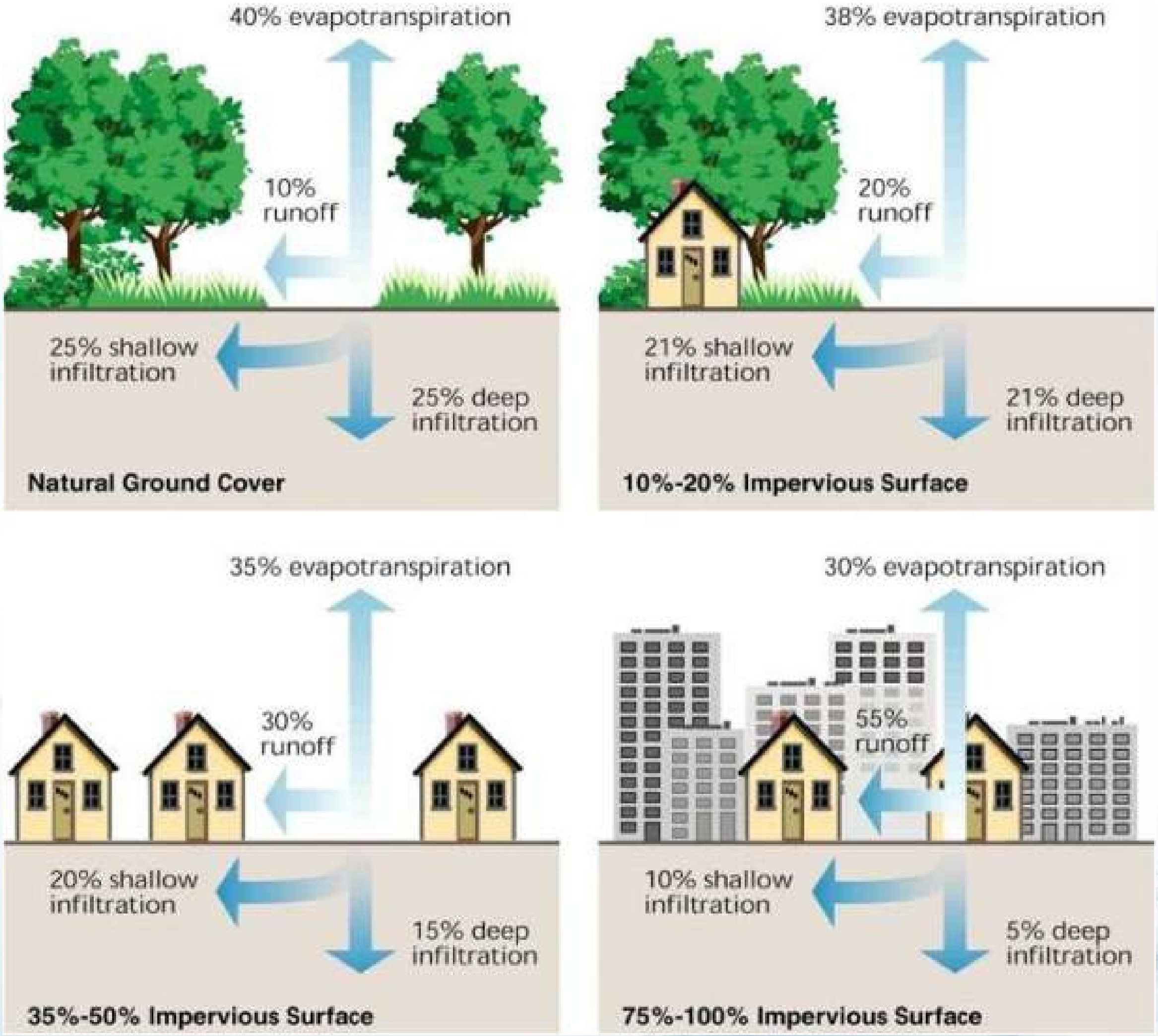
Day 2

1. History of SWMM
2. Using SWMM for Low Impact Development
3. Building LID Model
4. Demonstration of EPA Stormwater Calculator
5. Ground-truthing SWMM
6. Day Two Wrap-up

Day 3

1. Interpreting More Complicated SWMM Results
2. Where to get Data
3. SWMM Climate Adjust Tool
4. Ground Truthing SWMM
5. Course Wrap Up

Urbanization Changes the Hydrologic Cycle



- Soils and vegetation are replaced with impervious surfaces
- Impervious surfaces are connected to dense drainage networks
- Runoff drains directly into streams, lakes, wetlands, and coastal waters
- Even small storms generate significant runoff

EPA United States Environmental Protection Agency

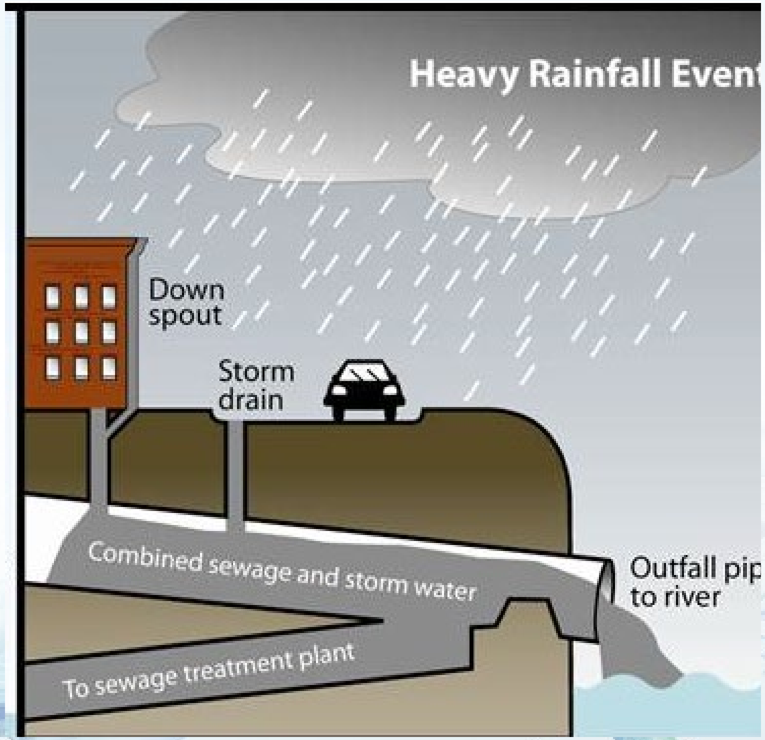
Urban Stormwater Impacts

Hydrologic, Geomorphic, and Biological Impacts:

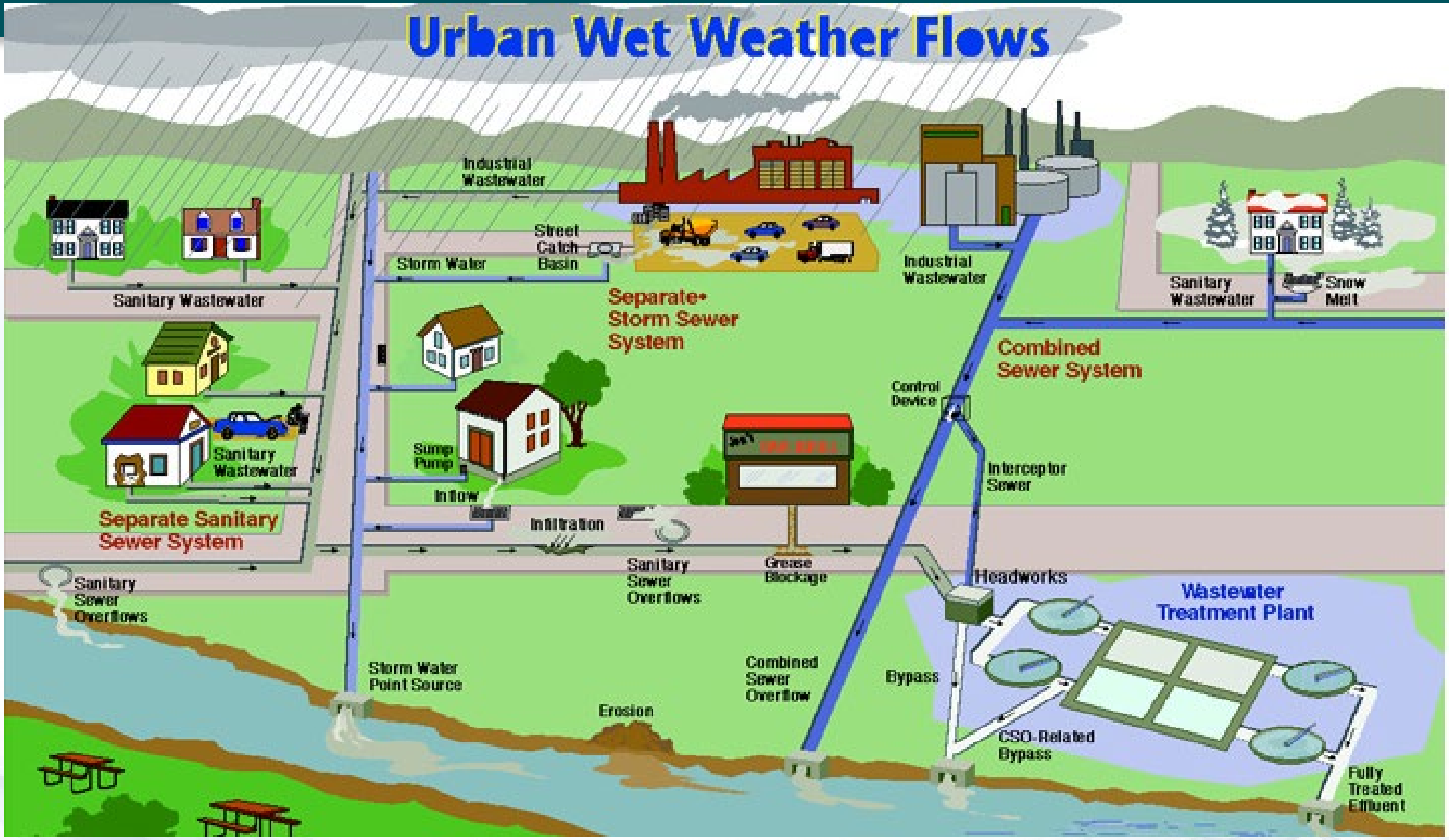
- Increased stormwater volume and velocity causes flooding, erosion, and sewer overflows.

- Impaired habitat and water quality impact fisheries and shellfish harvesting due to pathogens, metals, PAHs, and other pollutants.

- Reduced groundwater recharge impacts water supplies.



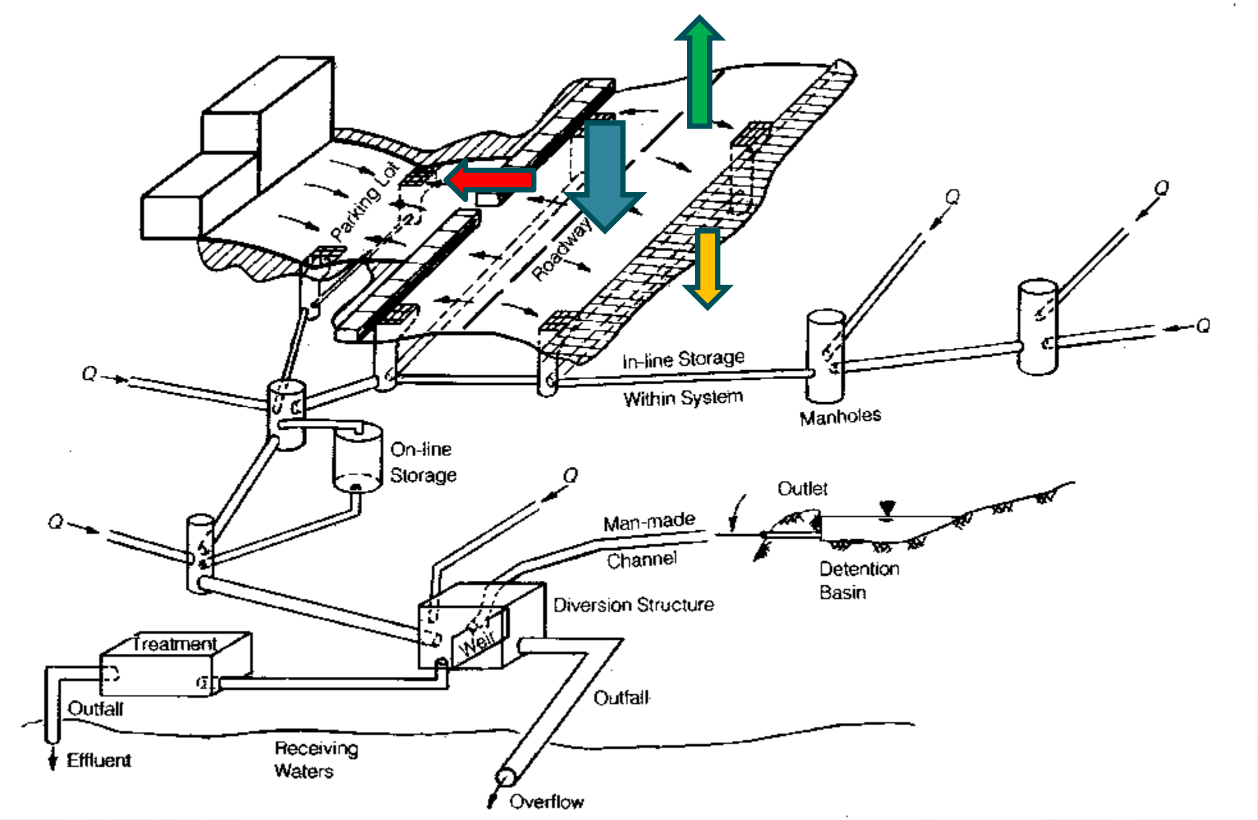
What is SWMM?



SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

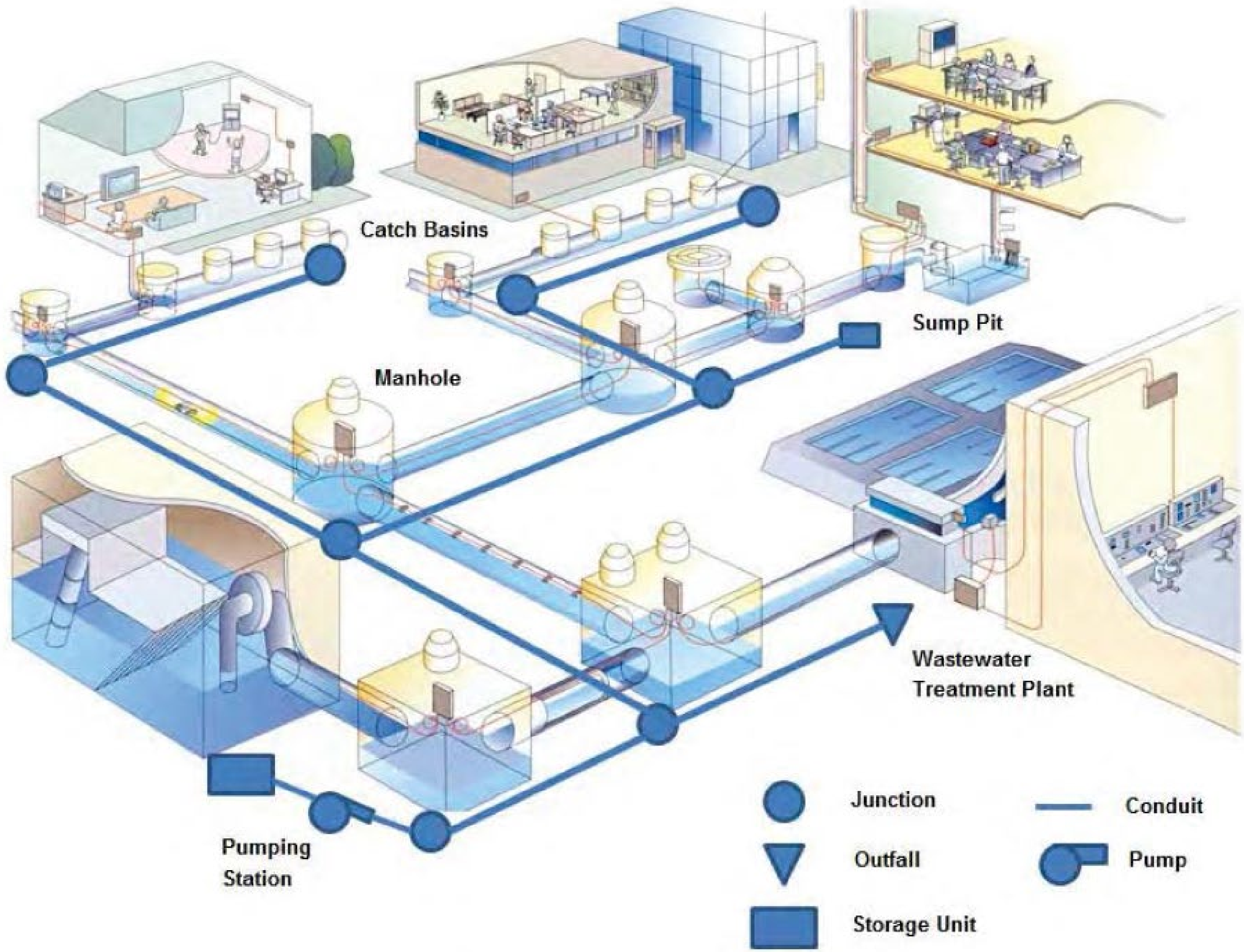
United States Environmental Protection Agency

How does SWMM Model?



SWMM is a **distributed**, **dynamic rainfall-runoff** simulation model used for **single event** or long-term (**continuous**) simulation of runoff quantity and quality from **primarily urban** areas.

Hydraulic Model



Why We Need SWMM (CSO, MS4, TMDL, NPDES)

Design and sizing of drainage system.

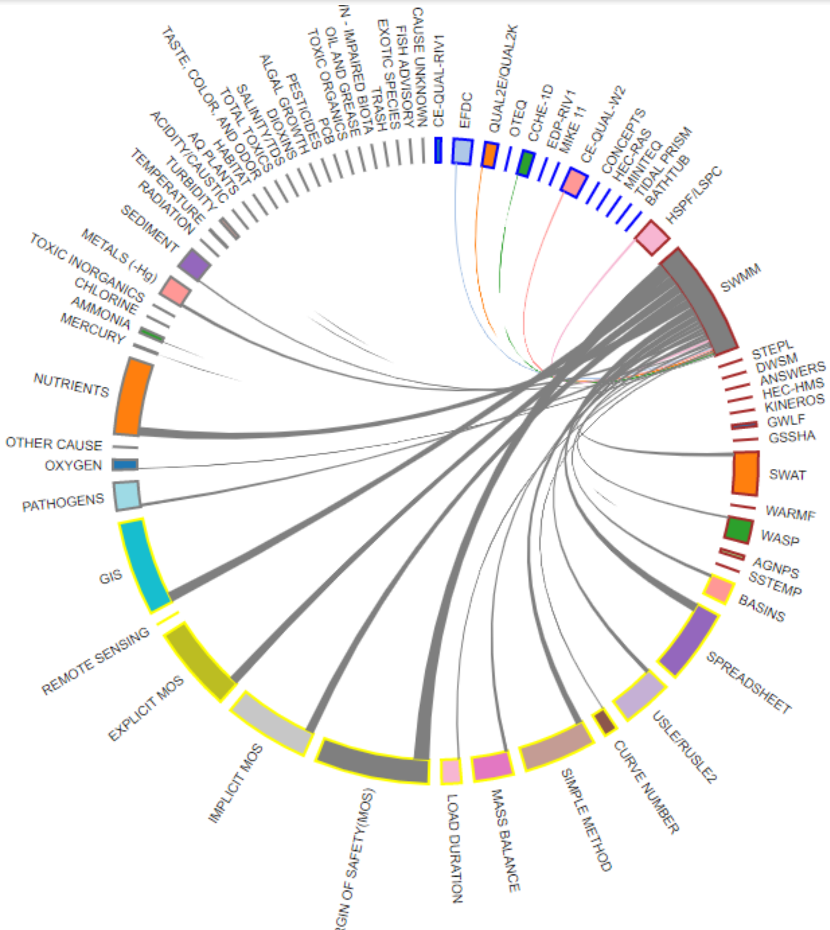
Control of combined and sanitary sewer overflows.

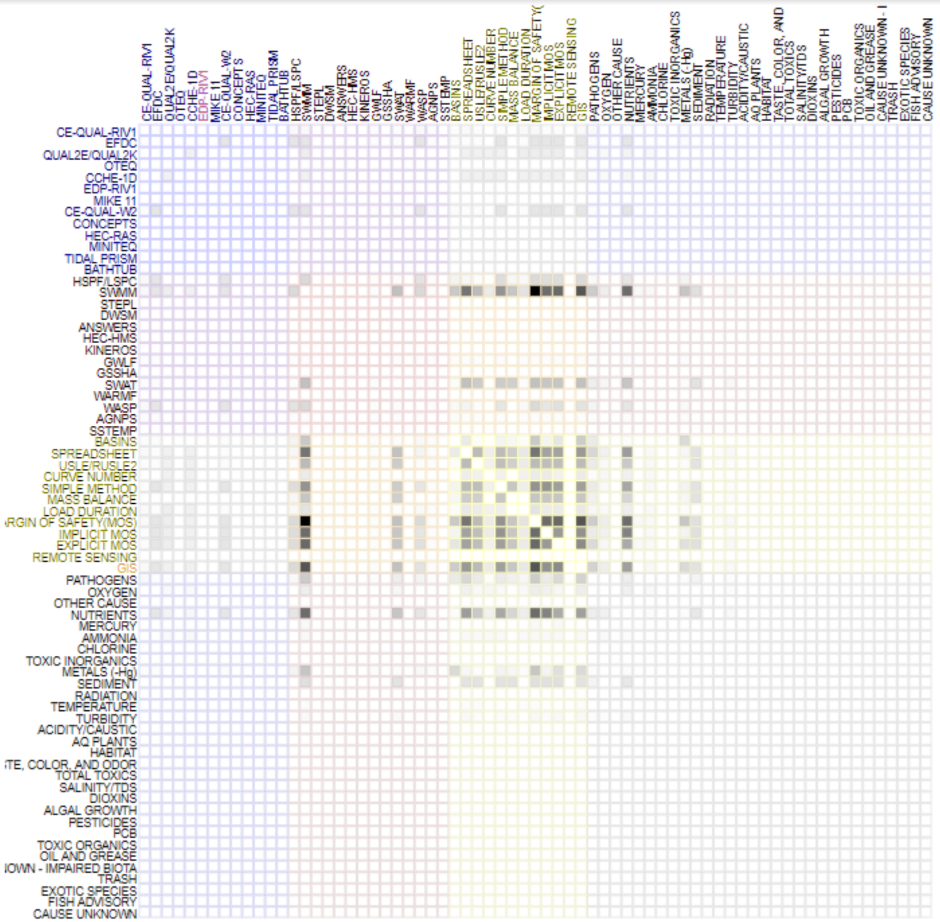
Modeling Inflow & Infiltration in sanitary sewer systems.

Generating non-point source pollutant loadings for waste load allocation studies.

Evaluating green infrastructure.

Total Maximum Daily Loads Tool

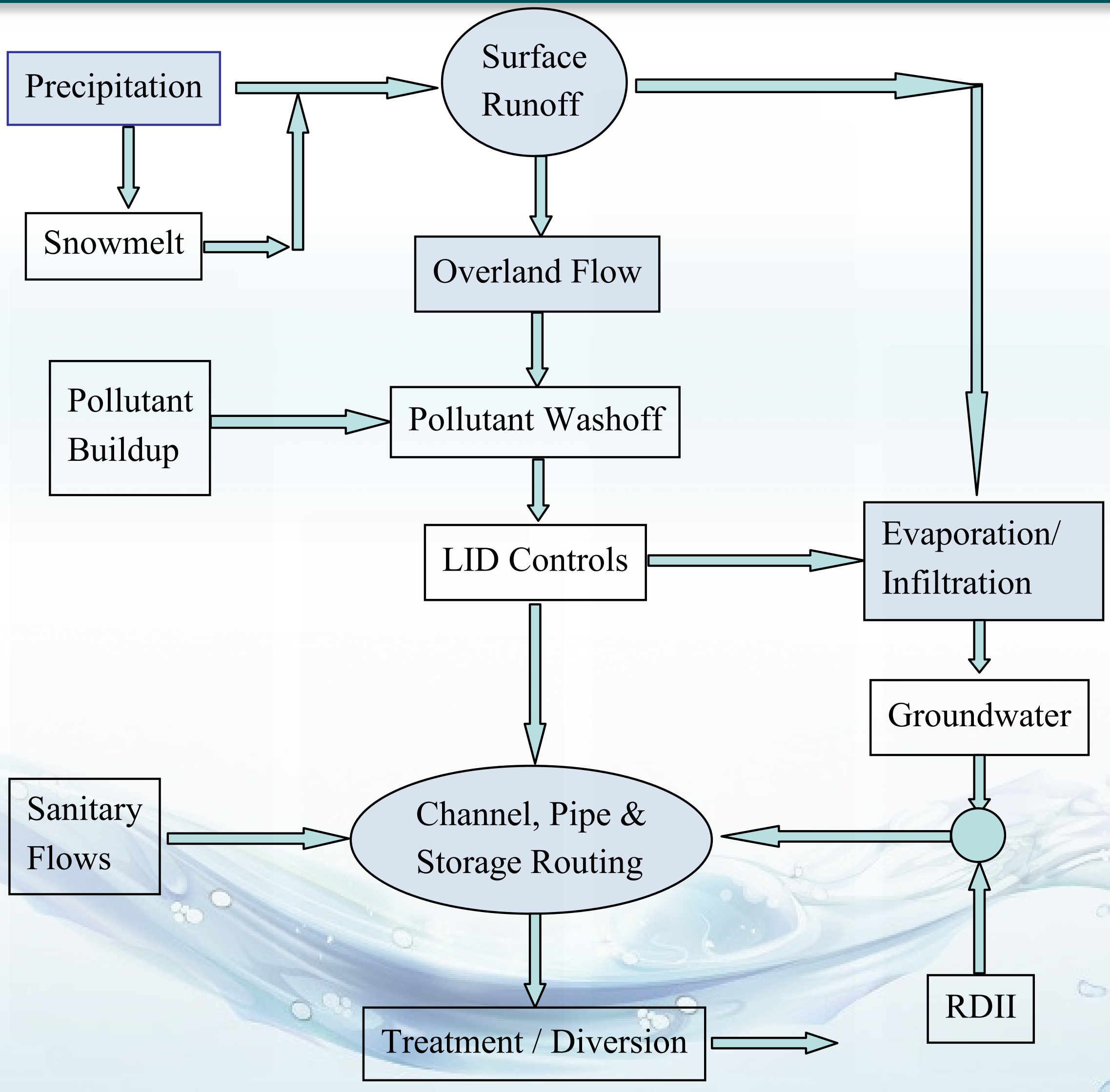




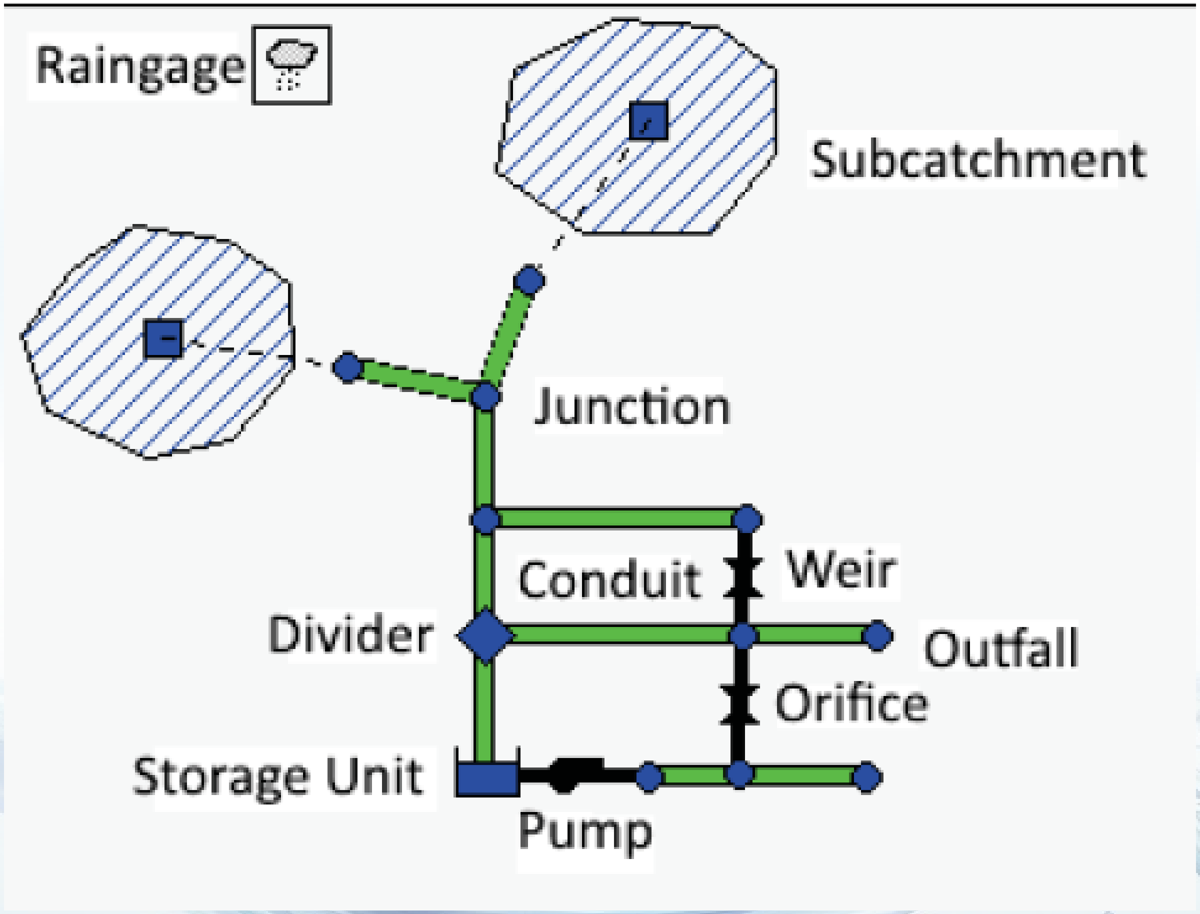
https://occviz.com/tmdl/

United States Environmental Protection Agency

SWMM's Process Models



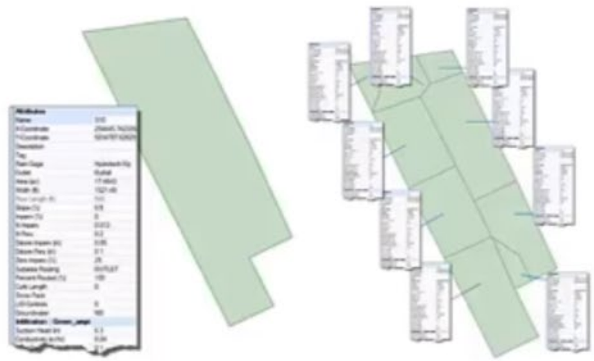
SWMM's Conceptual Model



Idealized Subcatchment (Courtesy of Rob James, CHI Water)

https://www.youtube.com/watch?v=HZnX_GsABUA

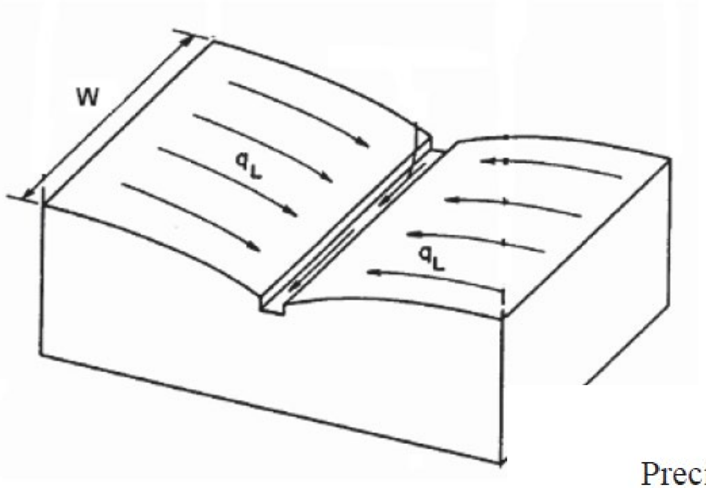
Subcatchment parameters

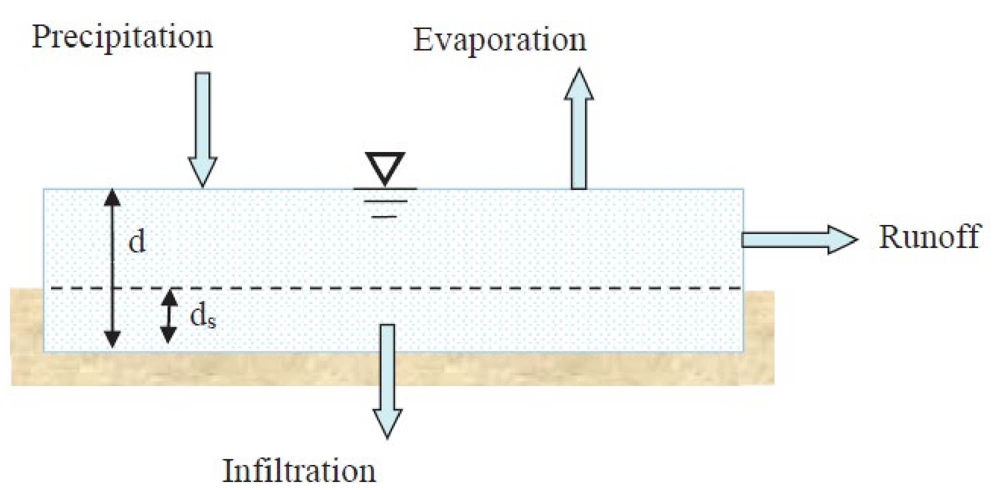


- Parameters may be averaged (lumped) over a coarse number of subcatchments
- Or further sub-divided (distributed) into a finer number of subcatchments

United States Environmental Protection Agency

Idealized Subcatchment





Subcatchment - Time of Concentration

United States
Department of
Agriculture

Natural Resources Conservation Service

Part 630 Hydrology
National Engineering Handbook

Chapter 15 Time of Concentration

(e) Relation between lag and time of concentration

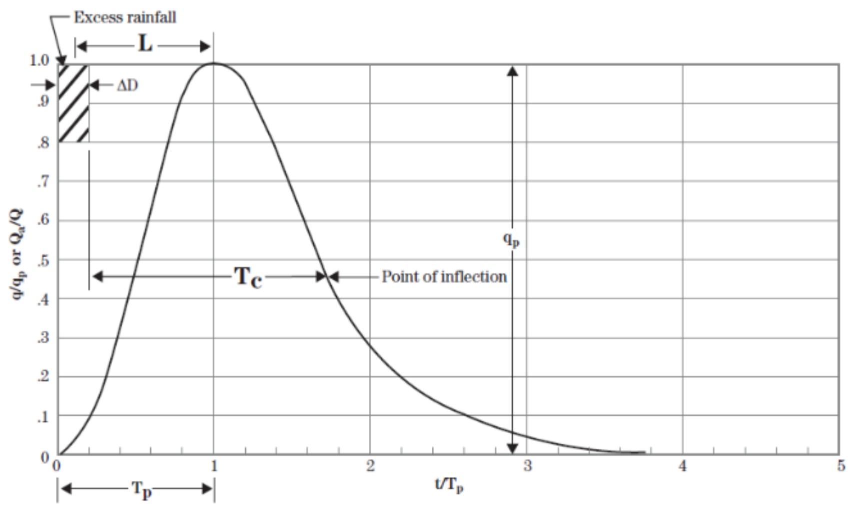
Various researchers (Mockus 1957; Simas 1996) found that for average natural watershed conditions and an approximately uniform distribution of runoff:

$$L = 0.6T_c \qquad \text{(eq. 15–3)}$$

where:
L = lag, h
T_c = time of concentration, h

When runoff is not uniformly distributed, the watershed can be subdivided into areas with nearly uniform flow so that equation 15–3 can be applied to each of the subareas.

Figure 15–3 The relation of time of concentration (T_c) and lag (L) to the dimensionless unit hydrograph



where:
L = Lag, h
T_c = time of concentration, h
T_p = time to peak, h
ΔD = duration of excess rainfall, h
t/T_p = dimensionless ratio of any time to time to peak
q = discharge rate at time t, ft^3/s
q_p = peak discharge rate at time T_p, ft^3/s
Q_a = runoff volume up to t, in
Q = total runoff volume, in

Infiltration

- Horton

$$F(t_p) = \int_0^{t_p} f_p dt = f_\infty t_p + \frac{(f_0 - f_\infty)}{k_d}\left(1 - e^{-k_d t_p}\right)$$

- Modified Horton

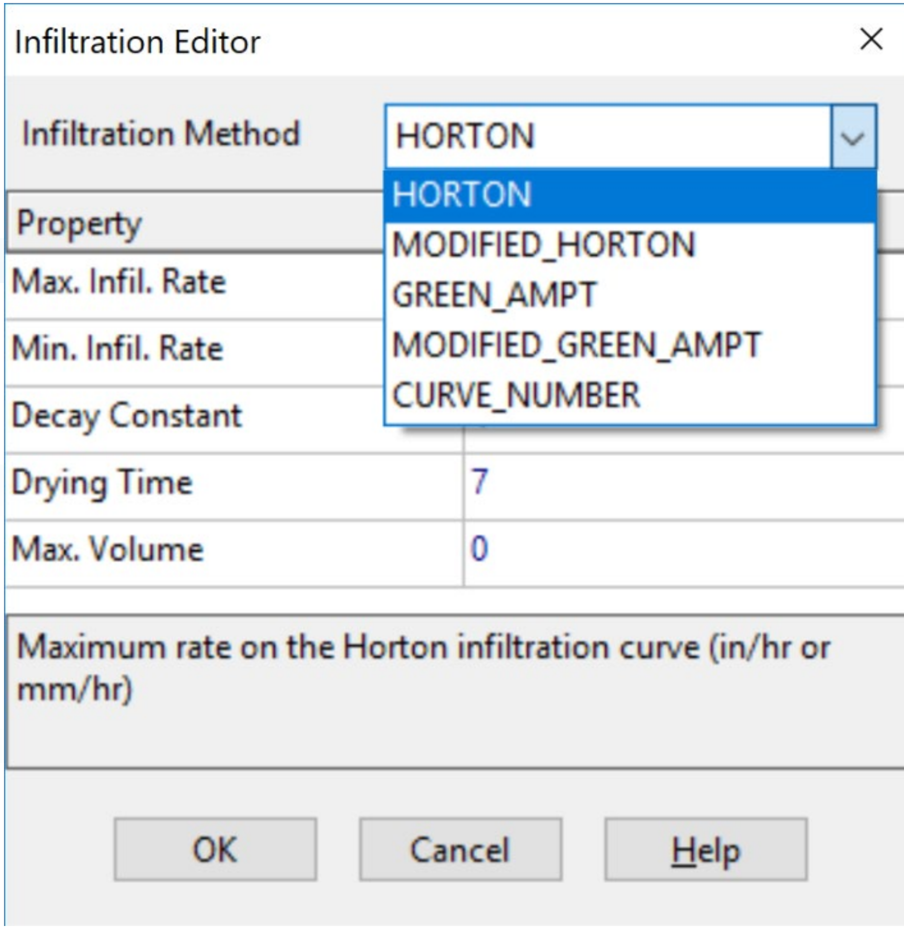
$$f_p = f_\infty + (f_0 - f_\infty)e^{-k_d t}$$

- Green_Ampt, Modified Green_Ampt

$$F = K_s + \psi_s \theta_d ln\left(1 + \frac{F}{\psi_s \theta_d}\right)$$

- Curve_Number

$$S_{max} = \frac{1000}{CN} - 10$$



Hydrology – Governing equations

First Principle Conservation of Mass

$$\frac{\partial d}{\partial t} = r - i - e - f - q \qquad \text{(modified 3-1)}$$

where:

r = runoff from upgradient subcatchment (if present), (m/s)

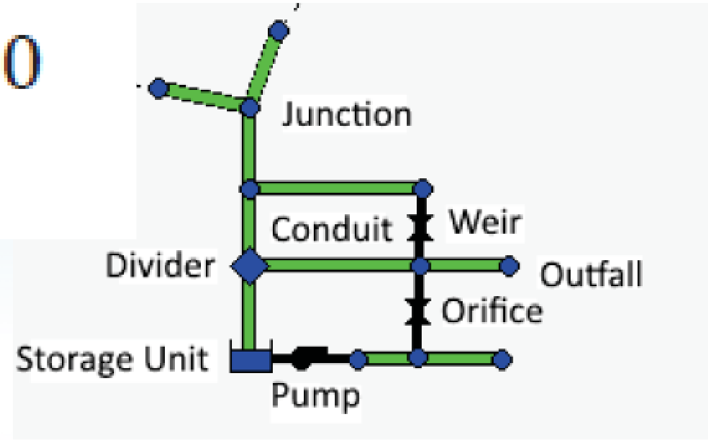
i = rate of rainfall + snowmelt (m/s)
e = surface evaporation rate (m/s)
f = infiltration rate (m/s)
q = runoff rate (m/s).

Note that the fluxes *i, e, f,* and *q* are expressed as flow rates per unit area (m3/sec/m^2 = m/s).

Hydraulic Governing Equations

Continuity

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



where

A = flow cross sectional area (m^2)

Q = flow rate (m^3/sec)

t = time (sec)

x = distance (m)

SWMM - Manning Equation

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

where

Q = flow rate (m^3/sec)

n = Manning roughness coefficient

A = flow cross sectional area (m^2)

R = hydraulic radius (m)

S = slope (m/m)

Pipes with Circular Force
Main Cross sections

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

Governing Equations

Momentum

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

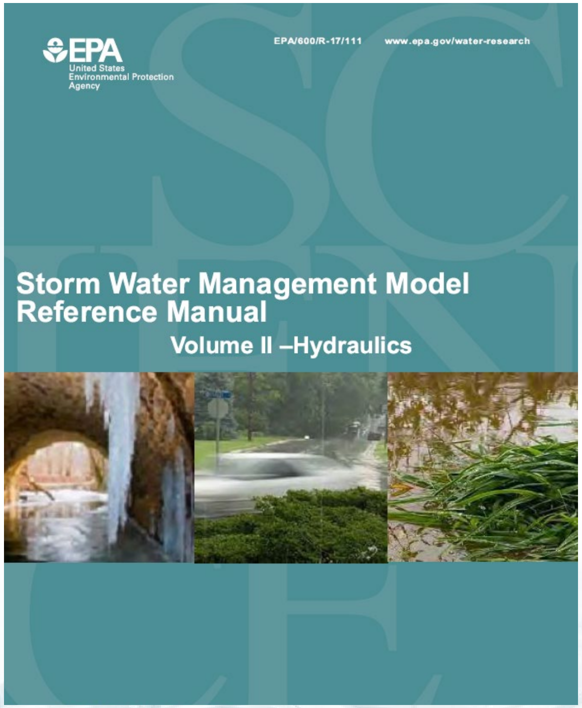
where

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

Assumptions

- Assumes varied, unsteady flow (Saint Venant Equations)

- Level of Sophistication
  - Steady Flow Routing
  - Kinematics Wave Routing
  - Dynamic Wave Routing



Kinematic Wave

Cannot have

- Looped networks
- Backwater effects
- Pressure-flow conditions

https://www.youtube.com/watch?v=ziWy5qbVIWo

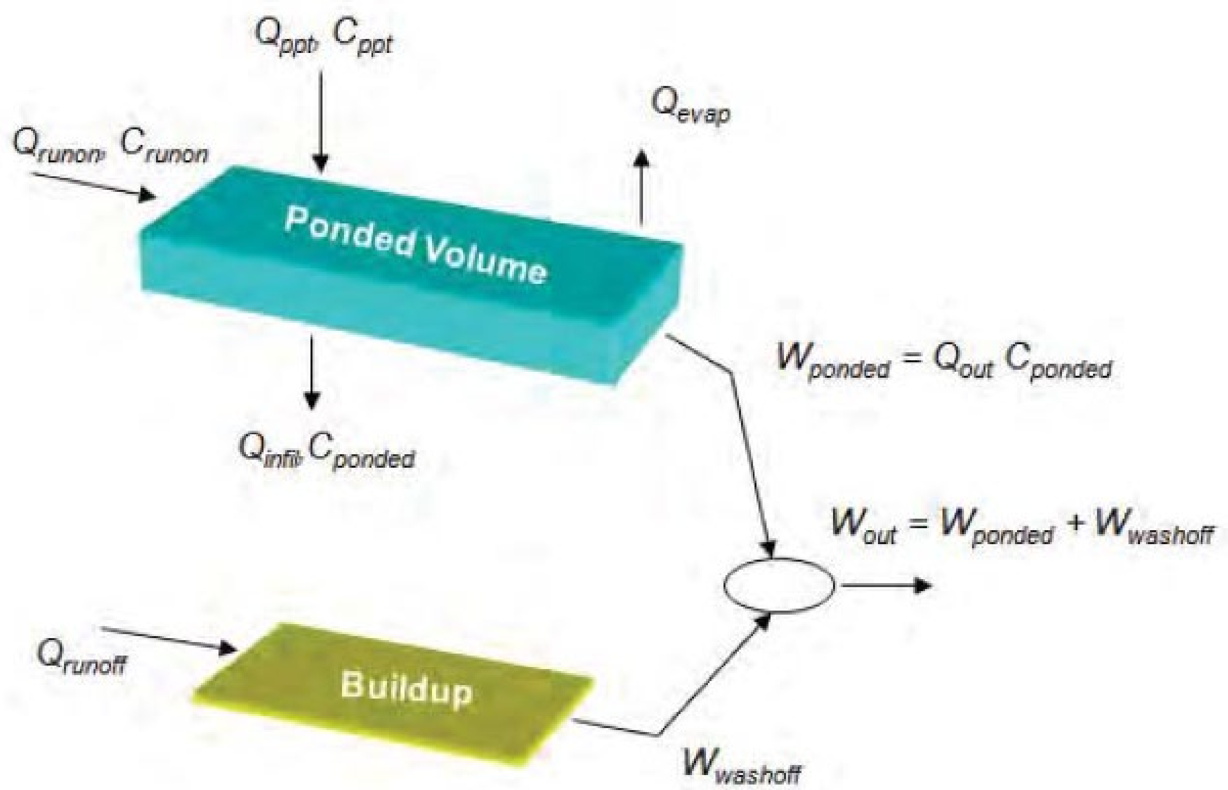
Dynamic Wave Routing

Used for

- Branched or looped networks
- Backwater due to tidal or other conditions
- Free-surface flow
- Pressure flow or surcharge
- Flow reversals

https://slideplayer.com/slide/6357250/

Pollutant Buildup and Wash off



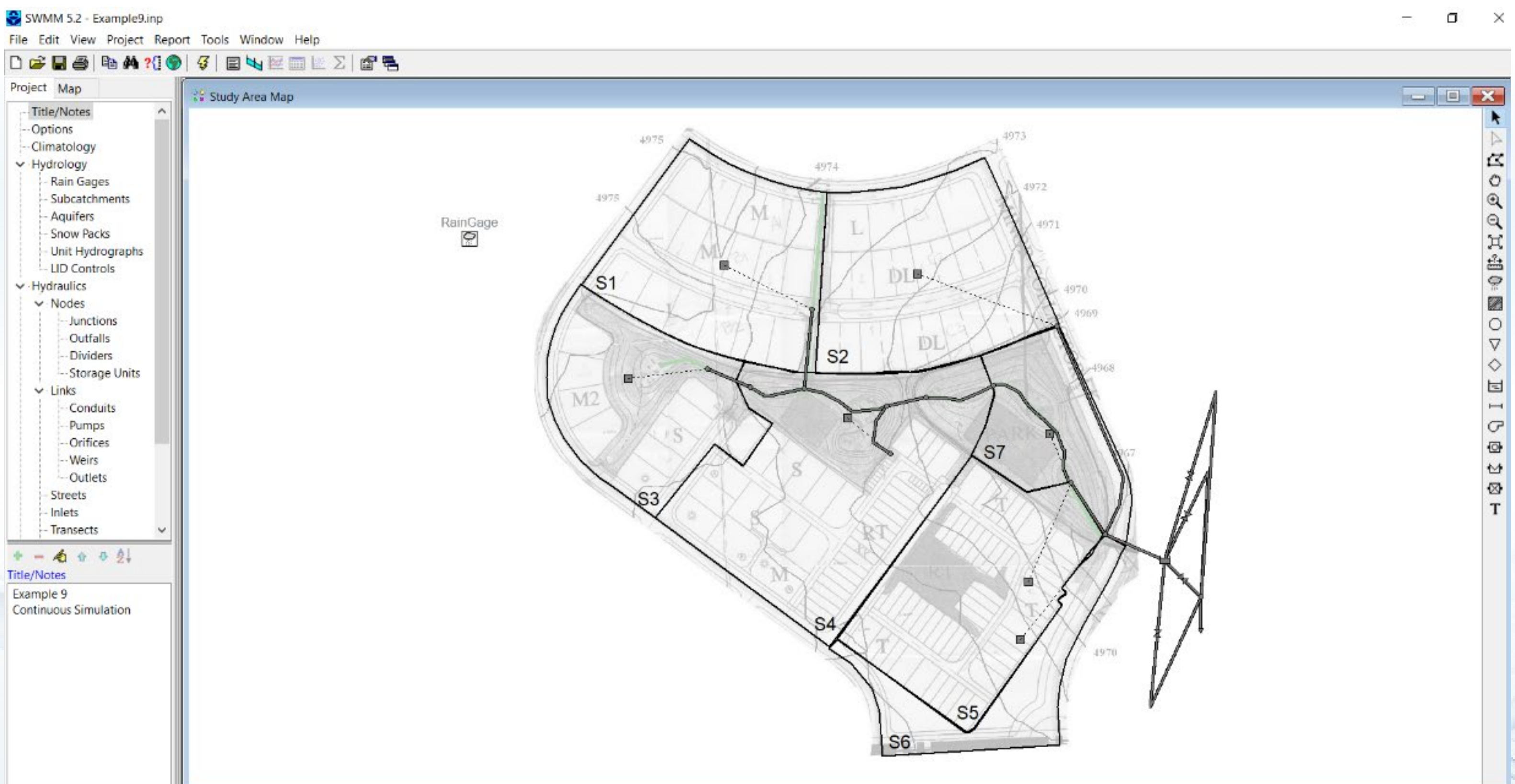
Questions?

Day 1

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Features in SWMM
5. Building the Hydrologic Model
6. Day One wrap-up

Storm Water Management Model

https://www.epa.gov/water-research/storm-water-management-model-swmm



SWMM Webpage, continued

https://www.epa.gov/water-research/storm-water-management-model-swmm

Software

Date	Description
02/01/2022	Self-extracting Installation Program for SWMM 5.2.0 (32-bit) (exe)
02/01/2022	Self-Extracting Installation Program for SWMM 5.2.0 (64-bit) (exe)
12/11/2014	SWMM-CAT Download Version 1 (zip)

Source Codes and Bug Fixes

Date	Description
02/01/2022	SWMM 5 Update Bugs and Fixes (txt)
02/01/2022	Source Code for the SWMM 5.2.0 Computational Engine (zip)
02/01/2022	Source Code for the SWMM 5.2.0 Graphical User Interface (zip)
02/01/2022	SWMM 5.2.0 API Guide (zip)

SWMM Webpage, continued

https://www.epa.gov/water-research/storm-water-management-model-swmm

Manuals and Guides

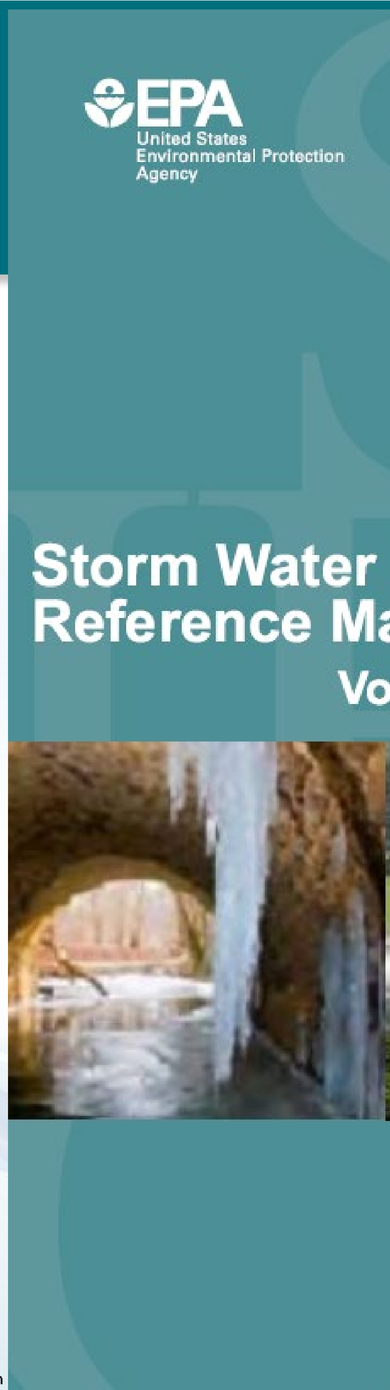
Date	Title
02/01/2022	SWMM 5.2 User's Manual (pdf)
09/01/2014	SWMM-CAT User's Guide (pdf)
09/07/2016	SWMM Applications Manual (zip)(7 MB)
03/19/2019	SWMM Reference Manuals Errata (Volume I and II) (pdf)
01/29/2016	SWMM Reference Manual Volume 1- Hydrology (pdf)
08/07/2017	SWMM Reference Manual Volume II- Hydraulics (pdf)
02/01/2022	SWMM Reference Manual Volume II – Addendum (pdf)
09/08/2016	SWMM Reference Manual Volume III—Water Quality (pdf) (Includes description of the LID Module)

United States
Environmental Protection
Agency

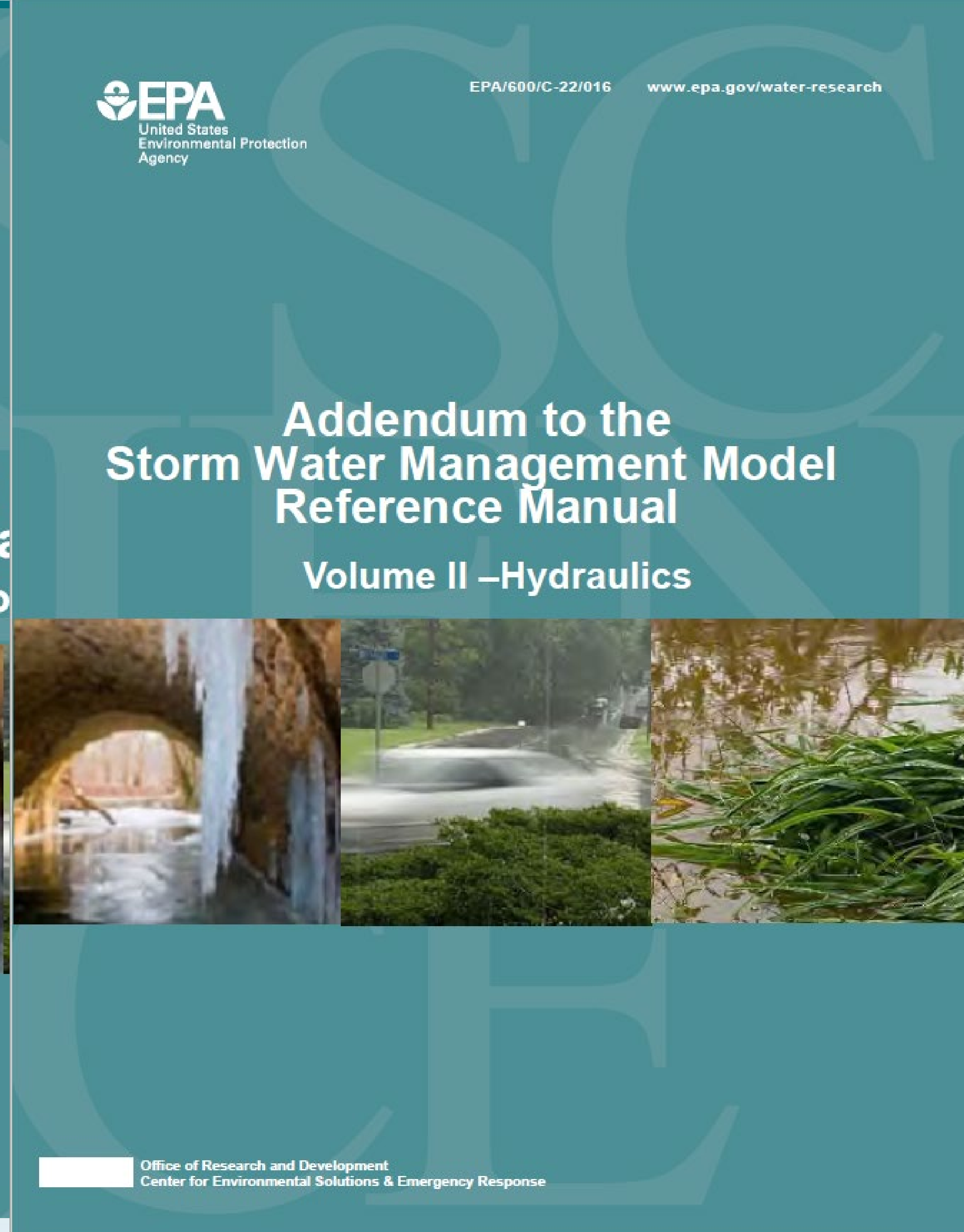
EPA/600/R-15/162A | January 2016 | www2.epa.gov/water-research

Storm Water Management Model Reference Manual

Volume I – Hydrology (Revised)


United States Environmental Protection Agency

Storm Water
Reference Ma
Vo


EPA/600/C-22/016 www.epa.gov/water-research

United States Environmental Protection Agency

Addendum to the Storm Water Management Model Reference Manual

Volume II –Hydraulics

Office of Research and Development
Center for Environmental Solutions & Emergency Response

United States Environmental Protection Agency

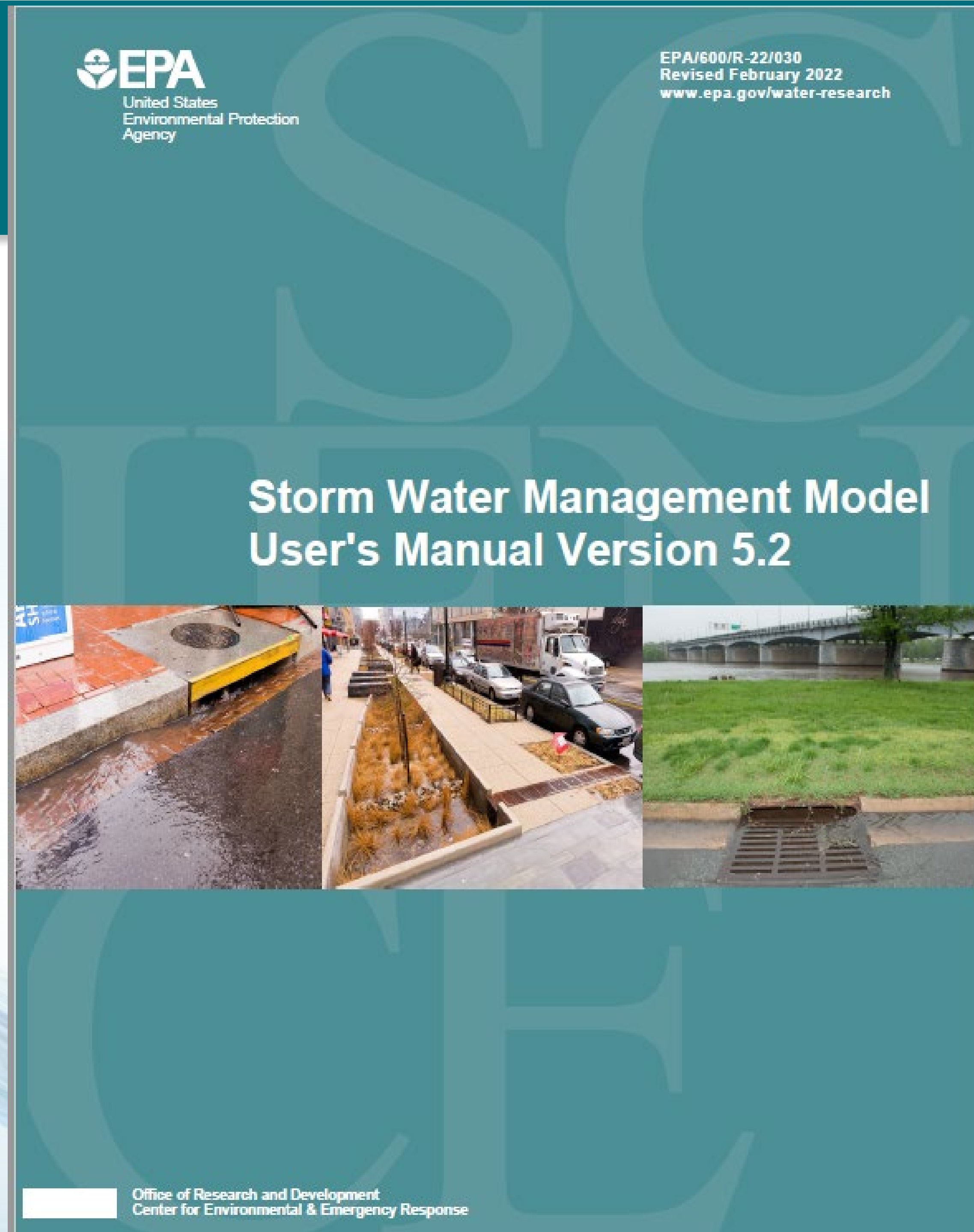
EPA/600/R-16/093 | July 2016 | www.epa.gov/water-research

United States
Enviromental Protection
Agency

Storm Water Management Model Reference Manual

Volume III – Water Quality

New User’s Manual



SWMM Reference Manuals

4.4 Green-Ampt Method

The Green-Ampt equation (Green and Ampt, 1911) has received considerable attention in recent years. The original equation was for infiltration with excess water at the surface at all times. Mein and Larson (1973) showed how it could be adapted to a steady rainfall input and proposed a way in which the capillary suction parameter could be determined. Chu (1978) has shown the applicability of the equation to the unsteady rainfall situation, using data for a field catchment. The Green-Ampt method was added into SWMM III in 1981 by R.G. Mein and W. Huber (Huber et al., 1981).

4.4.1 Governing Equations

The Green-Ampt conceptualization of the infiltration process is one in which infiltrated water moves vertically downward in a saturated layer, beginning at the surface (Figure 4-5). In the wetted zone the moisture content θ is at saturation θ_s while the moisture content in the un-wetted zone is at some known initial level θ_i.

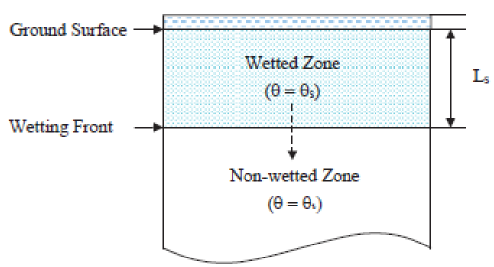


Figure 4-5 Two-zone representation of the Green-Ampt infiltration model (after Nicklow et al., 2006).

The water velocity within the wetted zone is given by Darcy's Law as a function of the saturated hydraulic conductivity K_s, the capillary suction head along the wetting front ψ_s, the depth of ponded water at the surface d, and the depth of the saturated layer below the surface L_s:

Manuals and Guides

Date	Title
02/01/2022	SWMM 5.2 User's Manual (pdf)
09/01/2014	SWMM-CAT User's Guide (pdf)
09/07/2016	SWMM Applications Manual (zip)(7 MB)
03/19/2019	SWMM Reference Manuals Errata (Volume I and II) (p
01/29/2016	SWMM Reference Manual Volume 1- Hydrology (pdf
	ıme II- Hydraulics (pd
	olume II – Addendum
	me III—Water Quality

$$f_p = K_s\left[\frac{d + L_s + \psi_s}{L_s}\right] \quad (4\text{-}26)$$

The depth of the saturated layer L_s can be expressed in terms of the cumulative infiltration, F, and the initial moisture deficit to be filled below the wetting front, $\theta_d = \theta_s - \theta_i$ as $L_s = F/\theta_d$. Substituting this into Equation 4-26 and assuming that d is small compared to the other depths gives the Green-Ampt equation for saturated conditions:

$$f_p = K_s\left[1 + \frac{\psi_s \theta_d}{F}\right] \quad (4\text{-}27)$$

Equation 4-27 applies only after a saturated layer develops at the ground surface. Prior to this point in time the infiltration capacity will equal the rainfall intensity:

$$f_p = i \quad (4\text{-}28)$$

As time increases, one can test whether saturation has been reached by solving 4-27 for F (which will be denoted as F_s) with f_p set equal to i and check if this value equals or exceeds the actual cumulative infiltration F:

$$F_s = \frac{K_s \psi_s \theta_d}{i - K_s} \quad (4\text{-}29)$$

Note that there is no calculation of F_s when $i <= K_s$, although F still gets updated during such periods. Finally, in this scheme the actual infiltration f is the same as the potential value f_p:

$$f = f_p \quad (4\text{-}30)$$

The two equations are illustrated in Figure 4-6 for the situation $K_s = 0.25$ in/hr, $\psi_s = 6.5$ in, and $\theta_d = 0.20$. The initial, flat portion of the curve corresponds to $f = i$, up to the point where $F = F_s$ (Equation 4-29). The remainder of the curve corresponds to the potential rate computed with Equation 4-27. Note that the infiltration rate approaches K_s (0.25 in/hr) asymptotically.

Use the SWMM Tutorials

CHAPTER 2 – QUICK START TUTORIAL

This chapter provides a tutorial on how to use EPA SWMM. If you are not familiar with the elements that comprise a drainage system, and how these are represented in a SWMM model, you might want to review the material in Chapter 3 first.

2.1 Example Study Area

In this tutorial we will model the drainage system serving a 12-acre residential area. The system layout is shown in Figure 2-1 and consists of subcatchment areas[3] *S1* through *S3*, storm sewer conduits *C1* through *C4*, and conduit junctions *J1* through *J4*. The system discharges to a creek at the point labeled *Out1*. We will first go through the steps of creating the objects shown in this diagram on SWMM's study area map and setting the various properties of these objects. Then we will simulate the water quantity and quality response to a 3-inch, 6-hour rainfall event, as well as a continuous, multi-year rainfall record.

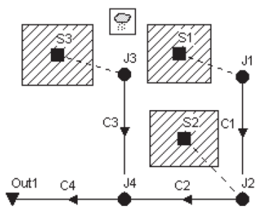


Figure 2-1 Example study area

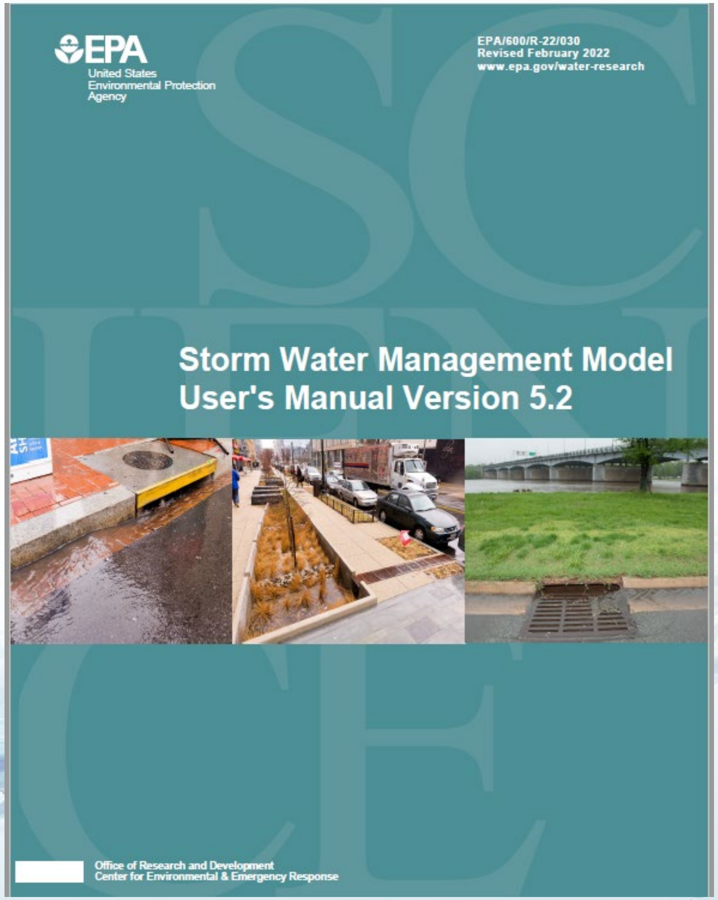
2.2 Project Setup

Our first task is to create a new SWMM project and make sure that certain default options are selected. Using these defaults will simplify the data entry tasks later on.

1. Launch EPA SWMM if it is not already running and select **File** >> **New** from the Main Menu bar to create a new project.
2. Select **Project** >> **Defaults** to open the Project Defaults dialog.

[3] A subcatchment is an area of land containing a mix of pervious and impervious surfaces whose runoff drains to a common outlet point, which could be either a node of the drainage network or another subcatchment.

https://swmm5.org/2017/08/14/epa-swmm5-tutorial-with-images-for-swmm-5-1-012/



Day 1

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Features in SWMM
5. Building the Hydrologic Model
6. Day One wrap-up

Demonstration of SWMM Tutorial

Demonstration of SWMM

- Walk through
  - Hydrology
  - Hydraulics
  - Water Quality
  - Low Impact Development

- Calibration of SWMM

Day 1

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Features in SWMM
5. Building the Hydrologic Model
6. Day One wrap-up

New Features Added to EPA SWMM

- HEC-22 Inlet Analysis
- Control Rule Extensions
- Variable Speed Pumps
- Functional Storage Shapes

HEC-22 Inlet Analysis

- Inlets convey runoff from street pavements into below ground storm sewers.
- Inlet type, sizing and spacing chosen to meet limits on spread & depth of water on pavement.
- FHWA "Urban Drainage Design Manual" (HEC-22) is the de facto standard for inlet analysis.

Factors Affecting Inlet Flow Capture

On-Grade Grates:

- Approach flow rate, velocity & spread
- Street cross slope & curb depression
- Grate width & length

On-Grade Curb Openings:

- Approach flow rate
- Street slope, cross slope, roughness & curb depression
- Opening length

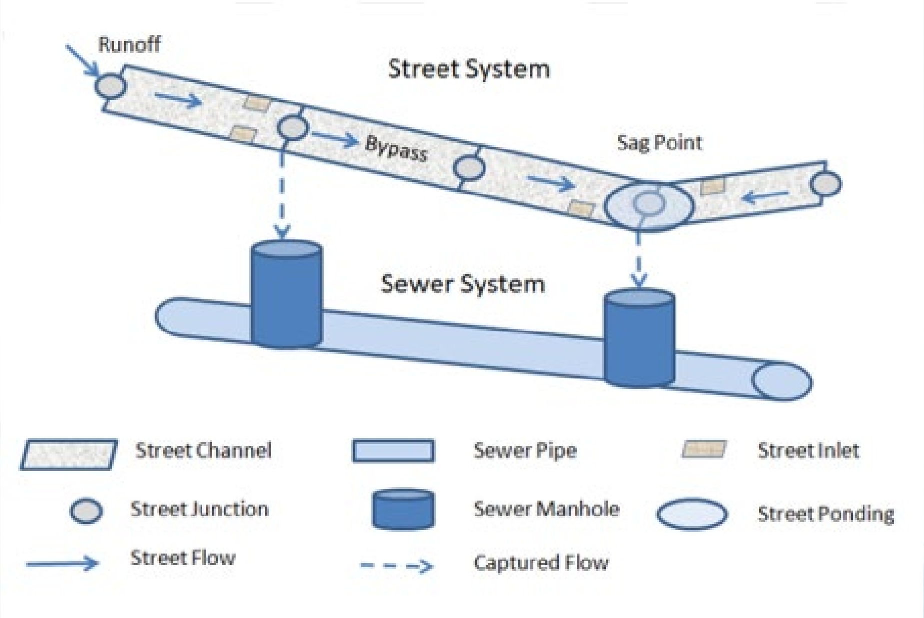
On-Sag Inlets:

- Depth of water at curb
- Grate width, length & area of openings
- Curb opening length & height

Modeling a Dual Drainage System

Methods for Modeling Dual Drainage Systems

- Flow divider nodes

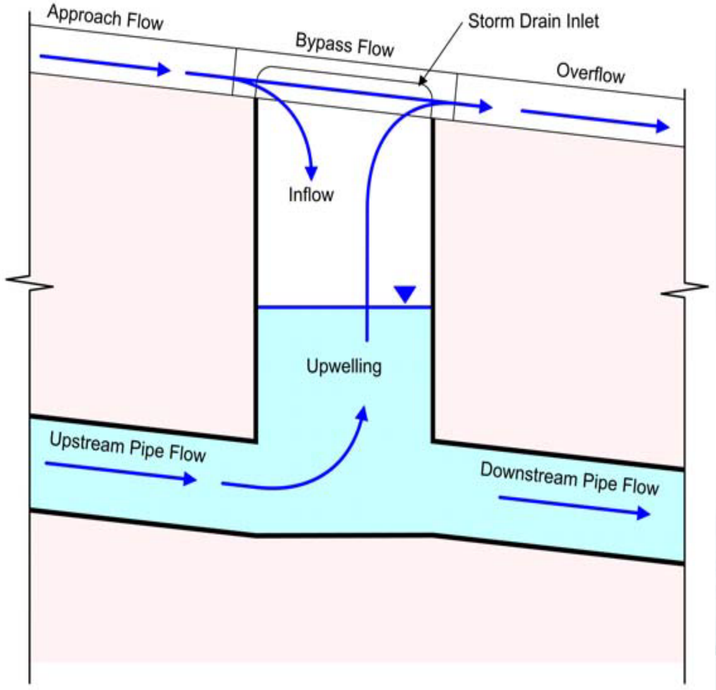


- Lateral flow adjustment

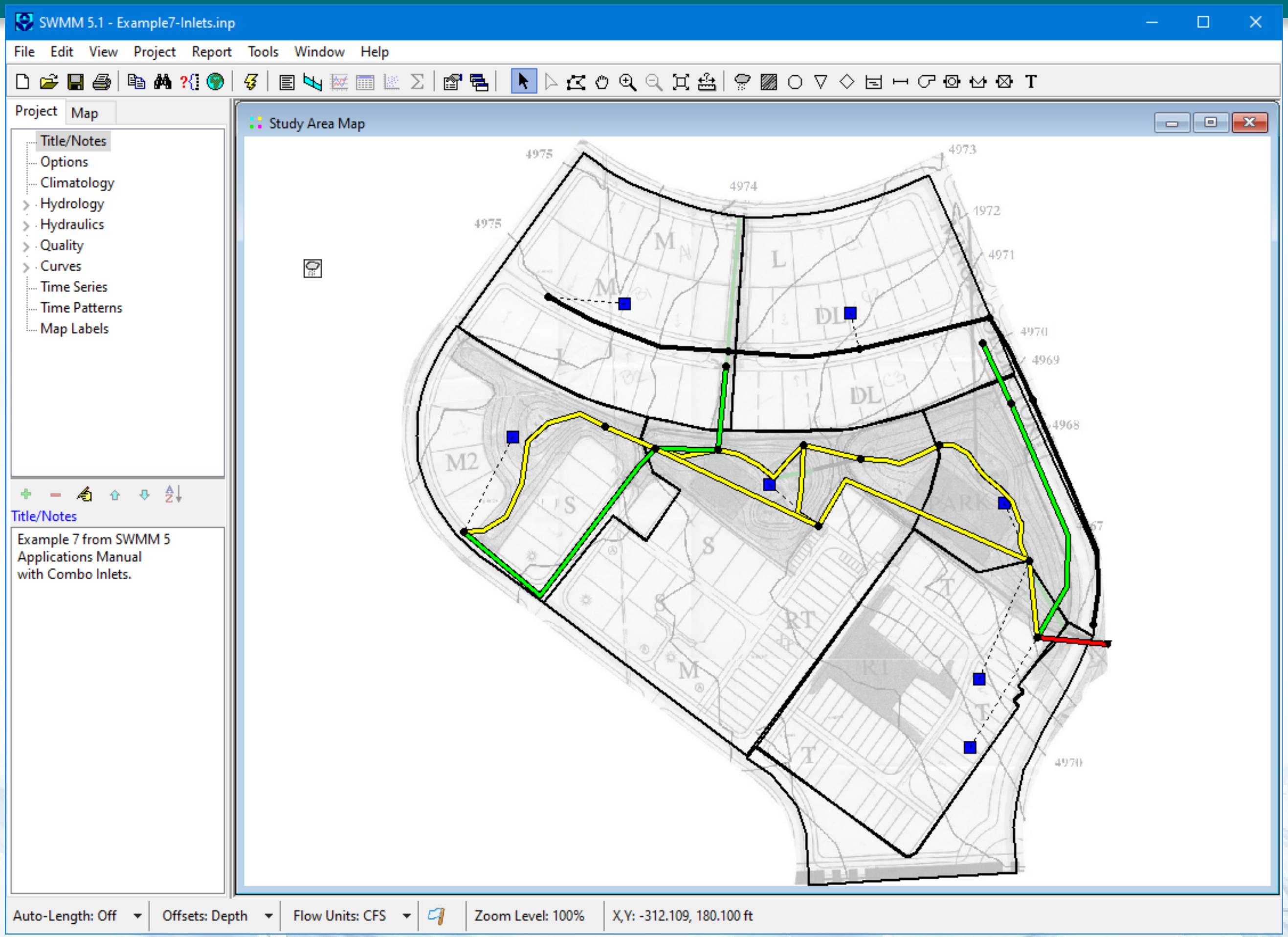
Inlet Analysis Using Lateral Flow Adjustment

At each flow routing time step:

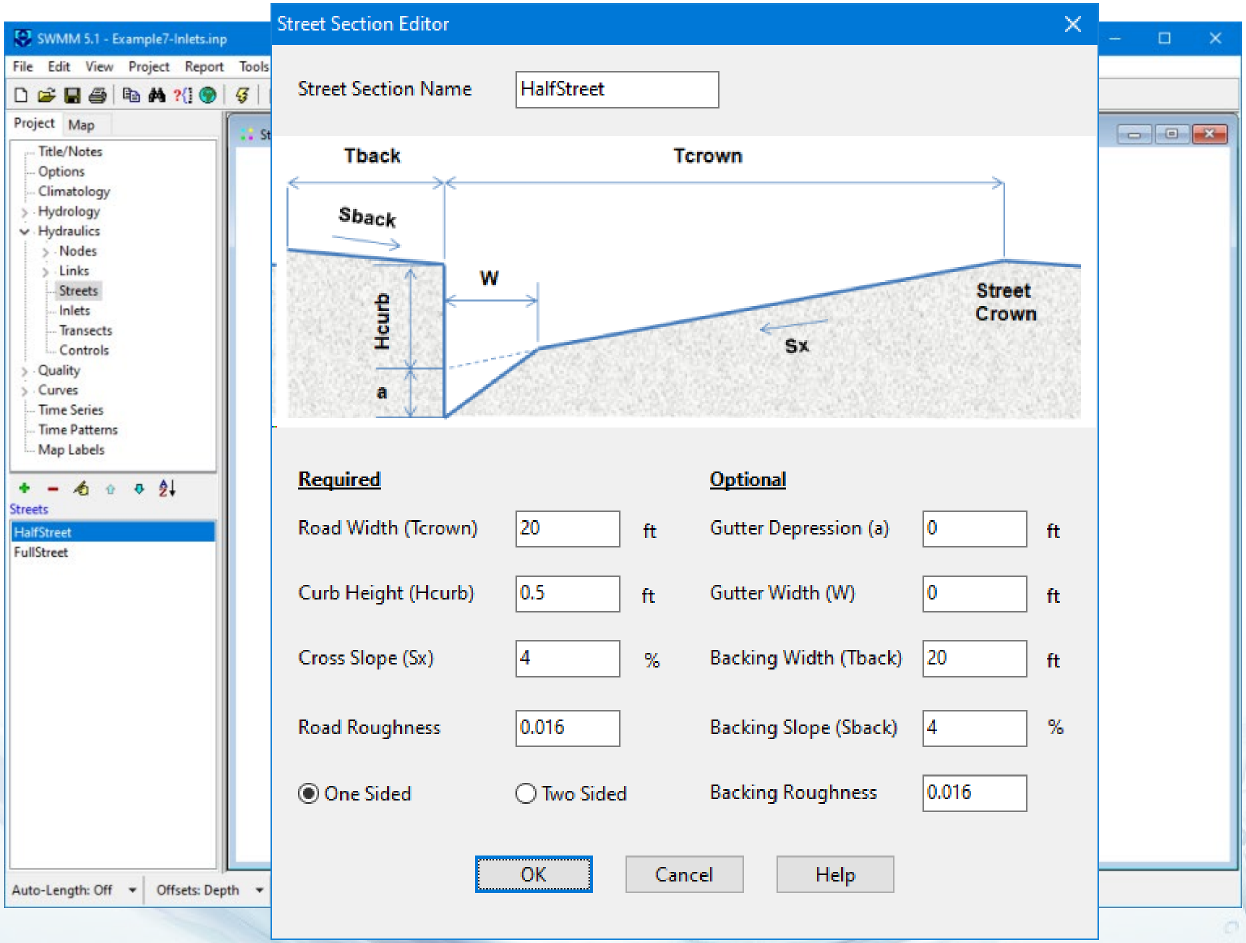
- Compute each inlet's flow capture (Qc) using HEC-22 methods
- Add Qc to sewer node's lateral inflow
- Subtract Qc from lateral inflow to inlet's street node
- Add any sewer node overflow to street node's lateral inflow
- Apply usual flow routing procedure



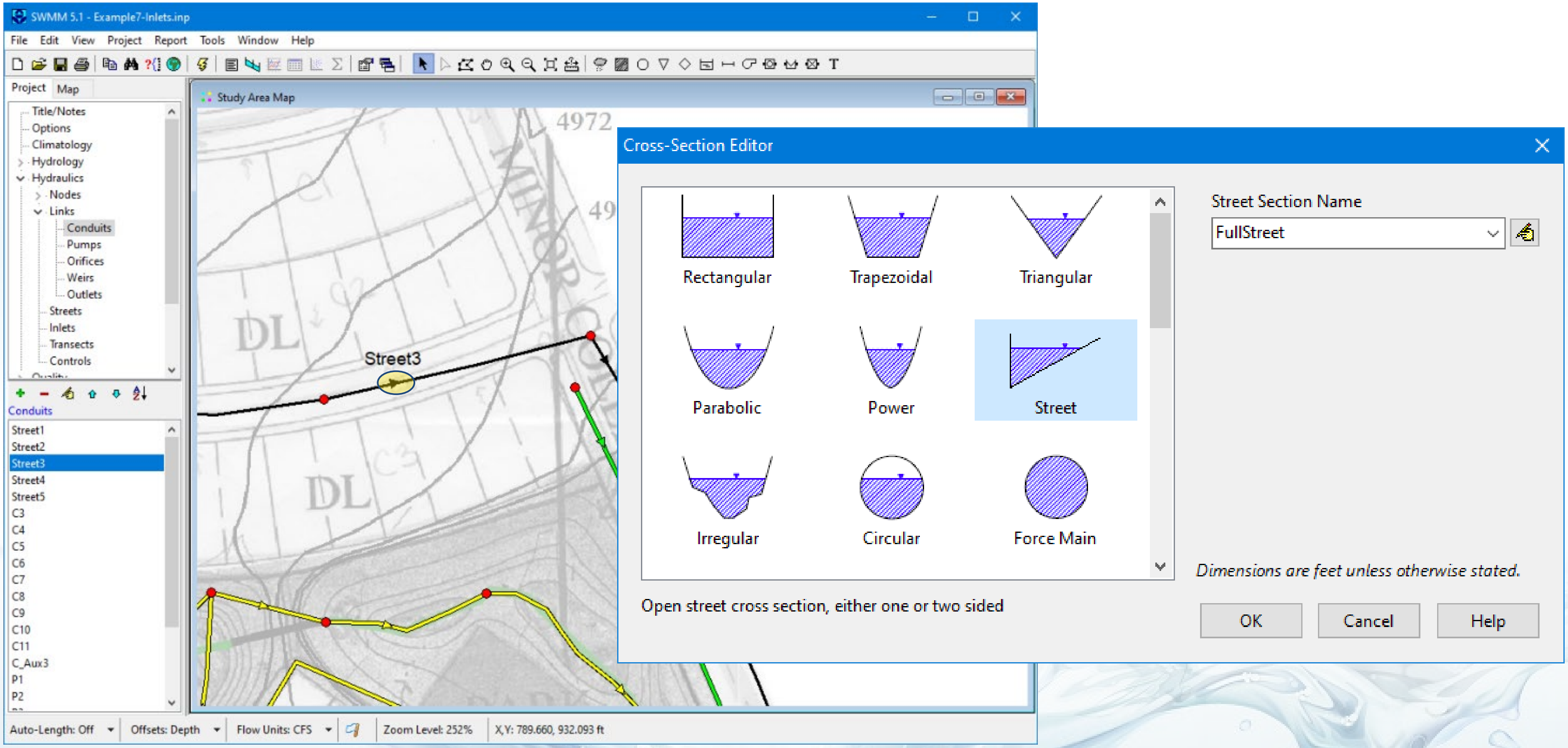
Step 1 - Layout the street and sewer networks



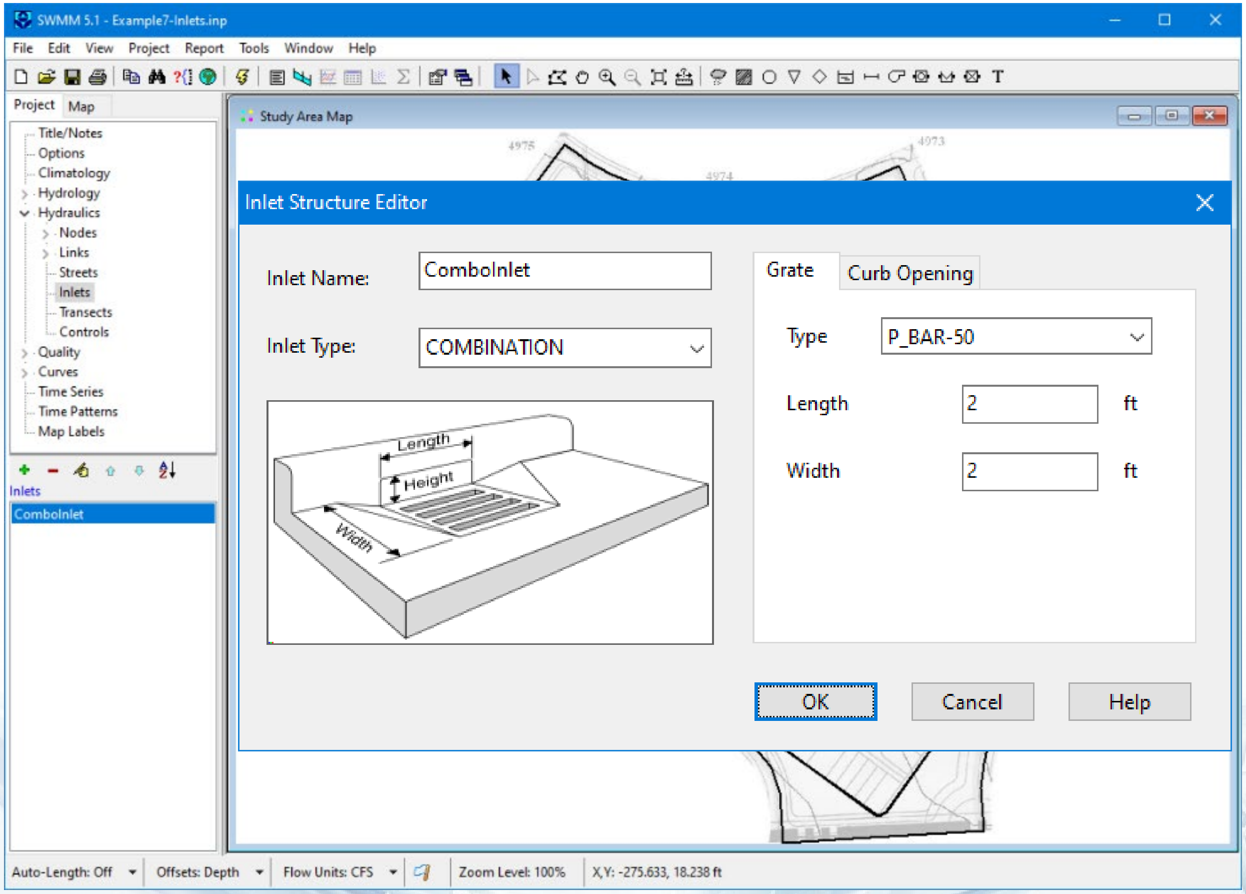
Step 2 - Create a collection of Street cross-sections



Step 3 - Assign Street cross-sections to street conduits

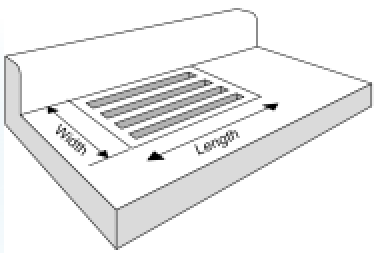


Step 4 - Create a collection of Inlet designs

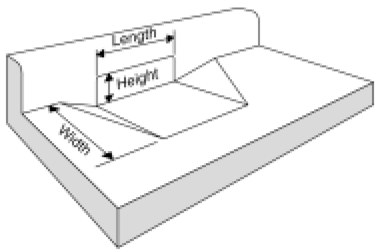


Supported Inlet Types

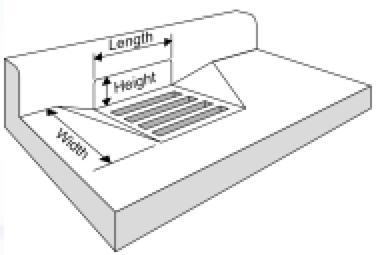
Curb & Gutter Inlets



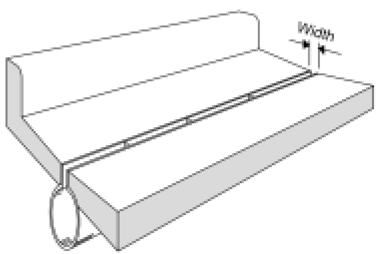
Grated Inlet



Curb-Opening Inlet

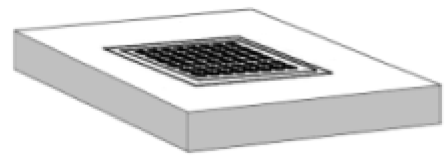


Combination Inlet

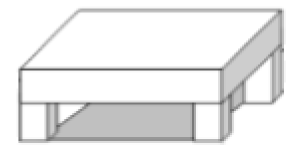


Slotted Drain Inlet

Drop Inlets

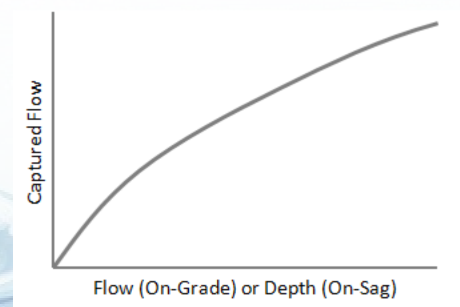


Drop Grate Inlet

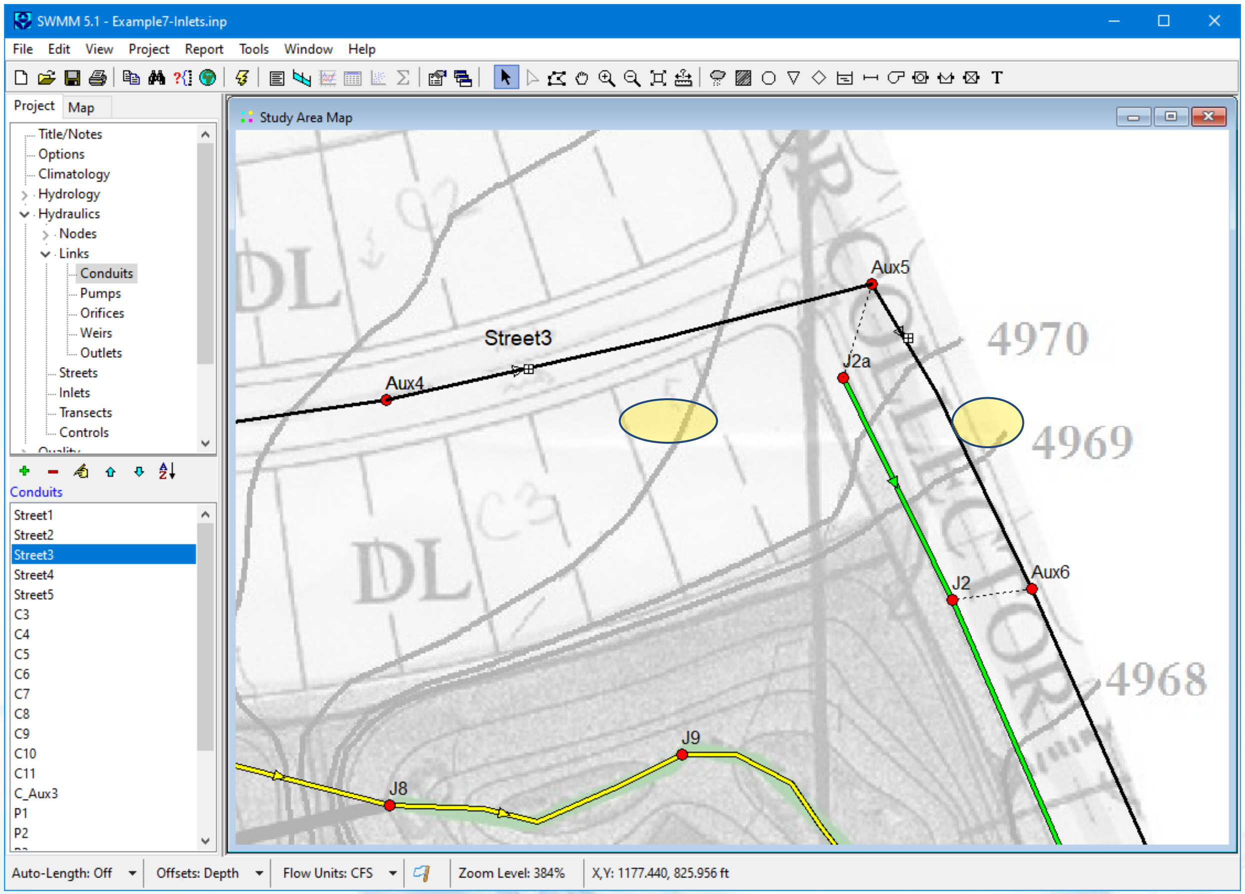


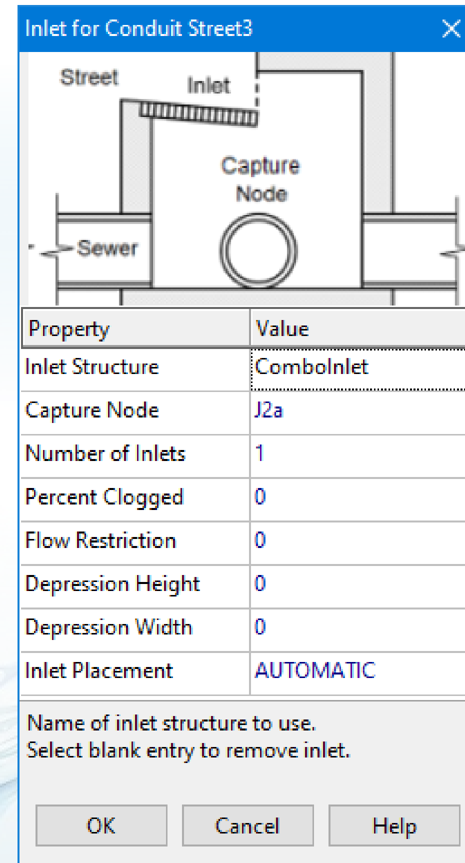
Drop Curb Inlet

Custom Inlet



Step 5 - Assign Inlet designs to streets





United States Environmental Protection Agency

Step 6 - Run an analysis and view the Street Flow Summary Report

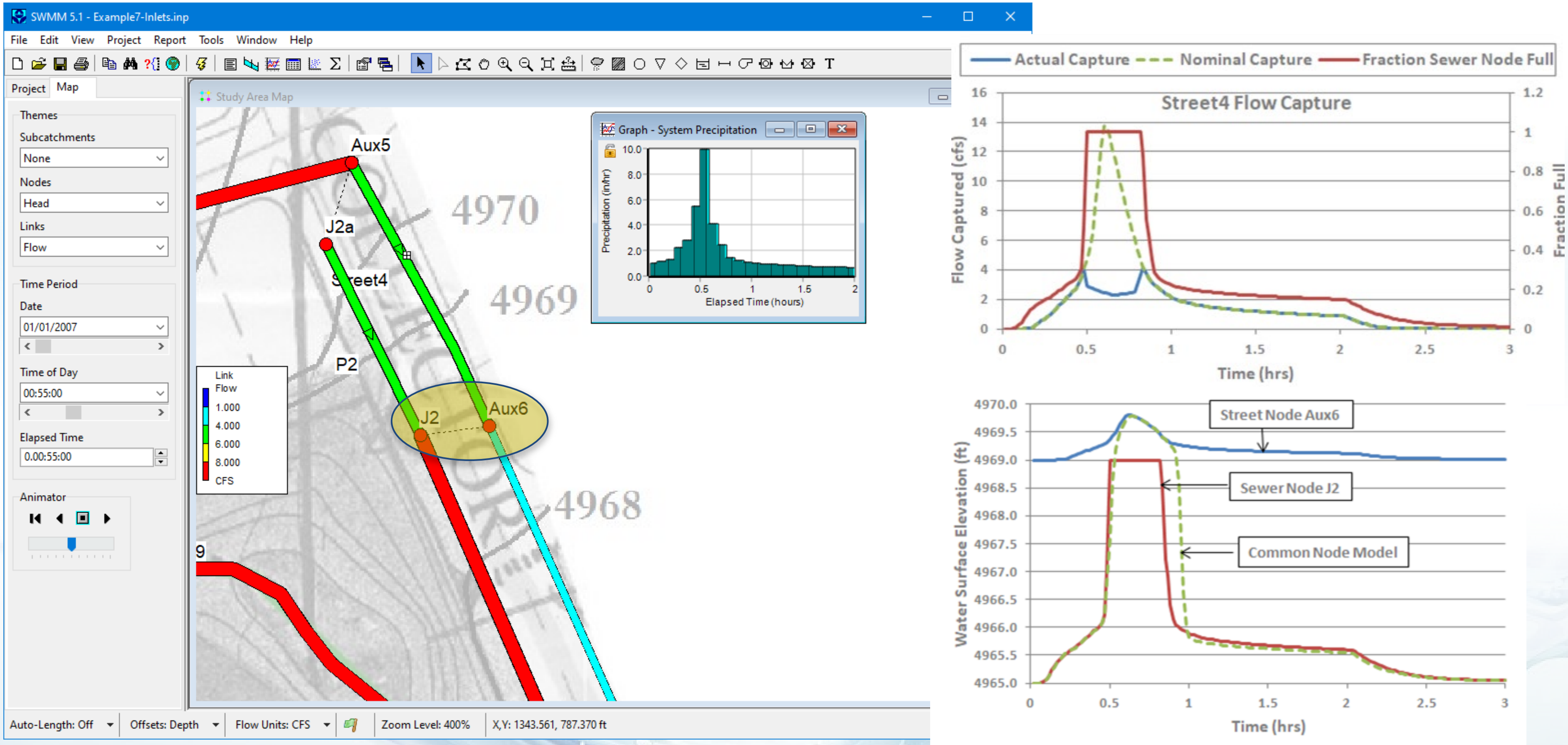
Summary Results

Topic: Street Flow

Click a column header to sort the column.

Street Conduit	Peak Flow CFS	Maximum Spread ft	Maximum Depth ft	Inlet Structure	Peak Flow Capture %	Average Capture %	Bypass Frequency %	Backflow Frequency %
Street1	37.33	19.99	0.65	ComboInlet	17.06	67.86	88.77	0.00
Street2	25.79	23.32	0.72					
Street3	59.91	28.22	0.83	ComboInlet	14.85	62.93	90.10	0.00
Street4	49.36	28.11	0.82	ComboInlet	4.94	64.30	86.82	0.00
Street5	45.02	30.73	0.93	ComboInlet	70.65	92.04	22.96	0.00

Reduced Capture Due to Full Manhole



Control Rule Enhancements

Control rule premise clauses expanded to include:

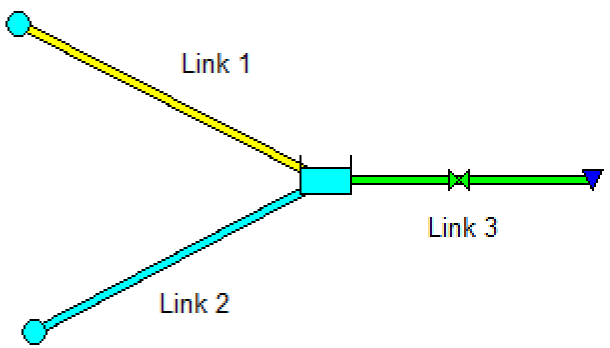
- additional control parameters
  - —rain gage current rainfall & next rainfall
  - —node full depth, volume, head
  - —conduit length, slope, full depth, full flow, velocity
- named variables as aliases for Object - ID - Property

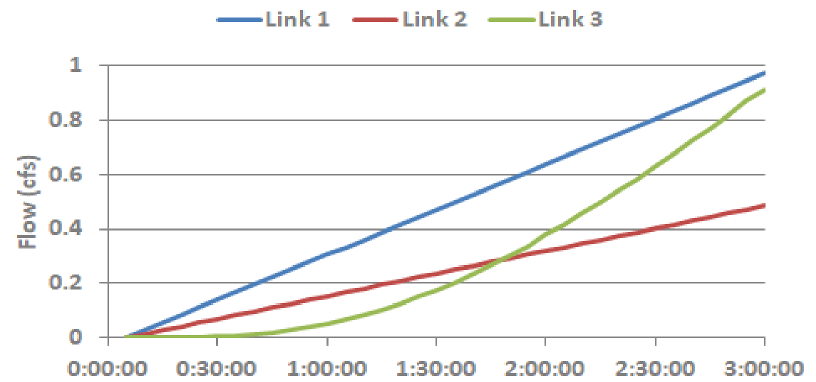
  Variable N23 = Node 23 Depth
- math expressions containing named variables

  Expression HGL = abs(H23.1-H23.2)/L23

EPA United States Environmental Protection Agency

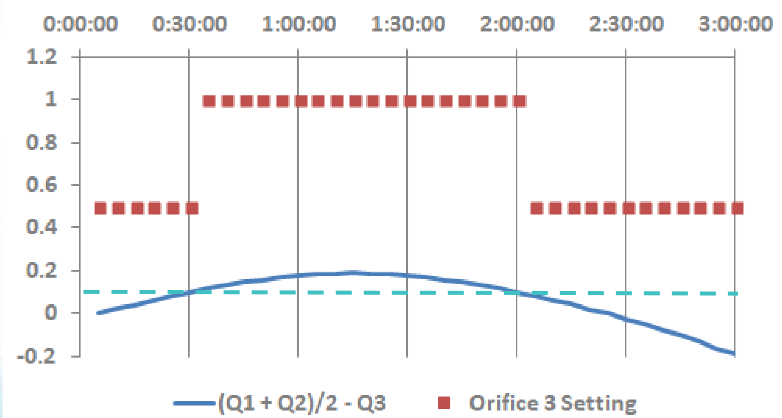
Example of Enhanced Control Rules






```
[RULES]
variable   Q1 = LINK 1 FLOW
variable   Q2 = LINK 2 FLOW
variable   Q3 = LINK 3 FLOW
expression Net_Inflow = (Q1 + Q2)/2 - Q3

rule 1
if Net_Inflow > 0.1
then ORIFICE 3 Setting = 1
else ORIFICE 3 Setting = 0.5
```

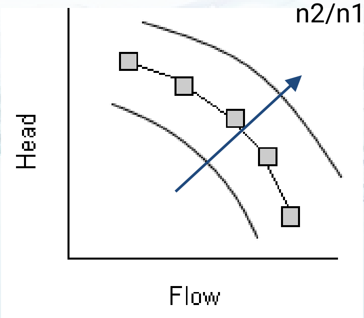


Variable Speed Pumps

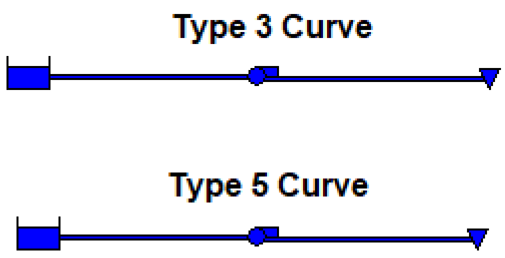
- Requires a Head (H) v. Flow (Q) performance curve that obeys the pump affinity laws:

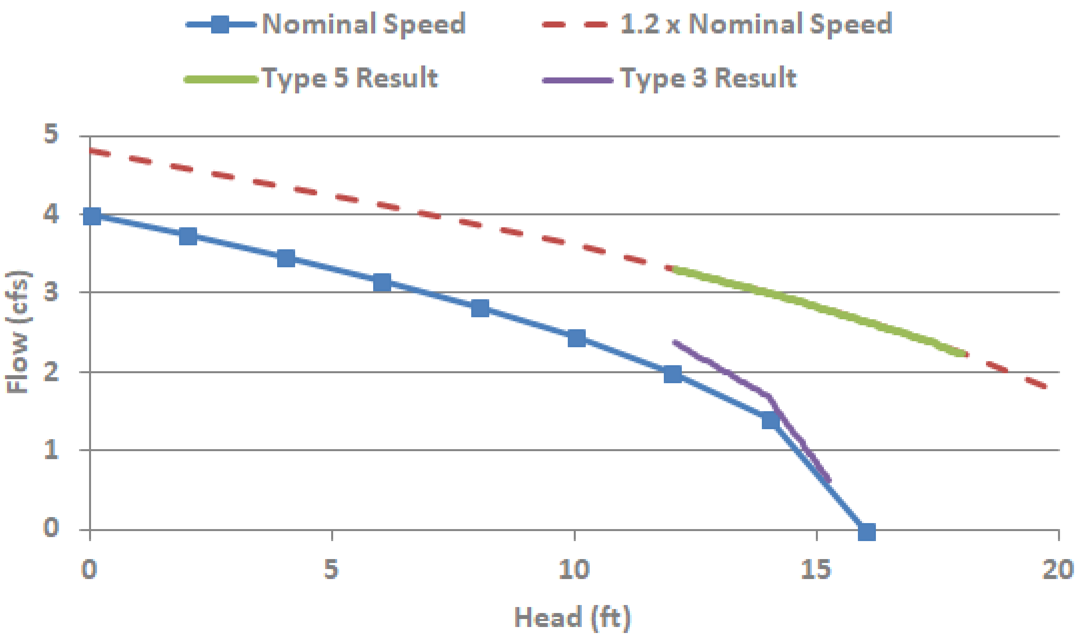
  $Q2/Q1 = n2/n1 \quad H2/H1 = (n2/n1)^2$

- These determine how the curve shifts as impeller speed changes from a nominal value n1 to n2.
  - SWMM's Type 3 Pump uses a H-Q curve that only follows the flow affinity law as its speed setting is changed.
  - A new Type 5 pump has been introduced that obeys both affinity laws.



New Type 5 Pump Curve v. Existing Type 3 Curve





If Simulation Time = 0

Then Pump Type3

Setting = 1.2

And Pump Type5 Setting

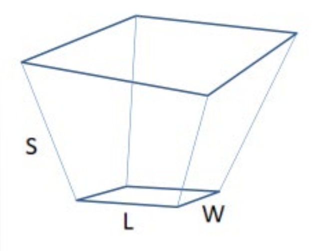
= 1.2

Storage Unit Curves

- SWMM represents storage unit shapes with a surface area v. depth curve.
- Either a tabular listing of area & depth points or a functional formula:

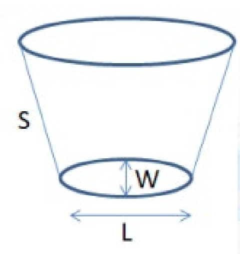
  Area = A0 + A1 * Depth^A2 can be used.
- The functional option cannot represent common regular shapes where all sides are sloping (e.g. truncated pyramids).

New Functional Storage Curves Added



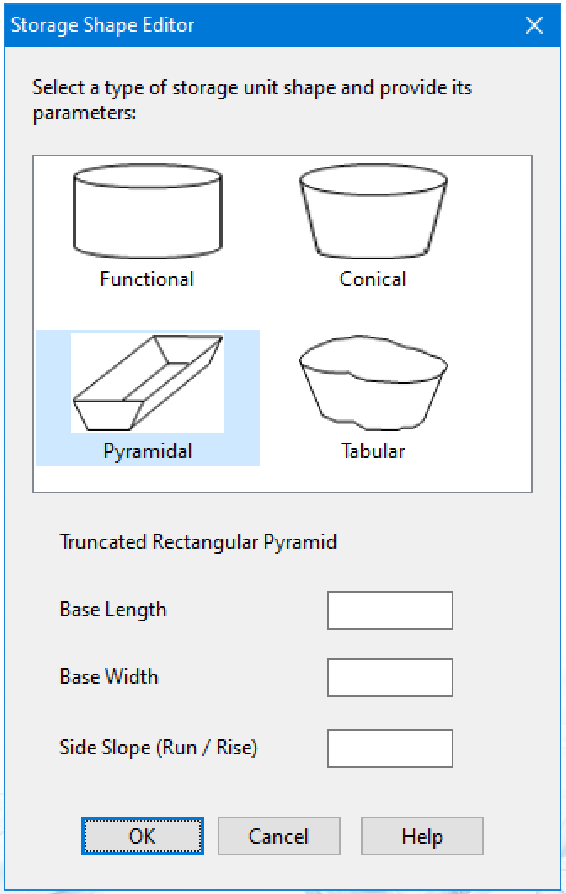
Truncated Rectangular Pyramid:

Area = L*W + 2*(L+W) * S*Depth + 4*(S*Depth)^2



Truncated Elliptical Cone:

Area = PI * (L*W + 2*W*S*Depth + (W/L)(S*Depth)^2)



Questions?

United States Environmental Protection Agency

Presentation Outline

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. Building the Hydrologic Model
5. Discussion of Results
6. Day One Wrap-up

Demonstration

Presentation Outline

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. Hydrologic Model
5. Discussion of Results
6. Day One Wrap-up

Demonstration

Presentation Outline

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. Hydrologic Model
5. Discussion of Results
6. Day One Wrap-up

Questions?

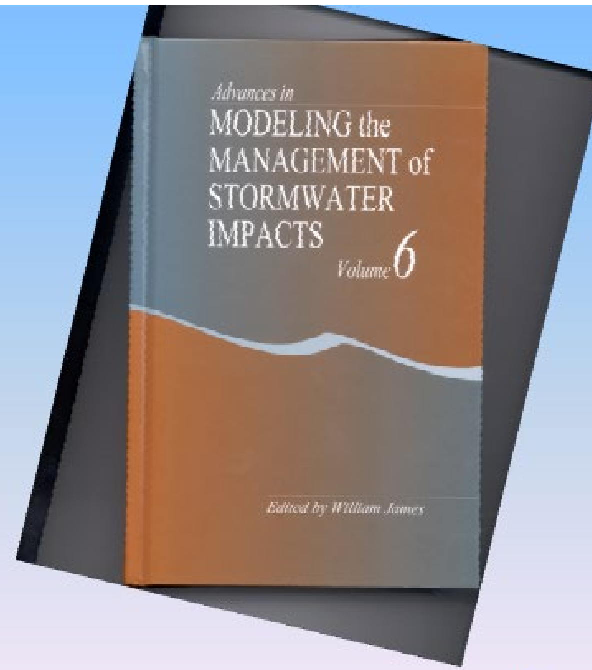
Next Day

Presentation Outline

1. History of SWMM
2. Using SWMM for Low Impact Development
3. Building LID Model
4. Demonstration of EPA Stormwater Calculator
5. Ground-Truthing SWMM
6. Day Two Wrap-up

United States Environmental Protection Agency

The people responsible



HED

s

20

Bob Dickinson, Rob James, Mitch Heineman, Bill James, Lew Rossman, 2002

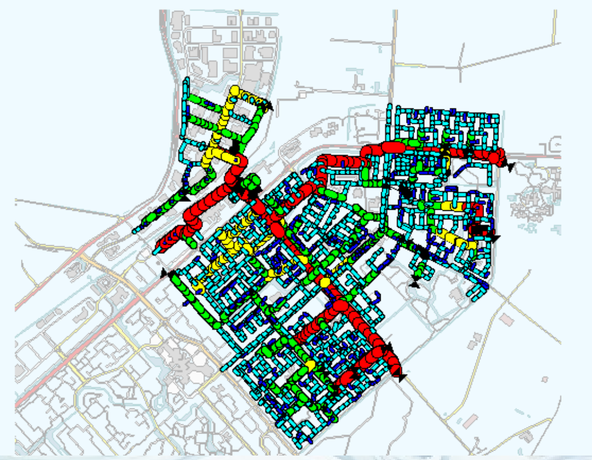
United States Environmental Protection Agency

History of EPA and SWMM

Community

SWMM Redevelopment Project

- 1971 — SWMM I
- 1975 — SWMM II
- 1981 — SWMM 3
- 1983 — SWMM 3.3
- 1988 — SWMM 4
- Others
- 2002 — SWMM Redevelopment Project
- 2005 — SWMM 5.0
- 2014 — SWMM 5.1
- 3/30/2017 — SWMM 5.2, SWMM-CAT 1.1



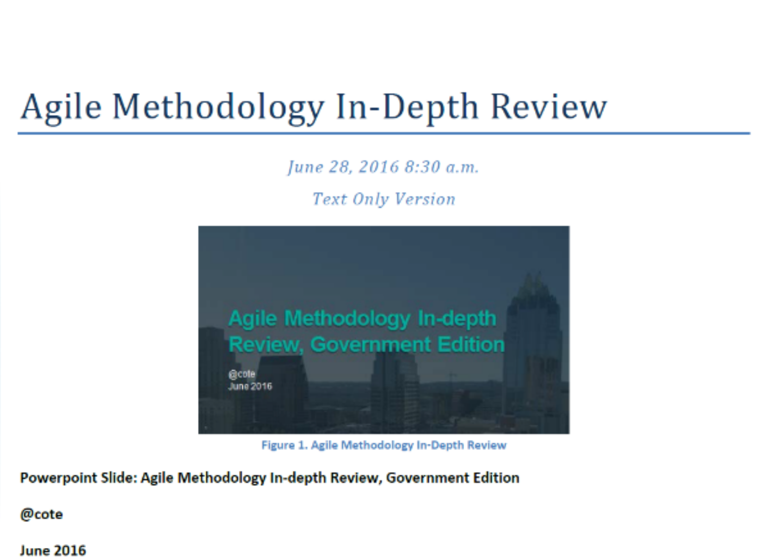
United States Environmental Protection Agency

SWMM 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 5	2018	EPA + Community	Community Development https://github.com/USEPA/Stormwater-Management-Model

EPA United States Environmental Protection Agency

Agile Development and Open-Source Community Process



Agile Methodology In-Depth Review

June 28, 2016 8:30 a.m.

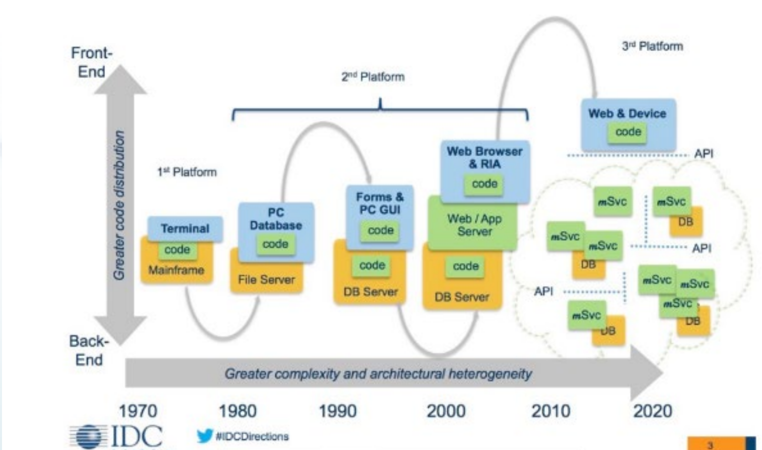
Text Only Version

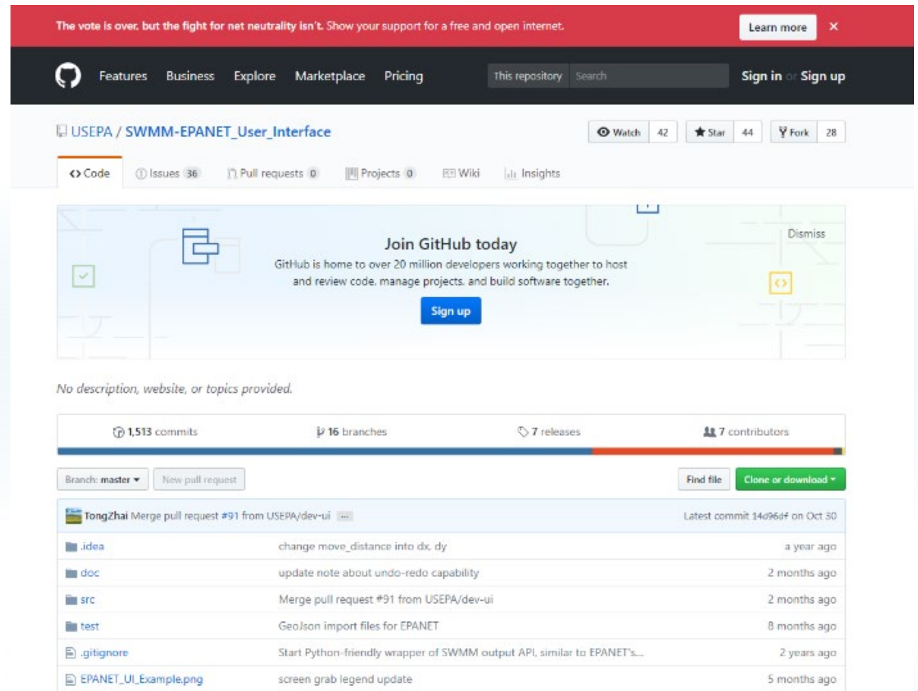
Figure 1. Agile Methodology In-Depth Review

Powerpoint Slide: Agile Methodology In-depth Review, Government Edition

@cote

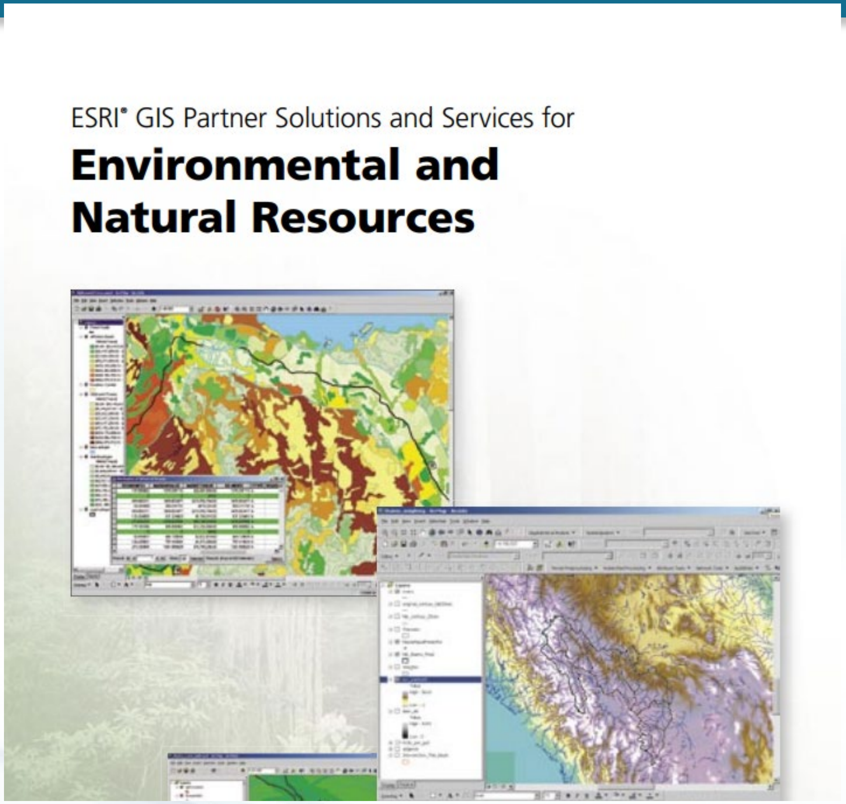
June 2016





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

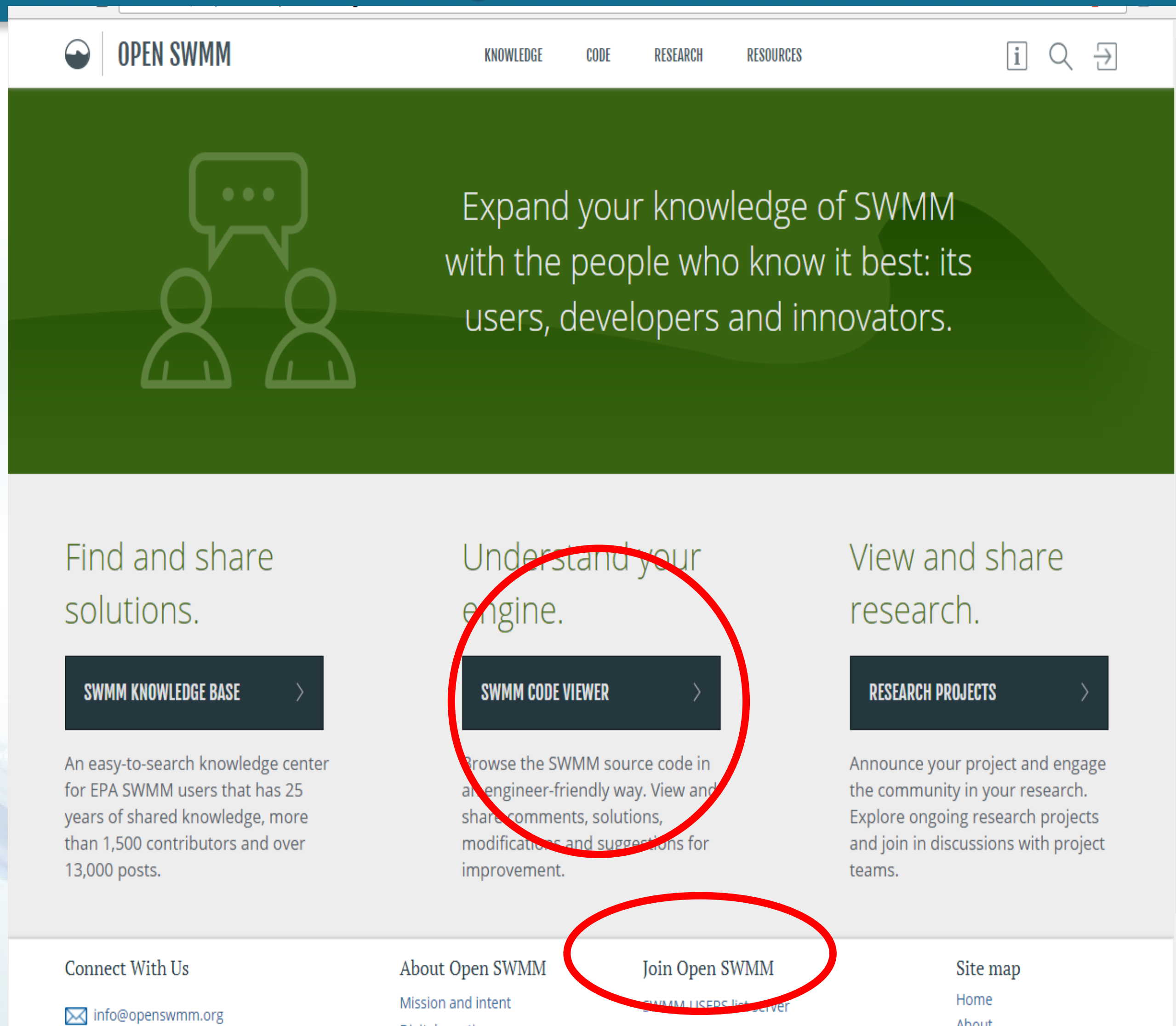
Stakeholders - >30,000 2022 downloads



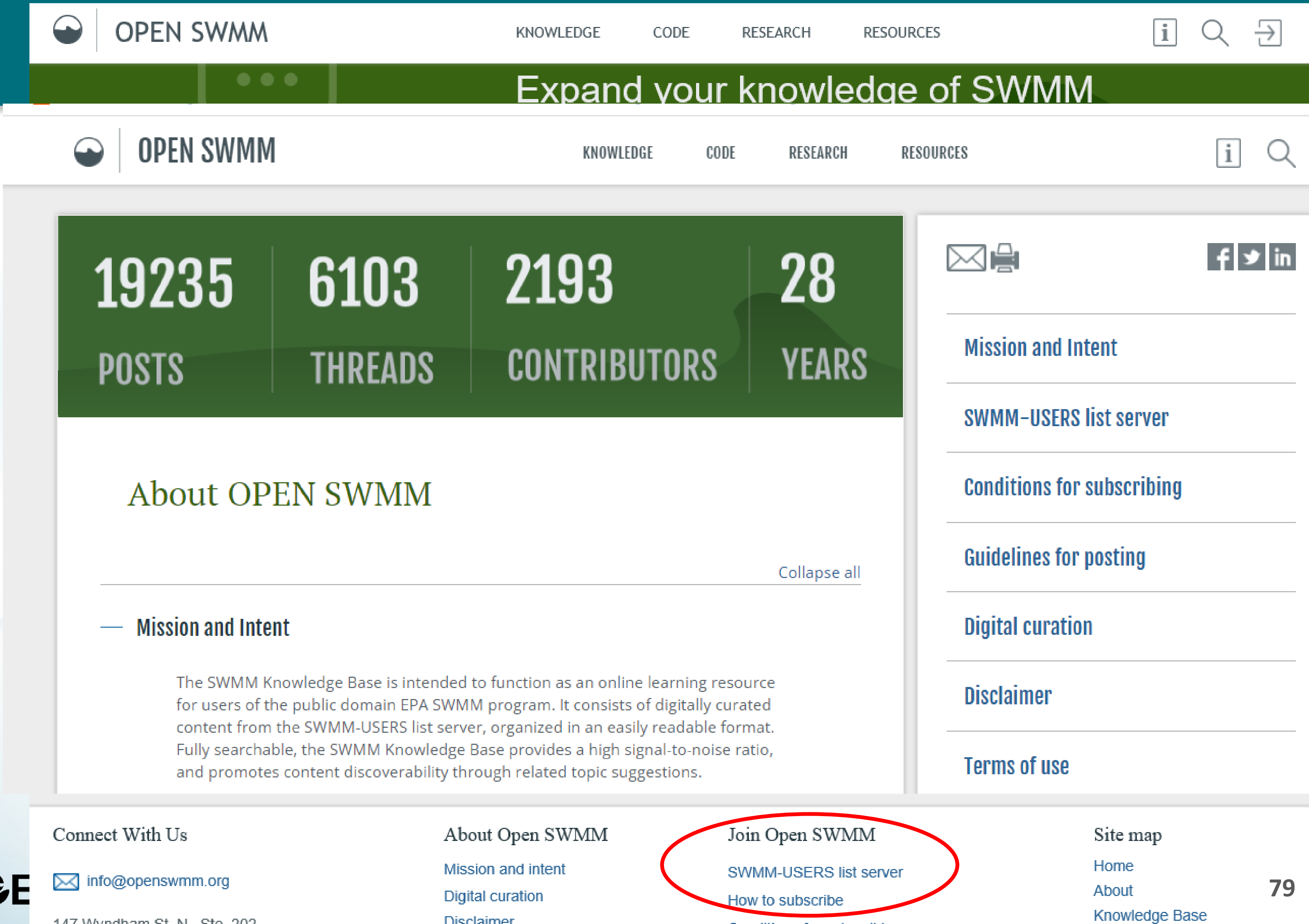
Regulators
Communities,
Utilities,
Private industry,
Consultants,
Academia

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

Open SWMM https://www.openswmm.org/



Technical Support - OPEN SWMM



USEPA – Curator of SWMM Code

- Contribute to improve scientific aspects of SWMM
- Work with Stakeholder community
- Assist where possible with testing and ground-truthing of SWMM's numerical models and other software
- Publish an Official Version of SWMM
- Move SWMM into 21st Century

https://www.epa.gov/water-research/storm-water-management-model-swmm

United States Environmental Protection Agency

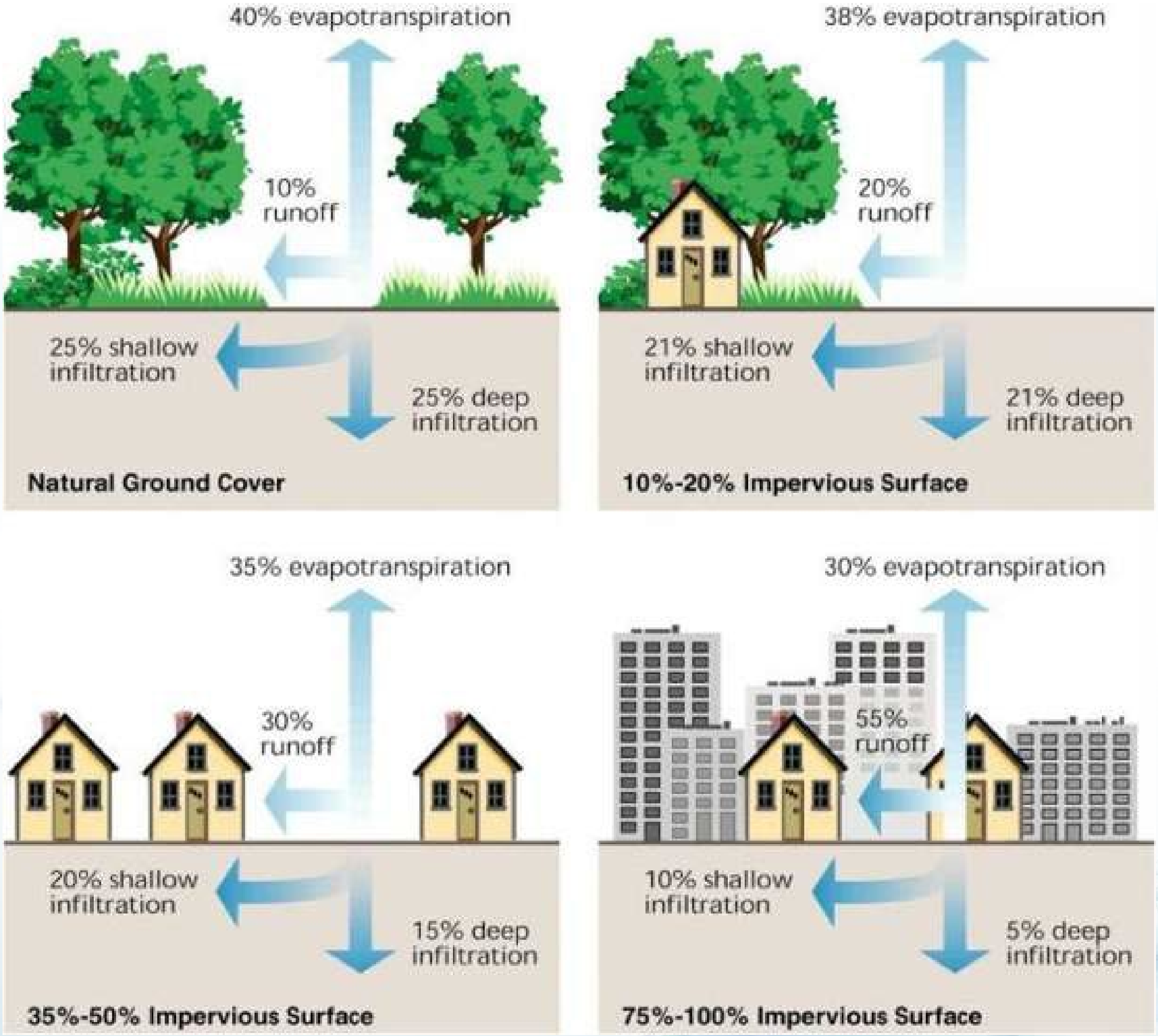
Questions?

United States Environmental Protection Agency

Presentation Outline

1. History of SWMM
2. Using SWMM for Low Impact Development
3. Building LID Model
4. Demonstration of EPA Stormwater Calculator
5. Day Two Wrap-up

Urbanization Changes the Hydrologic Cycle



- Soils and vegetation are replaced with impervious surfaces
- Impervious surfaces are connected to dense drainage networks
- Runoff drains directly into streams, lakes, wetlands, and coastal waters
- Even small storms generate significant runoff

Approaches to Managing Stormwater

The Conveyance Approach –
Rapidly remove stormwater from impervious surfaces to receiving streams by way of engineered drainage systems (e.g. culverts, storm drains, and channelized streams).

"Water is a problem. Its the enemy. Get it away from here. NOW!"

The Infiltration Approach –
Retain stormwater as close as possible to its originating source(s), infiltrating as much as possible into the soil by using best management practices and strategies.

"Water is a precious resource, keep it here, clean it, save it for later -we need it, and our local our ecosystems need it too!"

EPA United States Environmental Protection Agency

LID Modeling in SWMM

End-of-Pipe Stormwater BMPs

Ponds

Wetlands

Sand Filters

High Rate Treatment

Types of LIDs Modeled

Disconnection

Infiltration Basin

Rain Garden

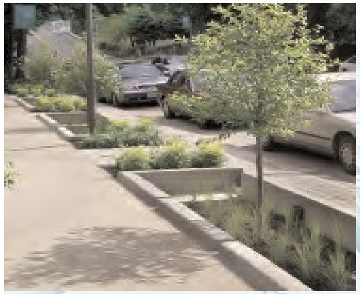
Cistern

Infiltration Trench

Green Roof

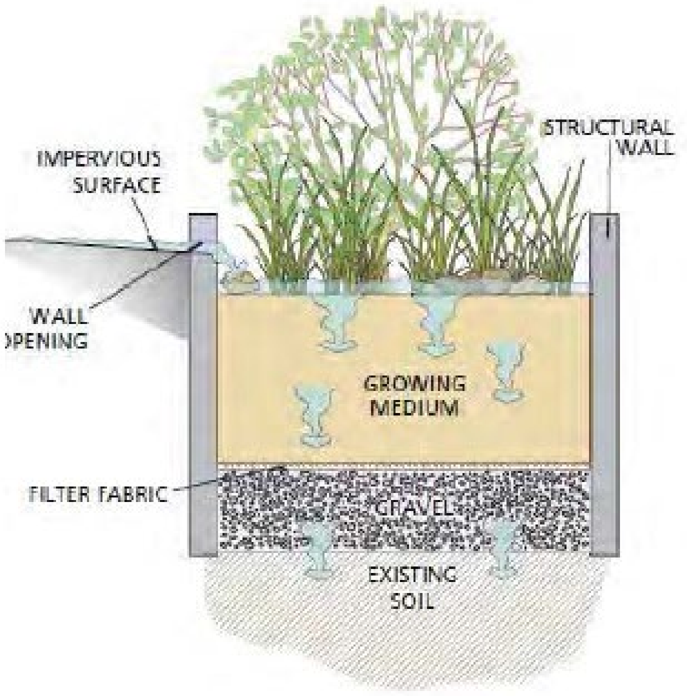
Porous Pavement

Vegetative Swale

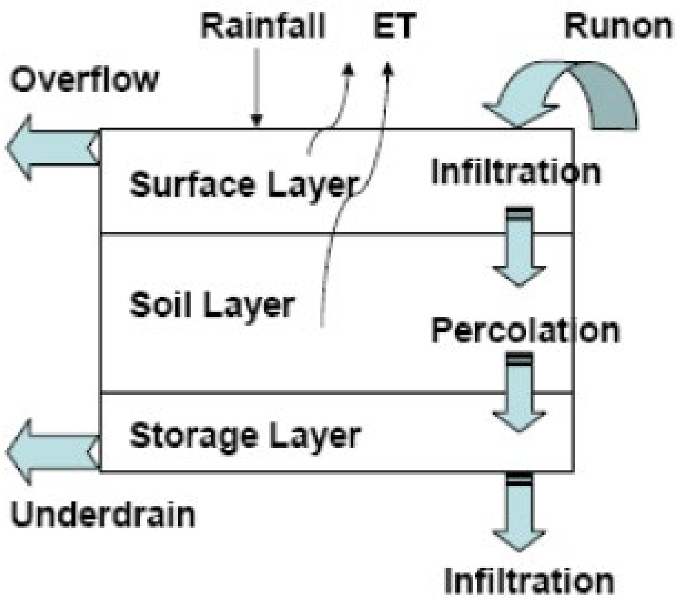


Street Planter

Green Infrastructure Subcatchment

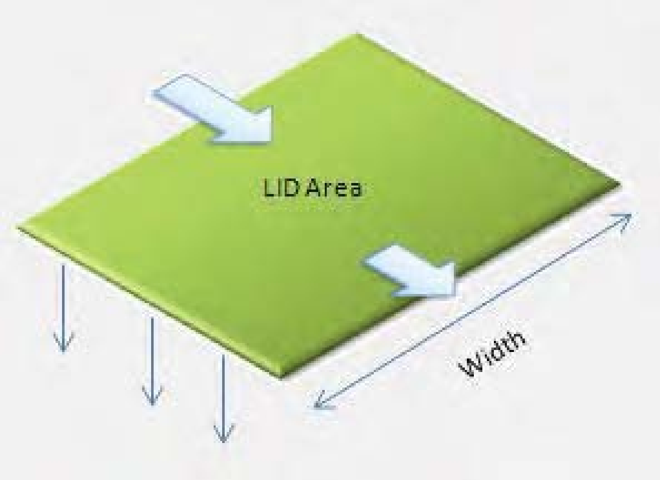


(A)

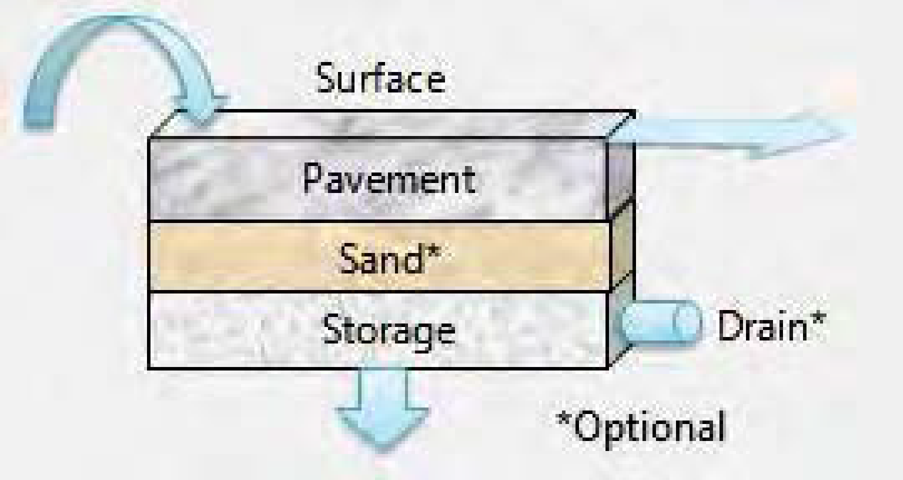


(B)

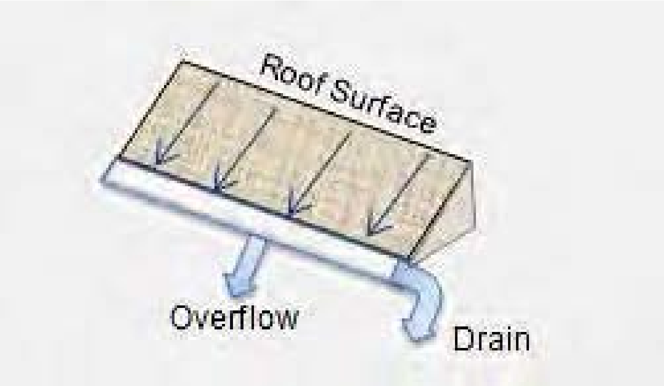
More Green Infrastructure Subcatchments



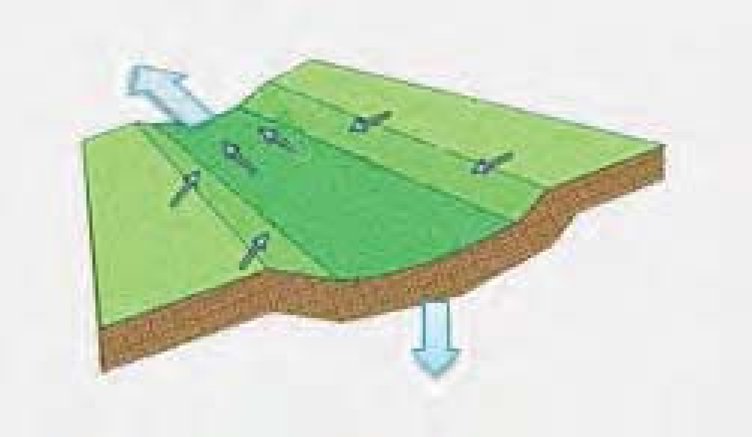
Green Roof



Permeable Pavement



Roof Disconnection



Vegetative Swale

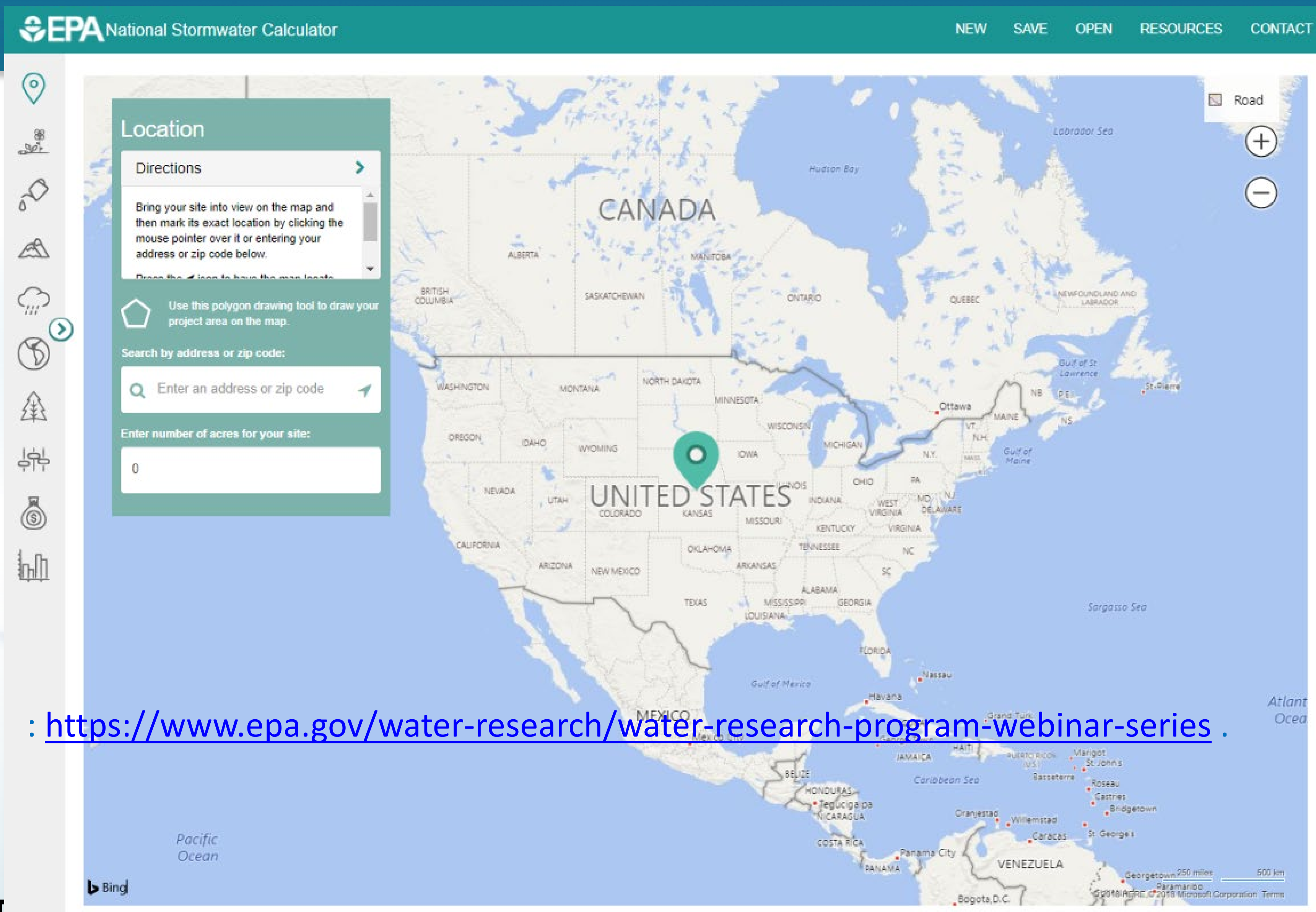
Building LID Module in SWMM

Questions?

Presentation Outline

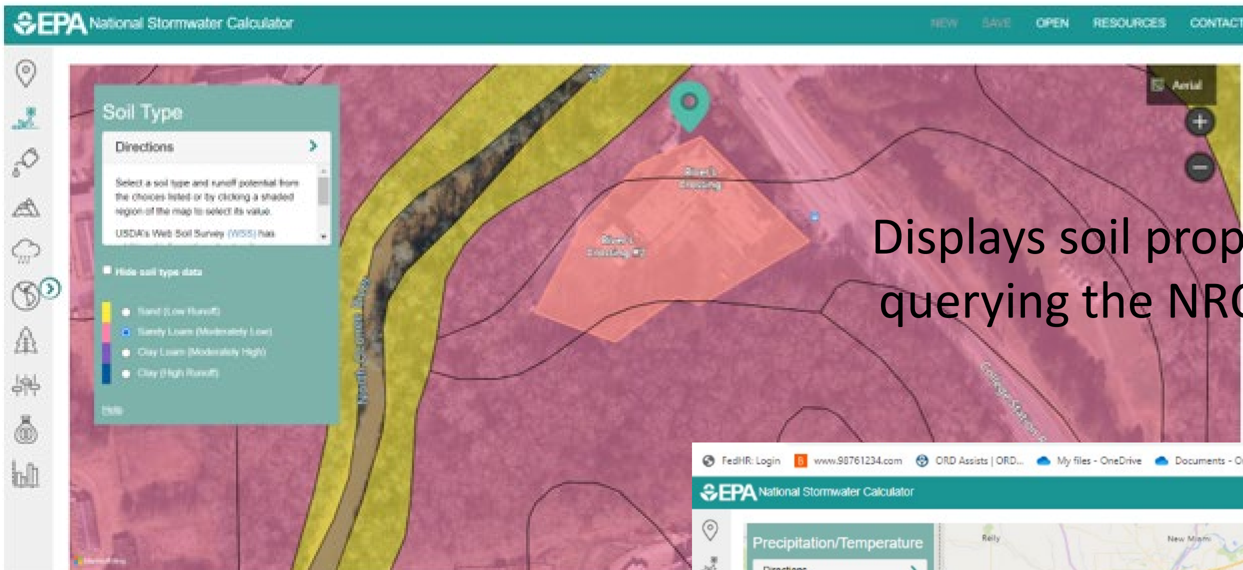
1. History of SWMM
2. Using SWMM for Low Impact Development
3. Building LID Model
4. Demonstration of EPA Stormwater Calculator
5. Day Two Wrap-up

National Stormwater Calculator (SWC)



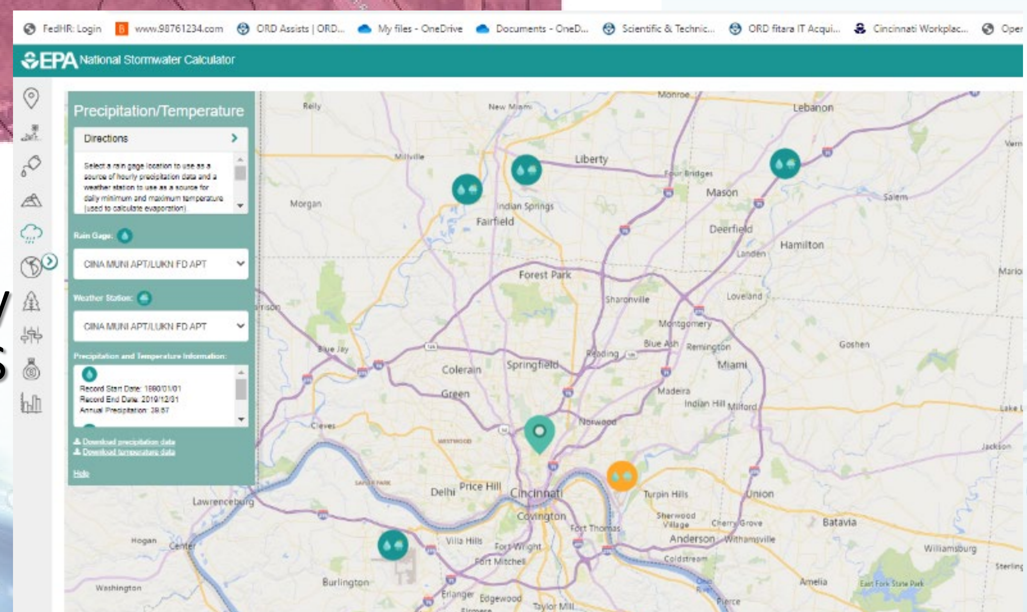
: https://www.epa.gov/water-research/water-research-program-webinar-series .

National Stormwater Calculator



Displays soil properties obtained from querying the NRCS SSURGO database

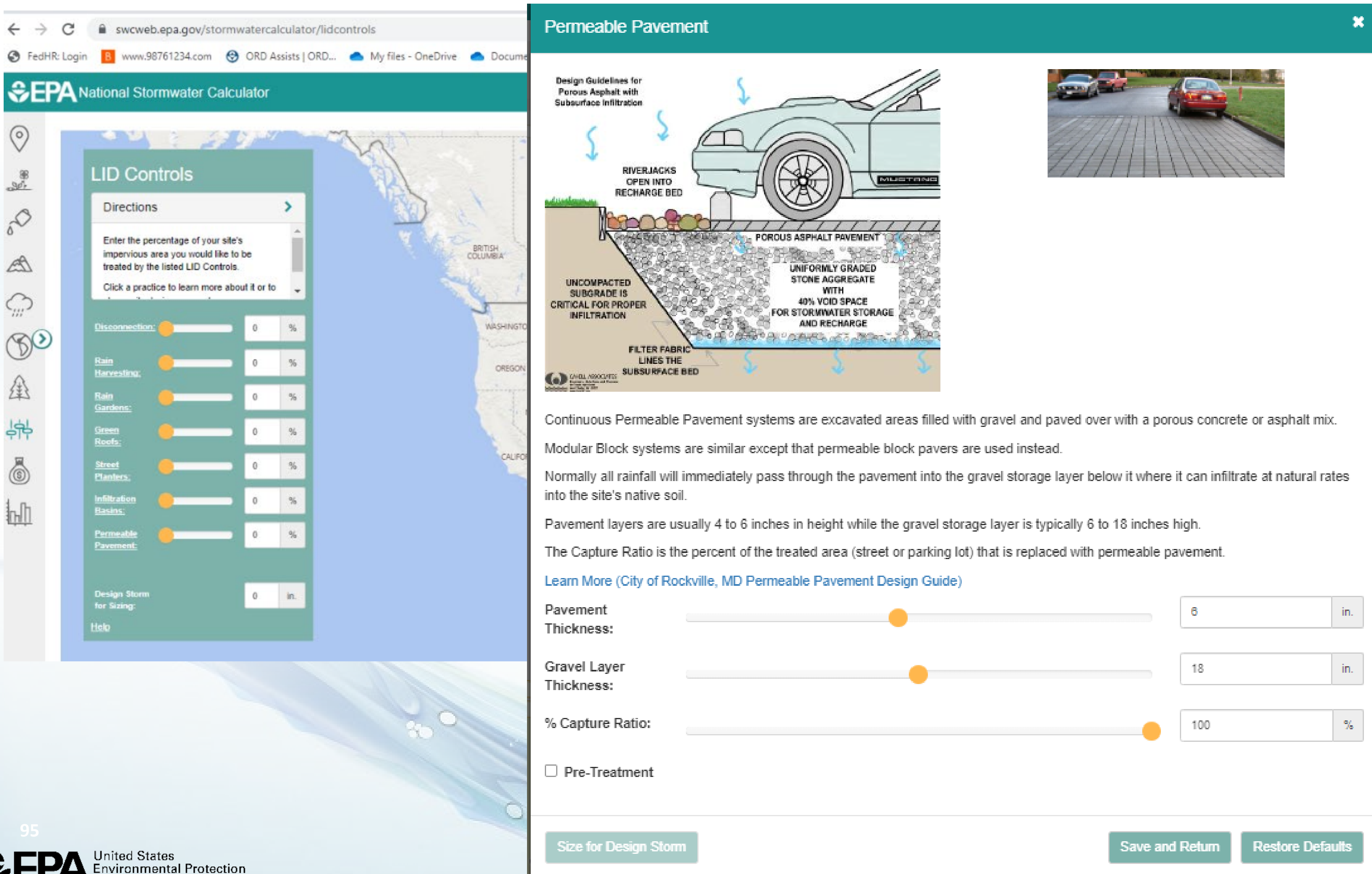
Uses a source of long term hourly rainfall data from over 7000 NWS measurement stations



EPA United States Environmental Protection Agency

National Stormwater Calculator

The user specifies the site's land cover and selects a set of LID controls.



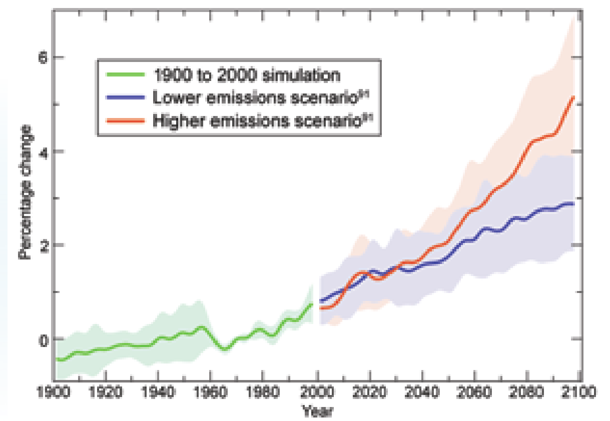
Climate Component Added to Calculator

To assess how resilient source controls will be to future meteorological conditions

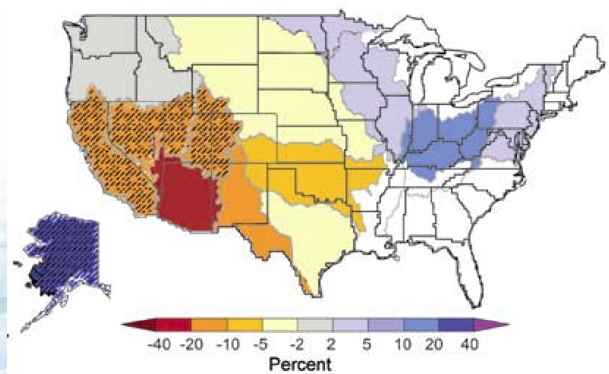
Impacts on small-scale hydrology:

- changes in seasonal precipitation patterns
- more frequent occurrence of high intensity storm events
- changes in evaporation rates

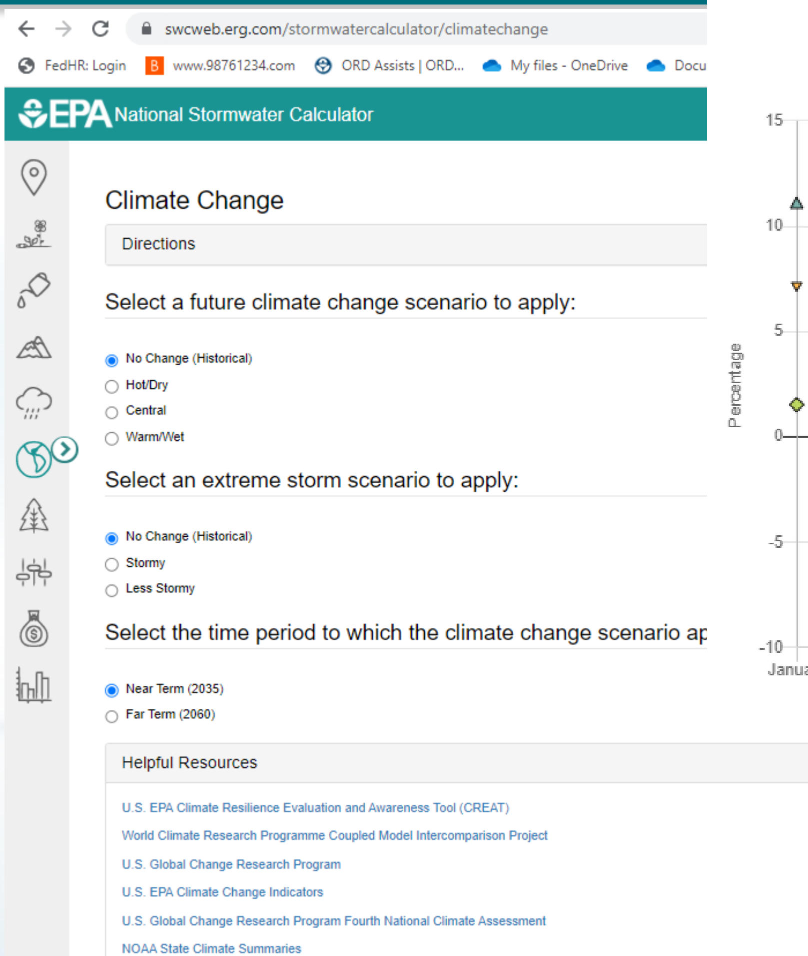
Global Increase in Heavy Ppt. Events

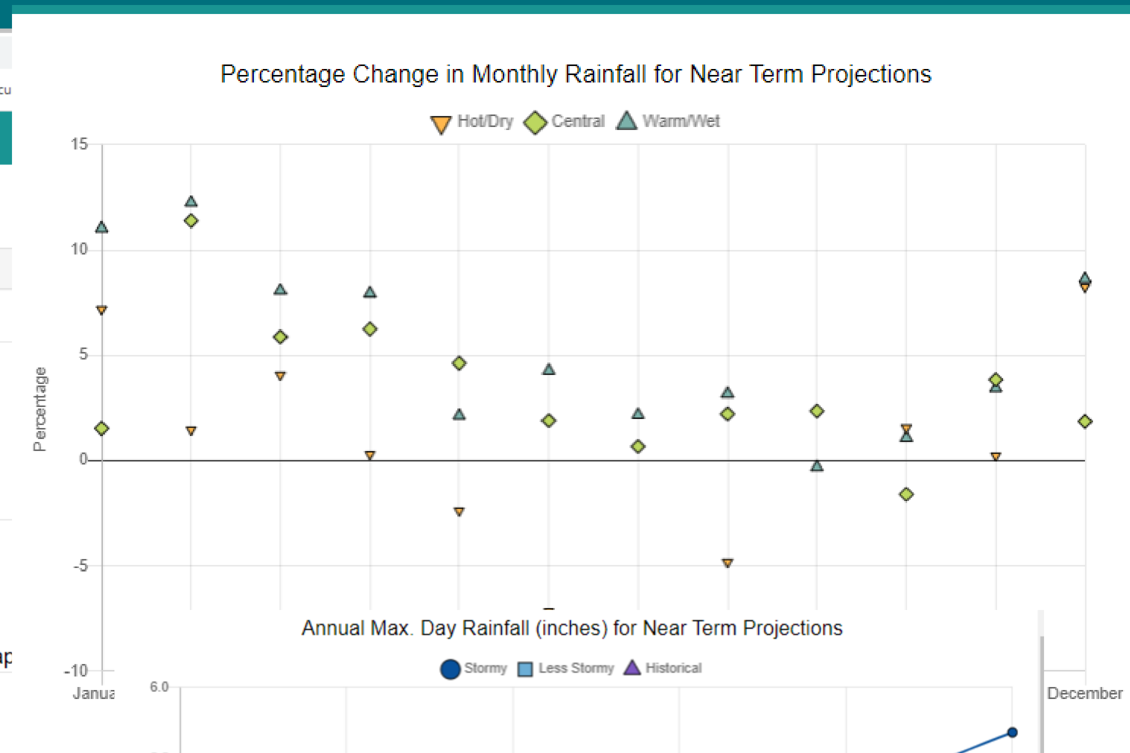


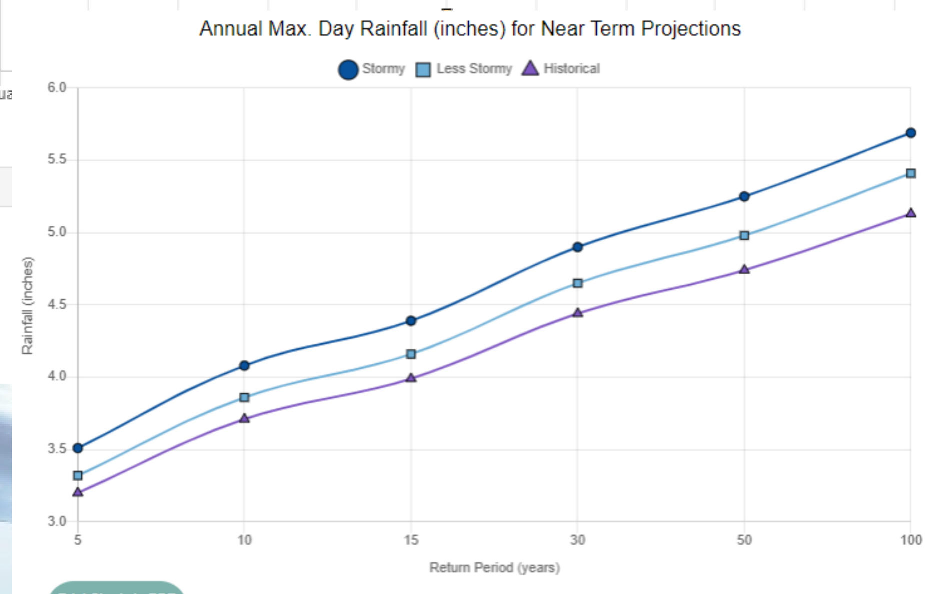
Projected Changes in Annual Runoff



Climate Change

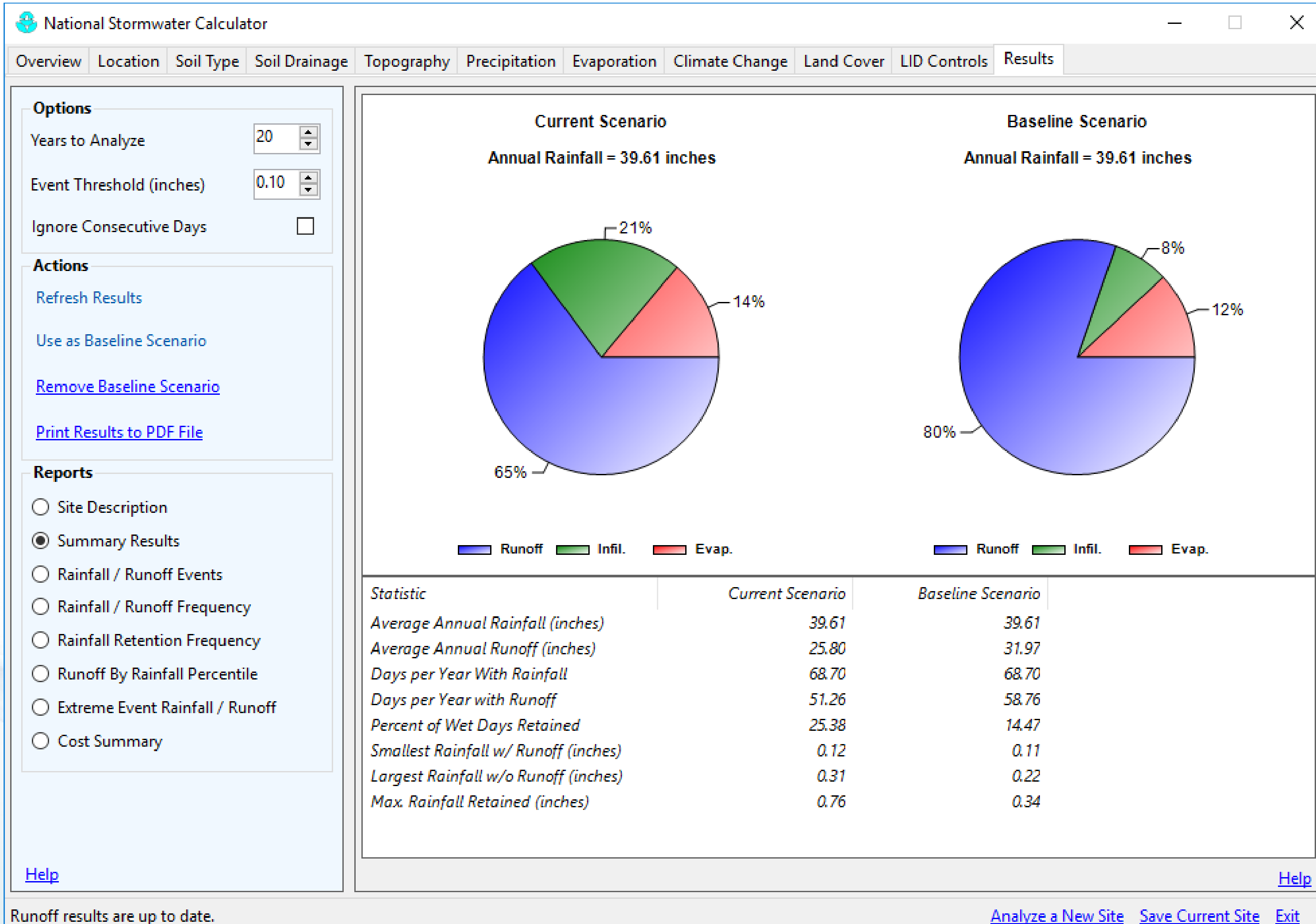






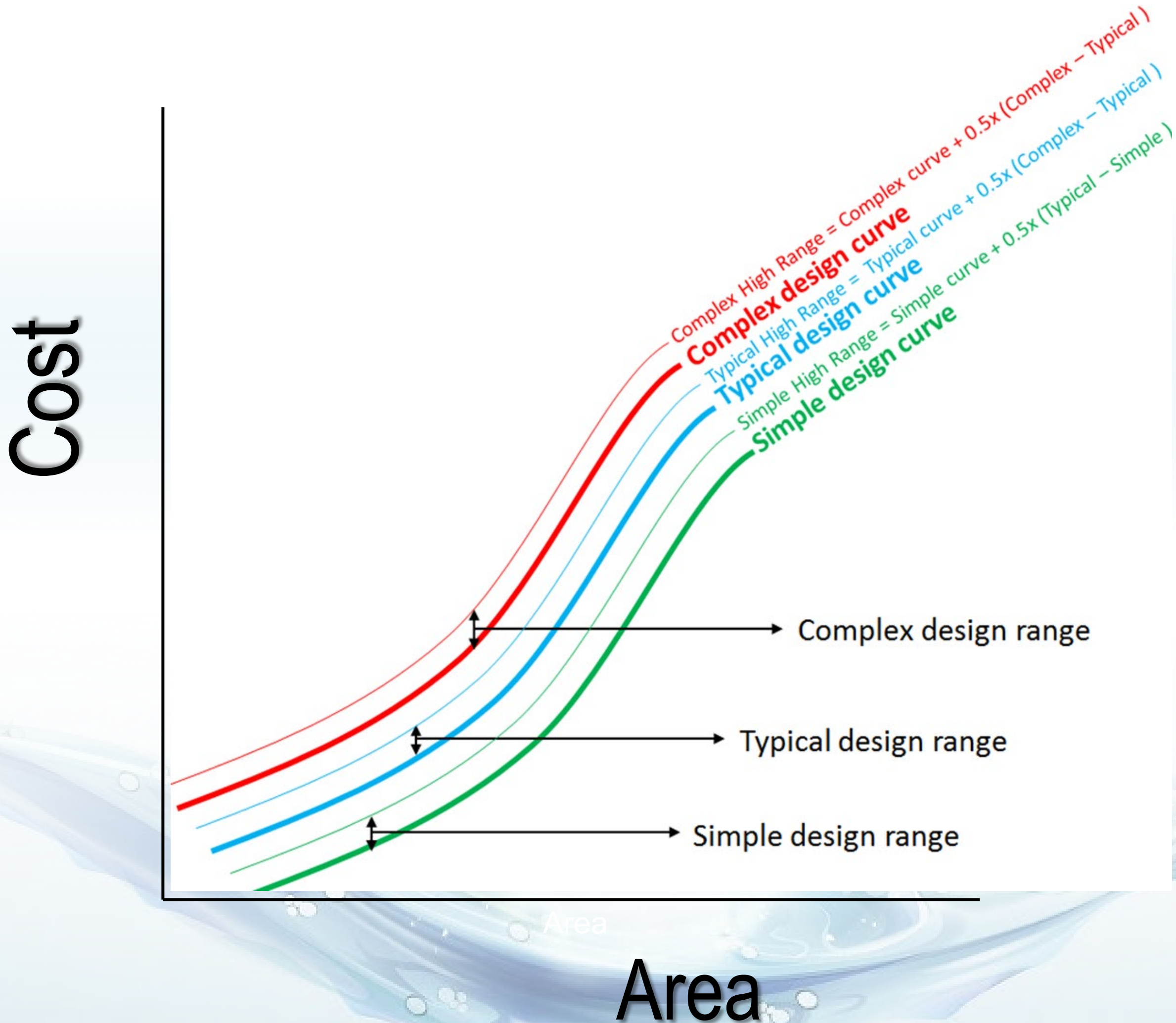
National Stormwater Calculator

SWC runs SWMM to generate daily rainfall/runoff statistics.



Statistic	Current Scenario	Baseline Scenario
Average Annual Rainfall (inches)	39.61	39.61
Average Annual Runoff (inches)	25.80	31.97
Days per Year With Rainfall	68.70	68.70
Days per Year with Runoff	51.26	58.76
Percent of Wet Days Retained	25.38	14.47
Smallest Rainfall w/ Runoff (inches)	0.12	0.11
Largest Rainfall w/o Runoff (inches)	0.31	0.22
Max. Rainfall Retained (inches)	0.76	0.34

LID Cost Estimation Module:

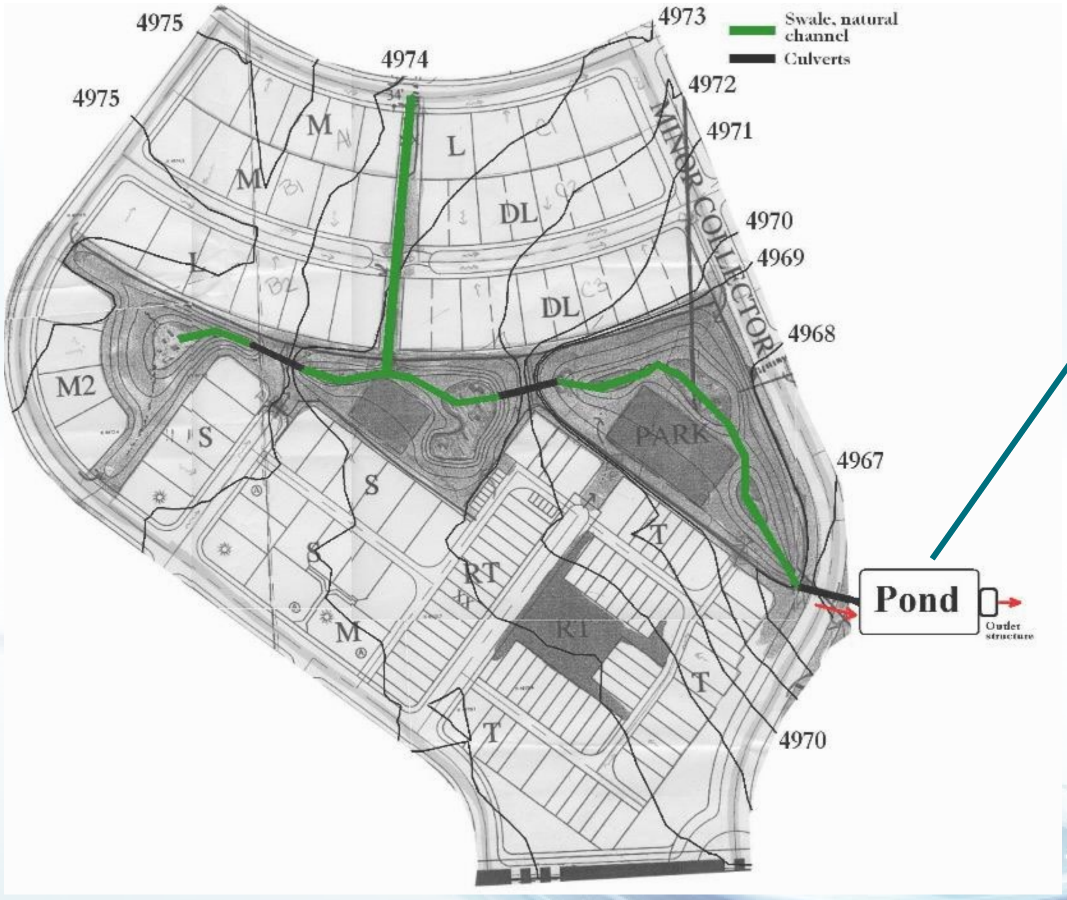


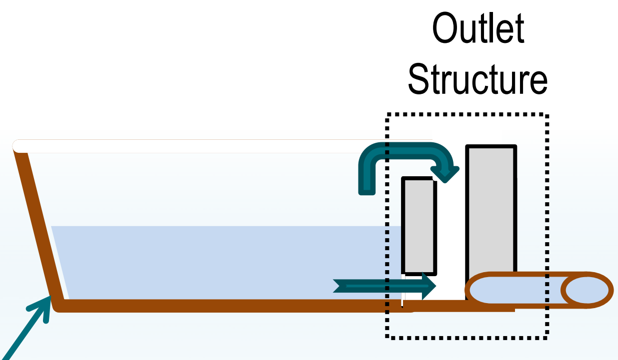
Questions?

Day 3

1. Interpreting More Complicated SWMM Results
2. Where to get Data
3. SWMM Climate Adjust Tool
4. Ground Truthing SWMM
5. Course Wrap Up

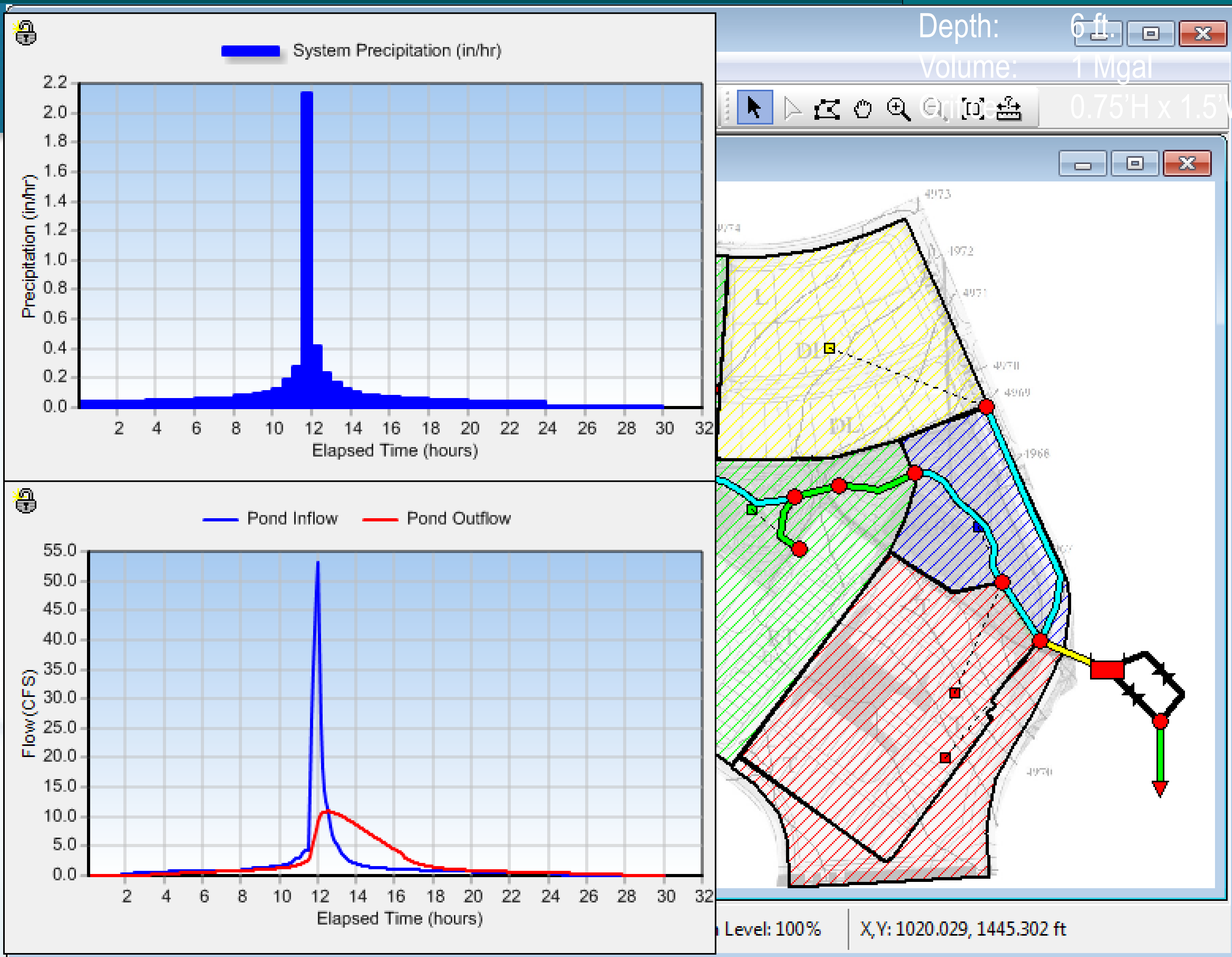
Detention Pond Design Example



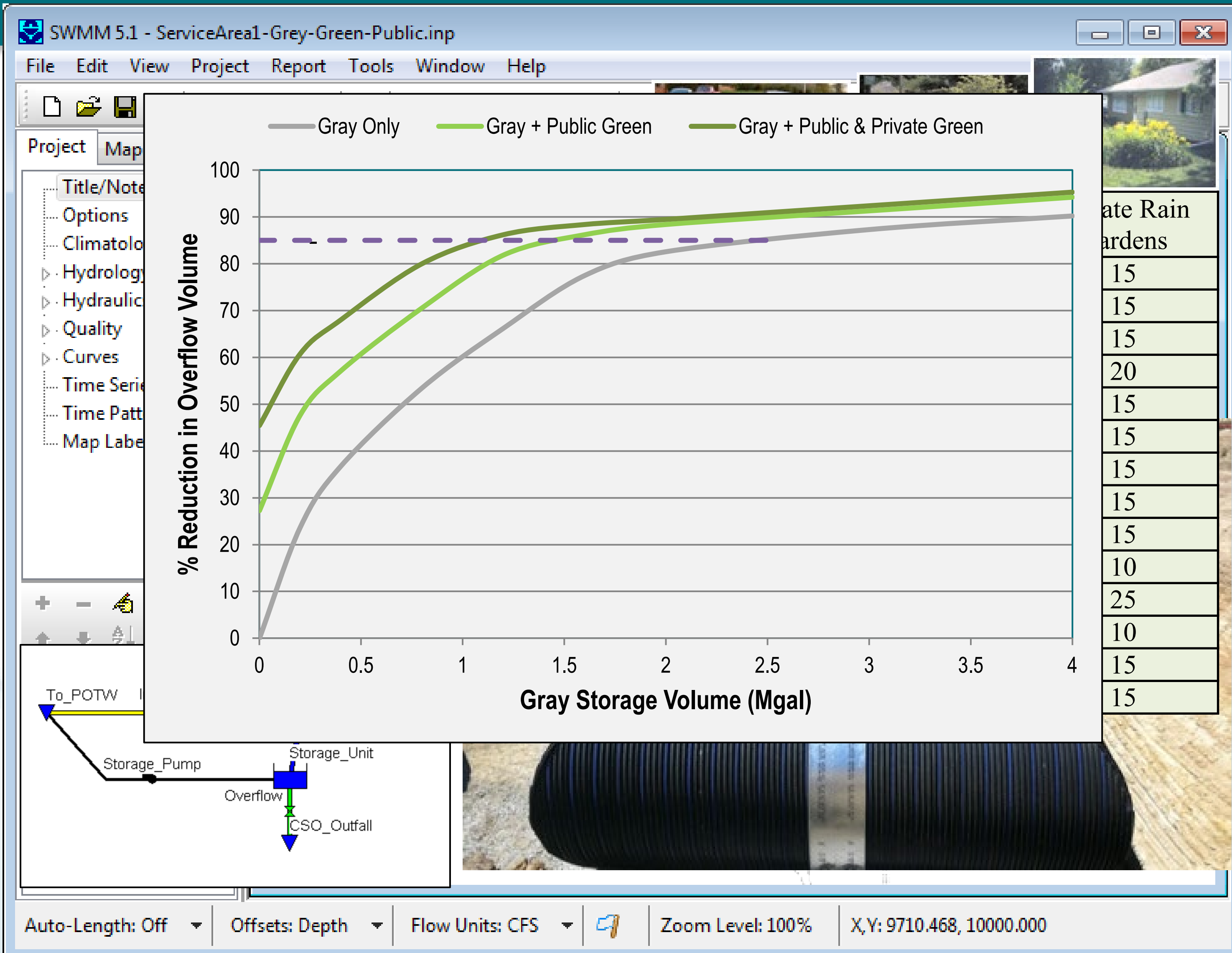


Design Requirement
Post development peak flow = pre-development peak flow (11 cfs) for the 10-yr, 24-hr design storm (2.8")

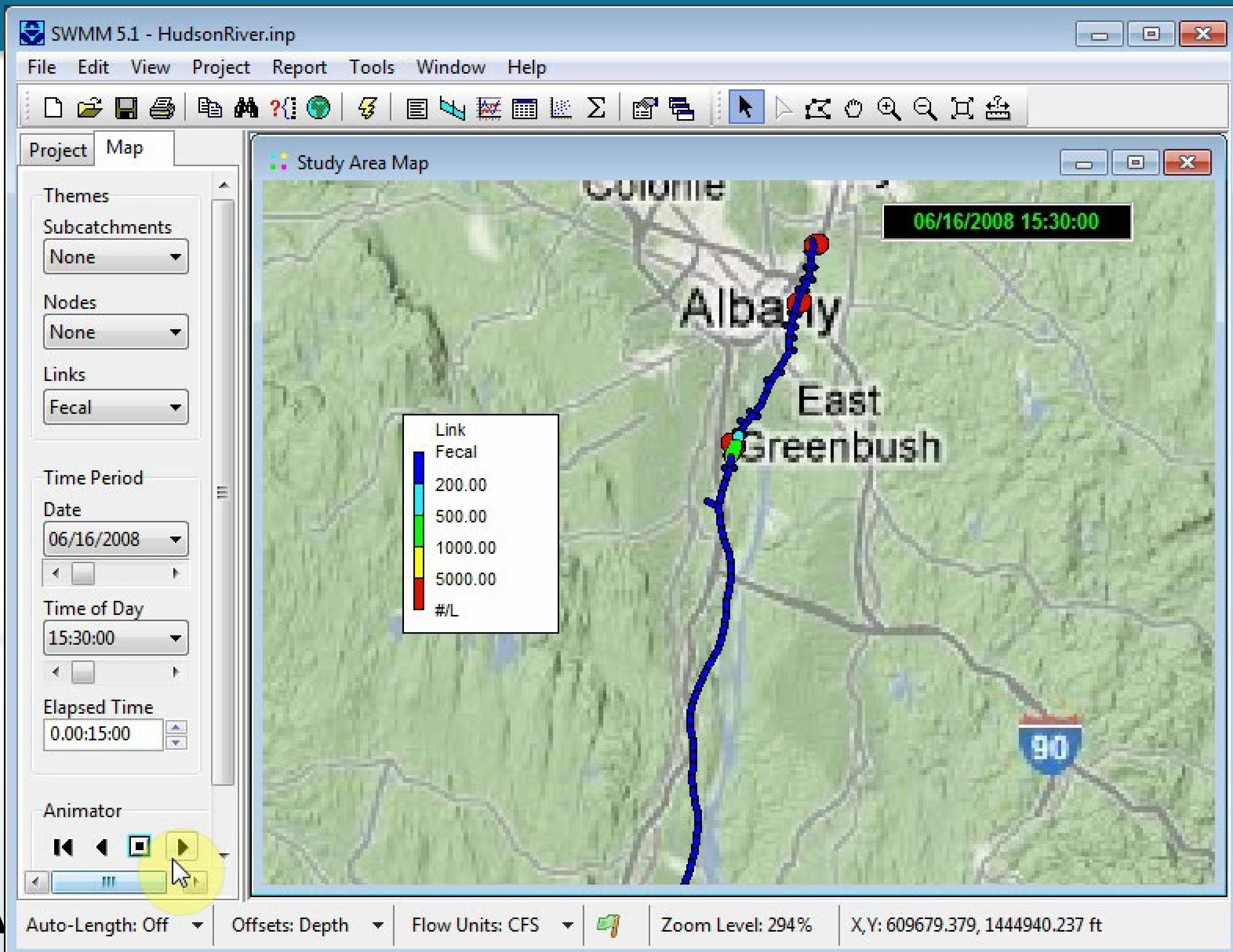
Pond Design:
Area: 0.5 acres
Depth: 6 ft.
Volume: 1 Mgal
0.75'H x 1.5'W



CSO Example – Green + Gray Options



Microbial Fate & Transport Example



EPA

Hydraulic Animation (Courtesy of Robert Dickinson, Innovyze)

Questions?

EPA United States Environmental Protection Agency

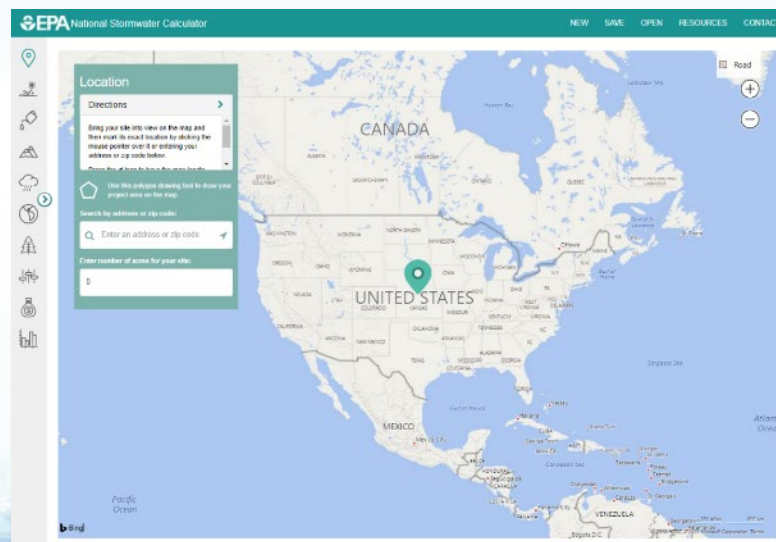
Day 3

1. Interpreting More Complicated SWMM Results
2. Where to get Data
3. SWMM Climate Adjust Tool
4. Ground Truthing SWMM
5. Course Wrap Up

Data that you need for SWMM

Either you measure it or

- Soil Infiltration from a Soil database (SSURGO or STATSGO)
- Land Use – Land Cover
- (National Land Cover Dataset – NLCD)
- Climatic Data – find closest NOAA station
  - (use Stormwater Calculator)
- Site Configuration
  - Subcatchment area
  - Drainage flow
- Hydraulic Configuration
  - Conduit geometry, length
  - Network schematic



Where to get information

https://www.epa.gov/exposure-assessment-models
https://www.nrcs.usda.gov
https://www.usgs.gov/science/mission-areas/water-resources
http://www.dynsystem.com/netstorm/cdmuswmm.htm

Gather Data

DEM and NLCD https://viewer.nationalmap.gov/basic/

Soils - https://www.nrcs.usda.gov

SSURGO

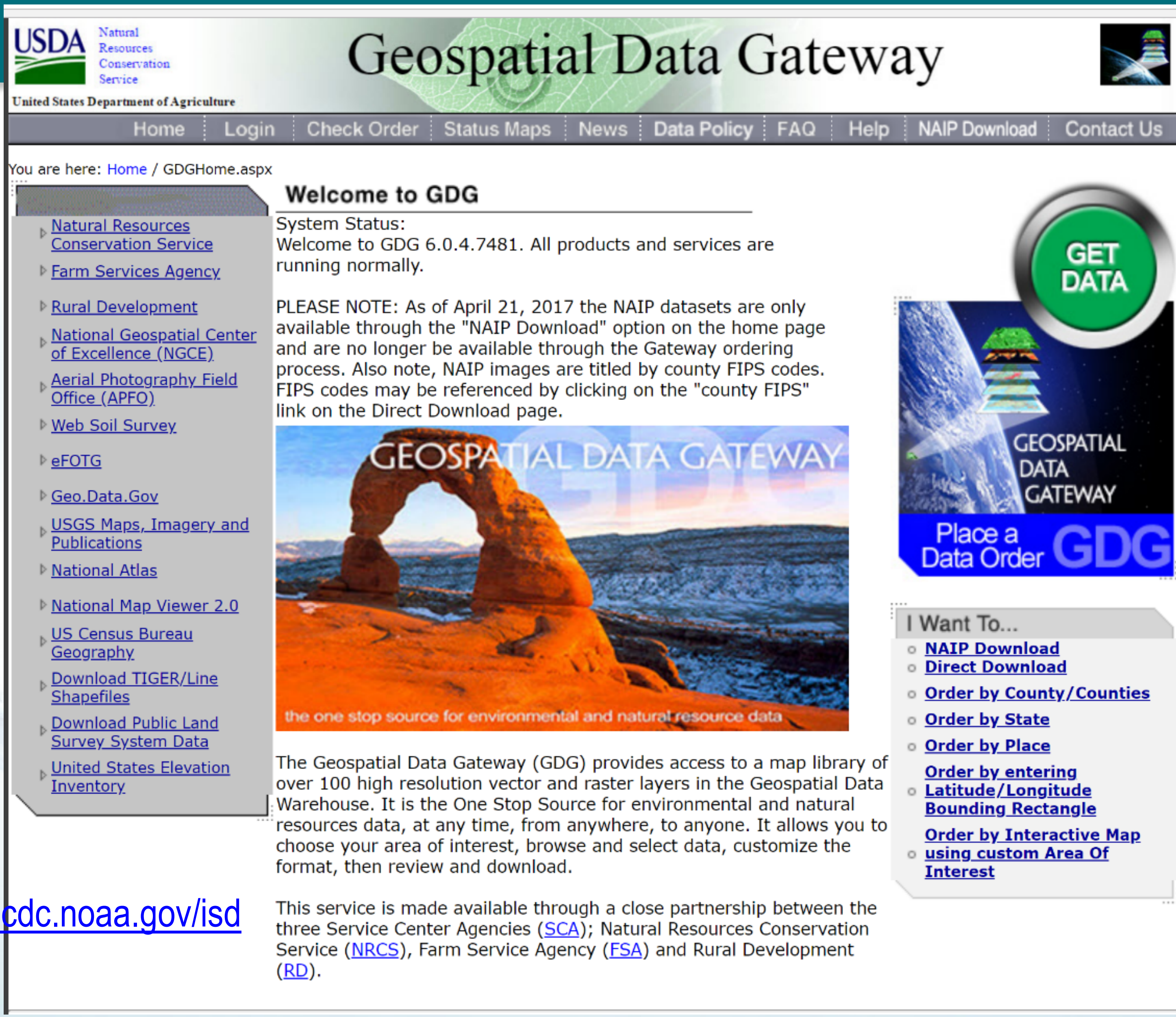
STATGO

Climate - NOAA National Centers for Environmental Information (www.ncdc.noaa.gov)

Hydrologic Unit Maps (HUC)

NRCS http://www.usda.gov/wps/portal/nrcs/main/national/water/watersheds

https://datagateway.nrcs.usda.gov/



USDA Natural Resources Conservation Service
United States Department of Agriculture

Geospatial Data Gateway

Home | Login | Check Order | Status Maps | News | Data Policy | FAQ | Help | NAIP Download | Contact Us

You are here: Home / GDGHome.aspx

- Natural Resources Conservation Service
- Farm Services Agency
- Rural Development
- National Geospatial Center of Excellence (NGCE)
- Aerial Photography Field Office (APFO)
- Web Soil Survey
- eFOTG
- Geo.Data.Gov
- USGS Maps, Imagery and Publications
- National Atlas
- National Map Viewer 2.0
- US Census Bureau Geography
- Download TIGER/Line Shapefiles
- Download Public Land Survey System Data
- United States Elevation Inventory

Welcome to GDG

System Status:
Welcome to GDG 6.0.4.7481. All products and services are running normally.

PLEASE NOTE: As of April 21, 2017 the NAIP datasets are only available through the "NAIP Download" option on the home page and are no longer be available through the Gateway ordering process. Also note, NAIP images are titled by county FIPS codes. FIPS codes may be referenced by clicking on the "county FIPS" link on the Direct Download page.

GEOSPATIAL DATA GATEWAY
the one stop source for environmental and natural resource data

The Geospatial Data Gateway (GDG) provides access to a map library of over 100 high resolution vector and raster layers in the Geospatial Data Warehouse. It is the One Stop Source for environmental and natural resources data, at any time, from anywhere, to anyone. It allows you to choose your area of interest, browse and select data, customize the format, then review and download.

This service is made available through a close partnership between the three Service Center Agencies (SCA); Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA) and Rural Development (RD).

GET DATA

GEOSPATIAL DATA GATEWAY
Place a Data Order GDG

I Want To...

- NAIP Download
- Direct Download
- Order by County/Counties
- Order by State
- Order by Place
- Order by entering Latitude/Longitude Bounding Rectangle
- Order by Interactive Map using custom Area Of Interest

https://www.ncdc.noaa.gov/isd

Key Websites discussed

Storm Water Management Model:
https://www.epa.gov/water-research/storm-water-management-model-swmm
https://github.com/USEPA/Stormwater-Management-Model

National Stormwater Calculator Website:
https://www.epa.gov/water-research/national-stormwater-calculator

Water Research Program Webinar Series Website:
https://www.epa.gov/water-research/water-research-program-webinar-series

USGS's online Seamless Data Warehouse:
https://datagateway.nrcs.usda.gov

YouTube Tutorials:
https://www.youtube.com

Openswmm:
https://www.openswmm.org/

Questions?

United States Environmental Protection Agency

Next Day

United States Environmental Protection Agency

Day 3

1. Interpreting More Complicated SWMM Results
2. Where to get Data
3. SWMM Climate Adjust Tool
4. Ground Truthing SWMM
5. Course Wrap Up

Climate Variables Influencing SWMM

- Precipitation
  - —Directly impacts runoff amounts.
  - —Determines whether drainage components (curb inlets, pipes, pumps, weirs, etc.) & stormwater control measures (ponds, LID practices, treatment devices) will meet their design objectives.
- Temperature
  - —Affects evaporation rates.
  - —Affects snowfall and snow melt amounts.

Challenges of Climate Change for Hydrology Models

- Complex regional and seasonal patterns of average precipitation changes will occur.
- Storm events may be less frequent but more intense.
- Winter snowfall and snow melt will be affected by warmer temperatures.
- Warmer temperatures will also increase evaporation rates which might affect groundwater flow and stream base flows.

EPA United States Environmental Protection Agency

Approaches to Incorporating Climate Change into Localized Hydrology Models

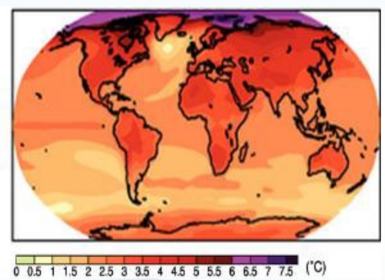
- Use the output of dynamic regional climate models to drive a localized runoff model.
- Allow model users to form their own scenarios for manipulating local historical records (BASINS-CAT).
- Develop sets of localized seasonal adjustment factors from downscaled global climate models that can be applied to local historical records (EPA-CREAT).

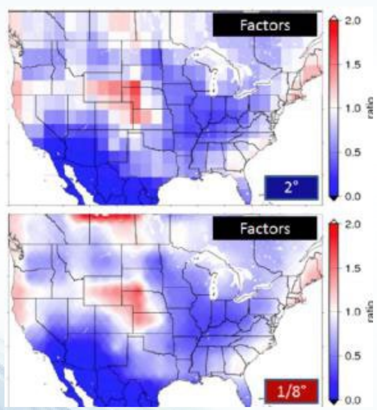
SWMM-CAT

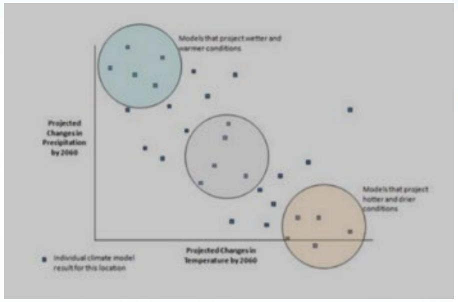
- Provides an add-in tool to SWMM to identify seasonal changes in precipitation and temperature, as well as changes in extreme design events, at a localized level.
- Uses downscaled GCM data to identify a range of precipitation and temperature adjustments at several thousand locations across the US for both near and far term future periods.
- Allows the user to apply their own climate adjustments if they so choose.

Source of Climate Change Data

IPCC/WCRP CMIP5	BOR/LLNL	EPA-CREAT 3.1	SWMM-CAT 1.1
Daily climate projections for 2020-2074 from 9 GCM models at a coarse (2-5°) scale.	Downscaled projections of monthly averages to ½ degree grid cells.	Select Warm/ Wet, Median, & Hot/Dry out-comes for each cell.	Mapping of monthly CREAT scenarios (including PET and extreme events) to 7,000 NWS stations.

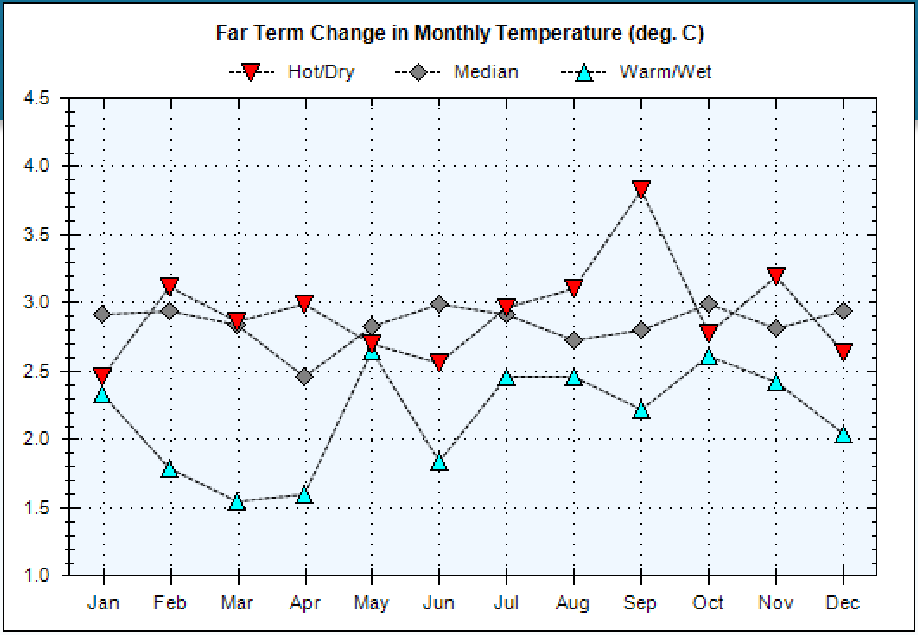


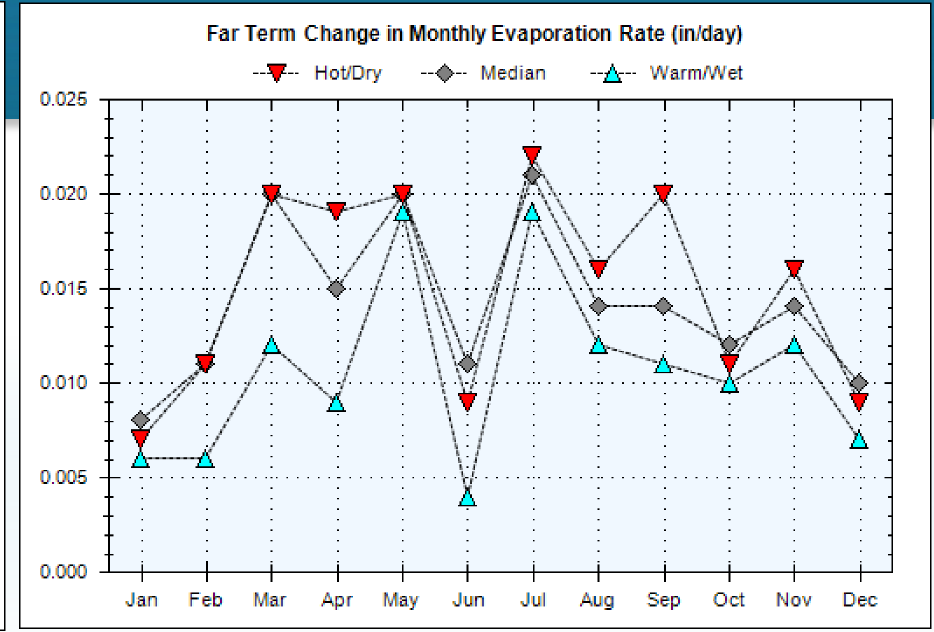


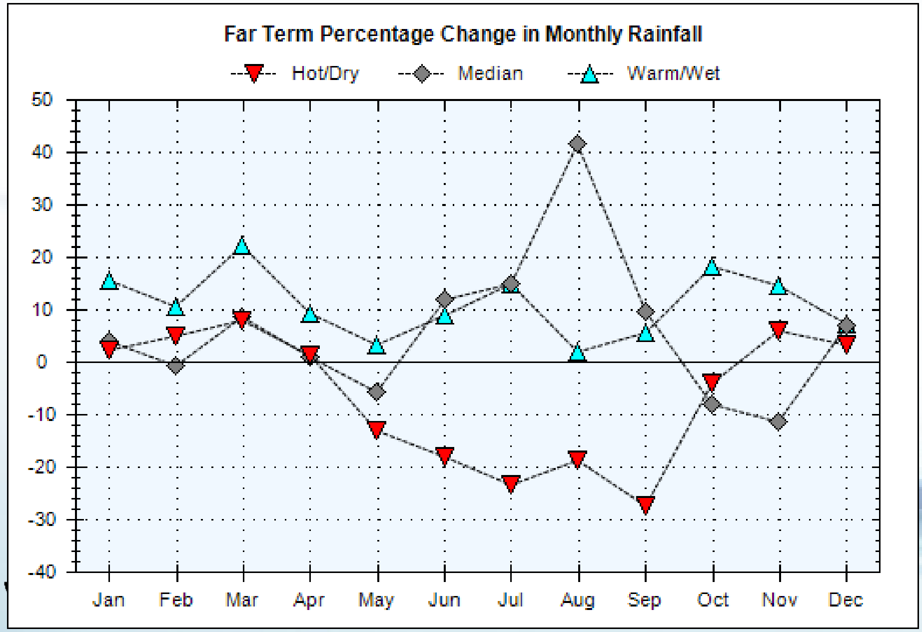


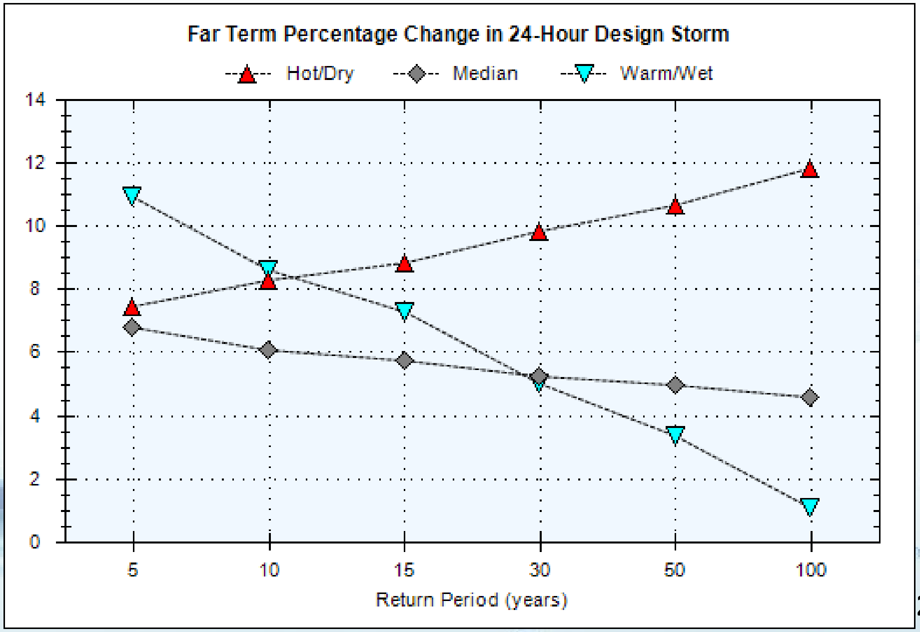
IPCC – International Program for Climate Change; WCRP – World Climate Research Program;
CMIP5 – 5th Coupled Model Intercomparison Project;
BOR – Bureau of Reclamation; LLNL – Lawrence Livermore National Laboratory;
CREAT - Climate Resilience Evaluation and Analysis Tool

Far-Term (2045-2074) Climate Adjustments for Cincinnati, OH

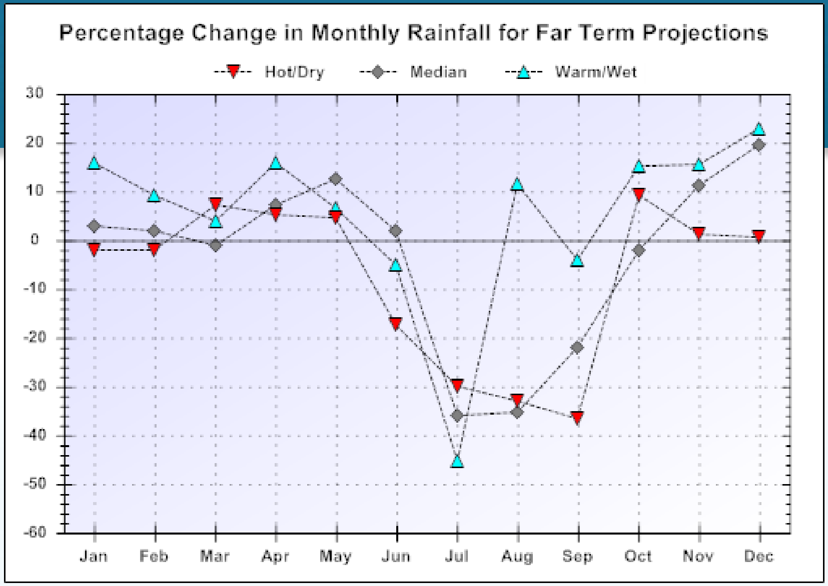




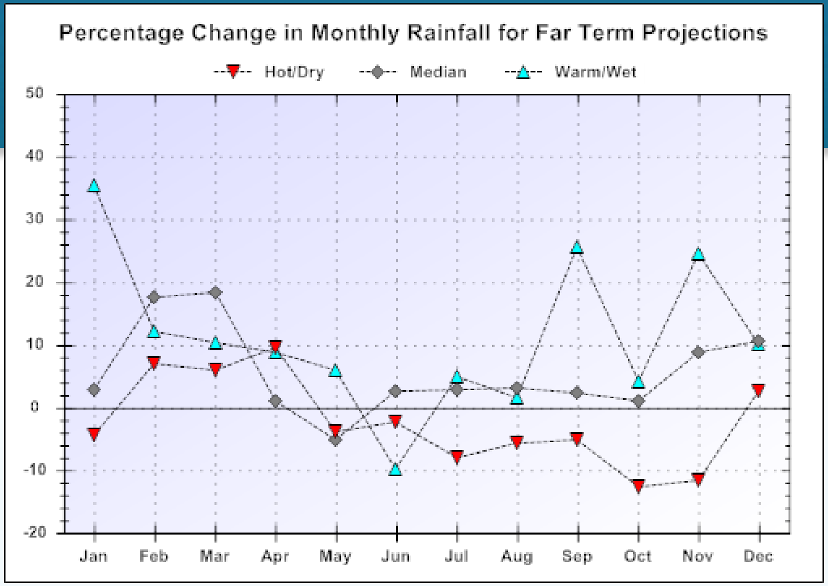




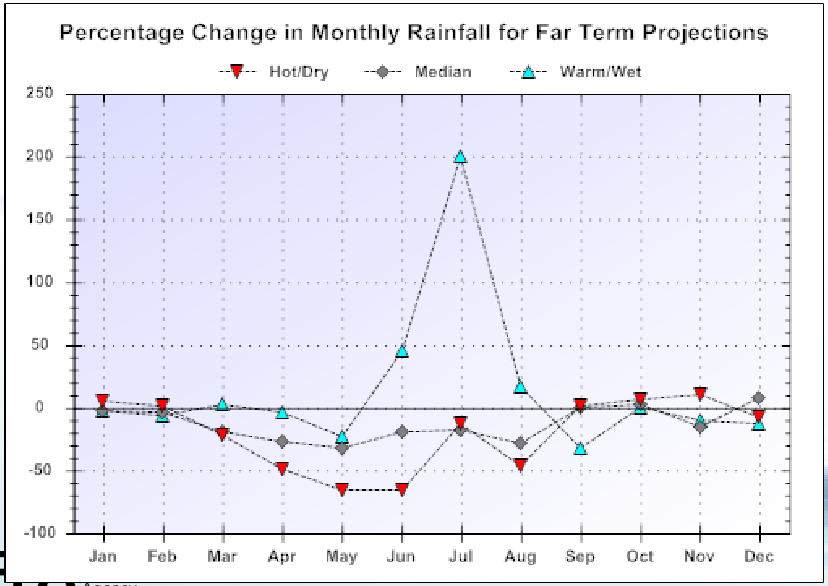
Seattle



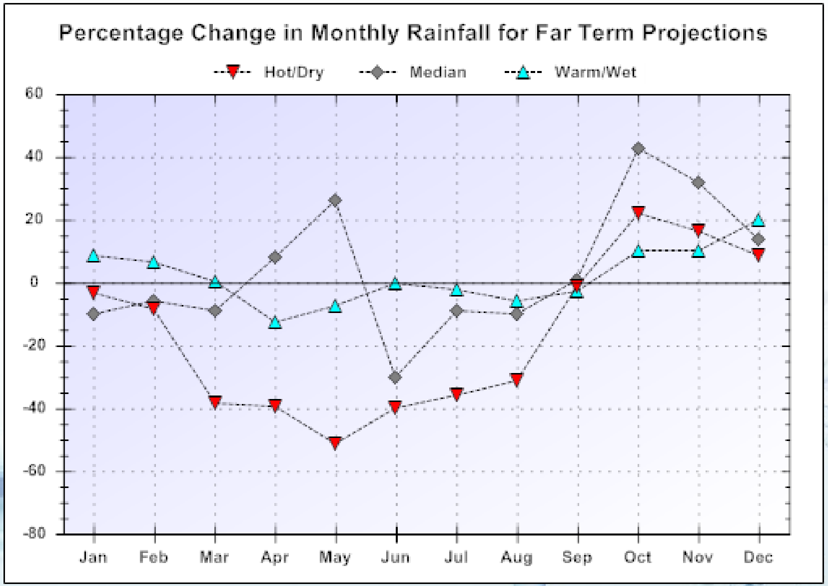
Boston



Phoenix



Miami



Agency

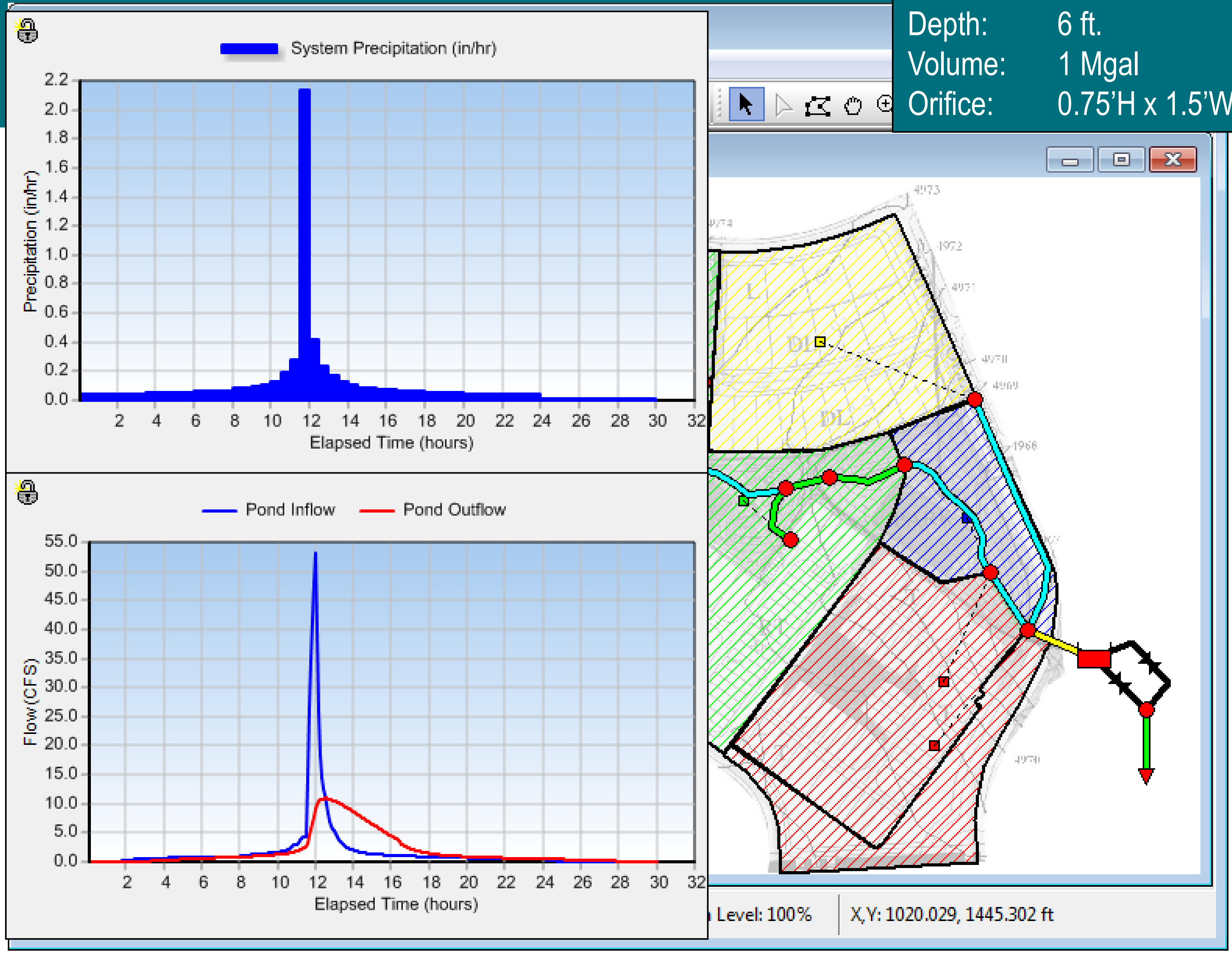
Pond Design:

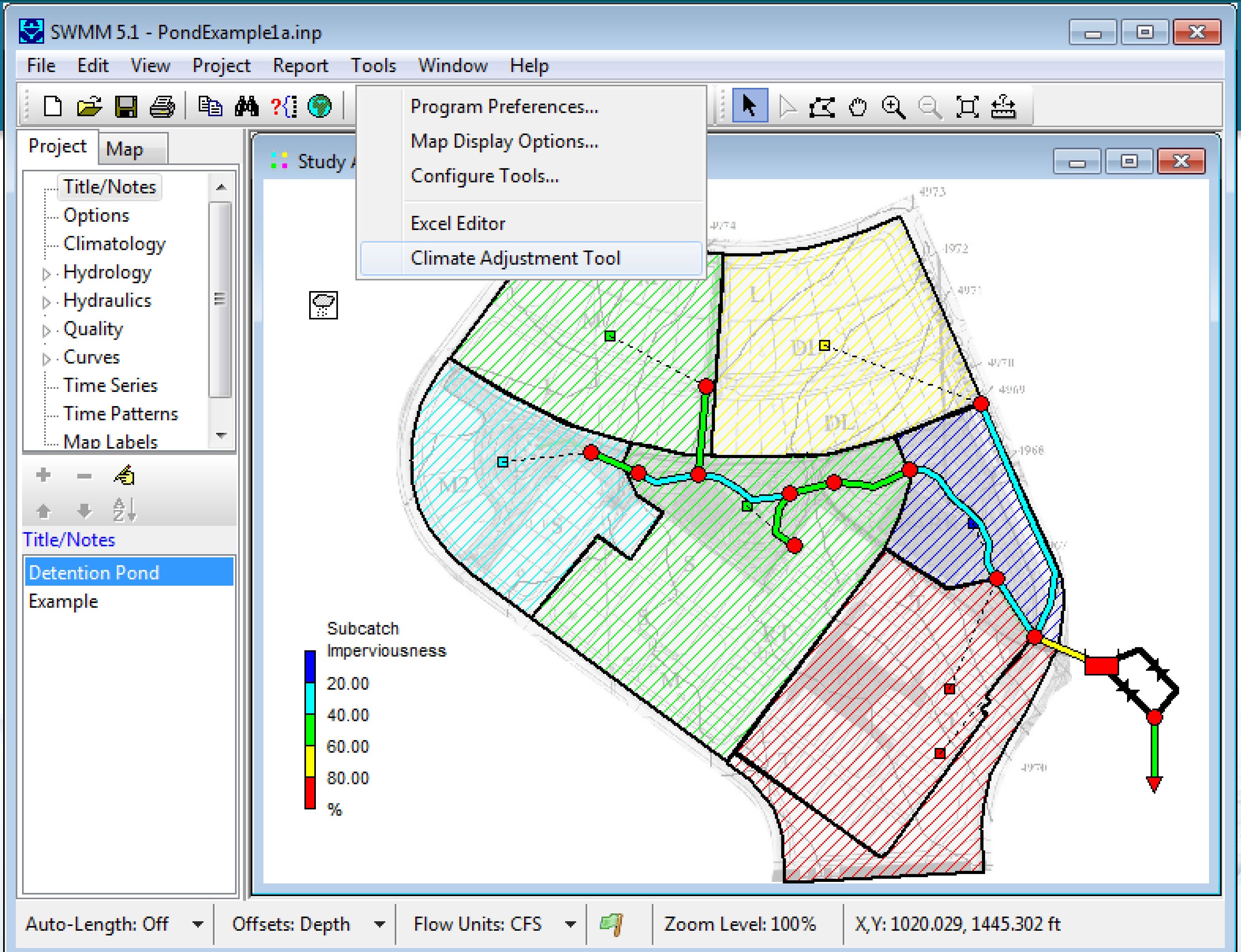
Area: 0.5 acres

Depth: 6 ft.

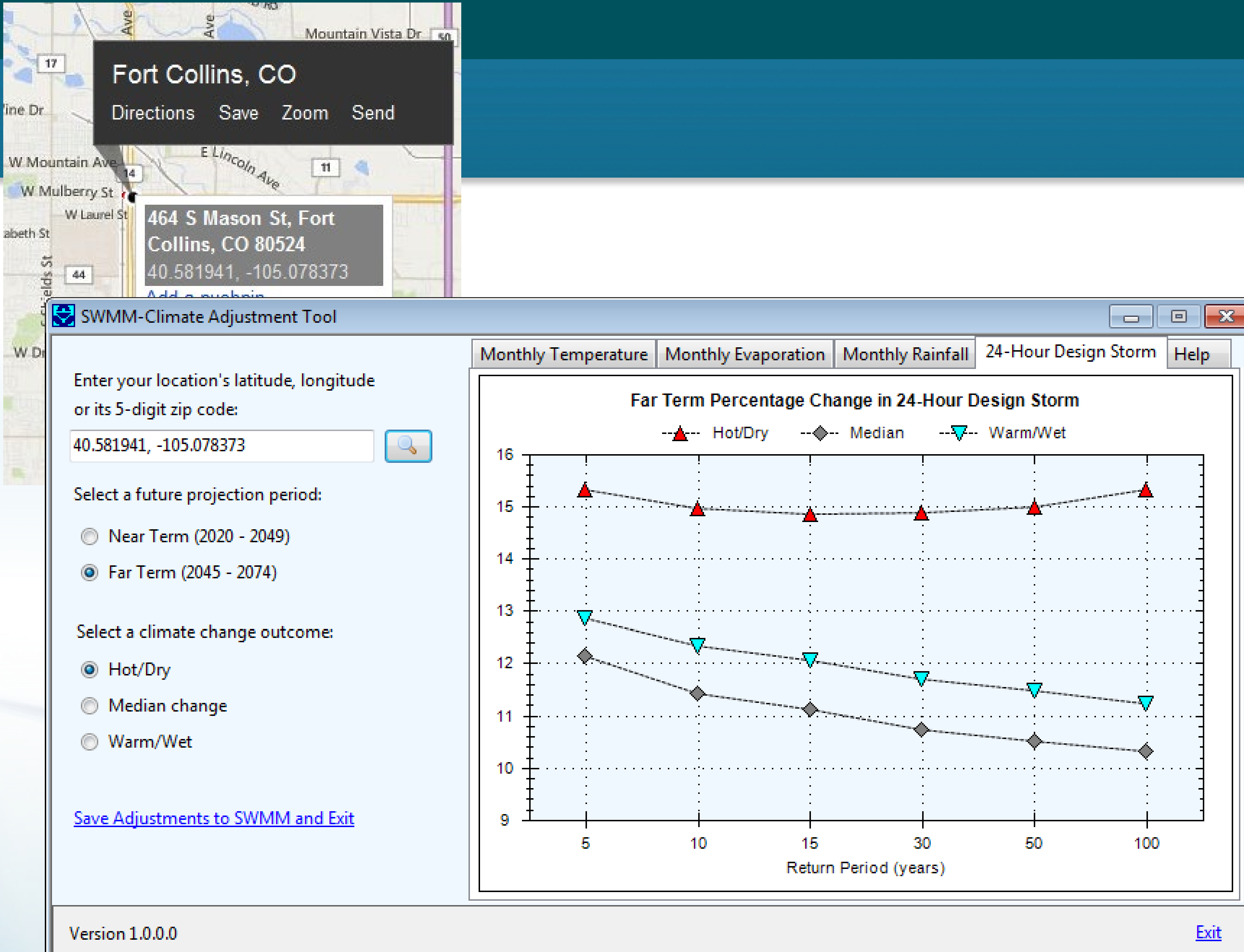
Volume: 1 Mgal

Orifice: 0.75'H x 1.5'W

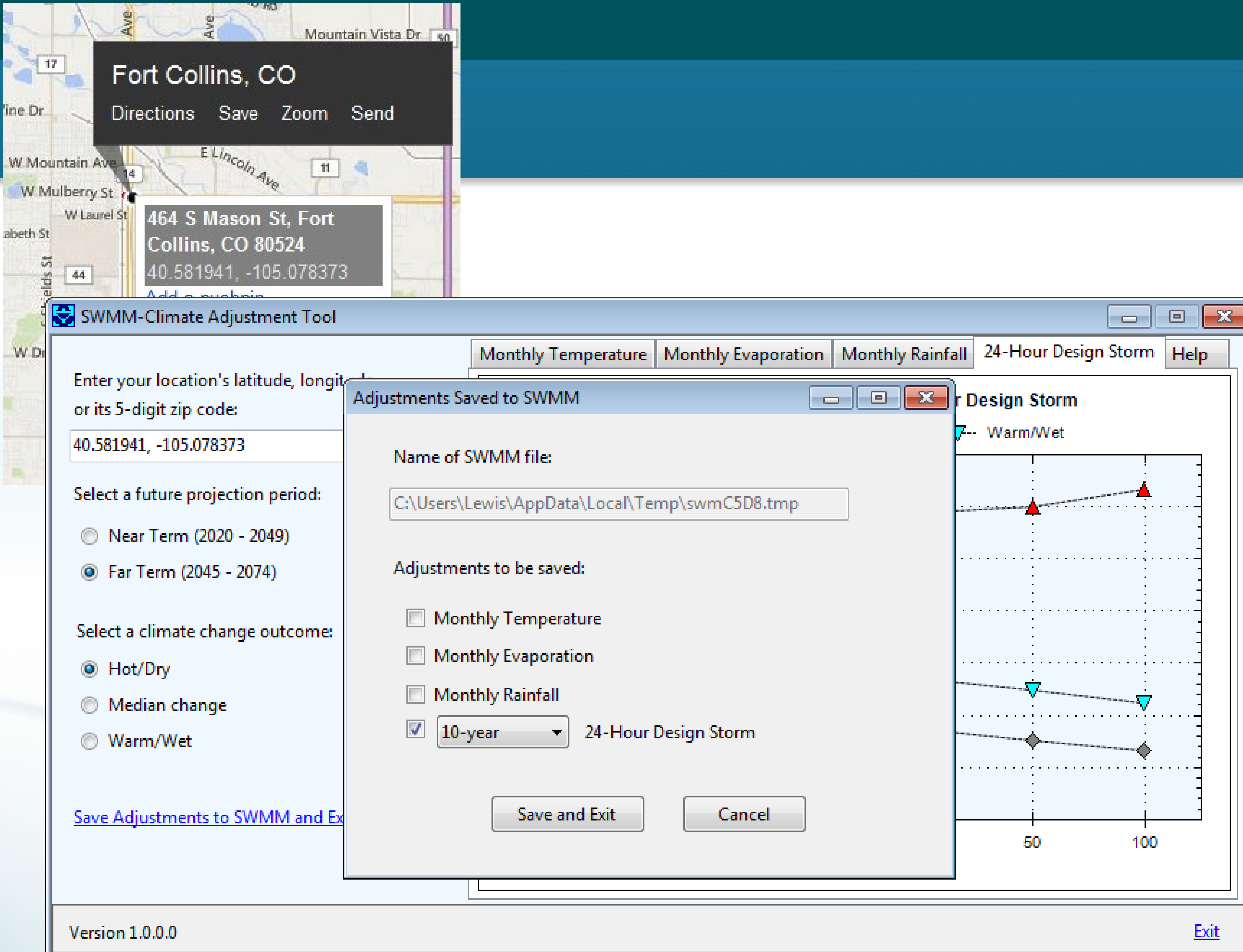




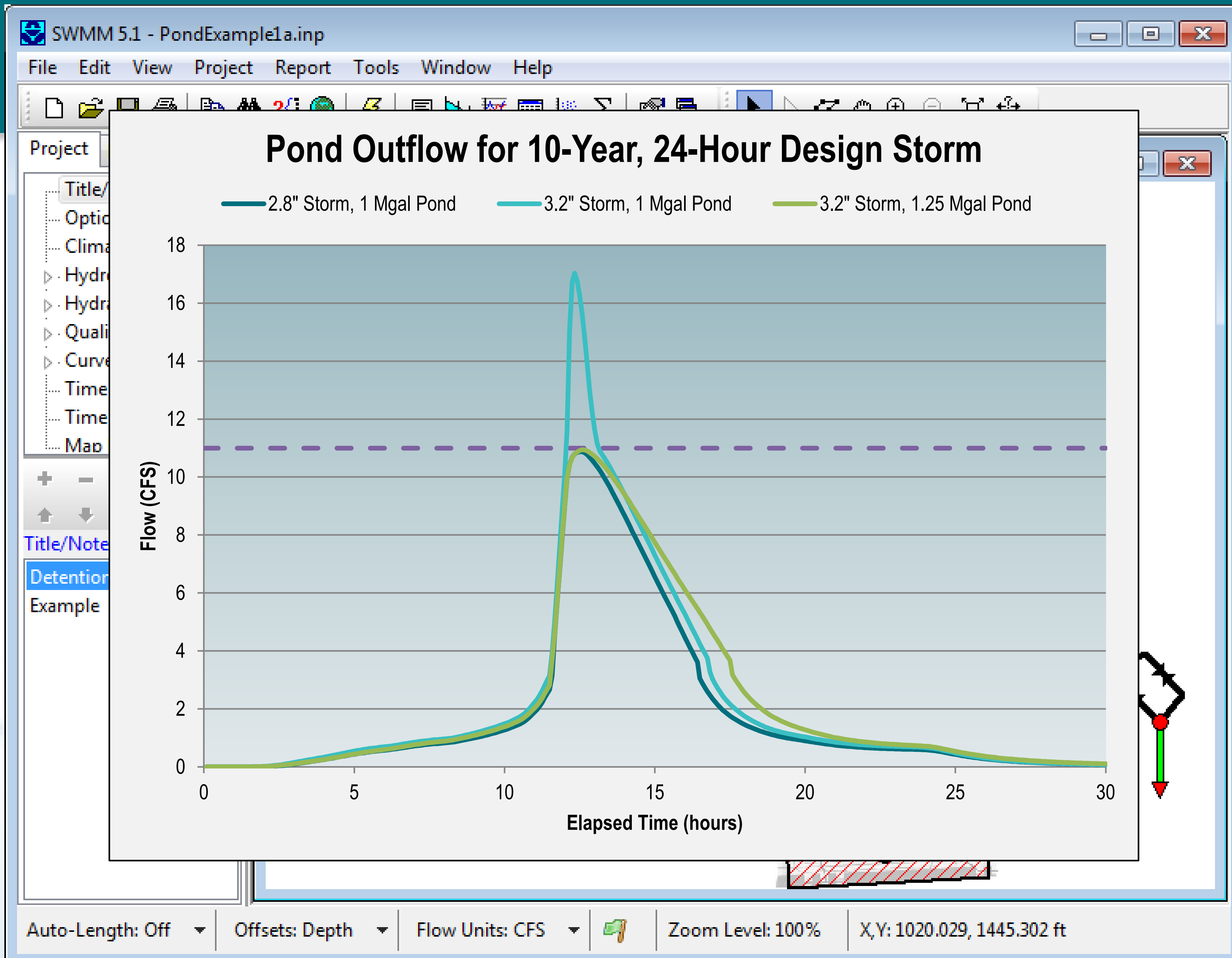
United States Environmental Protection Agency



United States Environmental Protection Agency



Mountain Vista Dr
Fort Collins, CO
Directions
Save
Zoom
Send
W Mountain Ave
E Lincoln Ave
W Mulberry St
W Laurel St
464 S Mason St, Fort Collins, CO 80524
40.581941, -105.078373
SWMM-Climate Adjustment Tool
Monthly Temperature
Monthly Evaporation
Monthly Rainfall
24-Hour Design Storm
Help
Enter your location's latitude, longitude
or its 5-digit zip code:
40.581941, -105.078373
Select a future projection period:
Near Term (2020 - 2049)
Far Term (2045 - 2074)
Select a climate change outcome:
Hot/Dry
Median change
Warm/Wet
Save Adjustments to SWMM and Ex
Adjustments Saved to SWMM
Name of SWMM file:
C:\Users\Lewis\AppData\Local\Temp\swmC5D8.tmp
Adjustments to be saved:
Monthly Temperature
Monthly Evaporation
Monthly Rainfall
10-year
24-Hour Design Storm
Save and Exit
Cancel
Warm/Wet
50
100
Version 1.0.0.0
Exit



United States Environmental Protection Agency

SWMM-CAT Summary

- Provides seamless integration of downscaled climate change scenarios with SWMM.
- Accounts for variability in climate projections and future prediction periods.
- Includes seasonal adjustments of average temperature, evaporation and precipitation.
- Includes changes in extreme event rainfall.
- Does not address changes in individual storm event magnitudes, durations, and frequencies.

Questions?

Day 3

1. Interpreting More Complicated SWMM Results
2. Where to get Data
3. SWMM Climate Adjust Tool
4. Ground Truthing SWMM
5. Course Wrap Up

Accuracy\Uncertainty

- Physical Reality
- Scientific Understanding
- Mathematical Abstraction
- Programming
- Parameter estimation
- Results, compared to observations
- Repeat

What is a model?

A useful simplification of a complex reality

Abstraction

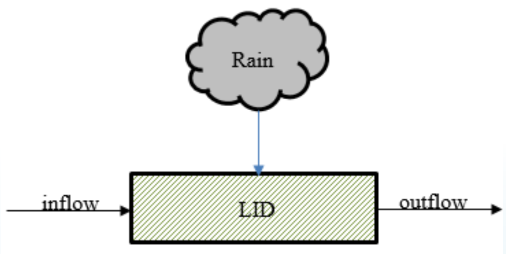
Fidelity
- Behavior
- Mechanism

What's the goal?

https://www.google.com/search?q=mathematical+abstraction+of+hydrology+images&tbm=isch&source=iu&ictx=1&fir=eDv9KY_znXaWIM%253A%252CYzICHXicd0xv_M%252C_&usg=AI4_-kS544Xrnn5UpDuff0UJU6D1Tpt-VA&sa=X&ved=2ahUKEwjT0vG6jb7eAhXN0VMKHWipC30Q9QEwAHoECAQQBA#imgdii=j7R4otA9j2apTM:&imgrc=B3LrwJmLR84z9M:

131

Types of LIDs Hydrology Tested



Platz, M.; M. Simon; and M. Tryby (2020). "Testing of the SWMM Model's LID Modules." *Journal of Sustainable Water in the Built Environment*

https://doi.org/10.1111/1752-1688.12832

Rain Garden/Bioretention

Infiltration Trench

Green Roof

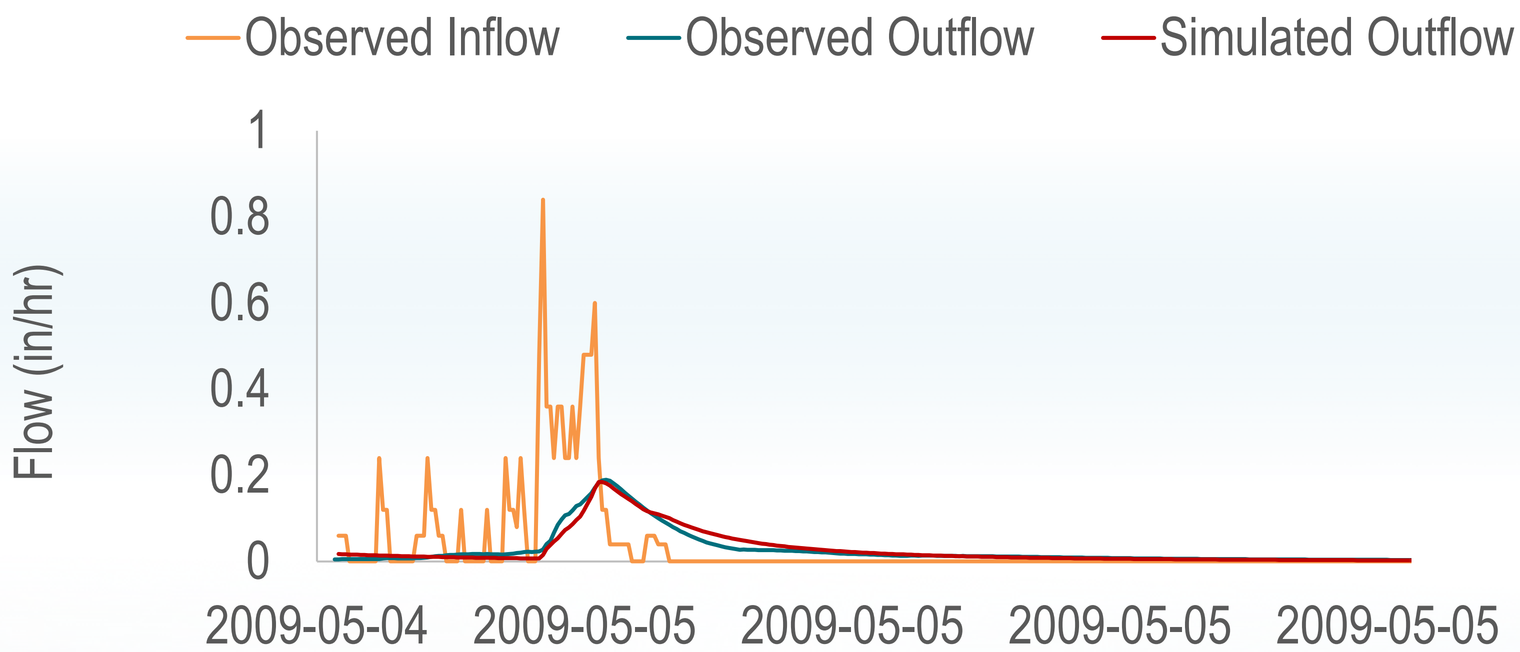
Vegetative Swale

Porous Pavement

LID Studies used for testing

LID Type	Research Organization Location	Name of Project	Reference
Bio-retention	North Carolina State University, NC	Graham Bio-Retention	(Passeport et al. 2009)
Rain Garden	Villanova University, PA	Villanova BTI Rain Garden	(Lord 2013)
Infiltration Trench	Villanova University, PA	Villanova Infiltration Trench	(Emerson 2008)
Vegetated Swale	University of Maryland, Savage, MD	UMD BioSwale	(Davis et al. 2012)
Vegetated Swale	Washington State Department of Transportation, King County, WA	Washington DOT BioSwale	(Maurer 2009)
Green Roof	City of Portland, OR	Hamilton Ecoroof	(Hutchinson et al. 2003) (She and Pang 2010)
Green Roof	City of Seattle, WA	EOC Green Roof	(Cardno TEC. 2012)
Green Roof	City of Seattle, WA	FS10 Green Roof	(Cardno TEC. 2012)
Porous Pavement	North Carolina State University, Kingston, NC	Boone Porous Pavement	(Wardynski et al. 2013)

Seattle ECO Green Roof Hydrograph



United States Environmental Protection Agency

Goodness of Fit

Coefficient of Determination

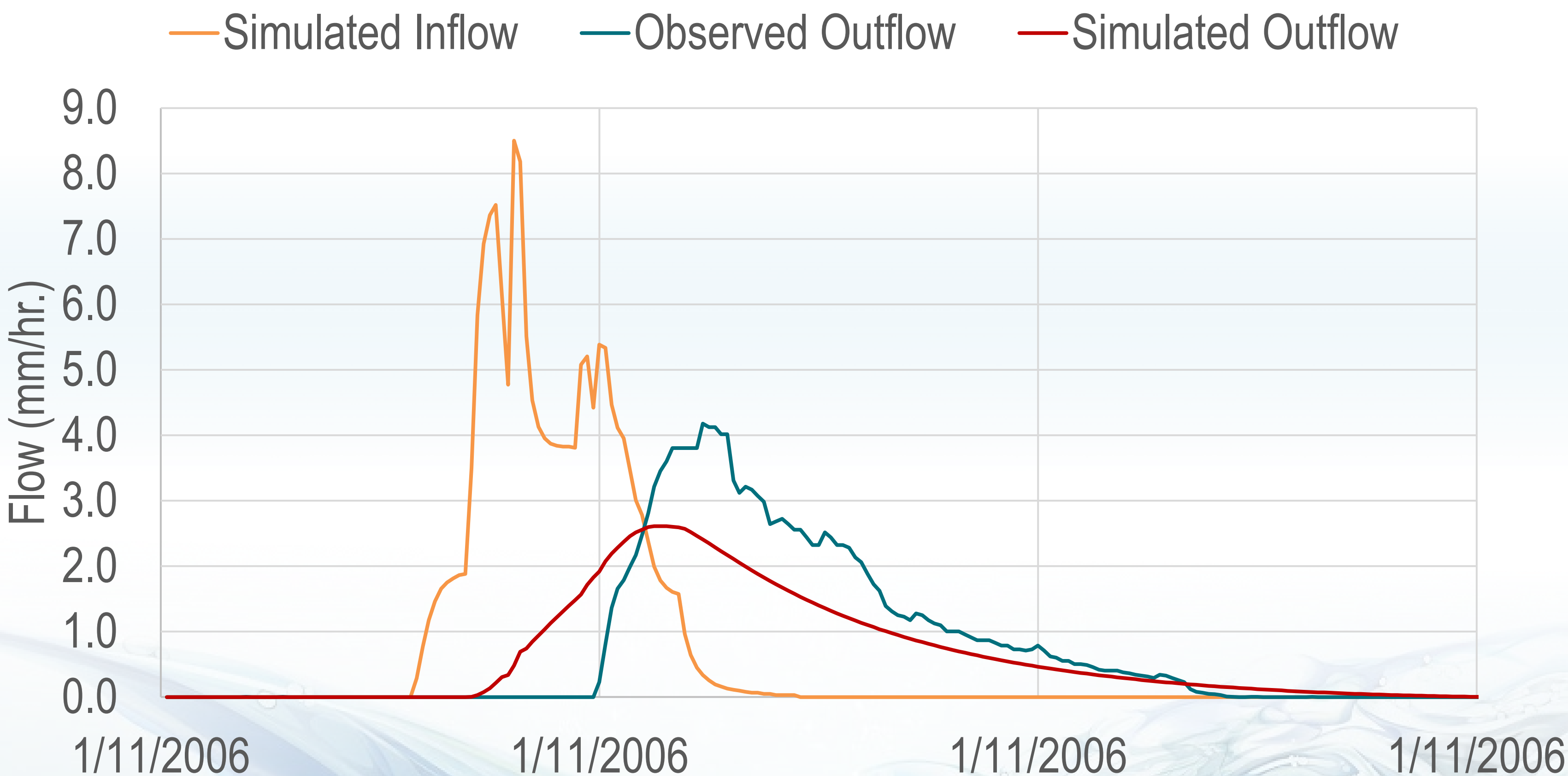
$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - O^{mean})(P_i - P^{mean})}{\sqrt{\sum_{i=1}^{n} (O_i - O^{mean})^2} \sqrt{\sum_{i=1}^{n} (P_i - P^{mean})^2}} \right)^2$$

Nash-Sutcliffe Efficiency Statistic

$$N - S = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O^{mean})^2}$$

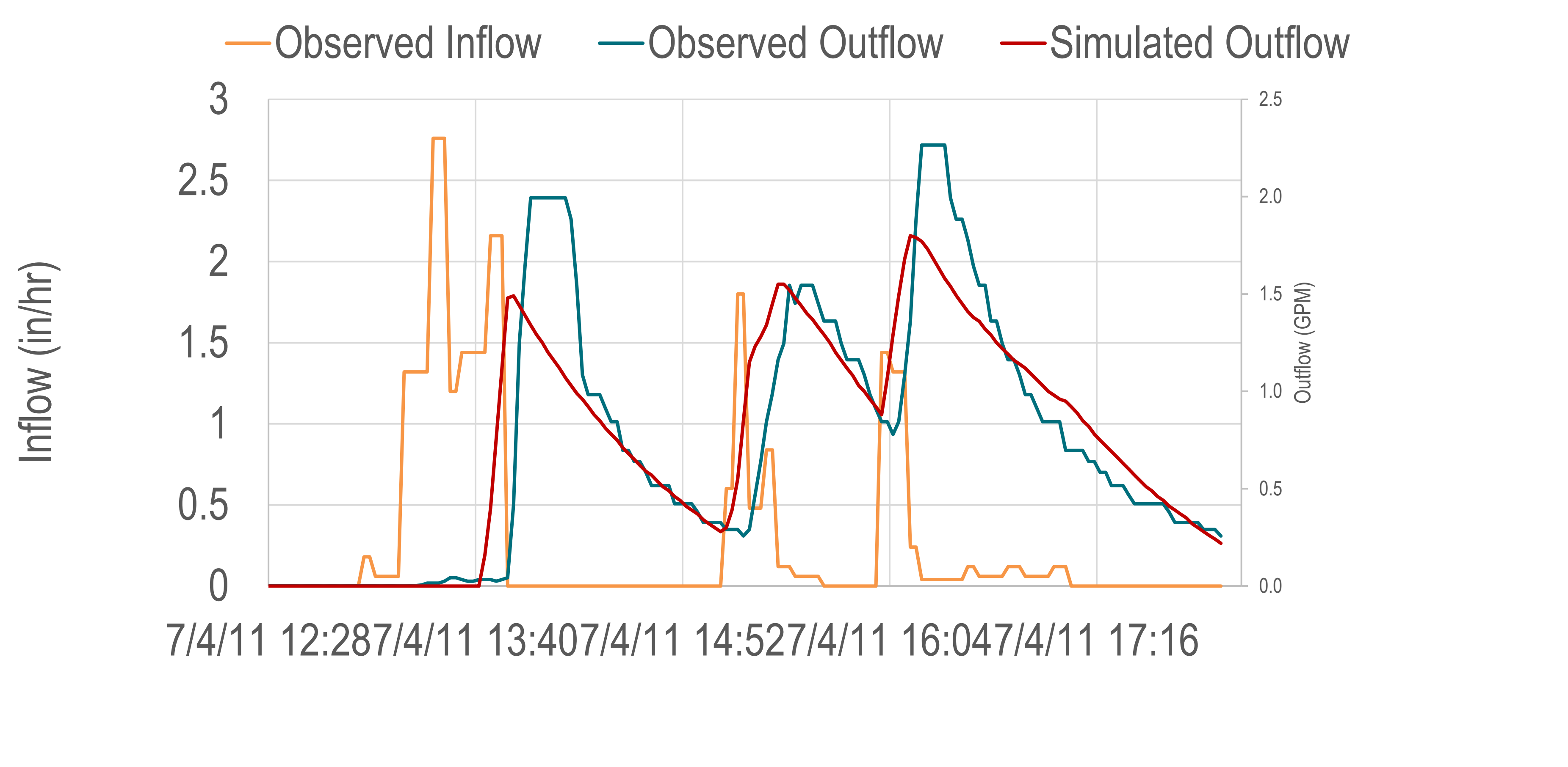
United States Environmental Protection Agency

Hydrograph from *UMD Bioswale* analysis depicting early outflow start-time



United States Environmental Protection Agency

Boone Porous Pavement hydrograph depicting early outflow start-time

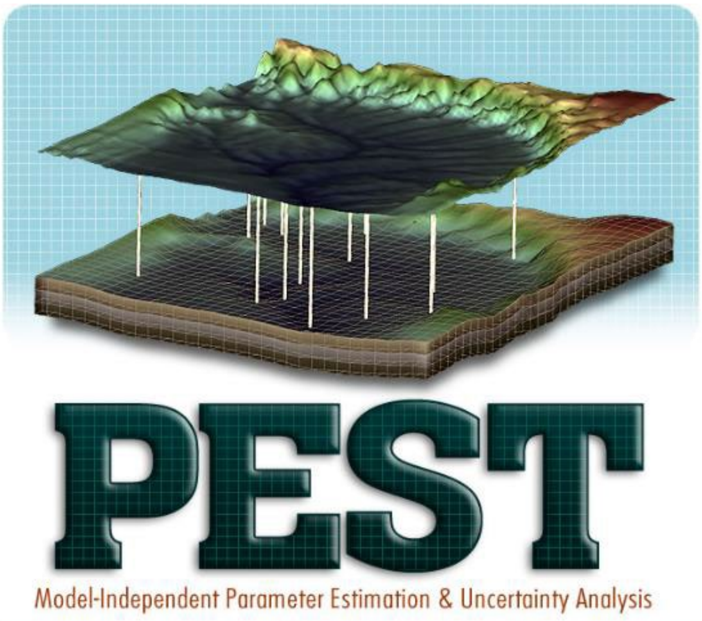


EPA United States Environmental Protection Agency

Multi-event Calibration Method

Storm 1	Storm 2	Storm 3	Storm 4	
Calibration NSE, R^2	NSE, R^2	NSE, R^2	NSE, R^2	**Storm 1 Calibration AVG NSE, R^2**
NSE, R^2	Calibration NSE, R^2	NSE, R^2	NSE, R^2	**Storm 2 Calibration AVG NSE, R^2**
NSE, R^2	NSE, R^2	Calibration NSE, R^2	NSE, R^2	**Storm 3 Calibration AVG NSE, R^2**
NSE, R^2	NSE, R^2	NSE, R^2	Calibration NSE, R^2	**Storm 4 Calibration AVG NSE, R^2**

PEST

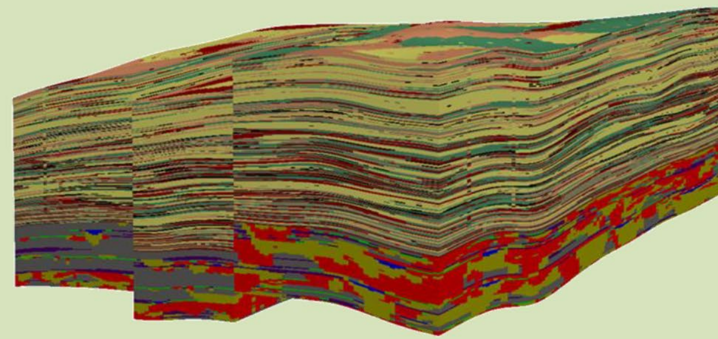


http://www.pesthomepage.org/

Calibration and Uncertainty Analysis

for

Complex Environmental Models



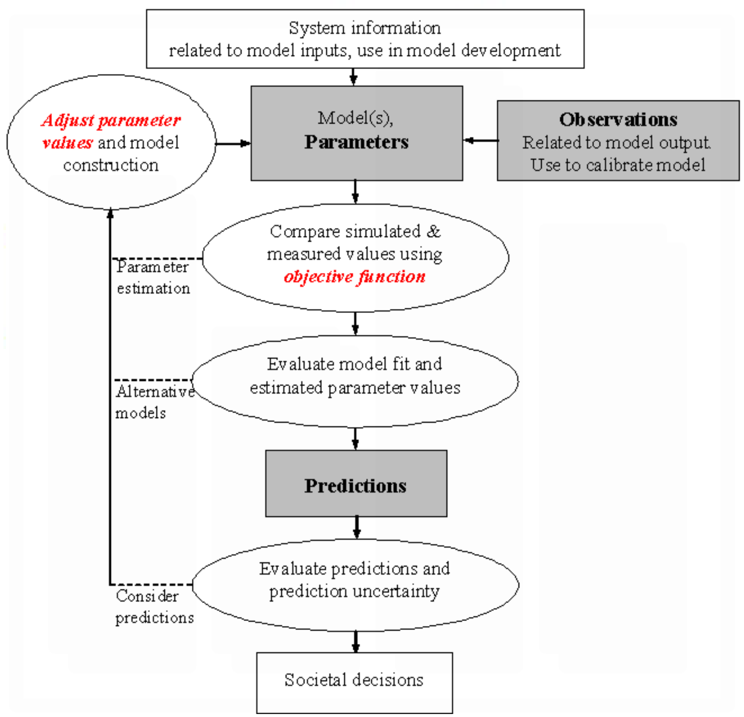
PEST: complete theory and what it means for modelling the real world

John Doherty

How PEST Works

PEST (Parameter Estimation Software)

PEST is a nonlinear parameter estimation package capable of estimating parameters for any computer model. It solves a nonlinear least squares problem and minimizes the differences between the model's outputs and field measurements such as the calculated and measured discharges.



PEST adapts to the model, the model does not need to adapt to PEST.

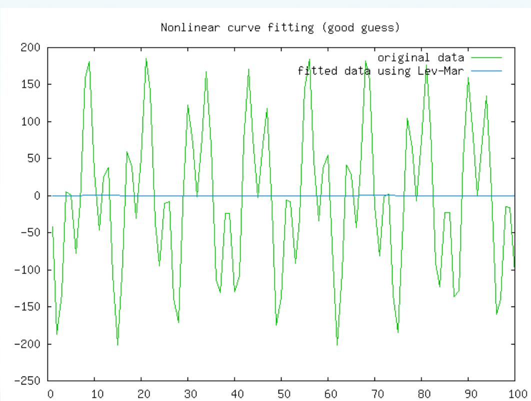
https://www.google.com/search?q=parameter+estimation+images&tbm=isch&tbo=u&source=univ&sa=X&ved=2ahUKEwik0dbkzbHeAhVyTt8KHW6TDR0QsAR6BAgFEAE&biw=1680&bih=941#imgrc=FbdsdbiAFfzVvM: J. Doherty 2007

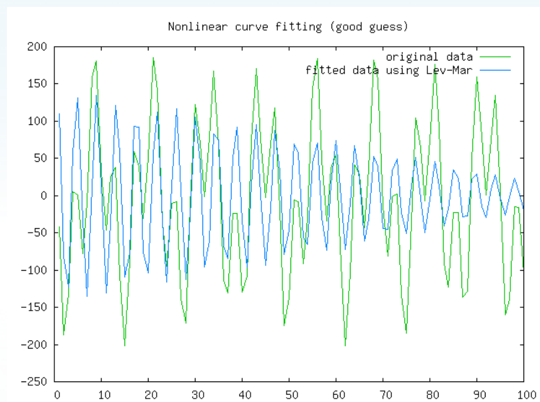
Parameter Estimation Algorithm

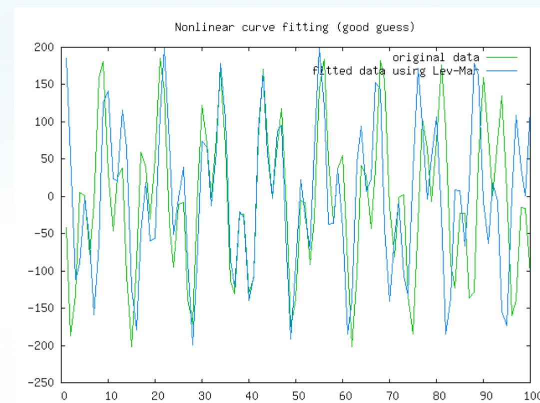
Levenberg–Marquardt algorithm (LMA or just LM), AKA damped least-squares (DLS)

$$f(x) = \frac{1}{2}\sum_{j=1}^{m} r_j^2(x)$$

$$\nabla^2 f(x) = J(x)^T J(x)$$



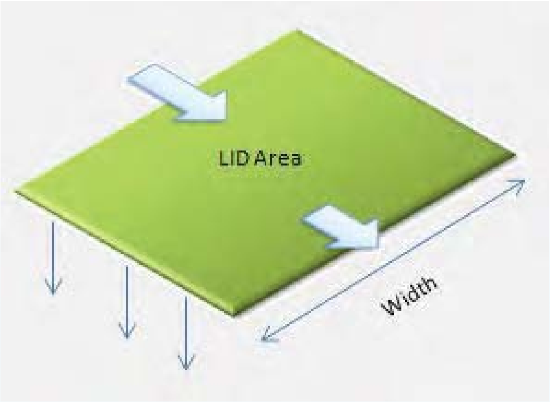


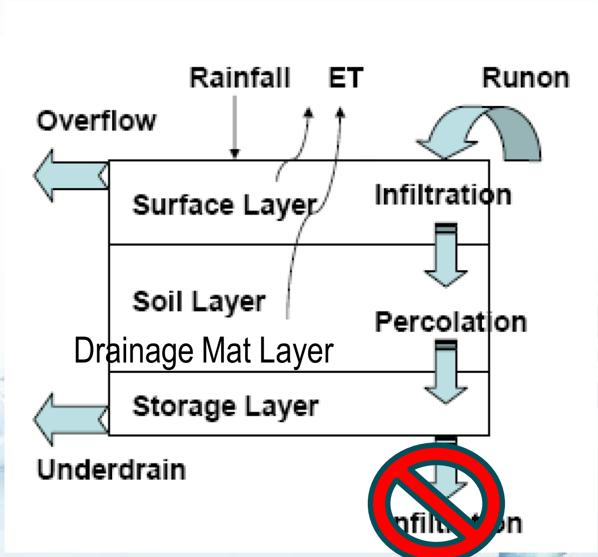


https://en.wikipedia.org/wiki/File:Lev-Mar-best-fit.png $y = a\cos(bX) + b\sin(aX)$

Parameters for a SWMM LID Green Roof

Parameter
Maximum Freeboard, inches (D_1)
Surface Void Fraction (ϕ_1)
Soil Layer Thickness, inches (D_2)
Soil Parameters:
Porosity (ϕ_2)
Field Capacity (θ_{FC})
Wilting Point (θ_{WP})
Plant Available Water (θ_{FC} - θ_{WP})
Saturated Hydraulic Conductivity, in/hr (K_{2S})
Wetting Front Suction Head, inches (ψ_2)
Percolation Parameter (HCO)
Drainage Layer Thickness, inches (D_3)
Drainage Layer Void Fraction (ϕ_3)
Drainage Layer Roughness (n_3)
Capture Ratio (R_{LID})





Most Sensitive Parameters

1 = most
7 = least

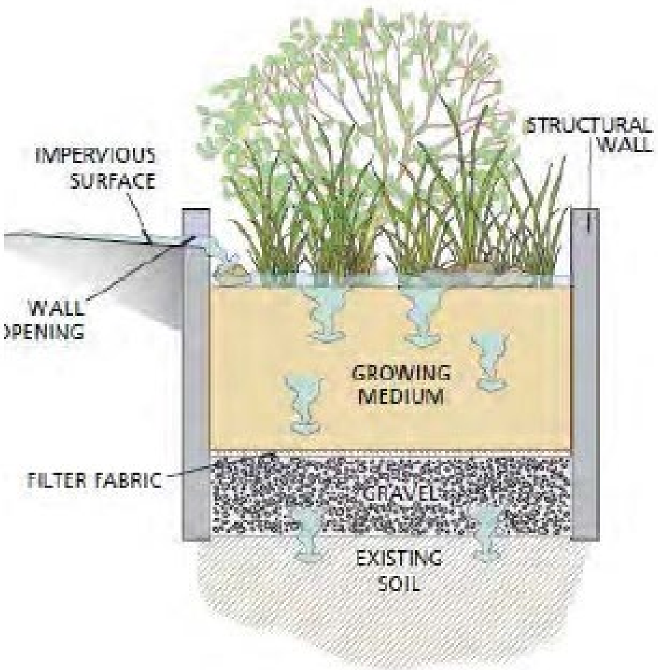
Parameter		Rank
LID Usage	Width	7
	Initial Saturation	5
Soil	Porosity	4
	Field Capacity	2
	Wilting Point	1
Drainage Mat	Void Ratio	3
	Roughness	6

United States Environmental Protection Agency

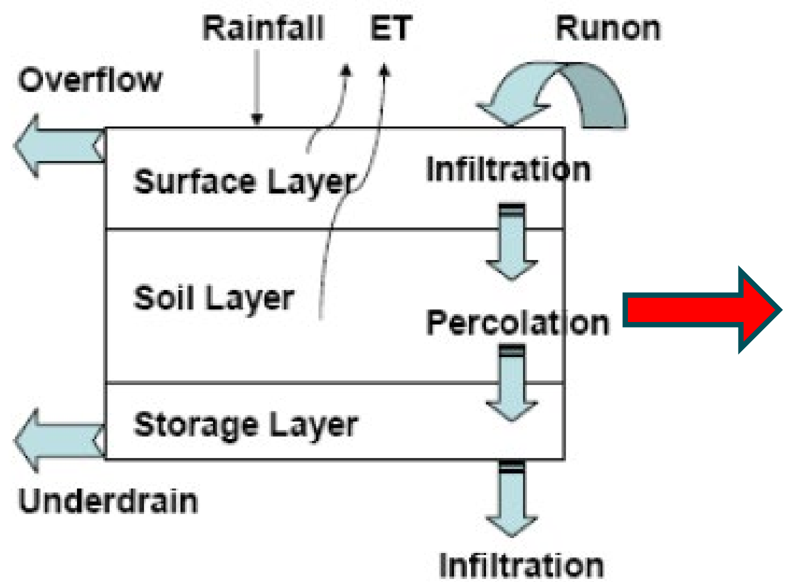
LID Module Performance Summary Table

LID Name	Average NSE Value	Average r^2 Value
Graham Bio-retention	0.86	0.93
Villanova BTI Rain Garden	0.86	0.96
Villanova Infiltration Trench	0.65	0.67
UMD BioSwale	0.78	0.87
Washington DOT BioSwale	0.70	0.91
Hamilton Ecoroof	0.92	0.90
EOC Green Roof	0.94	0.97
FS10 Green Roof	0.93	0.84
Boone Porous Pavement	0.74	0.89

SWMM LID Modeling Weakness



(A)



(B)

LID Study Conclusions

- PEST is a useful tool for parameter estimation
- Multi-storm calibration quantified variance in calibration method
- SWMM LID can model hydrology with
  - NSE ranging from 0.65- 0.94
  - R^2 ranging from 0.67 – 0.97
- SWMM LID Module does not account for lateral exfiltration which is important for deep, narrow, LIDs, such as Infiltration Trenches
- EWRI LID Group was formed to improve scientific underpinnings of SWMM
- Next step – test water quality and LID aggregations

Questions?

Summary of Presentation

1. SWMM Fundamentals
2. Getting Started with SWMM
3. Building the Hydraulic Model
4. New Hydraulic Features to SWMM
5. Building the Hydrologic Model
6. History of SWMM
7. Using SWMM for Low Impact Development
8. Building LID Model
9. Demonstration of EPA Stormwater Calculator
10. Ground-truthing SWMM
11. Interpreting More Complicated SWMM Results
12. Where to get Data
13. SWMM Climate Adjust Tool
14. Conclusions

Thank You!

Michelle Simon
U.S. EPA Office of Research and Development (ORD)
513-569-7469 Simon.michelle@epa.gov

United States Environmental Protection Agency