An Introduction to the Storm Water Management Model (SWMM)

Michelle Simon

March 5, 2020

Chicago, IL

Disclaimer

Any opinions expressed in this presentation are those of the author and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. But it has been through USEPA's official clearance process. 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, Associate Director of Science
Water Systems Division, National Risk Management Research Laboratory, 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

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. History of SWMM
7. Using SWMM for Low Impact Development
8. Building LID Model
9. Ground-truthing SWMM
10. Interpreting More Complicated SWMM Results
11. SWMM Climate Adjust Tool
12. Where to get Data
13. Demonstration of EPA Stormwater Calculator
14. Conclusions

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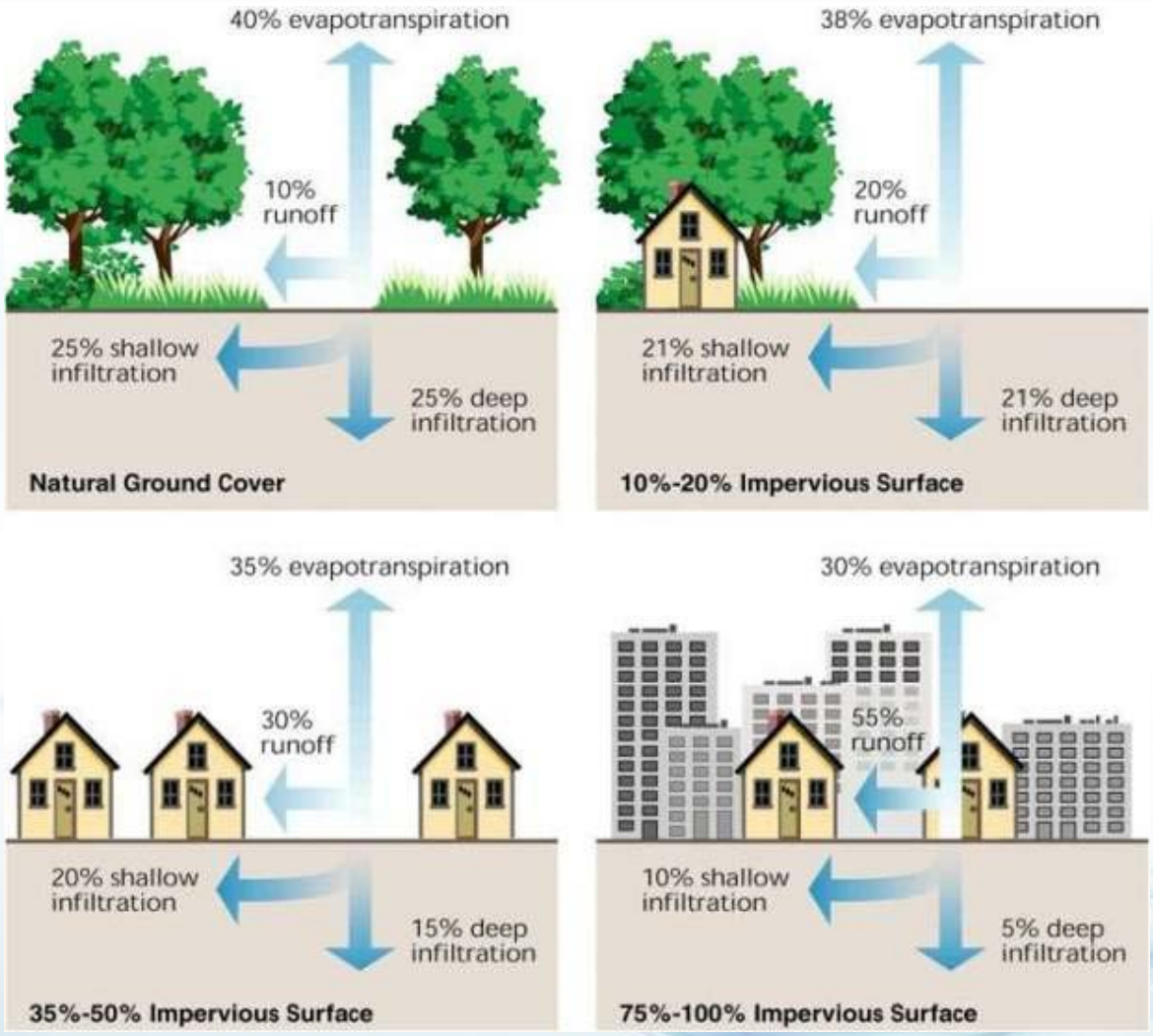
Urbanization Changes the Hydrologic Cycle

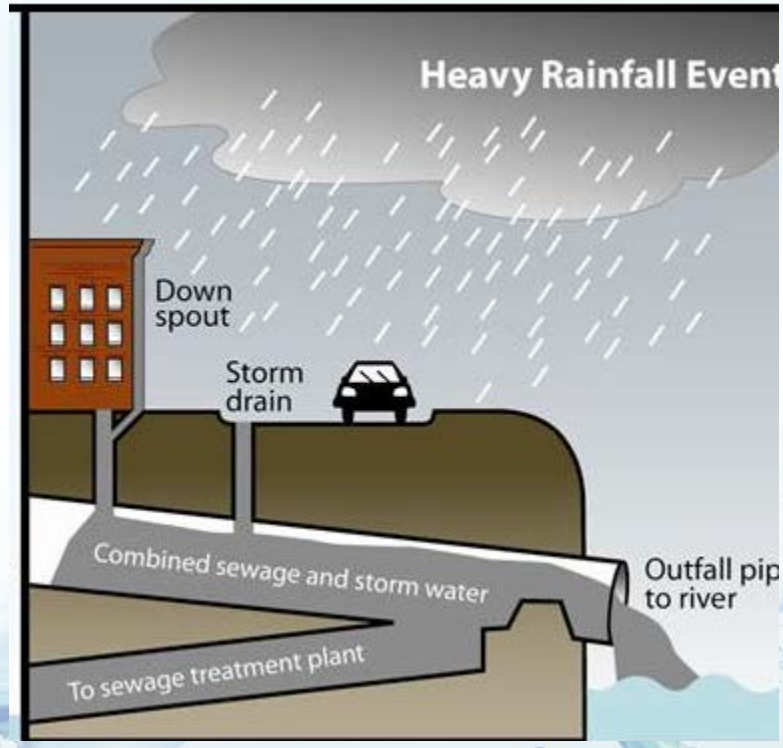


- Soils and vegetation are replaced with impervious surfaces
- Impervious surfaces are connected to dense drainage networks
- Runoff drains directly into streams, lakes, wetlands, and coastal waters
- Even small storms generate significant runoff

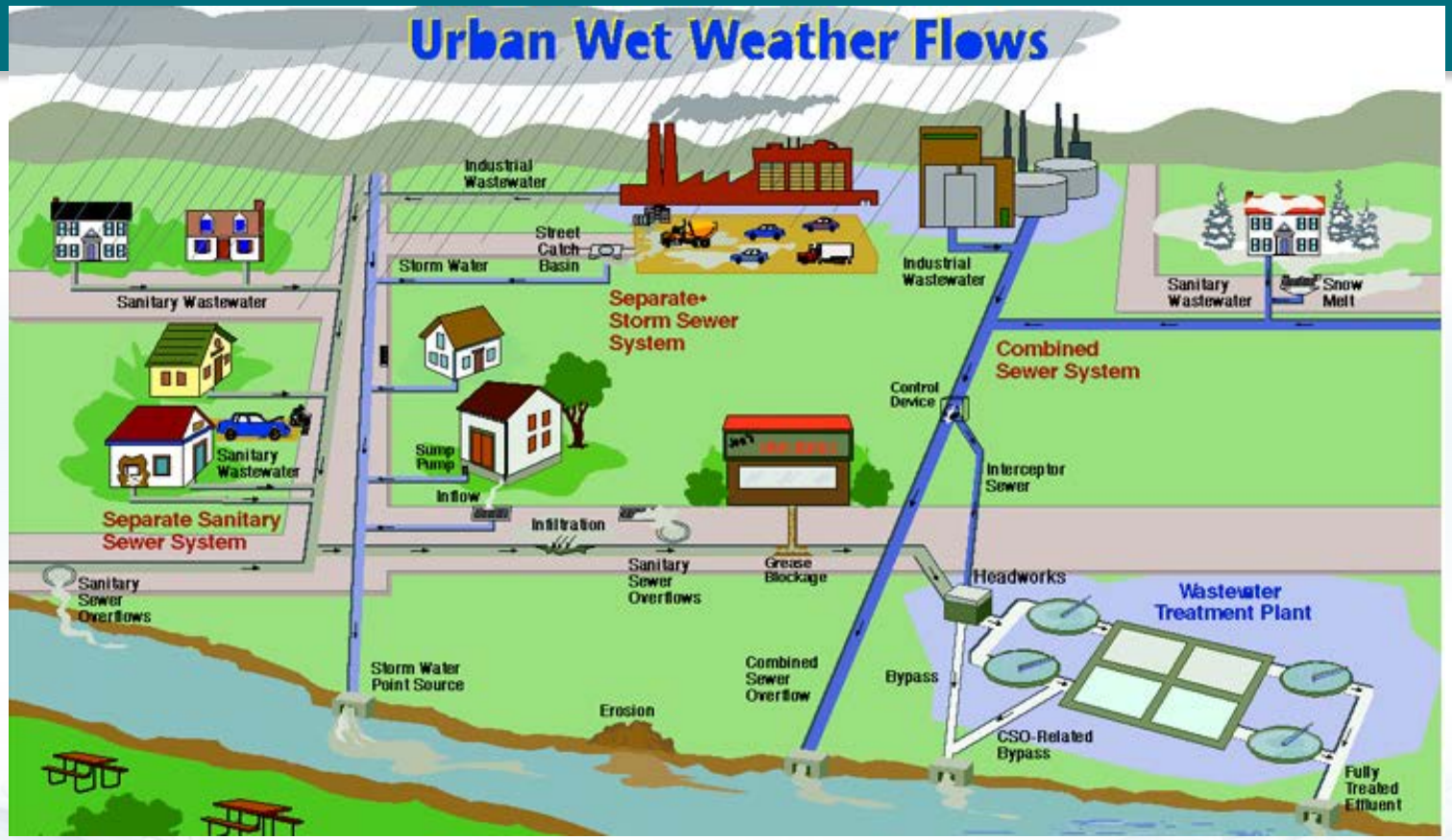
Urban Stormwater Impacts

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 E coli, metals, PAHs, and other pollutants.
- Reduced groundwater recharge impacts water supplies.

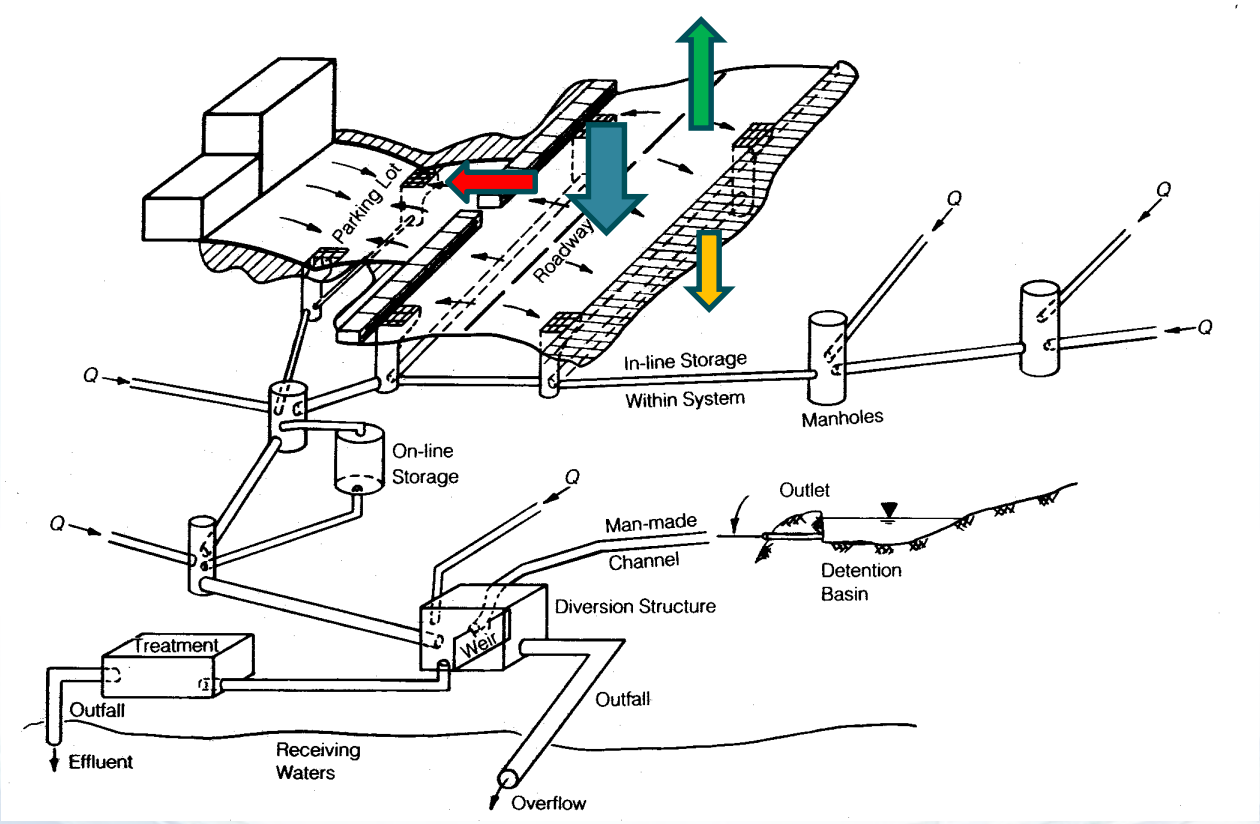


What is SWMM?



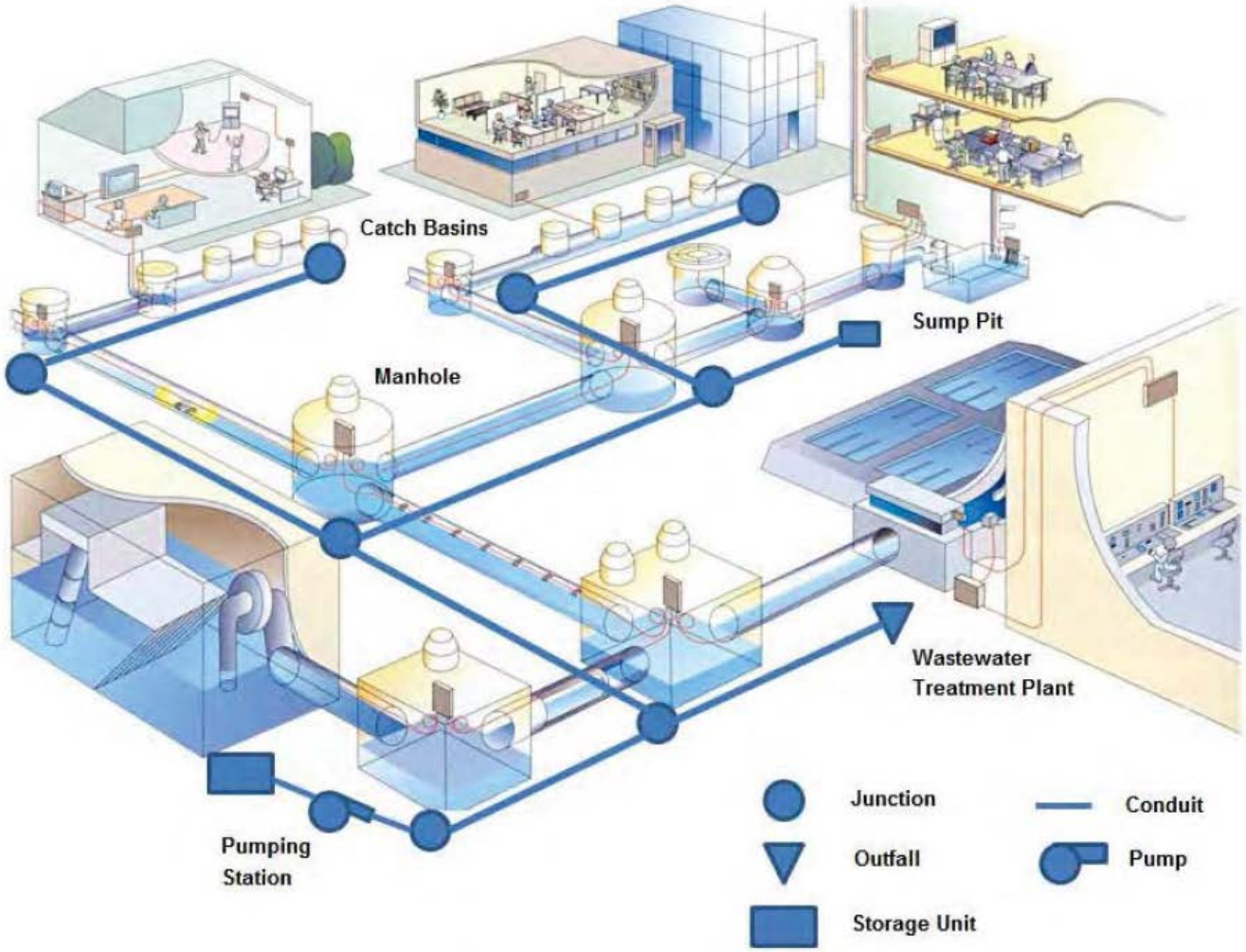
SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

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.

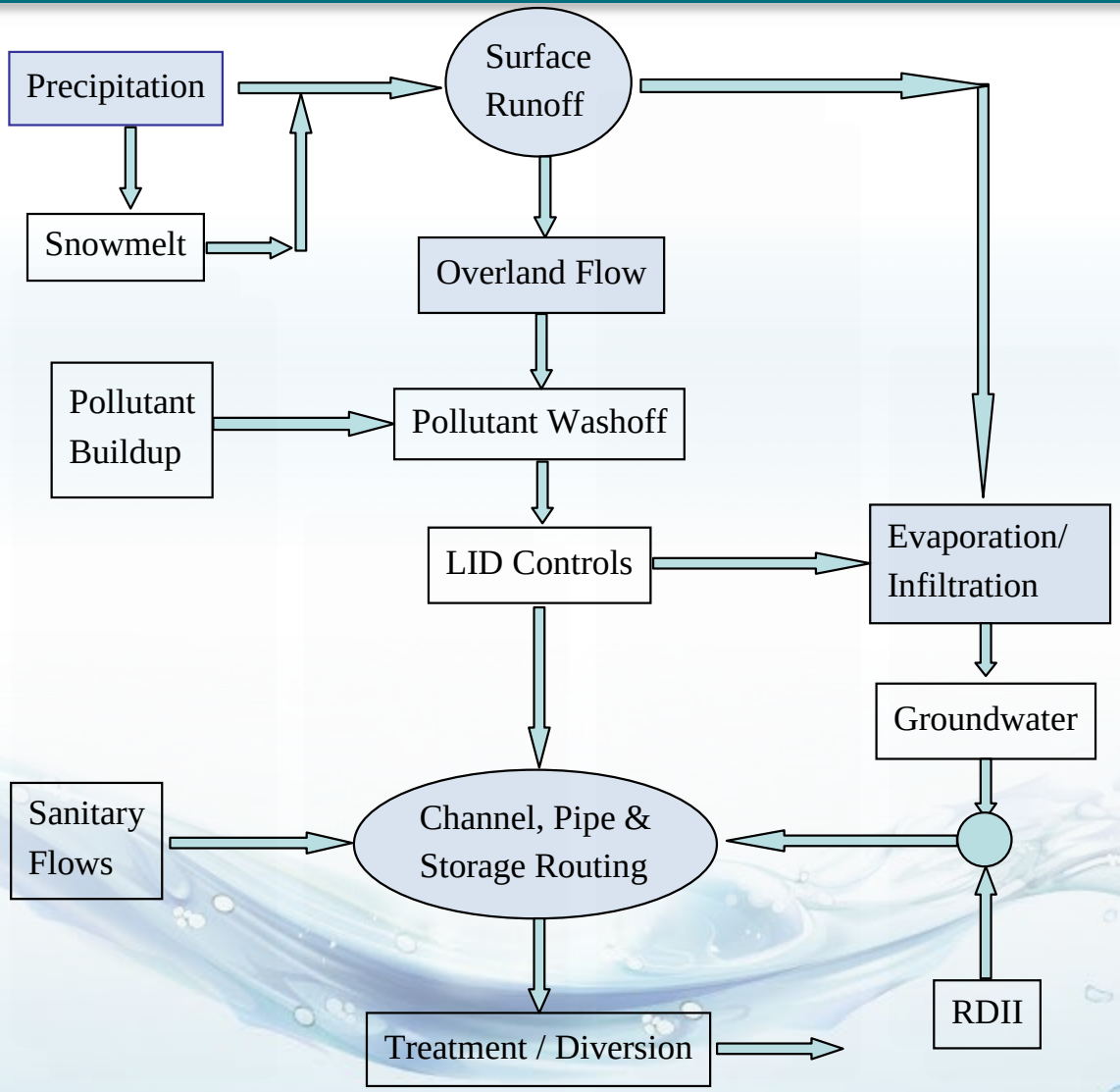
Control of combined and sanitary sewer overflows.

Modeling Inflow & Infiltration in sanitary sewer systems.

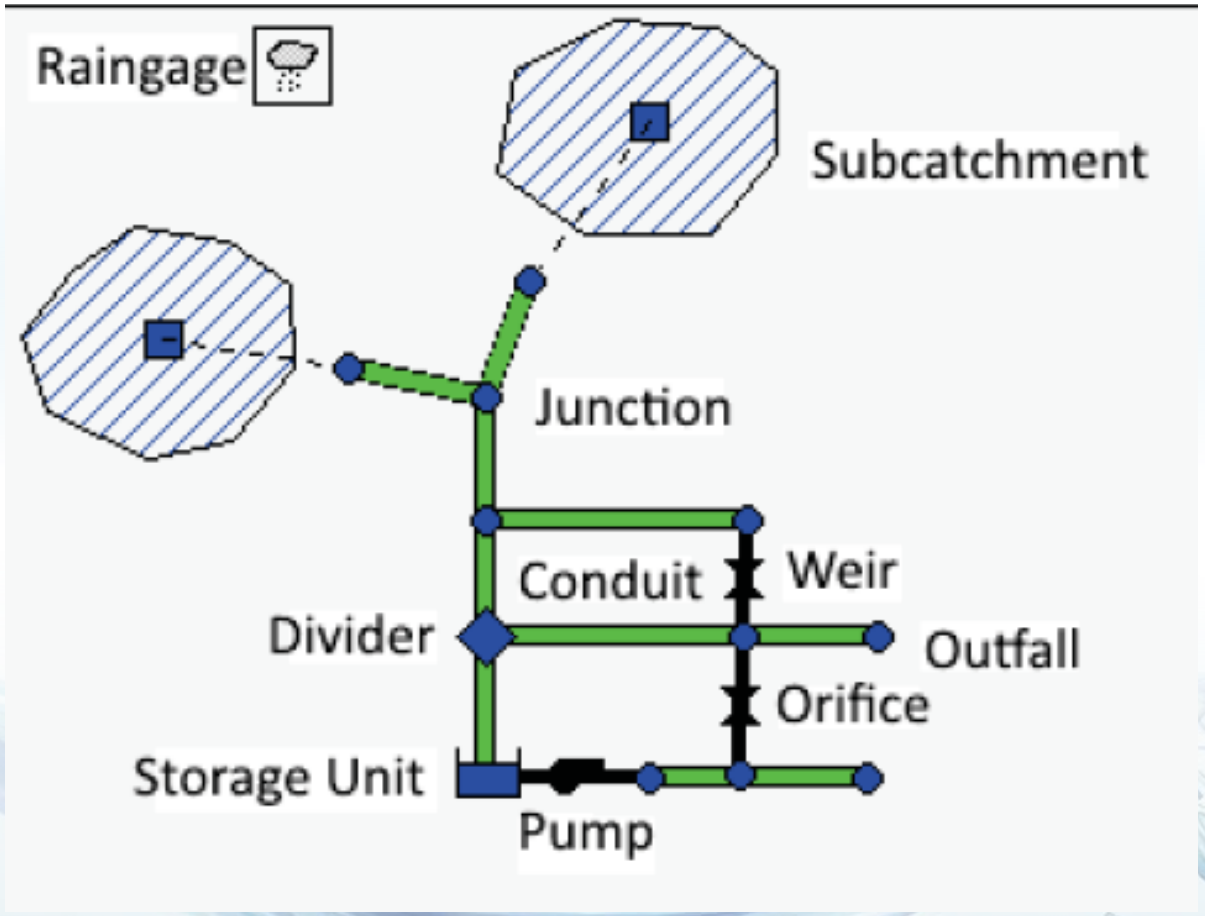
Generating non-point source pollutant loadings for waste load allocation studies.

Evaluating green infrastructure.

SWMM's Process Models



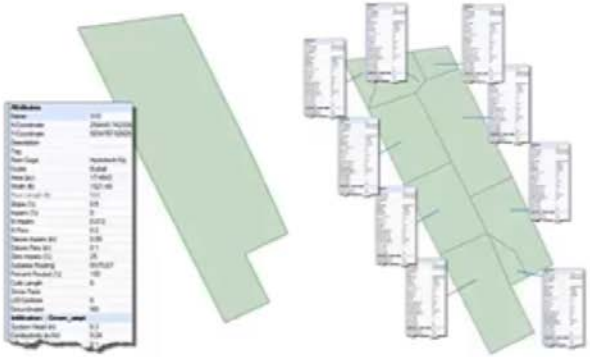
SWMM's Conceptual Model



Idealized Subcatchment (Courtesy of Rob James, CHI Water)

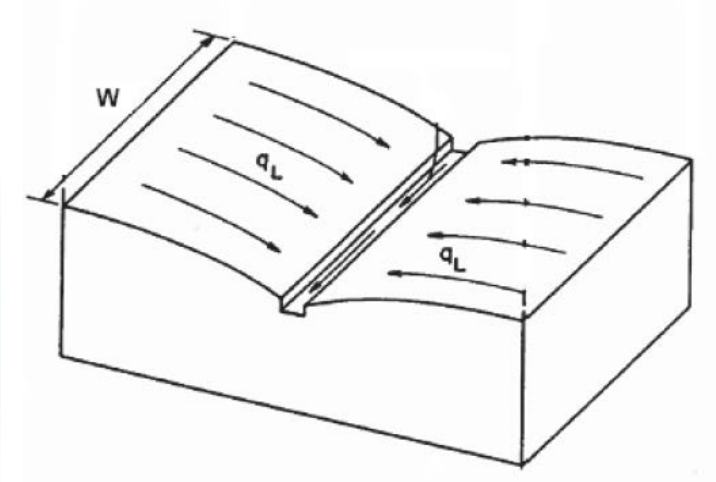
https://www.youtube.com/watch?v=HZnX_GsABUA

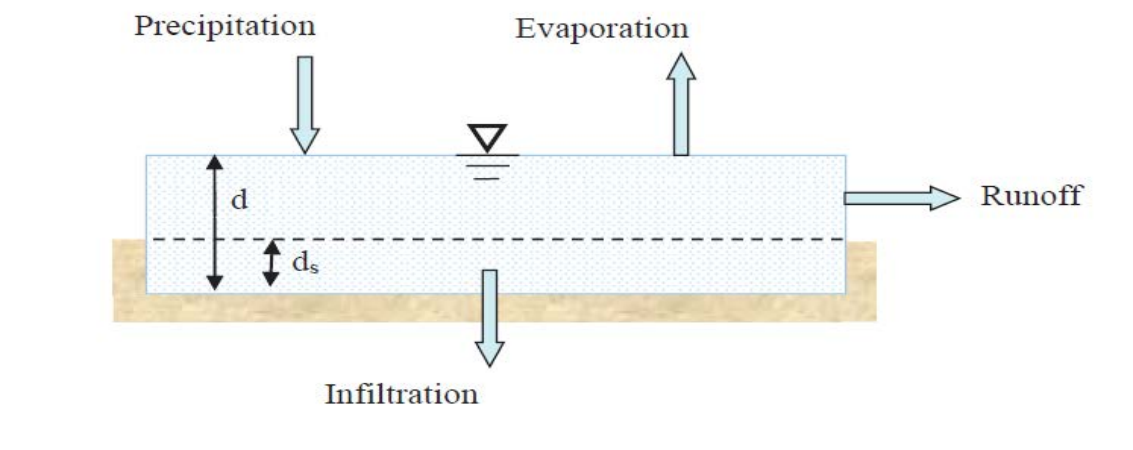
Subcatchment parameters



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

Idealized Subcatchment





Hydrology – Governing equations

First Principle Conservation of Mass

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

where:

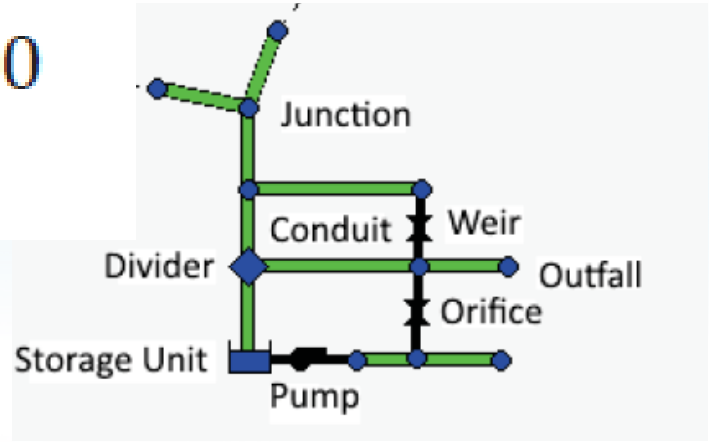
i = rate of rainfall + snowmelt (m/s)
e = surface evaporation rate (m/s)
f = infiltration rate (m/s)
q = runoff rate (fm/s).

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

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

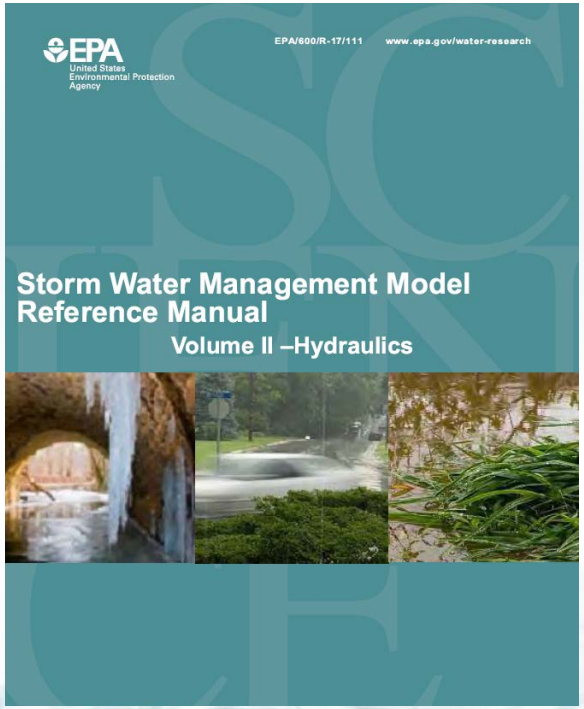
where

Q = flow rate (m^3/sec)
A = flow cross sectional area (m^2)
Z = conduit invert elevation (m)
Y = conduit water depth (m)
S_f = friction slope (head loss per unit length m/m)
g = acceleration of gravity (m/sec^2)

Assumptions

- Assumes varied, unsteady flow (Saint Venant Equations)

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



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/

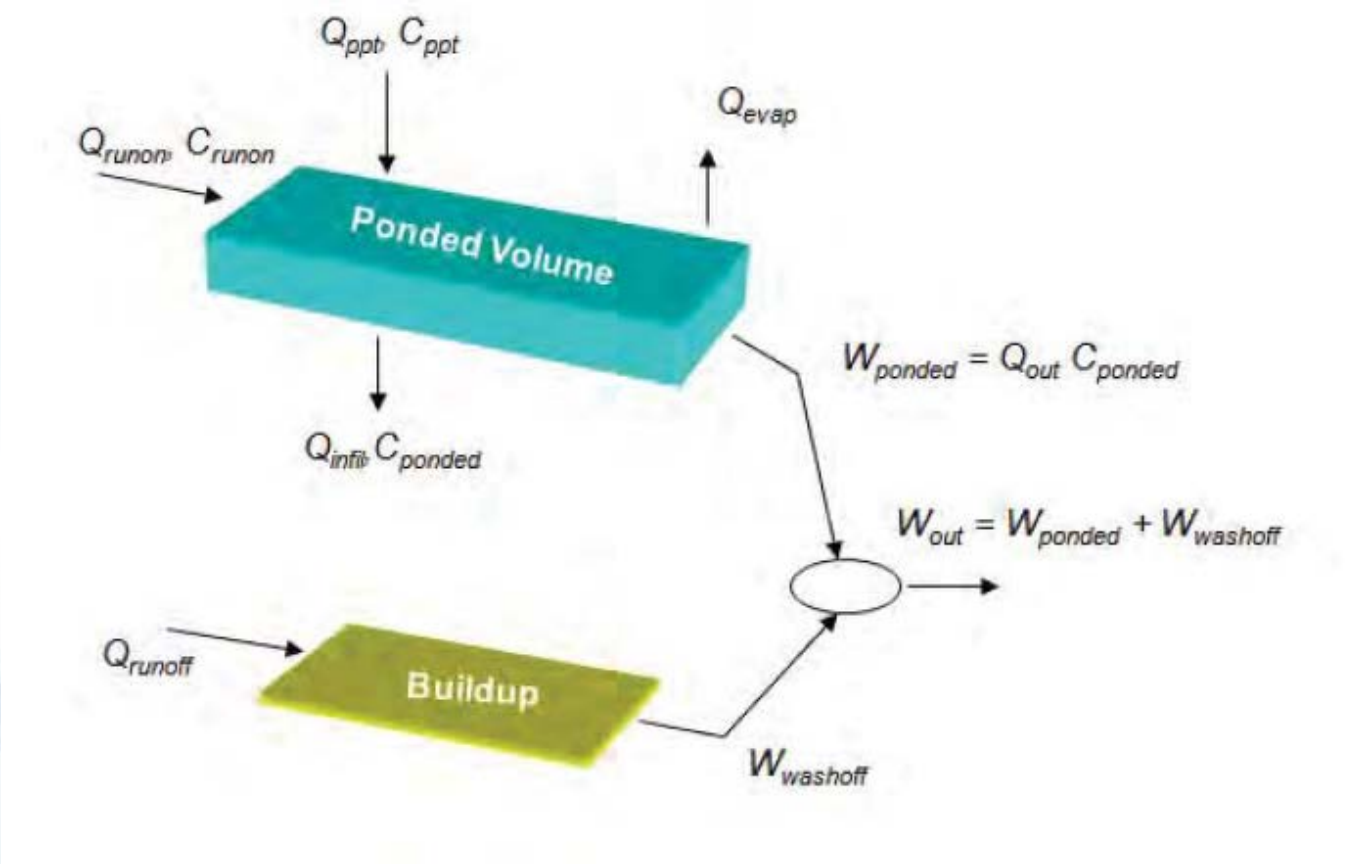
Kinematic Wave

Cannot have

- Looped networks
- Backwater effects
- Pressure-flow conditions

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

Pollutant Buildup and Wash off



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

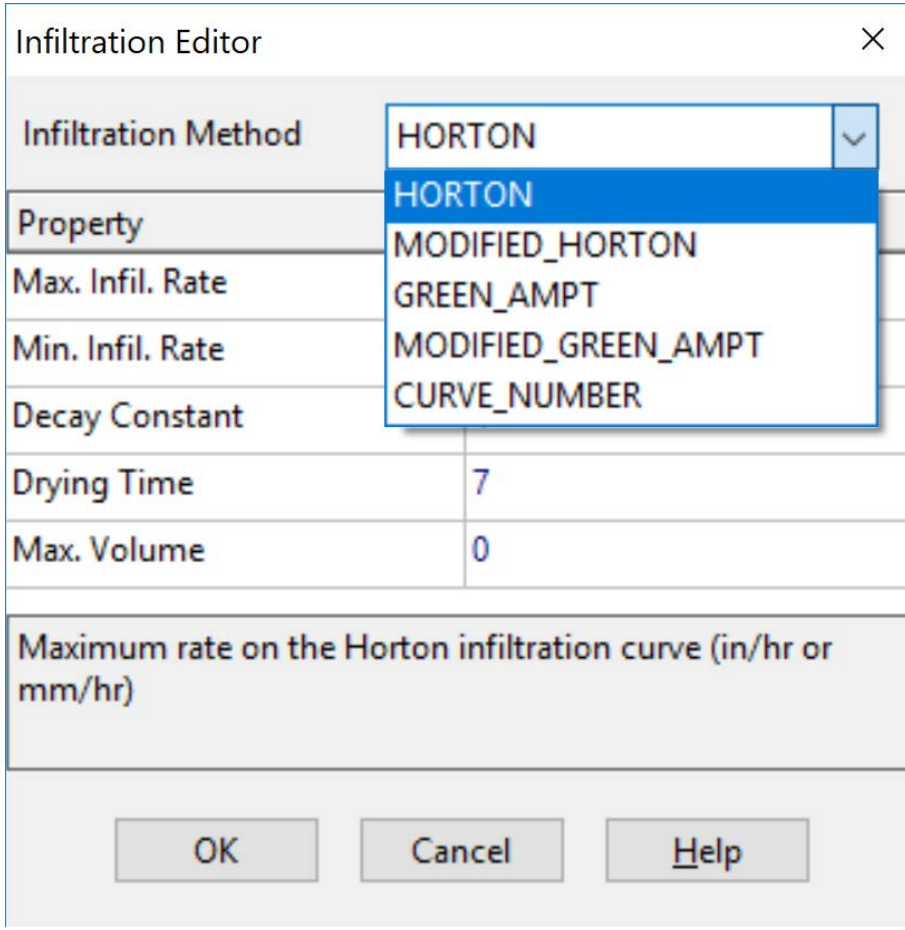
$$f_p = f_\infty + (f_0 - f_\infty)e^{-k_d t}$$

- Green_Ampt, Modified Green_Ampt

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

- Curve_Number

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



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Questions?

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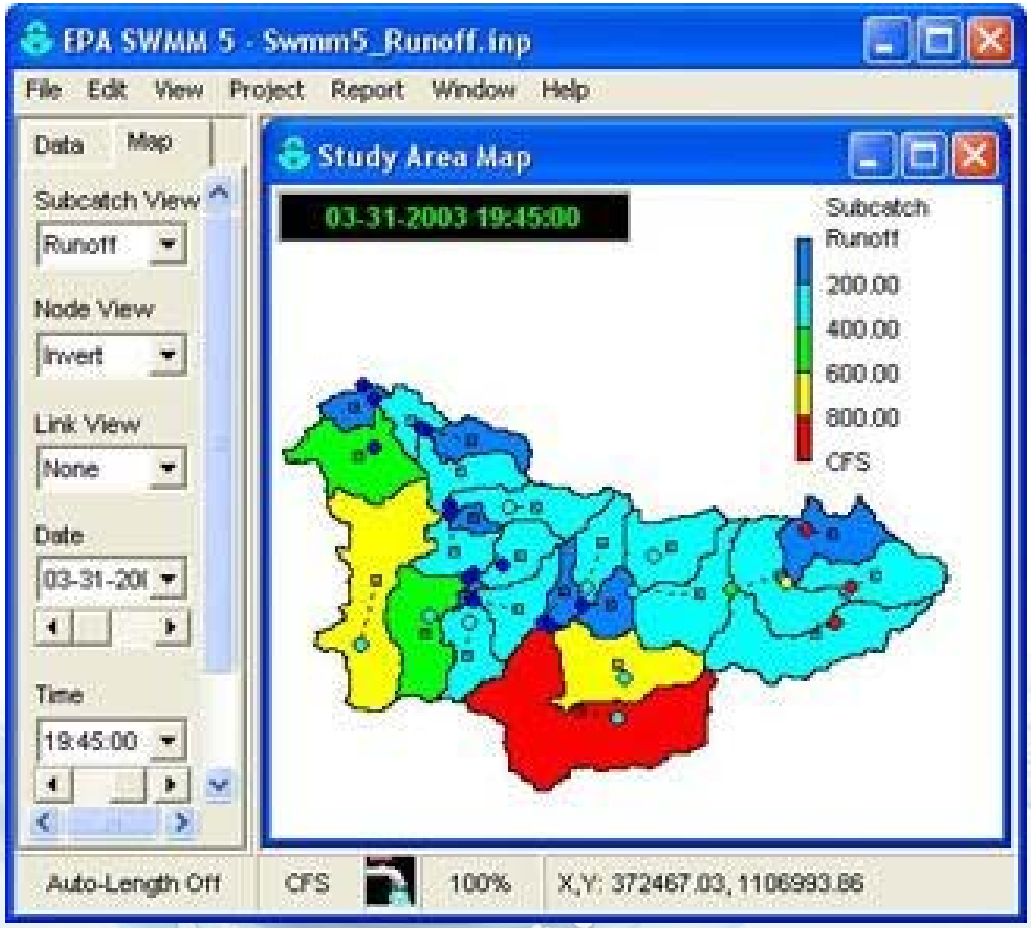
Storm Water Management Model

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

Downloads

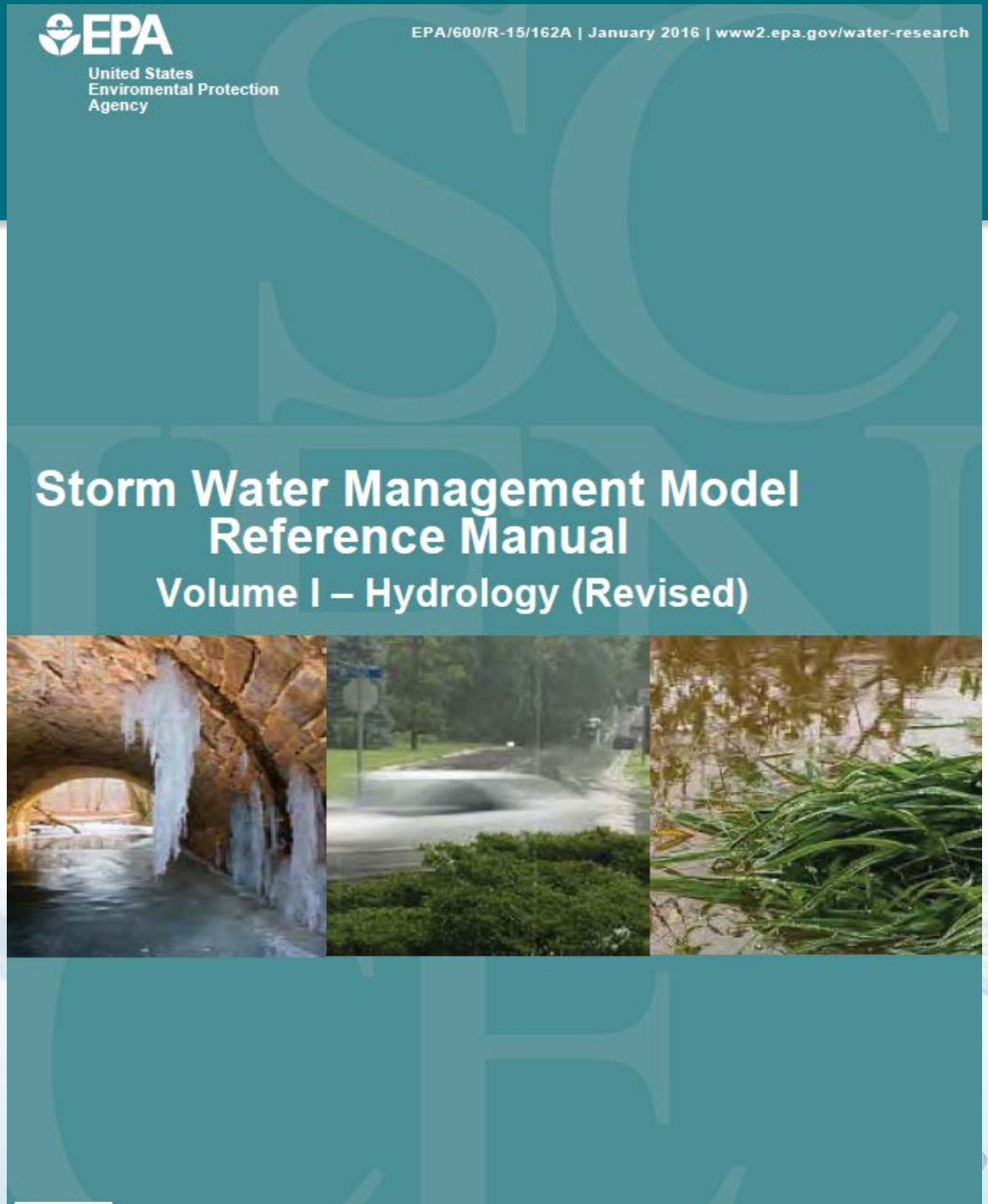
Date	Description
03/30/2017	Self-Extracting Installation Program for SWMM 5.1.012 (EXE) (5 MB)
12/11/2014	SWMM-CAT Download Version 1 (4 MB)
03/30/2017	List of SWMM 5 Updates and Bug Fixes (TXT) (1 pg, 132 K)
03/30/2017	Source Code for the SWMM 5.1.012 Computational Engine (ZIP) (375 K)
03/30/2017	Source code for the SWMM 5.1.012 graphical user interface (ZIP) (2 MB)
09/07/2016	SWMM 5.1 Interface Guide (ZIP) (47 K)
05/25/2005	Utility for converting SWMM 4 data files to SWMM 5 files (EXE) Version 1.2 (2 MB)

SWMM Webpage, continued

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

Documentation

Date	Title
09/30/2015	SWMM 5.1 User's Manual
09/01/2014	SWMM-CAT User's Guide
01/29/2016	SWMM Reference Manual Volume I—Hydrology
08/07/2017	SWMM Reference Manual Volume II—Hydraulics
09/08/2016	SWMM Reference Manual Volume III—Water Quality
01/31/2017	SWMM Technical Fact Sheet
07/06/2010	SWMM Applications Manual (ZIP) (7 MB)
09/19/2006	Quality Assurance Report for Dynamic Wave Flow Routing (ZIP) (3 MB)


EPA
United States
Enviromental 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

EPA/600/R-17/111 www.epa.gov/water-research

Storm Water Management Model Reference Manual

Volume II –Hydraulics

United States
Enviromental Protection
Agency

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

Storm Water Management Model Reference Manual

Volume III – Water Quality

SWMM Reference Manuals

Documentation

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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.

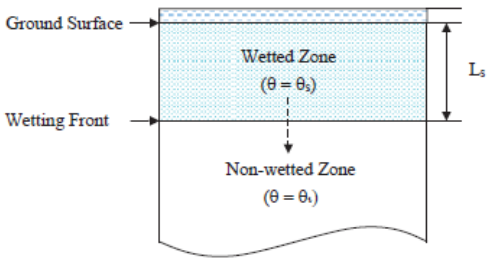

Figure 4-5 Two-zone representation of the Green-Ampt infiltration model (after Nicklow et al., 2006).

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:

$$f_p = K_s\left[\frac{d + L_s + \psi_s}{L_s}\right] \tag{4-26}$$

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:

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

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:

$$f_p = i \tag{4-28}$$

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:

$$F_s = \frac{K_s \psi_s \theta_d}{i - K_s} \tag{4-29}$$

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:

$$f = f_p \tag{4-30}$$

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.

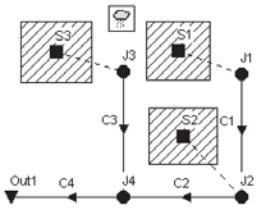

Figure 2-1 Example study area

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.

Documentation

Date	Title
09/30/2015	SWMM 5.1 User's Manual
09/01/2014	SWMM-CAT User's Guide
01/29/2016	SWMM Reference Manual Volume I—Hydrology
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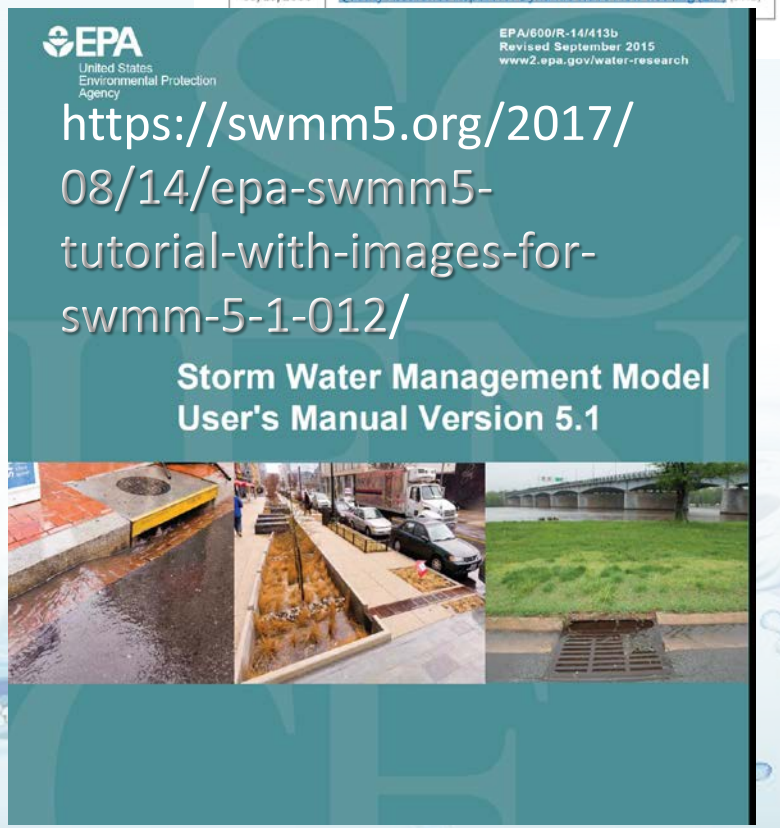

Demonstration of SWMM Tutorial

Demonstration of SWMM

- Walk through
  - Hydrology
  - Hydraulics
  - Water Quality
  - Low Impact Development
- Calibration of SWMM

SWMM Demonstration

- Go to Desktop SWMM

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Next Day

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The people responsible

ECI Conference: Fifty Years of Watershed Modeling; Past, Present and Future

September 24-26, 2012, Boulder, CO
Conference Program with Links to Presentations

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

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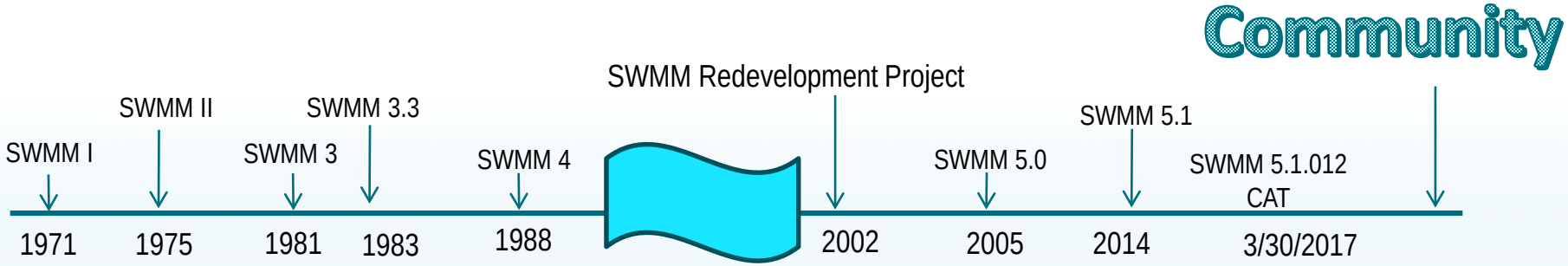
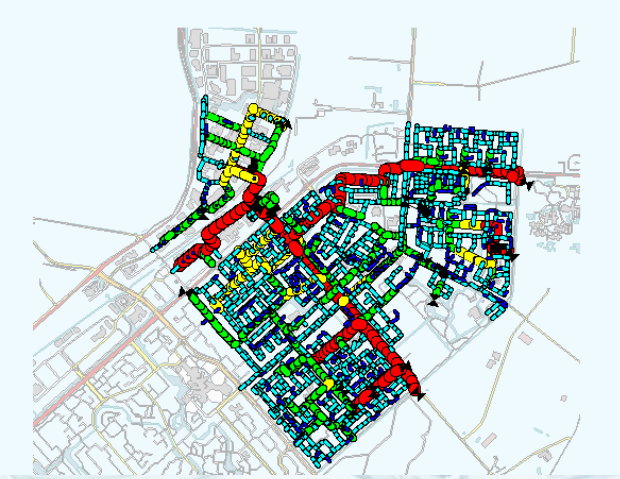
History of EPA and SWMM





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.

Agile Development and Open Source Community Process

Major Change to EPA Modeling

Agile Methodology In-Depth Review

June 28, 2016 8:30 a.m.

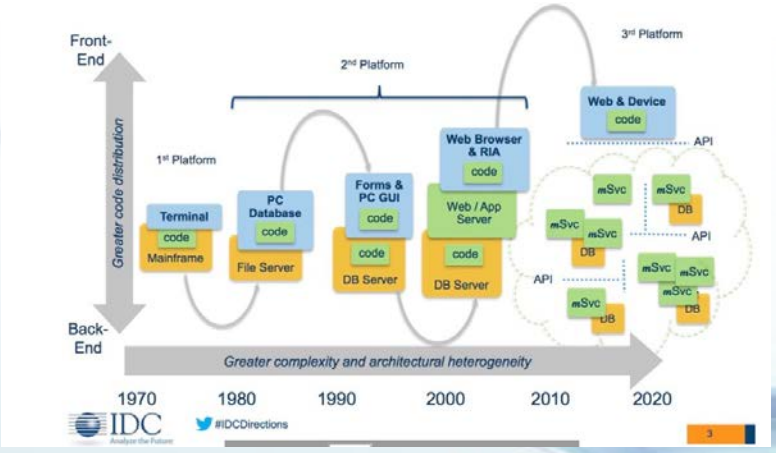
Text Only Version

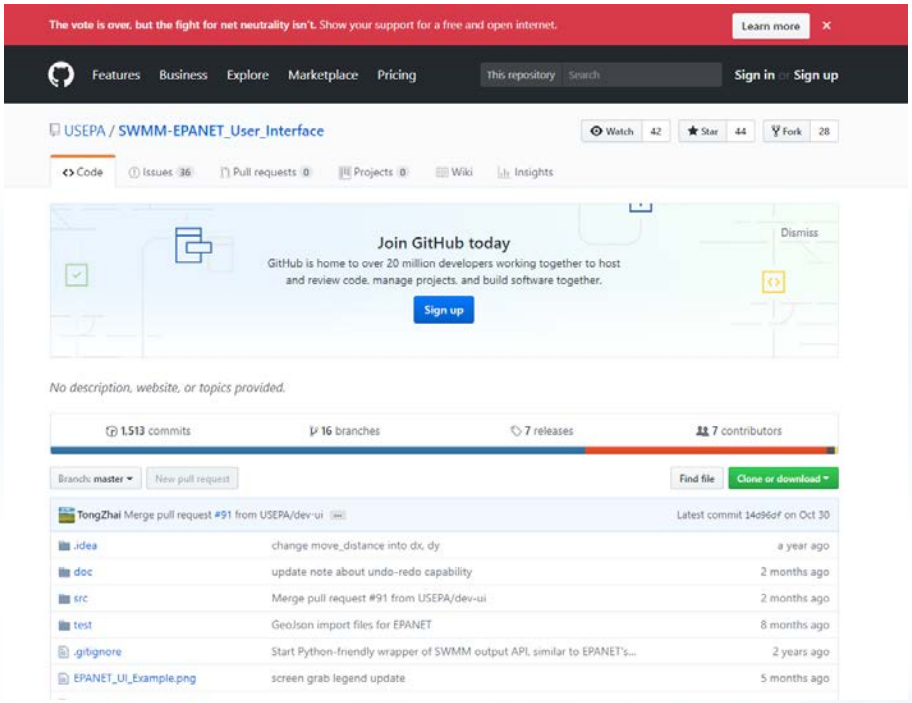
Figure 1. Agile Methodology In-Depth Review

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

@cote

June 2016



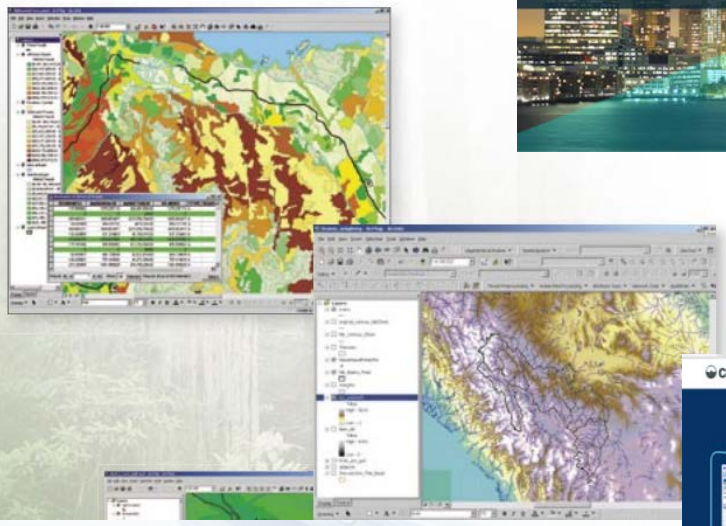


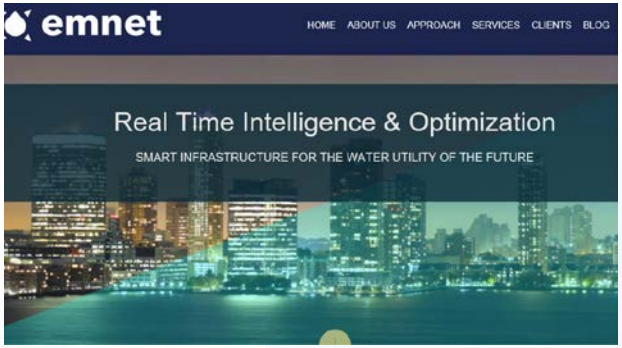
API, Thread Safe
PYSWMM
SWMM2PEST

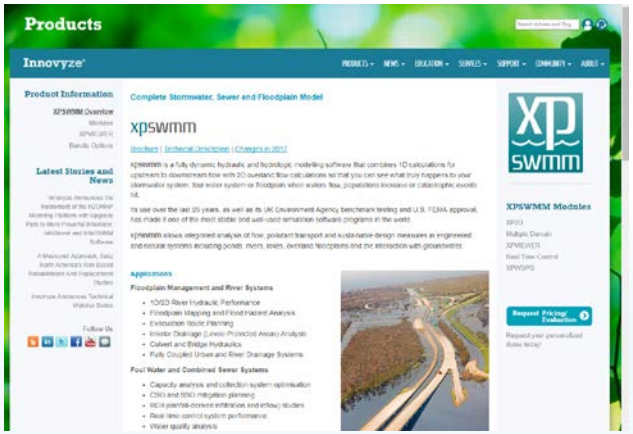
Stakeholders - >30,000 2018 downloads

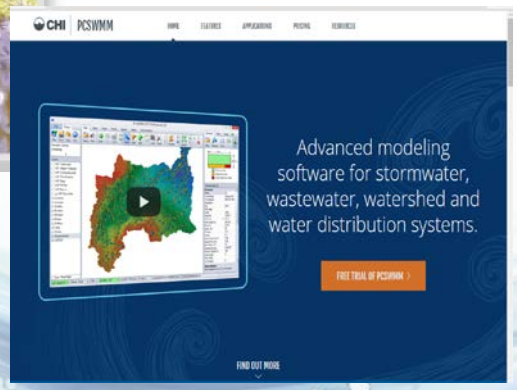
ESRI® GIS Partner Solutions and Services for

Environmental and Natural Resources



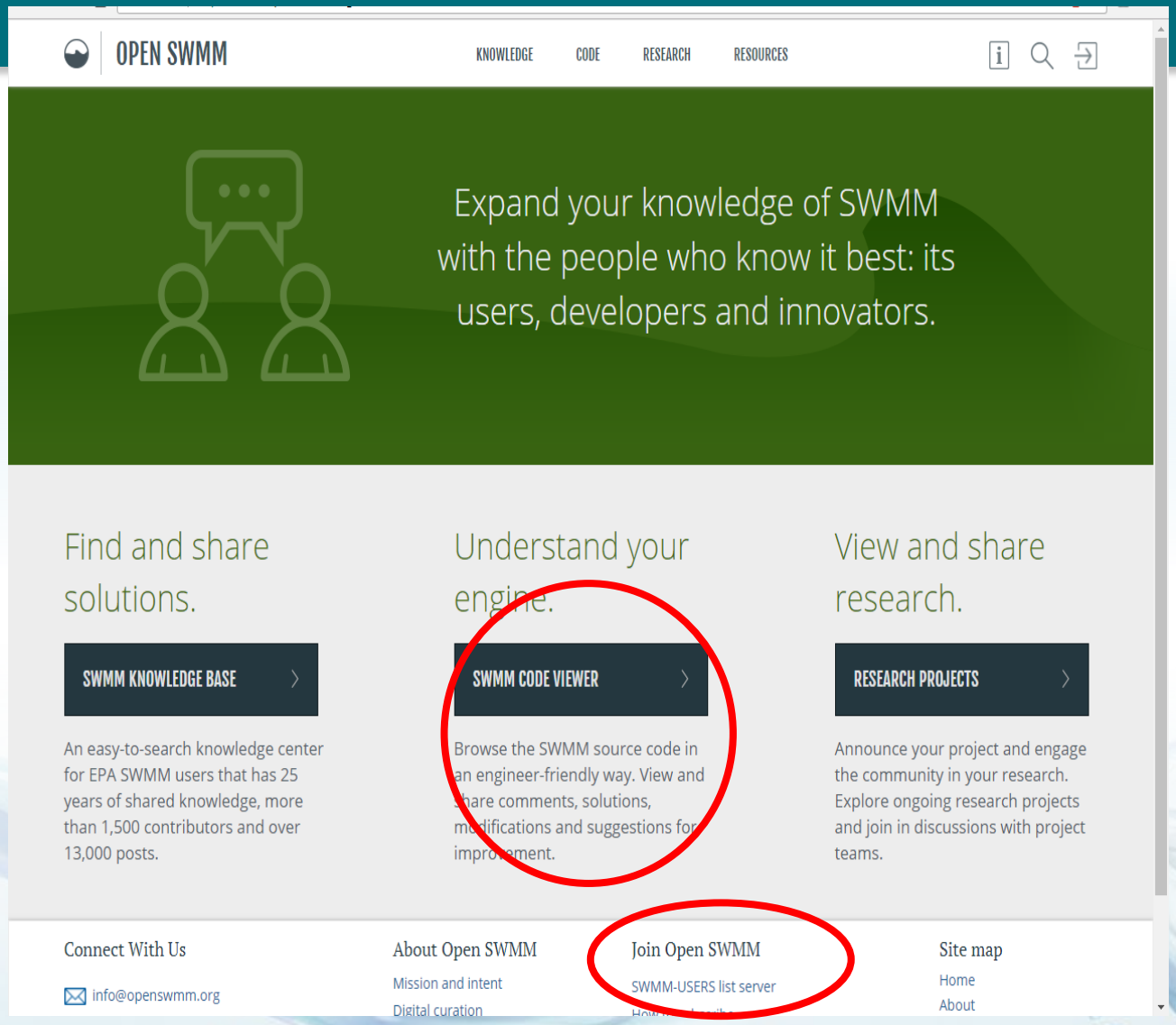






Regulators
Communities,
Utilities,
Private industry,
Consultants,
Academia

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



Technical Support - OPEN SWMM

OPEN SWMM

KNOWLEDGE CODE RESEARCH RESOURCES

/www.openswmm.org/Forum/About#swmm-userslistserver

13531	4778	1505	25
POSTS	THREADS	CONTRIBUTORS	YEARS

About OPEN SWMM

Collapse all

Mission and Intent

The SWMM Knowledge Base is intended to function as an online learning resource for users of the public domain EPA SWMM program. It consists of digitally curated content from the SWMM-USERS list server, organized in an easily readable format. Fully searchable, the SWMM Knowledge Base provides a high signal-to-noise ratio, and promotes content discoverability through related topic suggestions.

Together with the open access Journal of Water Management Modeling, the annual International Conference on Water Management Modeling, and the SWMM-USERS list server, the SWMM Knowledge Base rounds out a group of high quality resources that supports, promotes and encourages development of SWMM by the EPA and the user community.

The SWMM Knowledge Base continuously solicits feedback from the community in making the presentation and content as accessible and useful as possible. Please send any comments and questions to staff at info@openswmm.org. The SWMM Knowledge Base is hosted and moderated by the staff of CHI.

SWMM-USERS list server

The SWMM-USERS list server is an email-based forum for users of the public-domain US EPA SWMM program to share ideas and ask questions on issues related

- Mission and Intent
- SWMM-USERS list server
- Conditions for subscribing
- Guidelines for posting
- Digital curation
- Disclaimer
- Terms of use

Find and share solutions.

SWMM KNOWLE ECTS

An easy-to-search for EPA SWMM us years of shared kn 1,500 contributors posts.

ect and engage our research. search projects ons with project

Connect With Us

info@openswmm.org

147 Wyndham St. N., Ste. 202

About Open SWMM

- Mission and intent
- Digital curation
- Disclaimer

Join Open SWMM

- SWMM-USERS list server
- How to subscribe
- Conditions for subscribing

Site map

- Home
- About
- Knowledge Base

EPA – Curator of SWMM Code

- Contribute to improve scientific aspects of SWMM
- Cooperative Agreement with CIMM
- 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

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

Questions?

Presentation Outline

1. SWMM Fundamentals
2. Getting Started with SWMM
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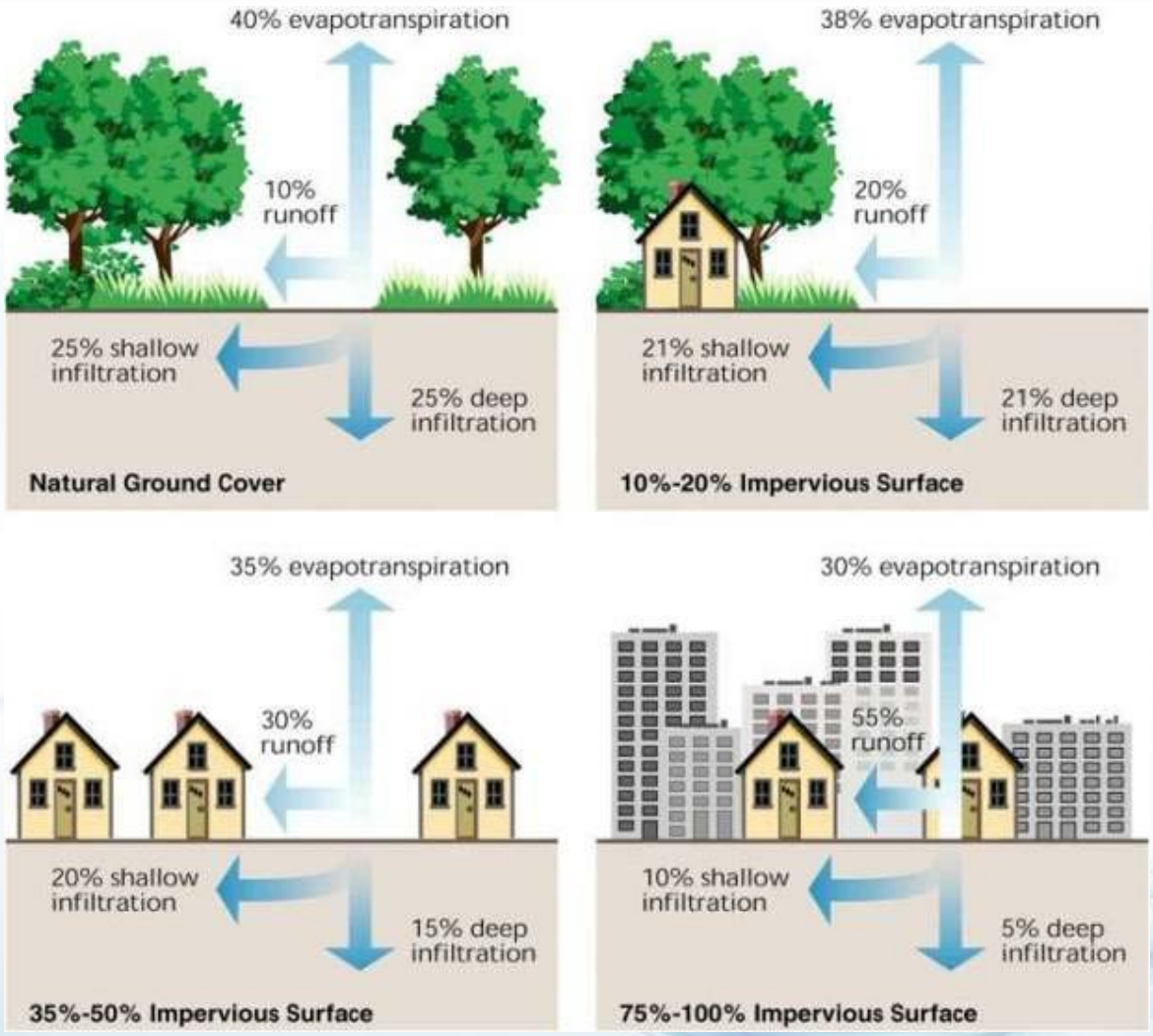
Urbanization Changes the Hydrologic Cycle



- 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!"

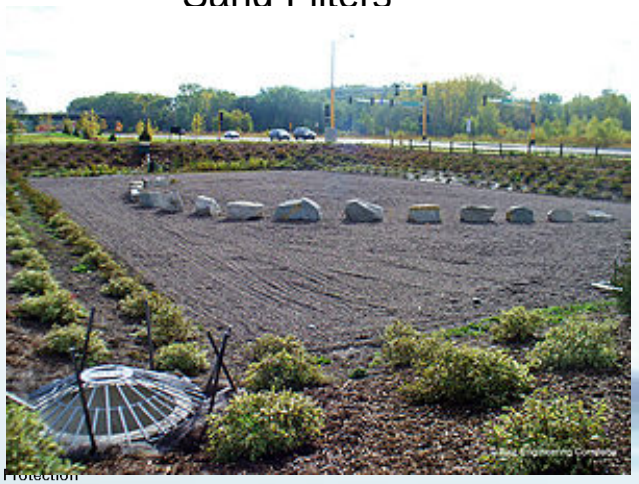
LID Modeling in SWMM

End-of-Pipe Stormwater BMPs

Ponds

Wetlands

Sand Filters



High Rate Treatment

Types of LIDs Modeled

Disconnection

Infiltration Basin

Rain Garden

Cistern

Infiltration Trench

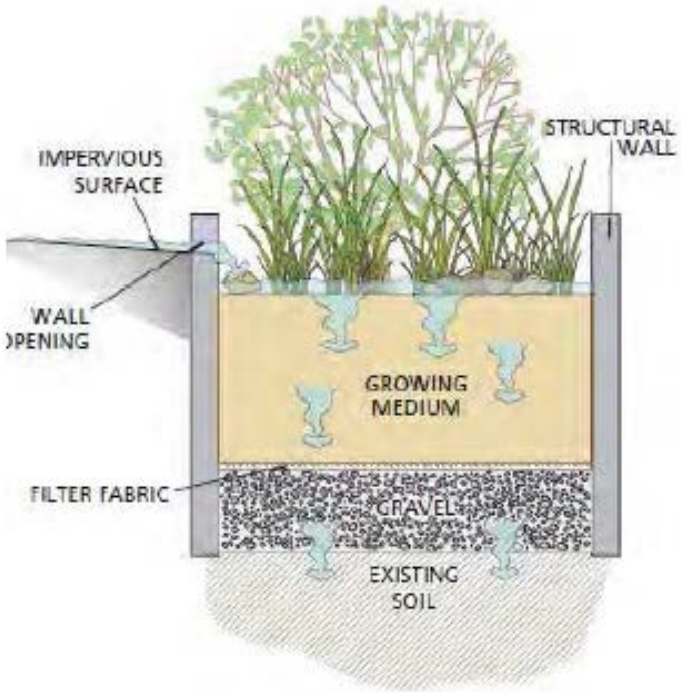
Green Roof

Porous Pavement

Vegetative Swale

Street Planter

Green Infrastructure Subcatchment



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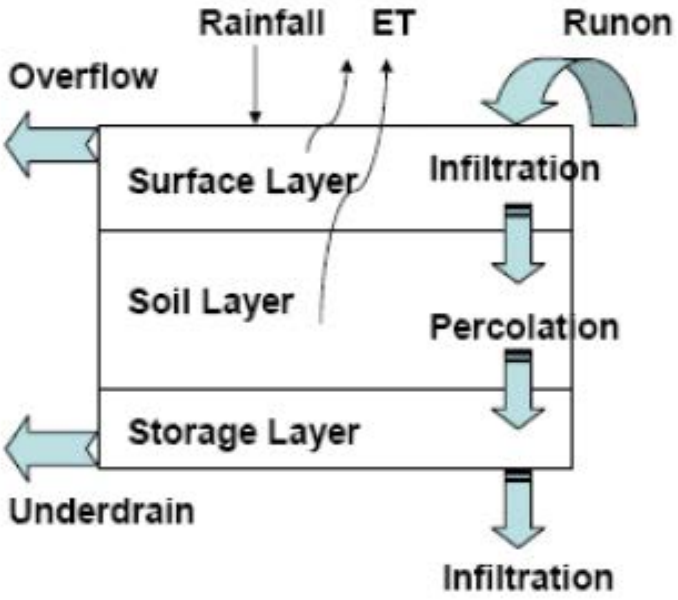
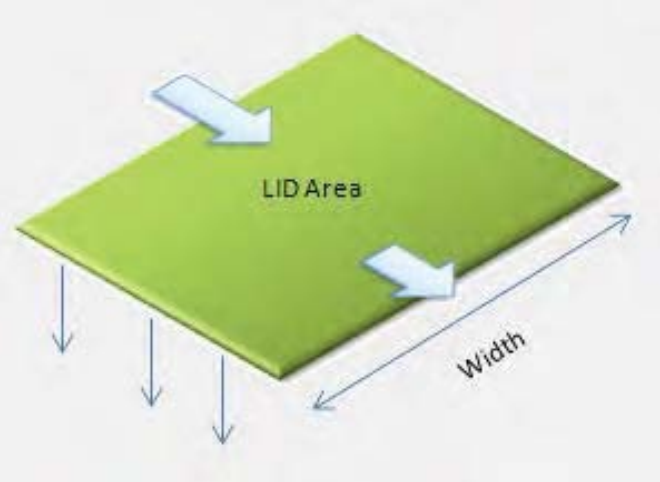
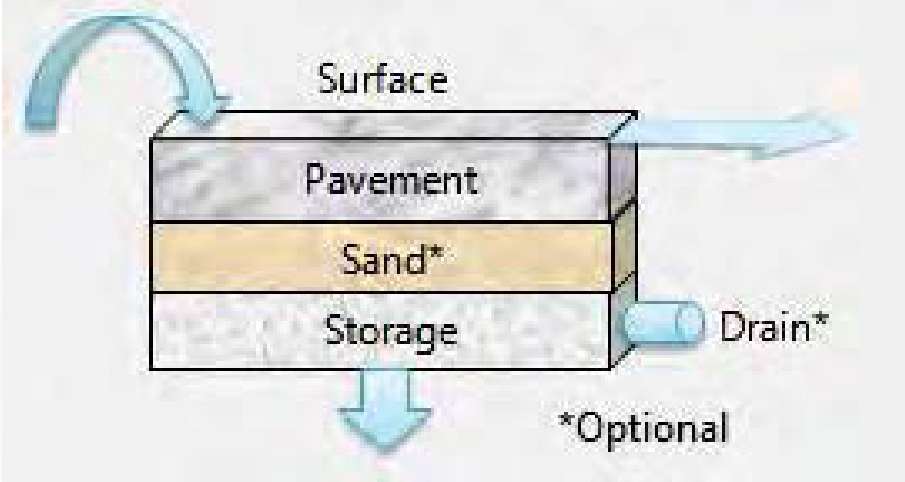


(B)

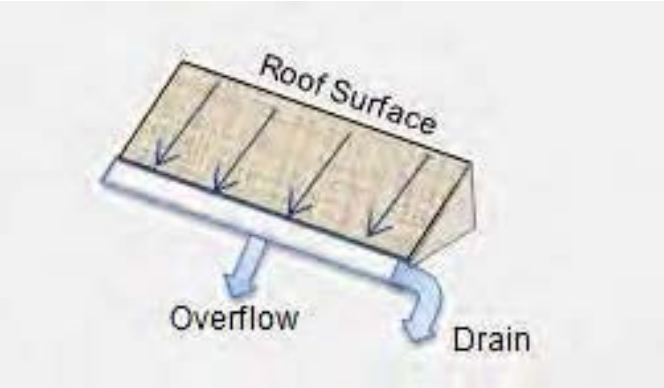
More Green Infrastructure Subcatchments



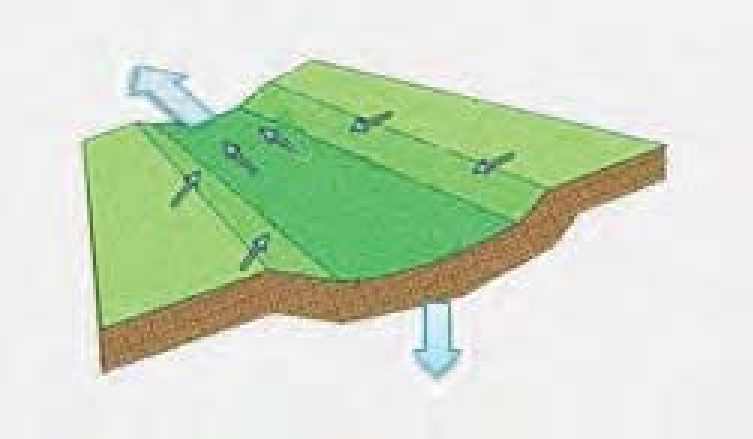
Green Roof



Permeable Pavement



Roof Disconnection



Vegetative Swale

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Building LID Module in SWMM

Questions?

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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

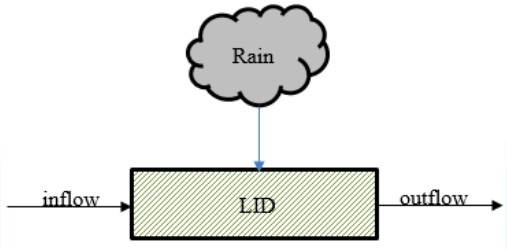
Fidelity — Behavior / Mechanism

What's the goal?

https://www.google.com/search?q=mathematical+abstraction+of+hydrology+images&tbm=isch&source=iu&ictx=1&fir=eDv9KY_znXaWlM%253A%252CYzICHXicd0xv_M%252C_&usg=AI4_-kS544Xrnn5UpDuff0UJU6D1Tpt-VA&sa=X&ved=2ahUKEwjT0vG6jb7eAhXN0VMKHWipC30Q9QEwAHoECAQQBA#imgdii=j7R4otA9j2apTM:&imgrc=B3LrwJmLR84z9M:

67

Types of LIDs Hydrology Tested



Platz, M.; M. Simon; and M. Tryby (2018). "Testing of the SWMM Model's LID Modules." Submitted to *Journal of Sustainable Water in the Built Environment*

Rain Garden/Bioretention

Infiltration Trench

Green Roof

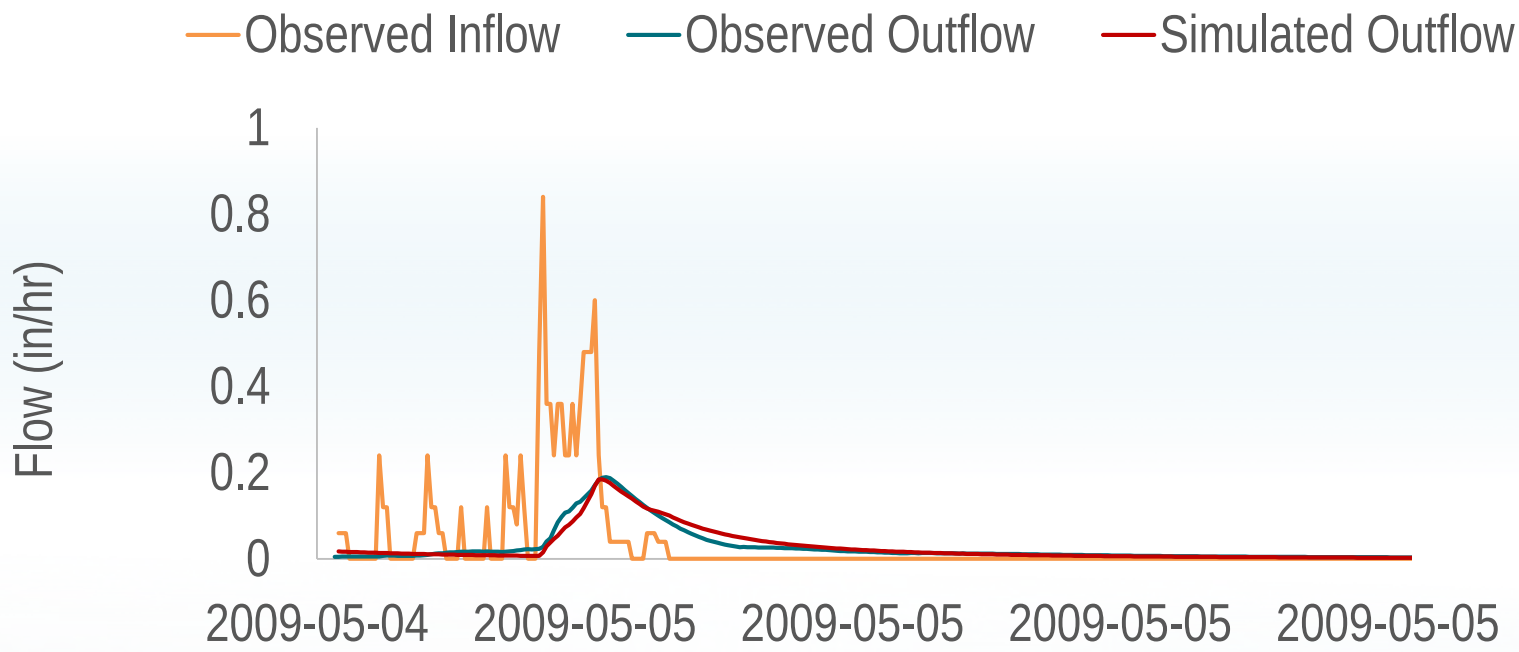
Porous Pavement

Vegetative Swale

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



Goodness of Fit

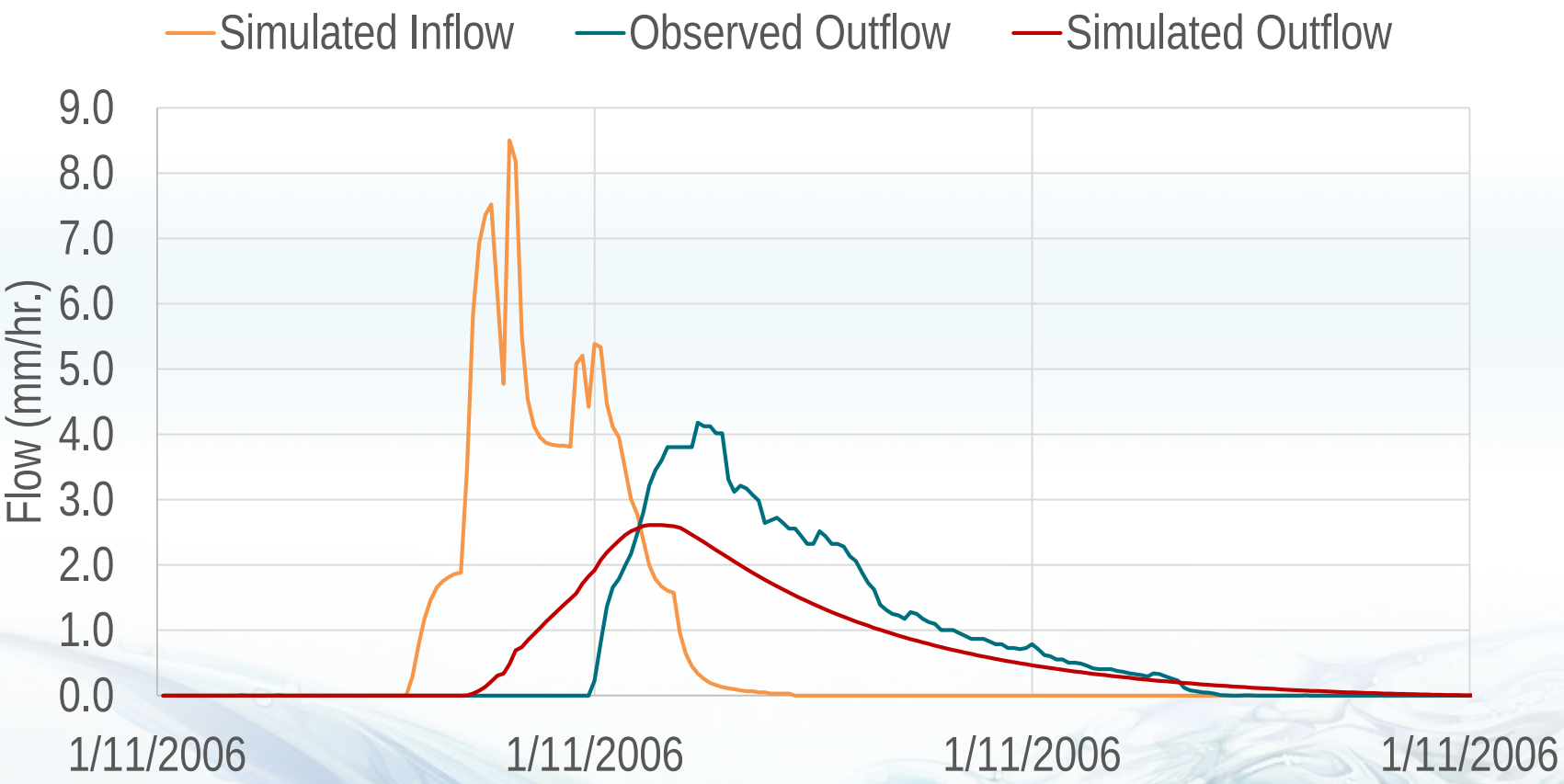
Coefficient of Determination

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

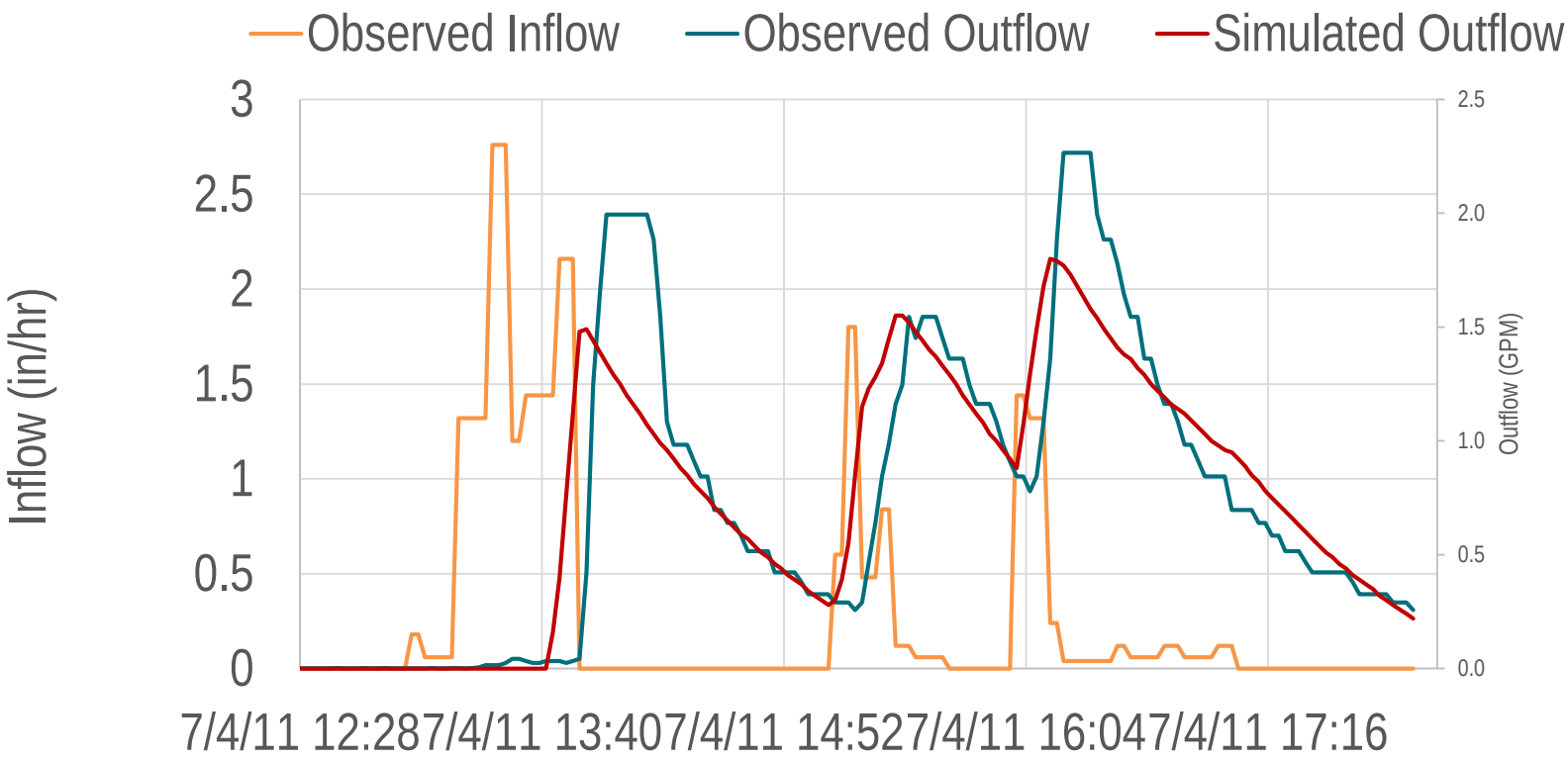
Nash-Sutcliffe Efficiency Statistic

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

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



Boone Porous Pavement hydrograph depicting early outflow start-time



Multi-event Calibration Method

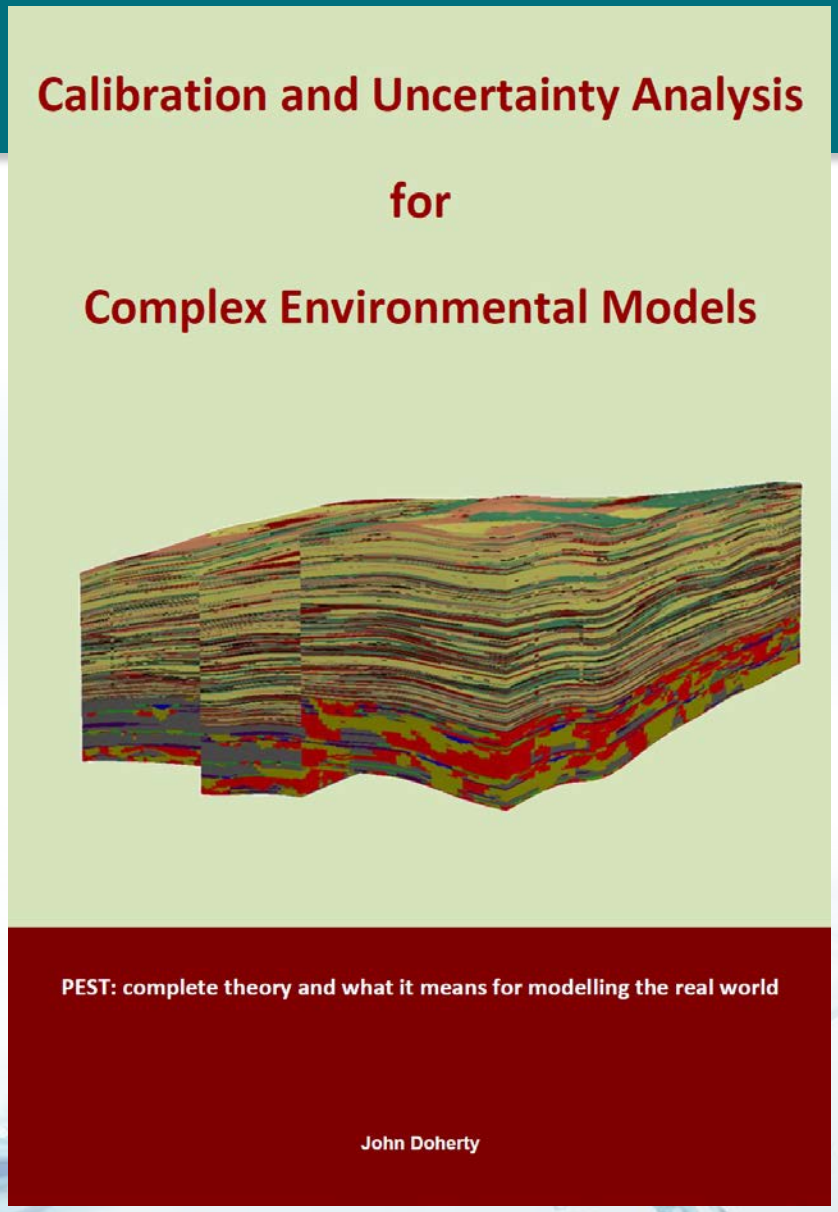
Storm 1	Storm 2	Storm 3	Storm 4	Average
Calibration NSE, R^2	NSE, R^2	NSE, R^2	NSE, R^2	Storm 1 Calibration AVG NSE, $\boldsymbol{R^2}$
NSE, R^2	Calibration NSE, R^2	NSE, R^2	NSE, R^2	Storm 2 Calibration AVG NSE, $\boldsymbol{R^2}$
NSE, R^2	NSE, R^2	Calibration NSE, R^2	NSE, R^2	Storm 3 Calibration AVG NSE, $\boldsymbol{R^2}$
NSE, R^2	NSE, R^2	NSE, R^2	Calibration NSE, R^2	Storm 4 Calibration AVG NSE, $\boldsymbol{R^2}$

PEST

PEST

Model-Independent Parameter Estimation & Uncertainty Analysis

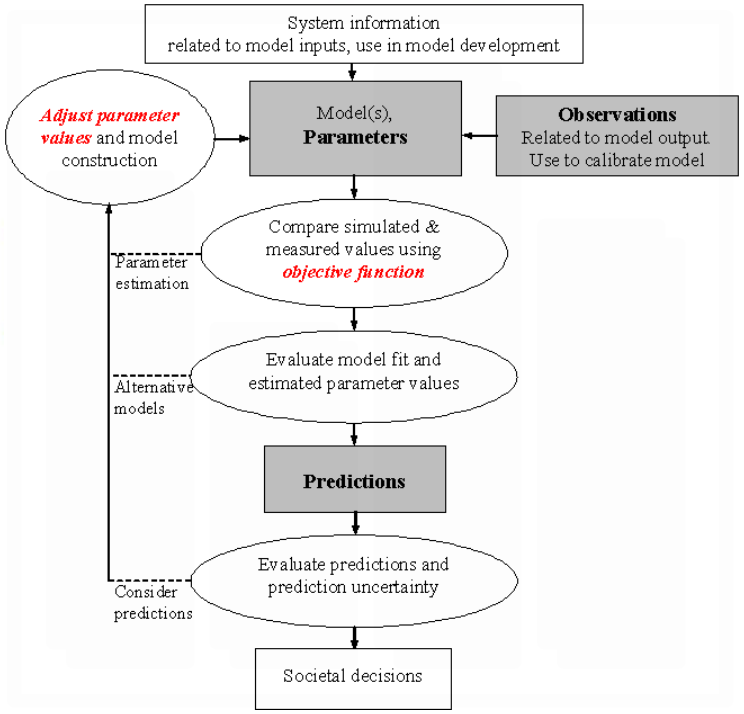
http://www.pesthomepage.org/



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.

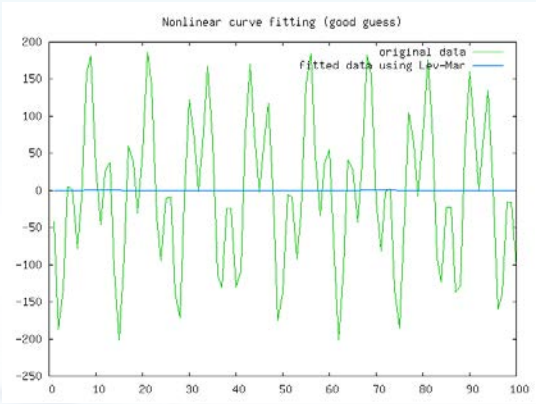
https://www.google.com/search?q=parameter+estimation+images&tbm=isch&tbo=u&source=univ&sa=X&ved=2ahUKEwik0dbkzbHeAhVyTt8KHW6TDR0QsAR6BAgFEAE&biw=1680&bih=941#imgrc=FbdsdbiAFfzVvM: J. Doherty 2007

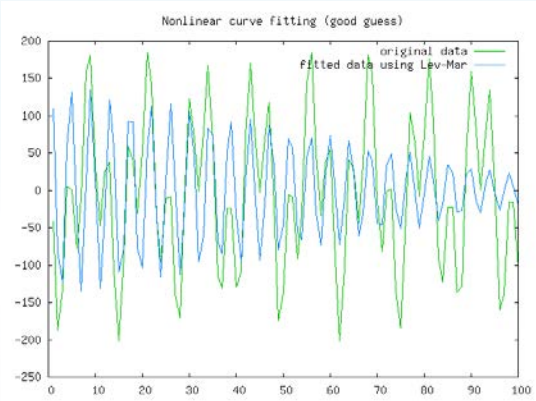
Parameter Estimation Algorithm

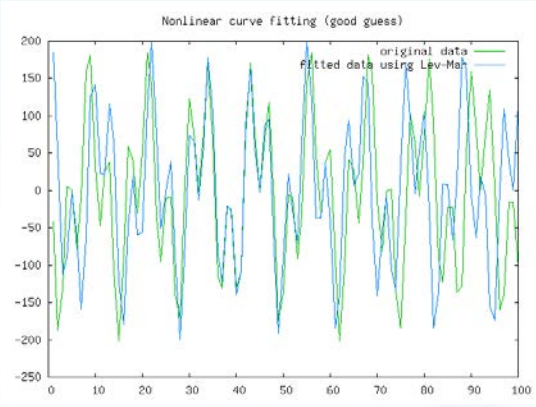
Levenberg–Marquardt algorithm (LMA or just LM), AKA damped least-squares (DLS)

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

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





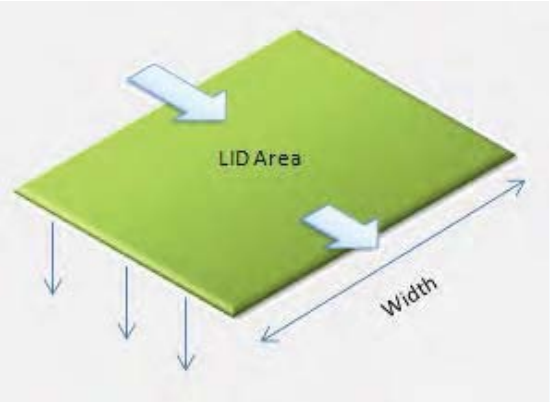


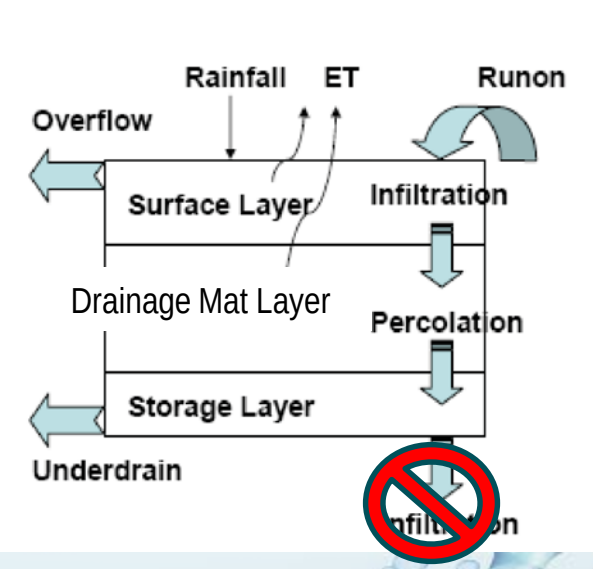
https://en.wikipedia.org/wiki/File:Lev-Mar-best-fit.png $y = a\cos(bX) + b\sin(aX)$

BY-SA 3.0, https://en.wikipedia.org/w/index.php?curid=7326407

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

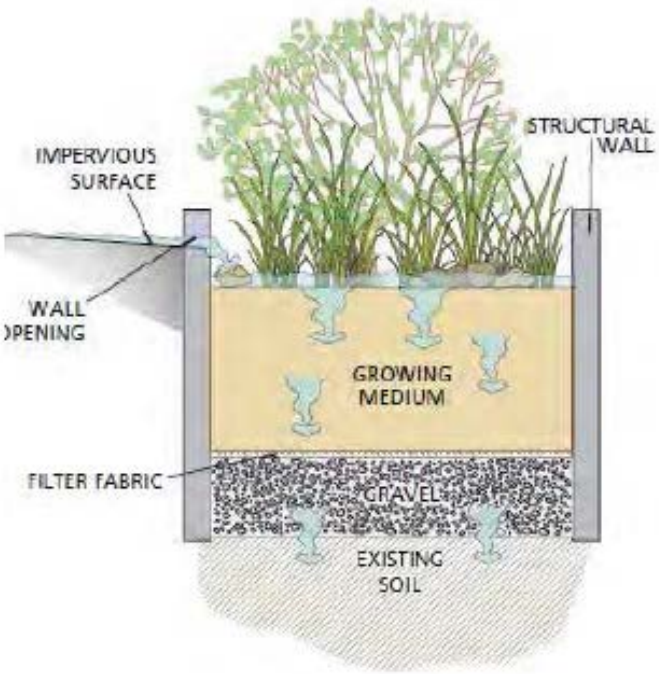
1 = most
7 = least

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

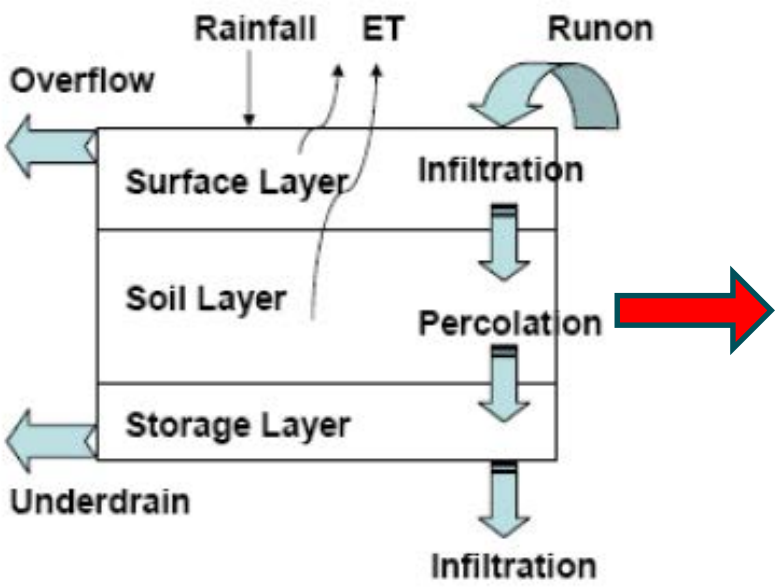
LID Module Performance Summary Table

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

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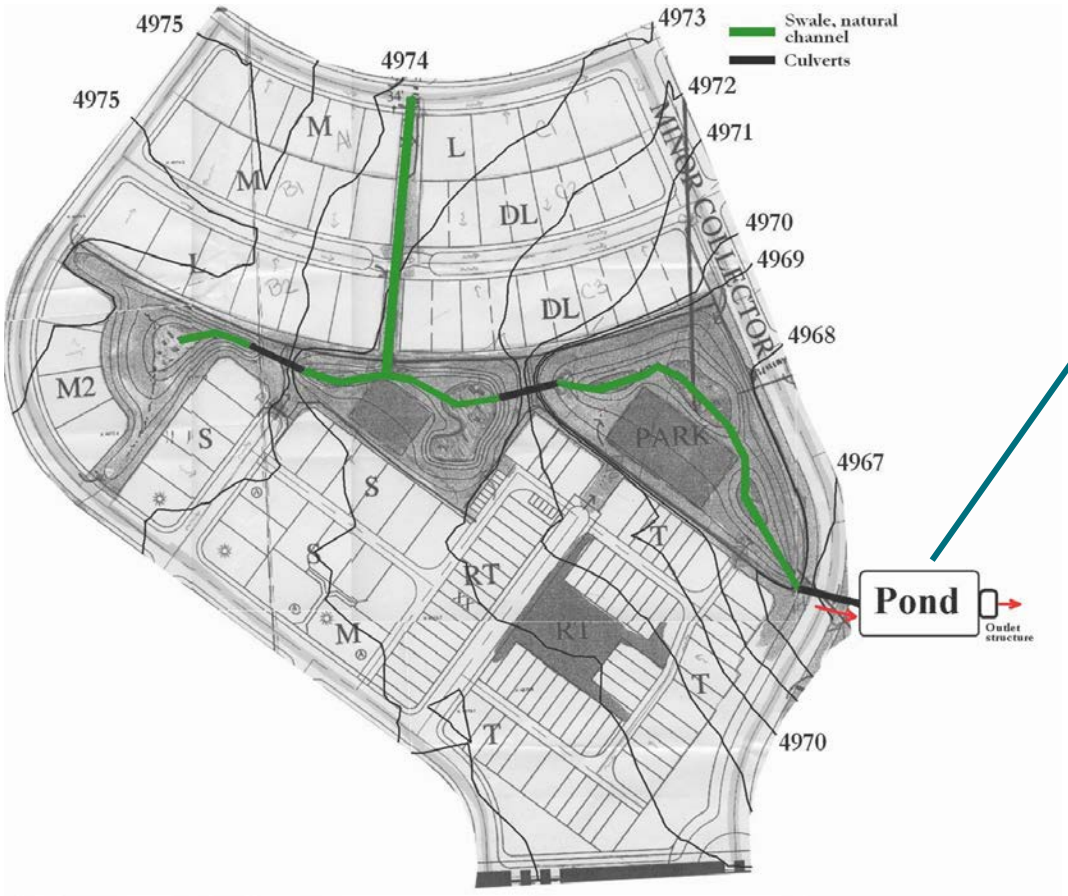
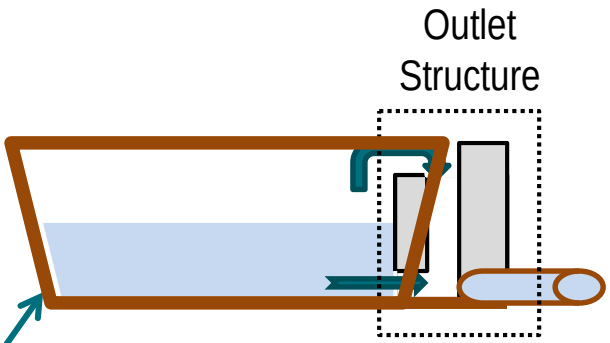
Detention Pond Design Example

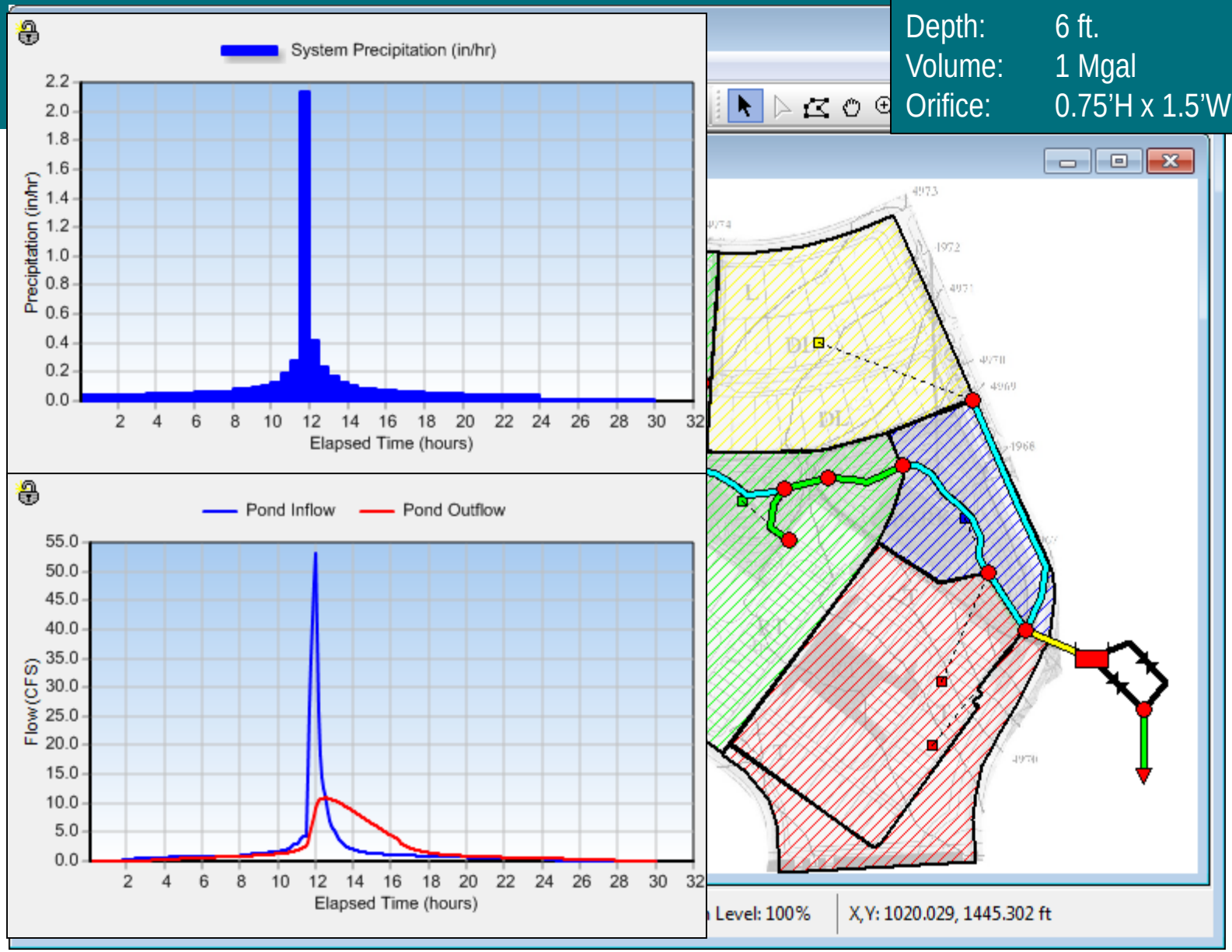




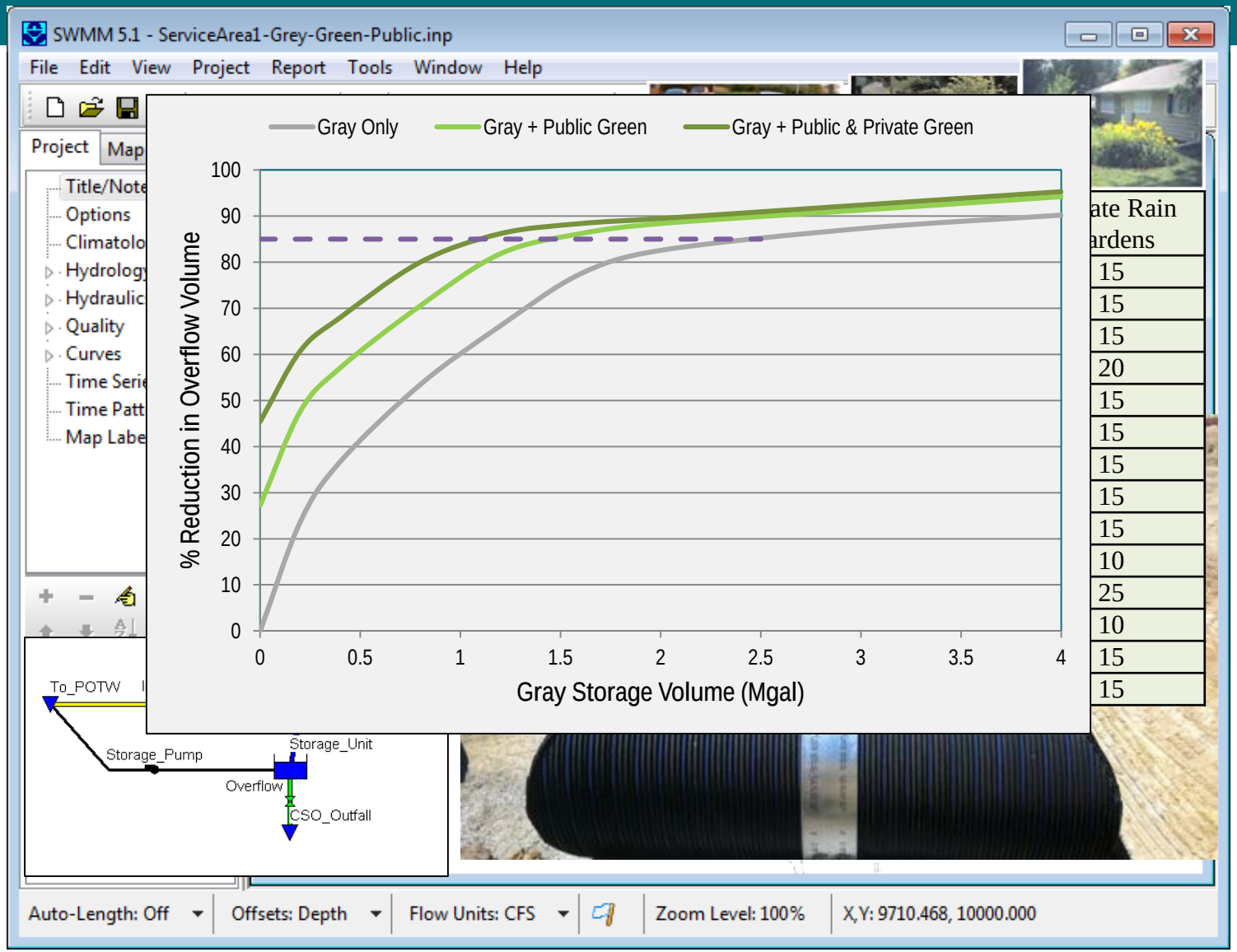
<u>Design Requirement</u>
Post development peak flow = pre-development peak flow (11 cfs) for the 10-yr, 24-hr design storm (2.8”)

Pond Design:

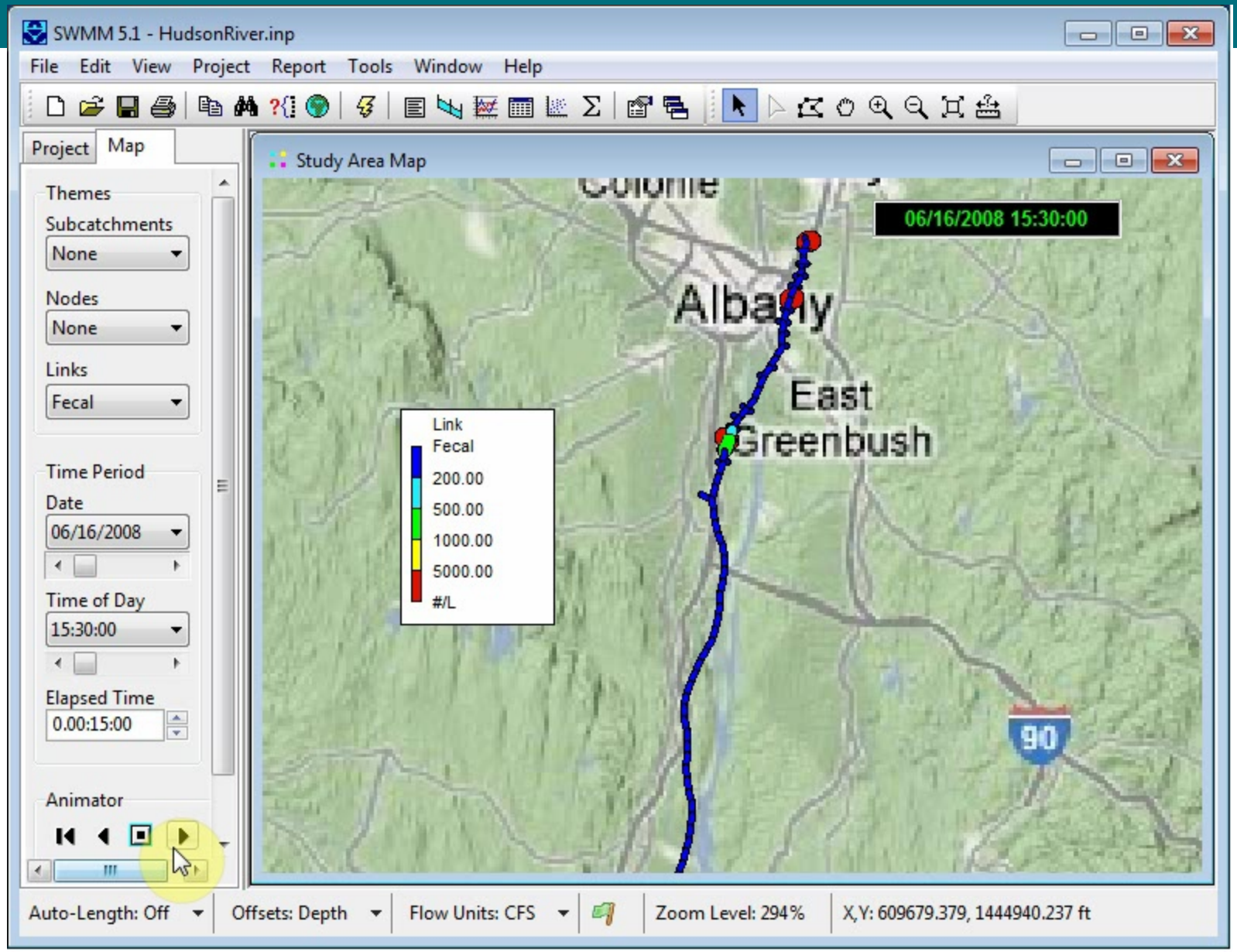
Area:	0.5 acres
Depth:	6 ft.
Volume:	1 Mgal
Orifice:	0.75'H x 1.5'W



CSO Example – Green + Gray Options



Microbial Fate & Transport Example



Hydraulic Animation
(Courtesy of Robert Dickinson, Innovyze)

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10. Interpreting More Complicated SWMM Results
11. SWMM Climate Adjust Tool
12. Where to get Data
13. Demonstration of EPA Stormwater Calculator
14. Conclusions

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.

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).

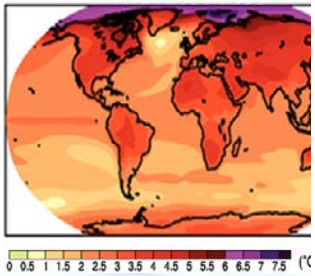
SWMM-CAT

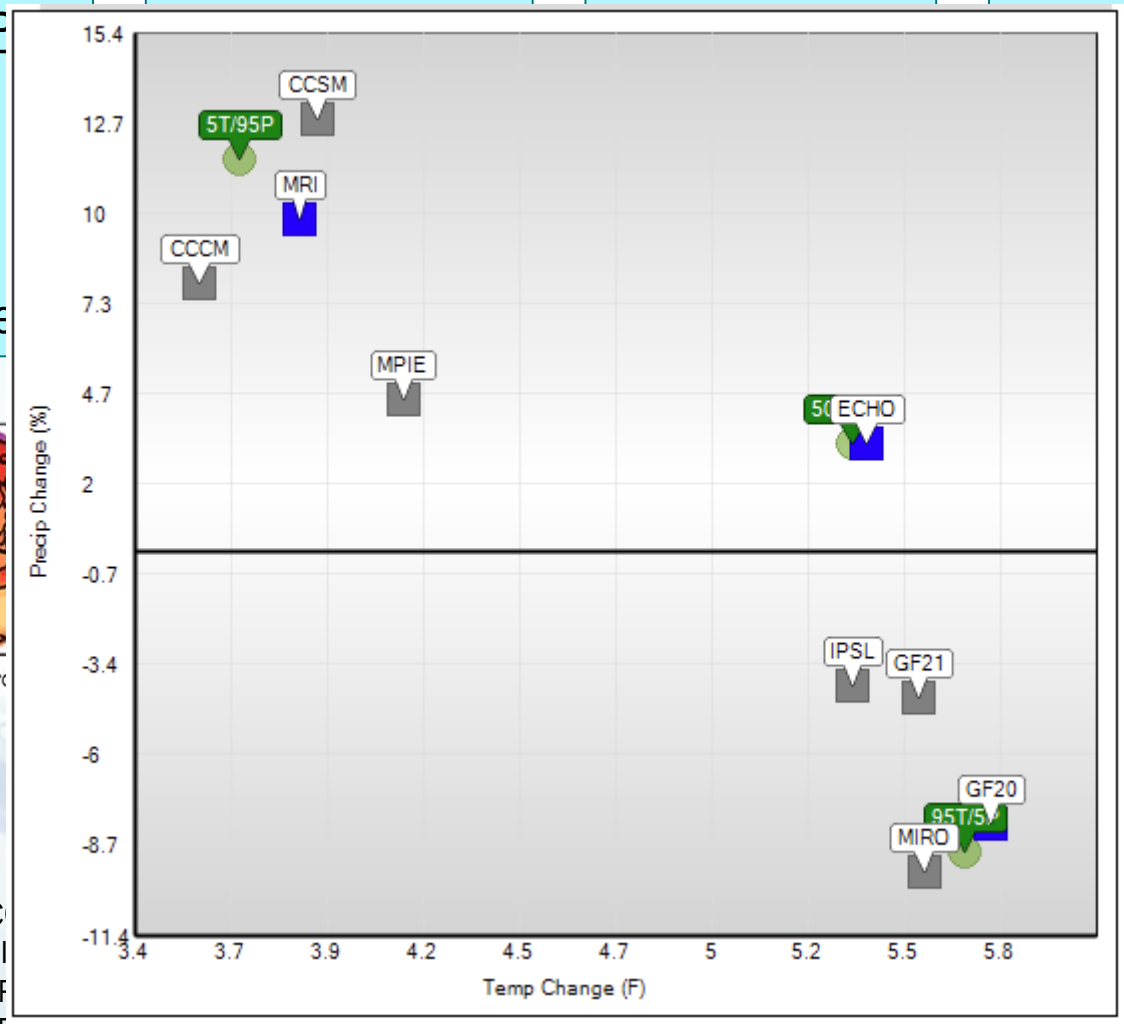
- Provides an add-in tool to SWMM to identify seasonal changes in precipitation and temperature, as well as changes in extreme design events, at a localized level.
- Uses downscaled GCM data to identify a range of precipitation and temperature adjustments at several thousand locations across the US for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

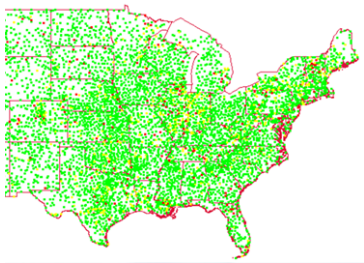
Source of Climate Change Data

IPCC/WCRP CMIP
Daily climate projections for 2020-2074 from 9 GCM models at a coarse (2-5°) scale

M-CAT
ng of monthly
T scenarios
ing PET and
e events) to
NWS stations.

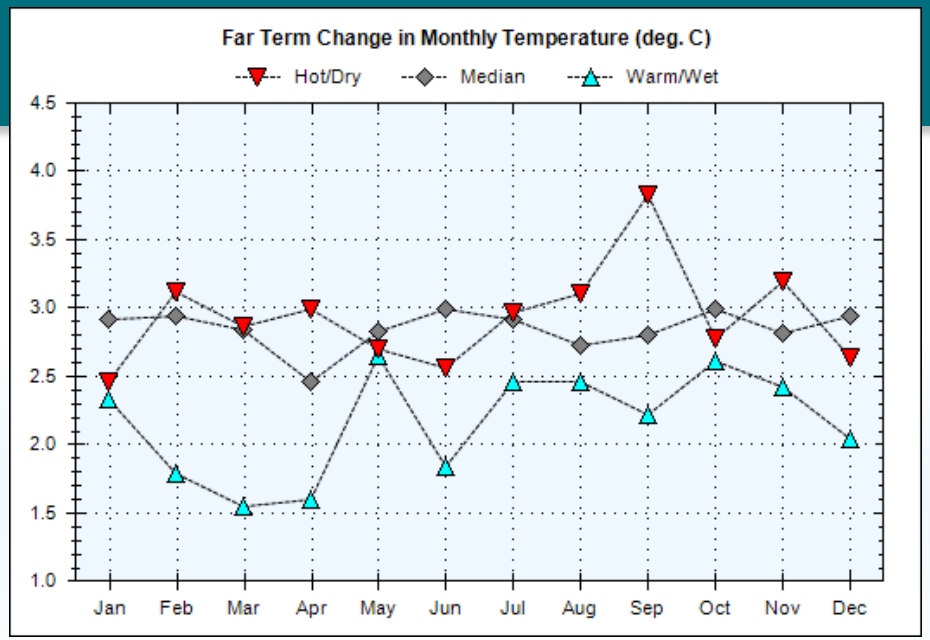


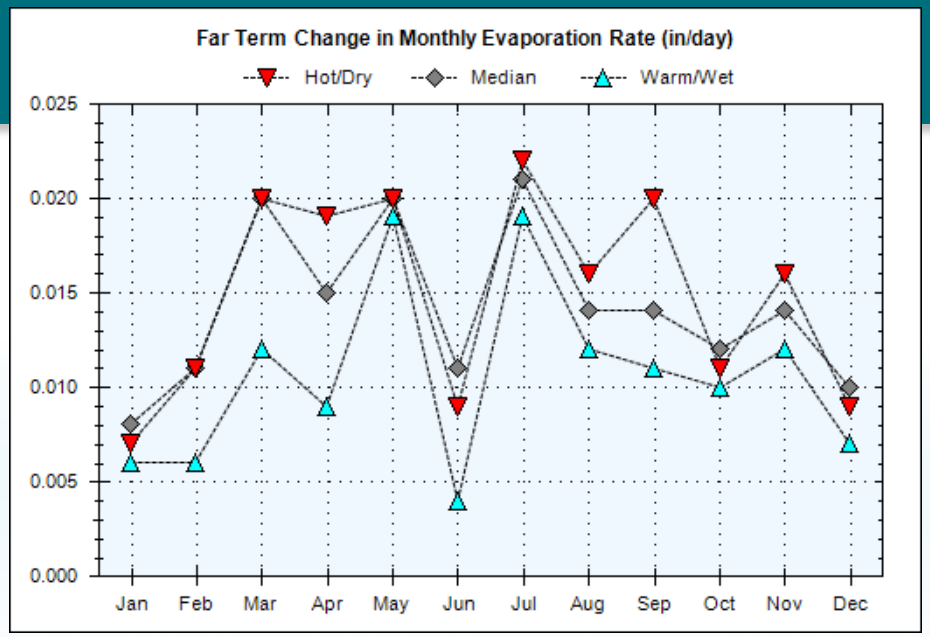


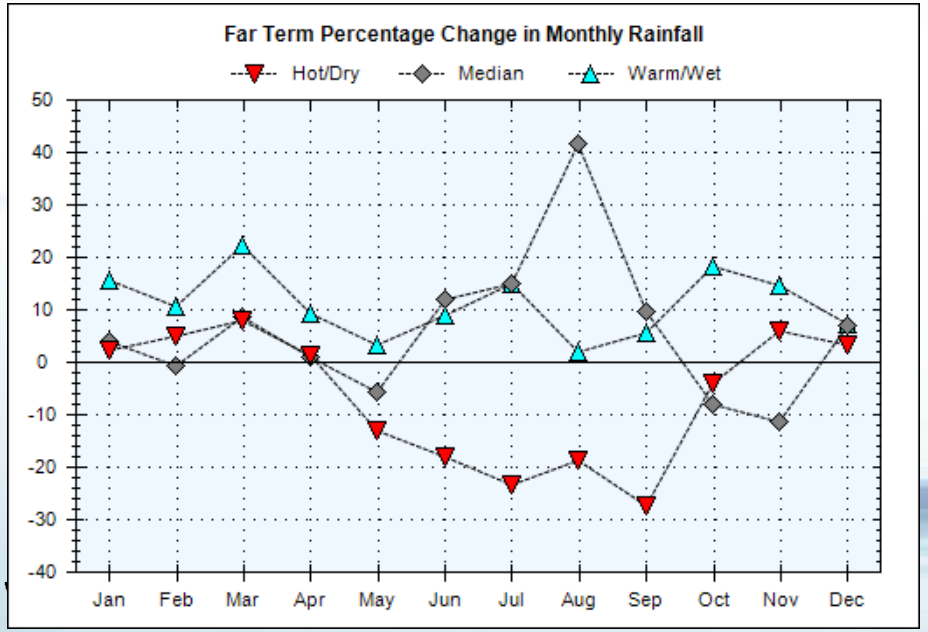


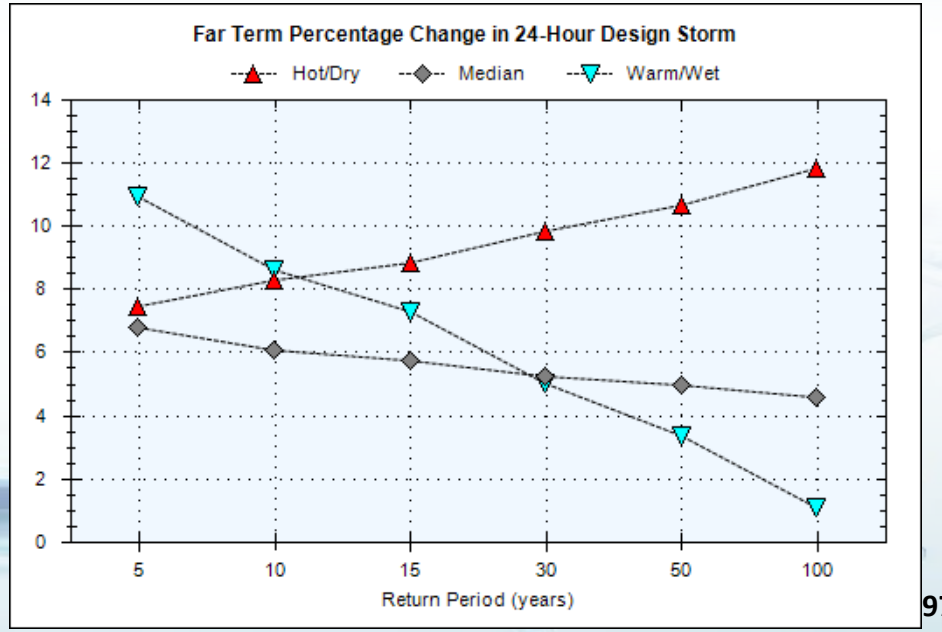
IPC
CMI
BOR
CREAT - Climate Resilience Evaluation and Analysis Tool

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

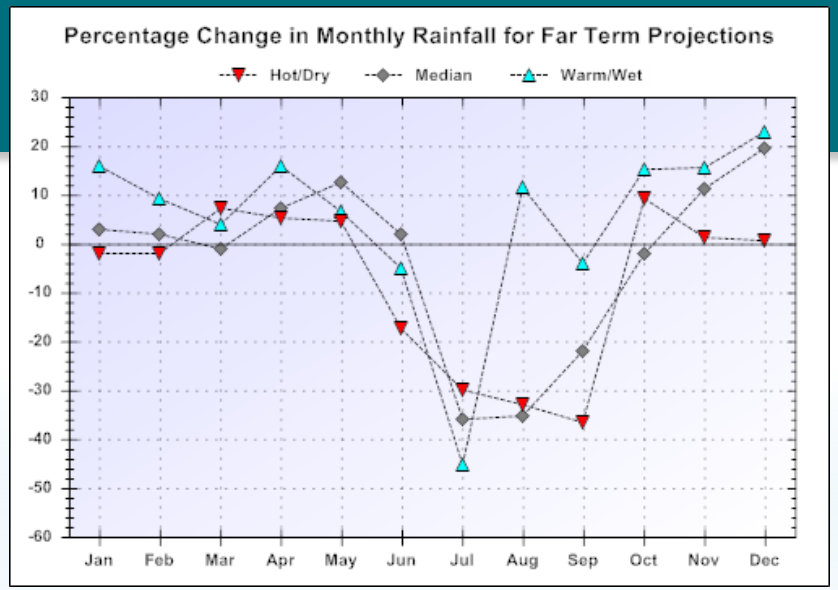




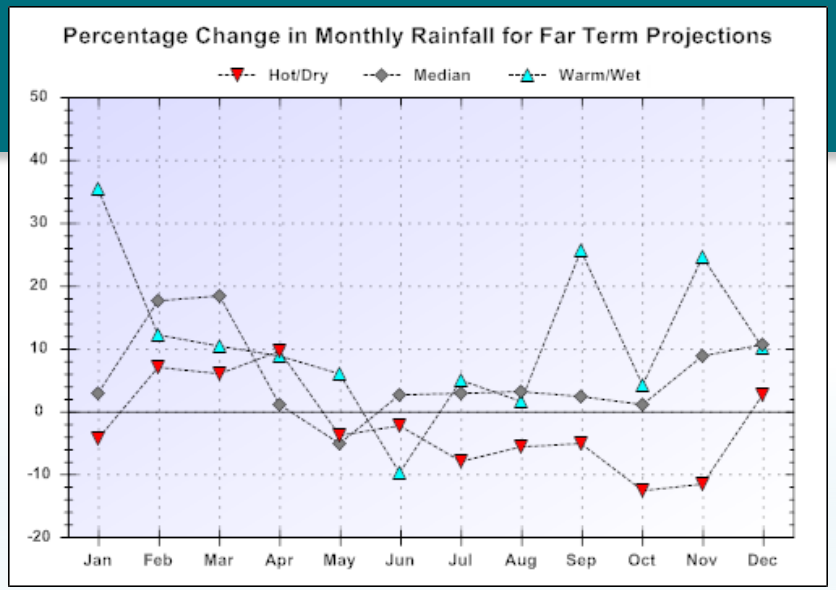




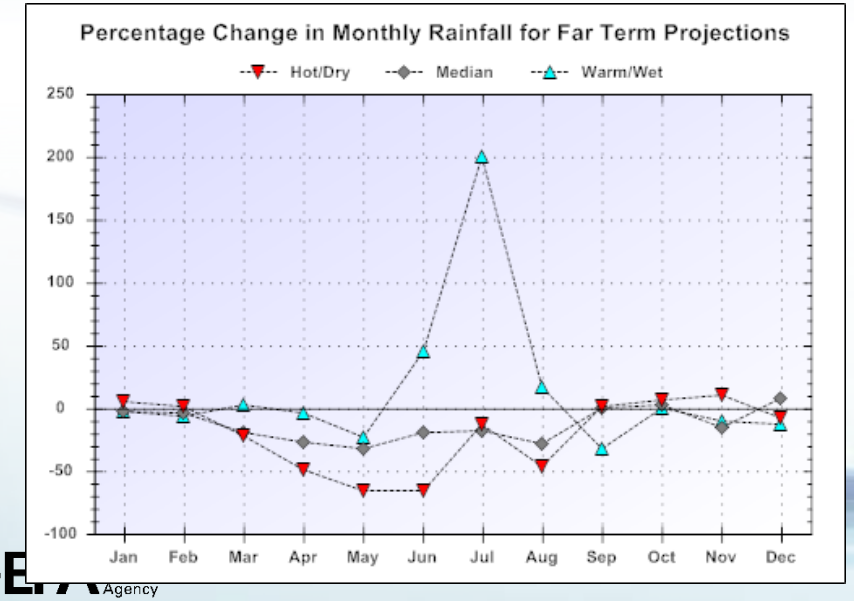
Seattle



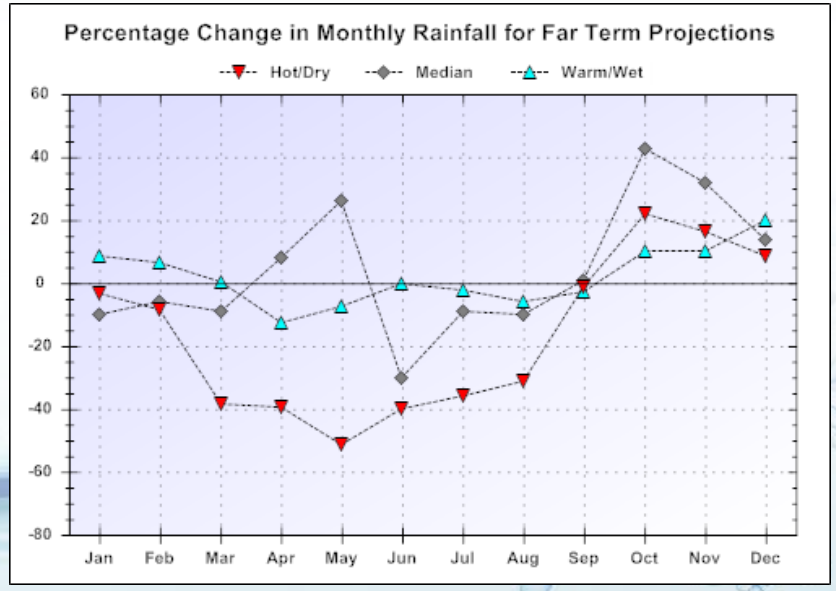
Boston



Phoenix

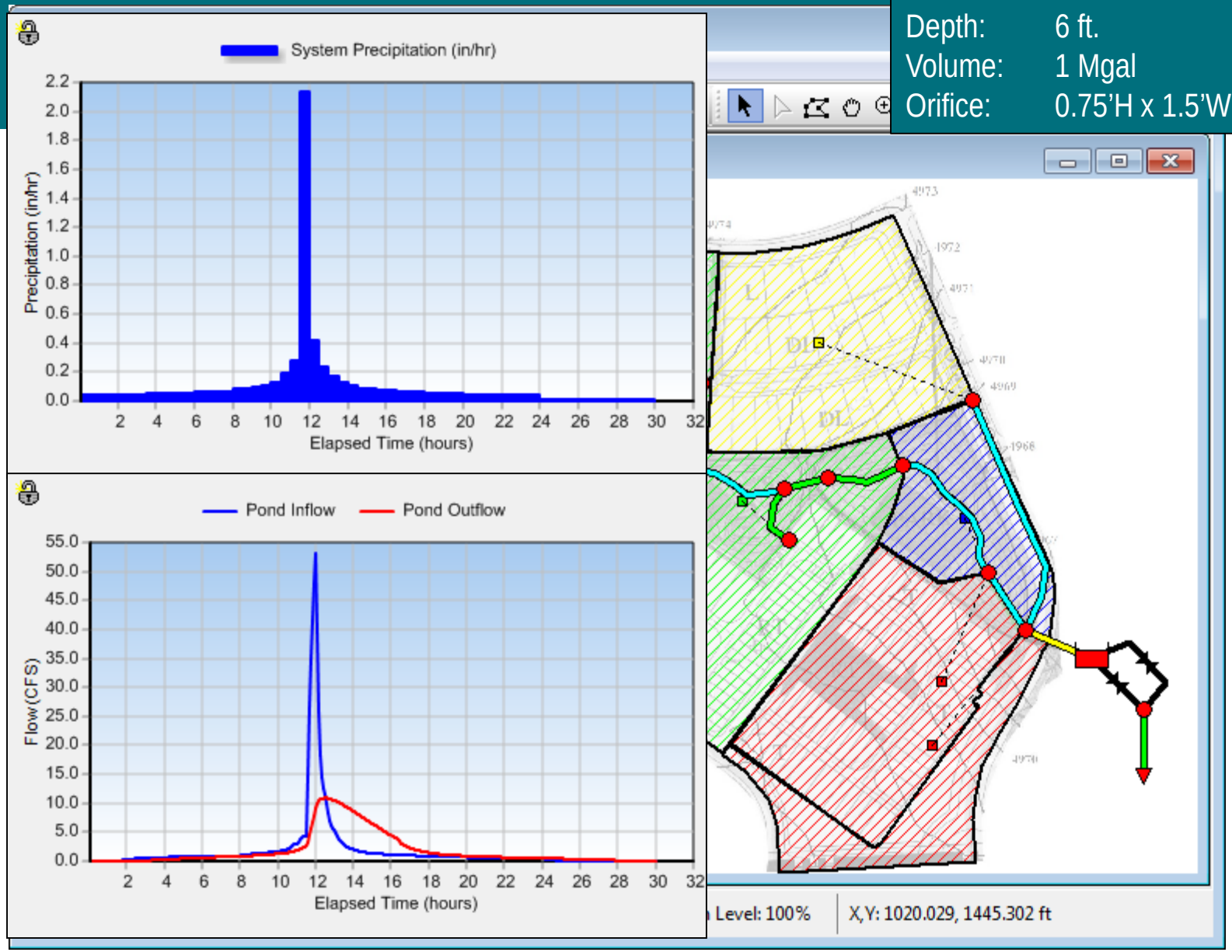


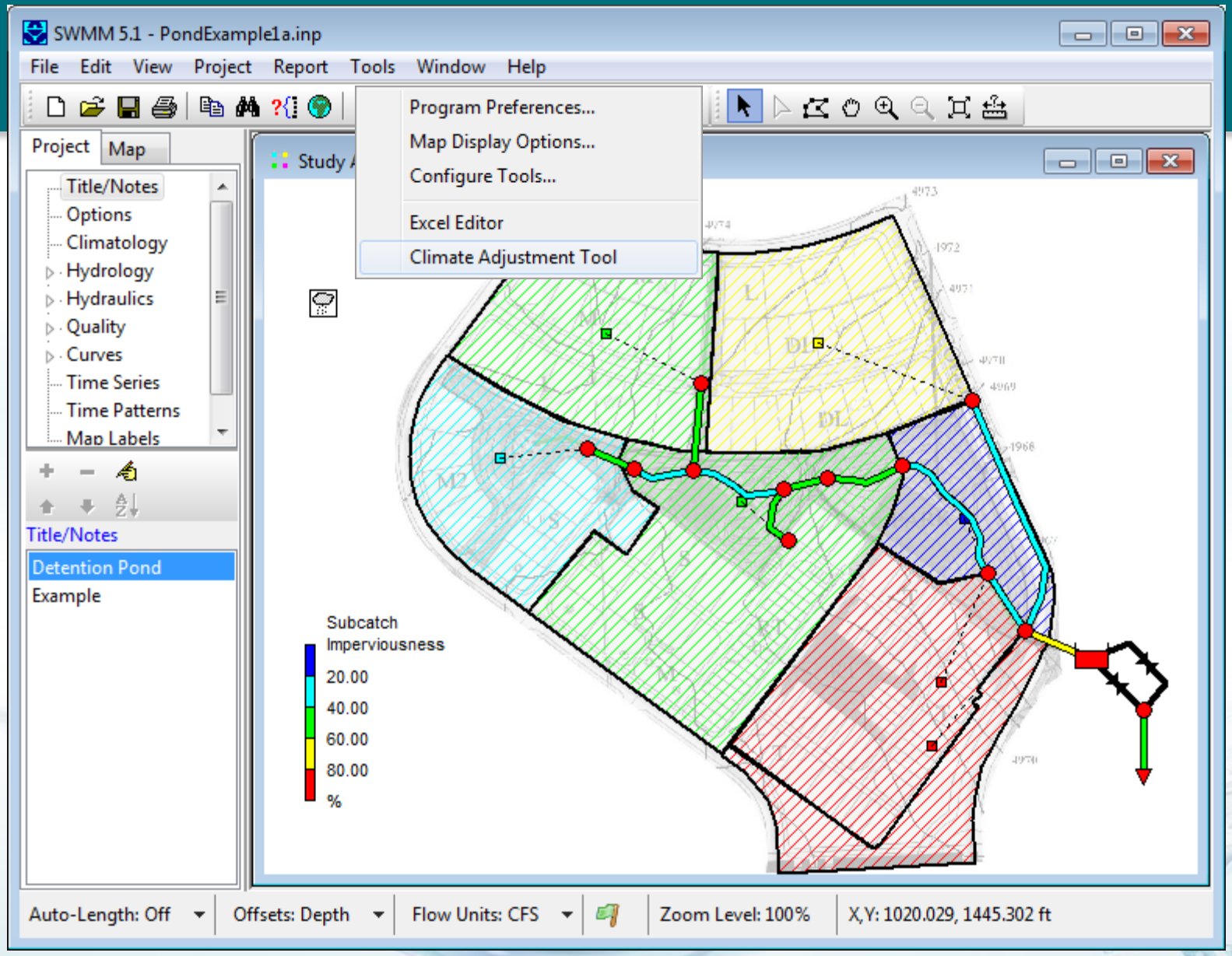
Miami

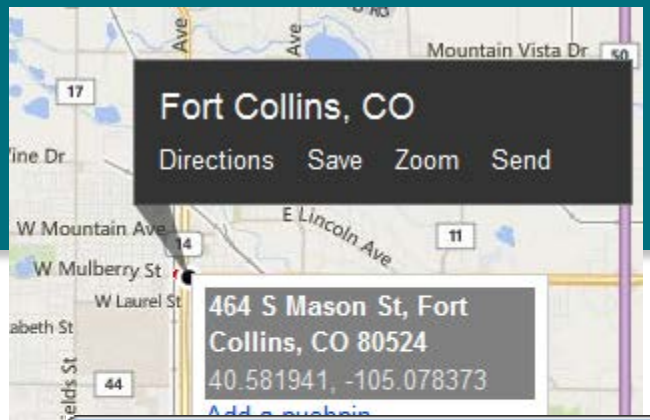


Pond Design:

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




SWMM 5.1 - PondExample1a.inp
File
Edit
View
Project
Report
Tools
Window
Help
Program Preferences...
Map Display Options...
Configure Tools...
Excel Editor
Climate Adjustment Tool
Project
Map
Title/Notes
Options
Climatology
Hydrology
Hydraulics
Quality
Curves
Time Series
Time Patterns
Map Labels
Title/Notes
Detention Pond
Example
Subcatch
Imperviousness
20.00
40.00
60.00
80.00
%
Auto-Length: Off
Offsets: Depth
Flow Units: CFS
Zoom Level: 100%
X,Y: 1020.029, 1445.302 ft



SWMM-Climate Adjustment Tool

Enter your location's latitude, longitude or its 5-digit zip code:

40.581941, -105.078373

Select a future projection period:

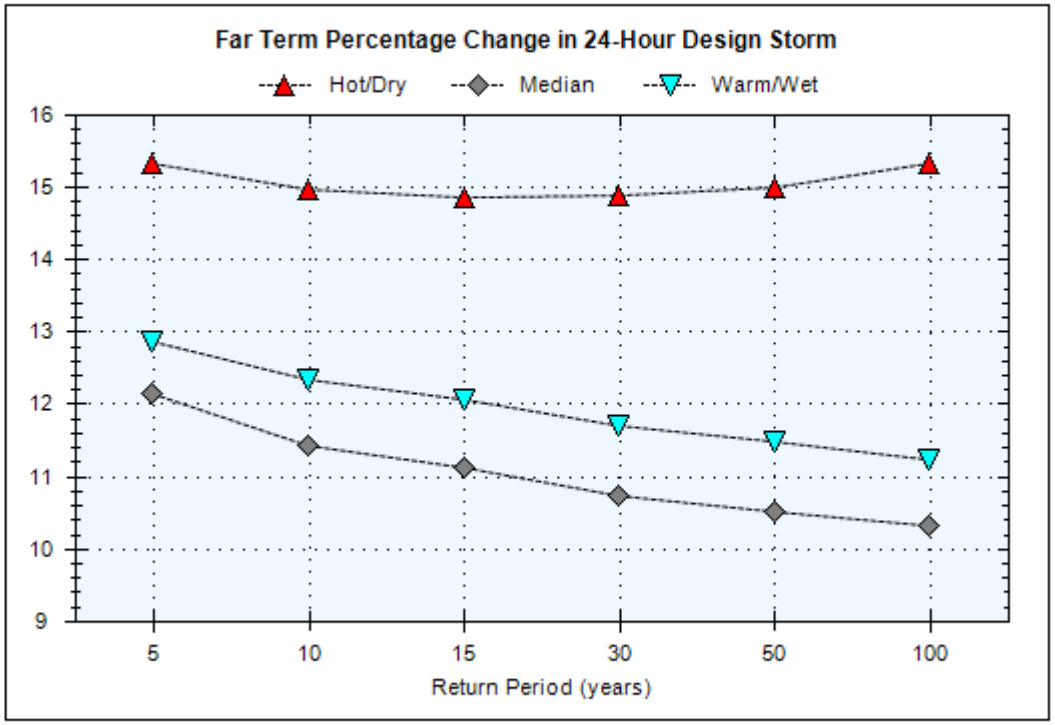
- Near Term (2020 - 2049)
- Far Term (2045 - 2074)

Select a climate change outcome:

- Hot/Dry
- Median change
- Warm/Wet

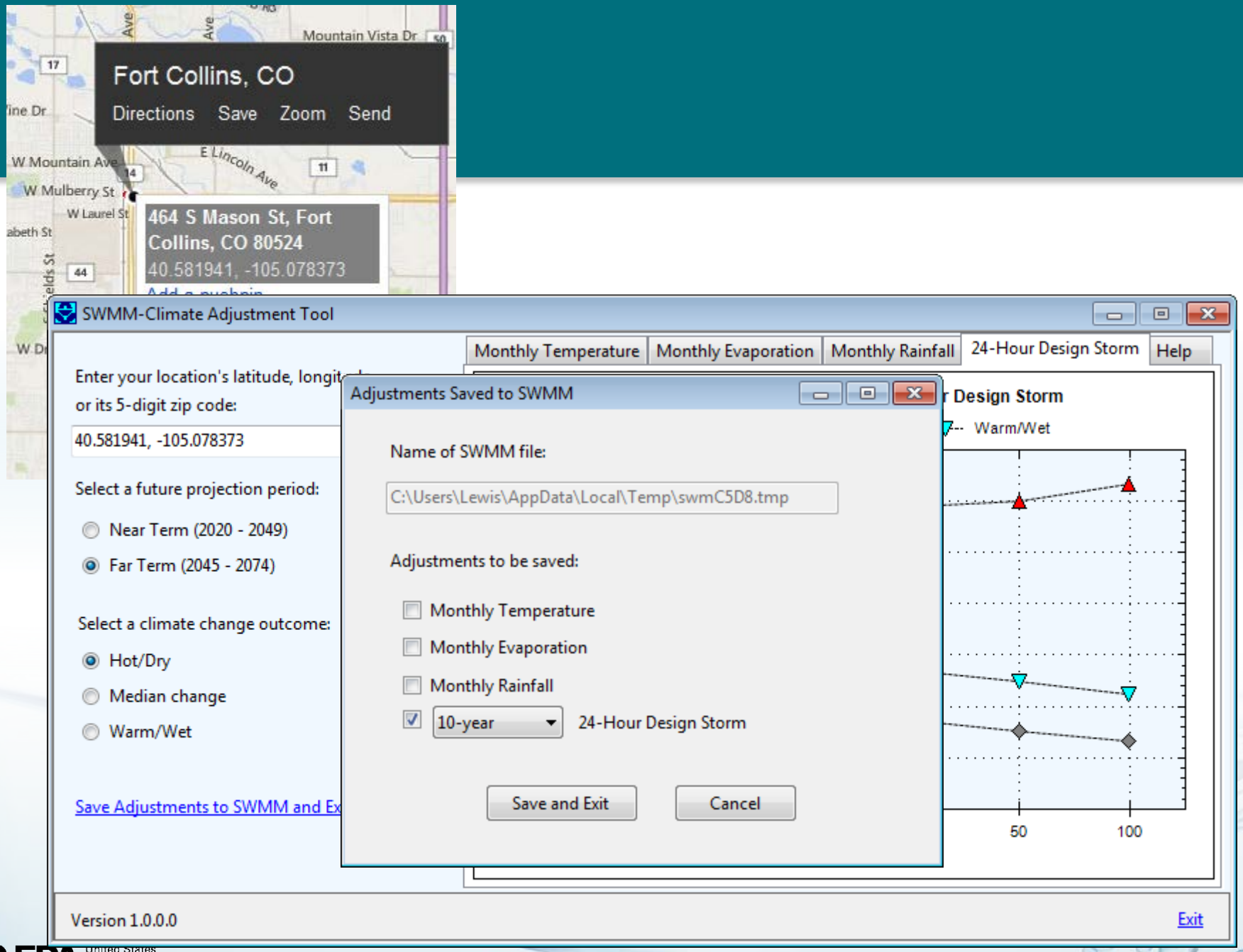
Save Adjustments to SWMM and Exit

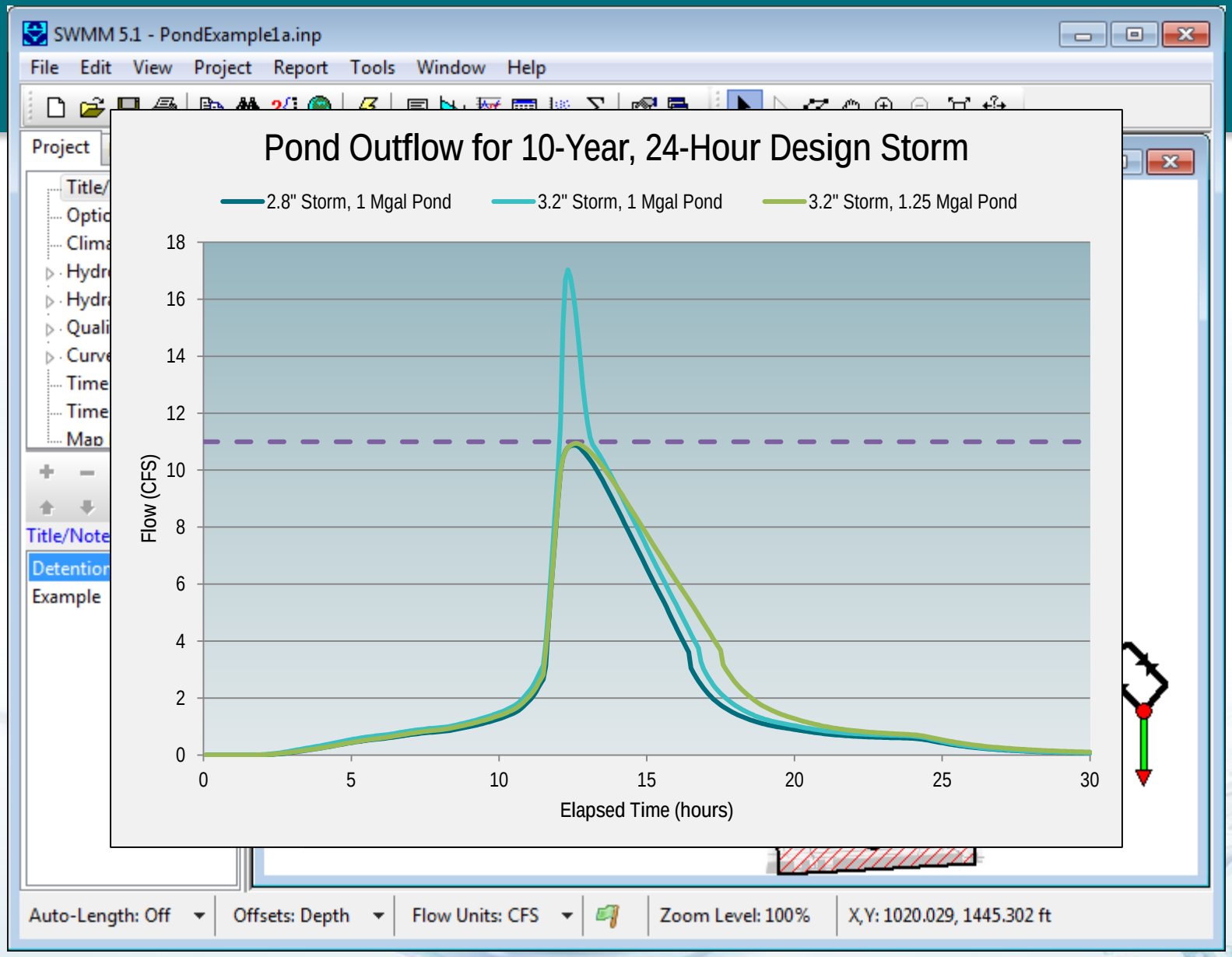
Monthly Temperature | Monthly Evaporation | Monthly Rainfall | 24-Hour Design Storm | Help



Version 1.0.0.0

Exit


Fort Collins, CO
Directions Save Zoom Send
Mountain Vista Dr
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, longit
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
Design Storm
Warm/Wet
50
100
Version 1.0.0.0
Exit


SWMM 5.1 - PondExample1a.inp
File Edit View Project Report Tools Window Help
Project
Title/
Optic
Clima
Hydr
Hydr
Quali
Curve
Time
Time
Map
Title/Note
Detention
Example
Pond Outflow for 10-Year, 24-Hour Design Storm
2.8" Storm, 1 Mgal Pond
3.2" Storm, 1 Mgal Pond
3.2" Storm, 1.25 Mgal Pond
Flow (CFS)
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30
Elapsed Time (hours)
Auto-Length: Off
Offsets: Depth
Flow Units: CFS
Zoom Level: 100%
X,Y: 1020.029, 1445.302 ft

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?

Presentation Outline

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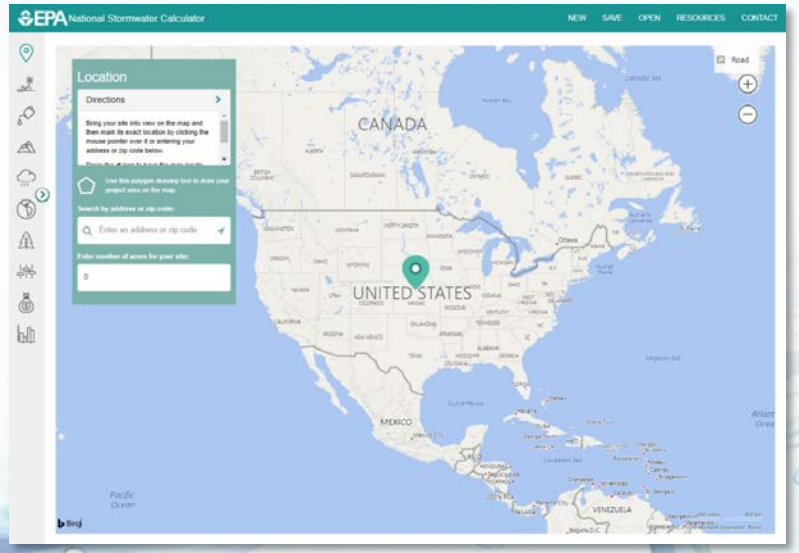
Data that you need for SWMM

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

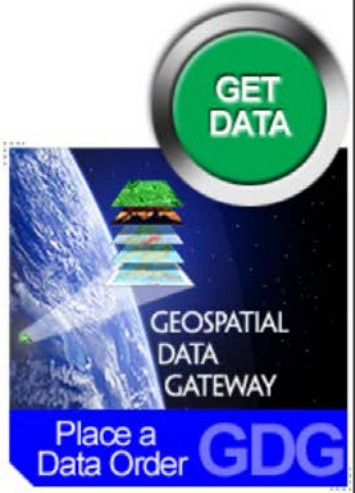
Welcome to GDG

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.

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).



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

Key Websites discussed

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

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/

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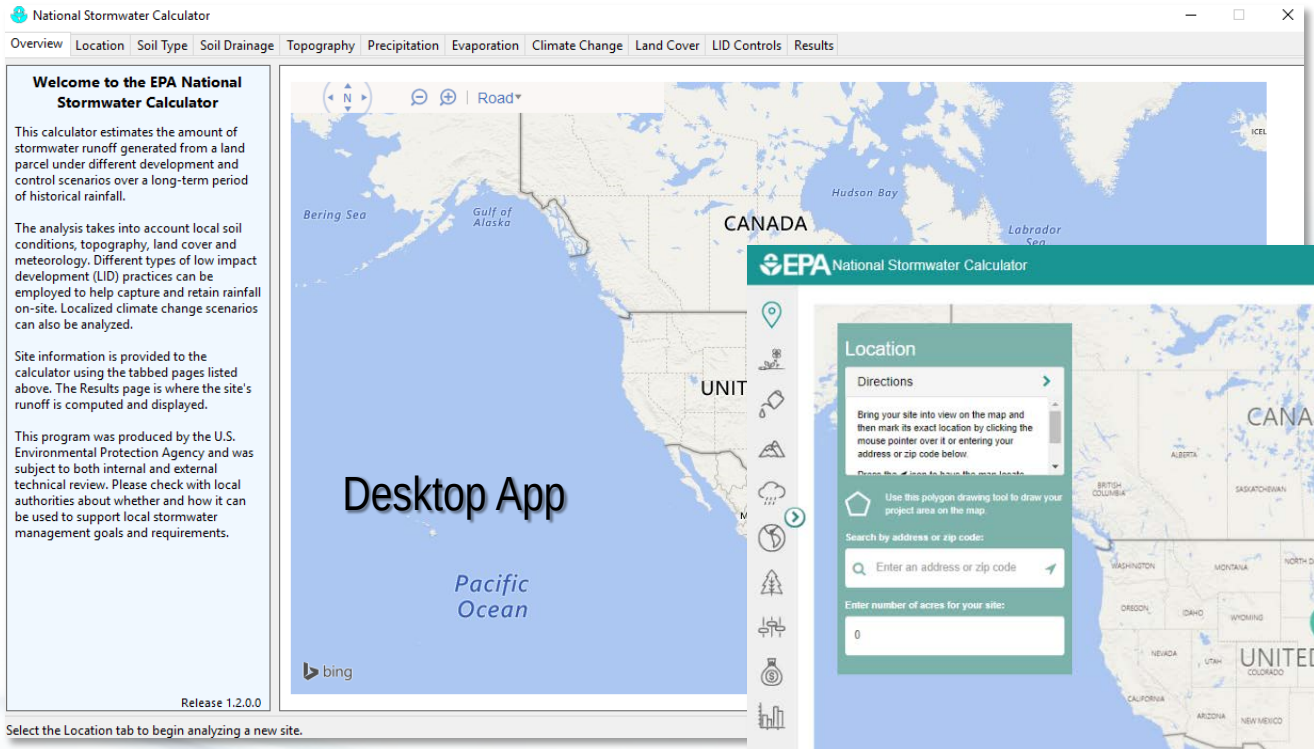
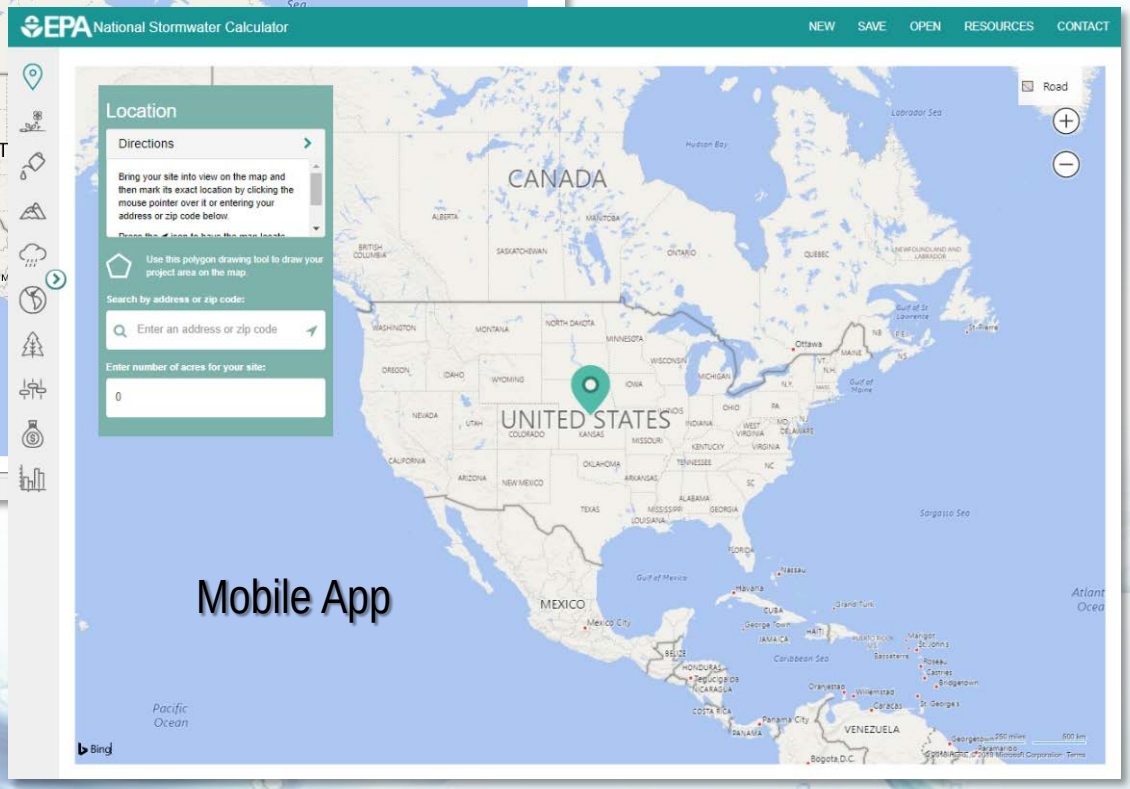
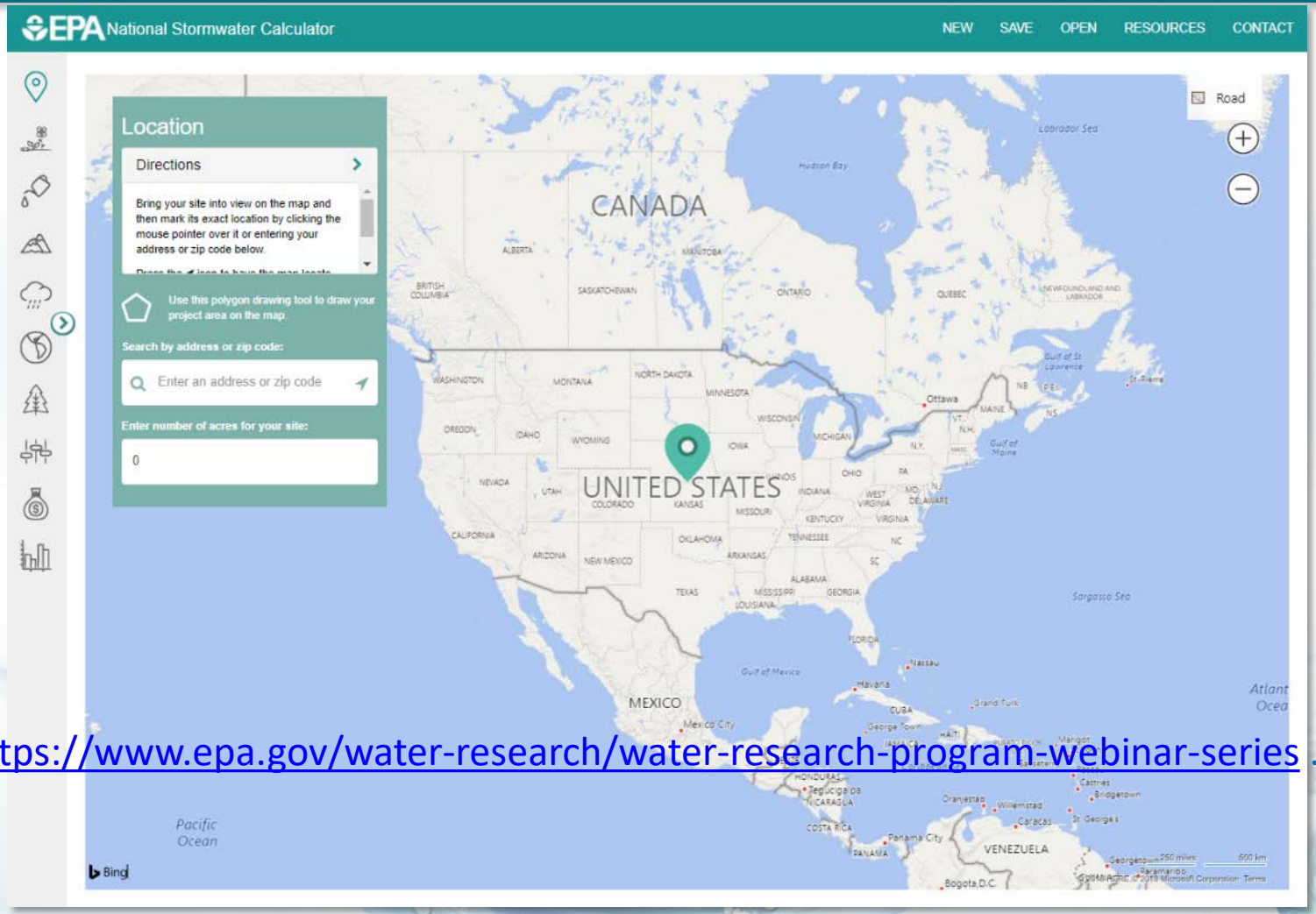
National Storm Water Calculator (SWC)





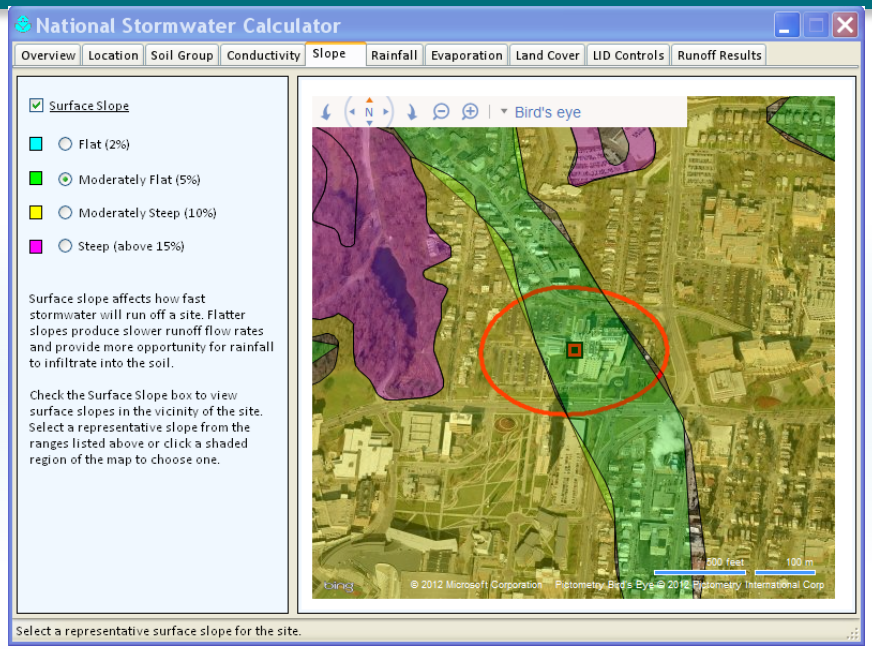
National Stormwater Calculator

https://www.epa.gov/water-research/national-stormwater-calculator



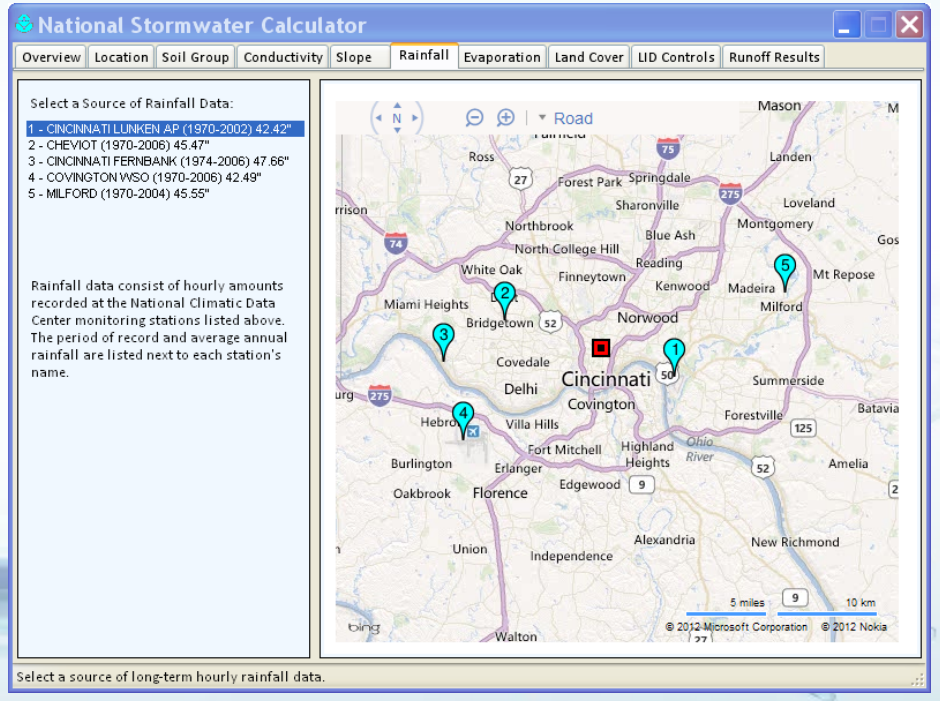
: https://www.epa.gov/water-research/water-research-program-webinar-series .

National Stormwater Calculator



Displays soil properties obtained from querying the NRCS SSURGO database

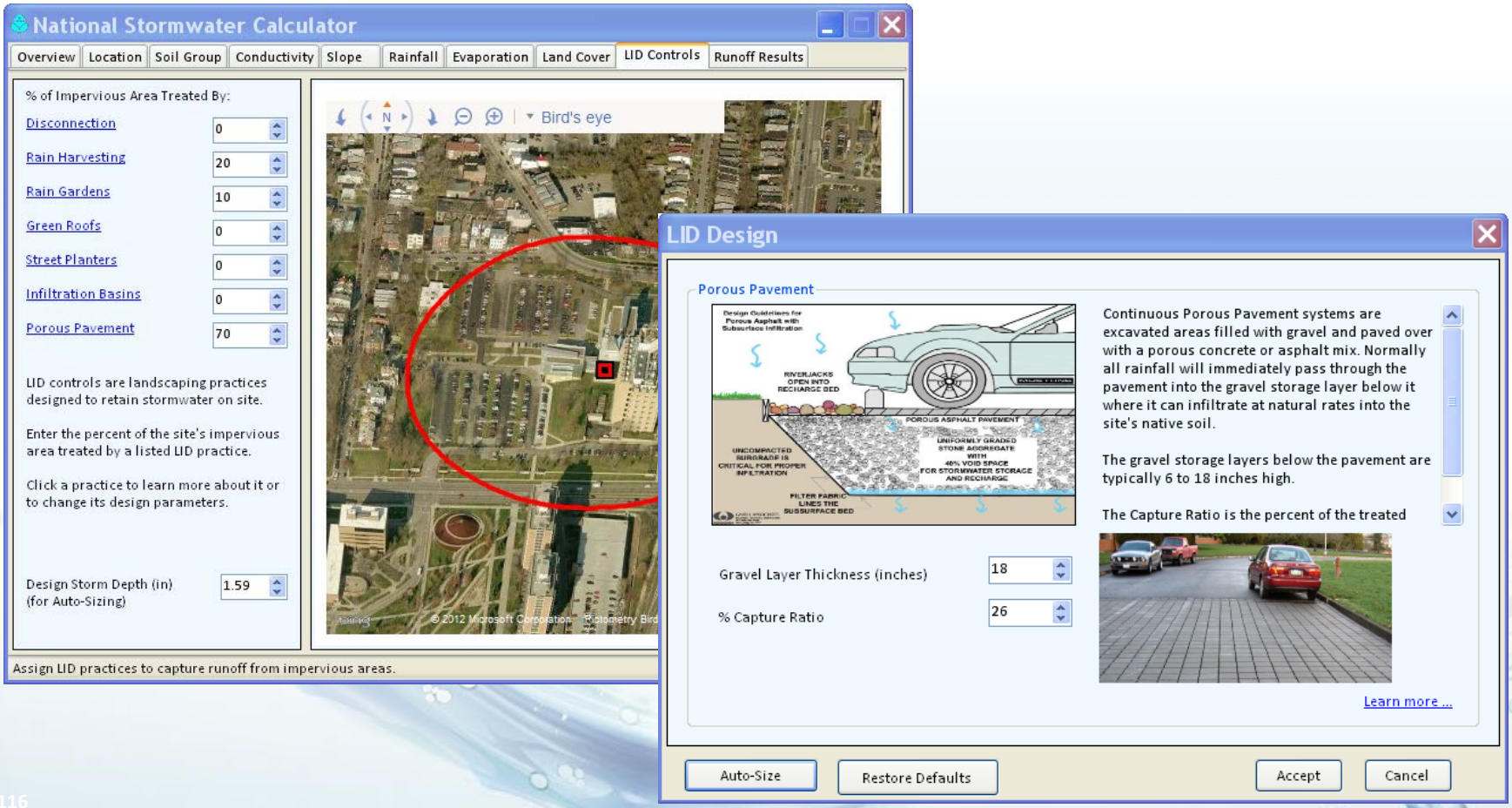
Uses a source of long term hourly rainfall data from over 7000 NWS measurement stations



United States Environmental Protection Agency

National Stormwater Calculator

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



United States Environmental Protection Agency

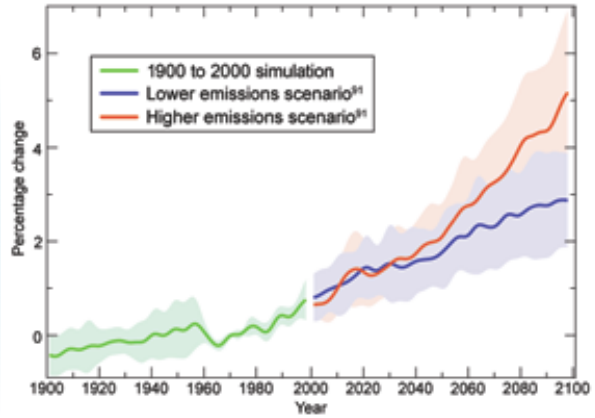
Climate Component Added to Calculator

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

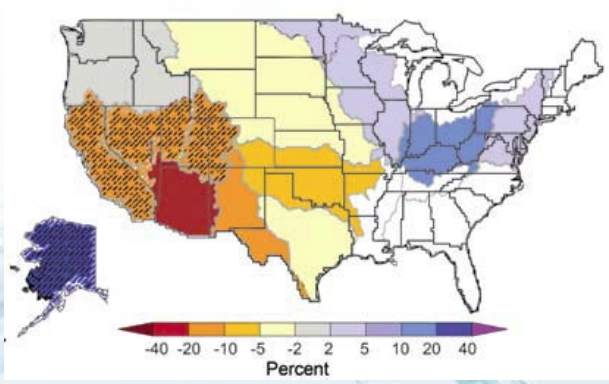
Impacts on small-scale hydrology:

- 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



National Stormwater Calculator

The Calculator runs SWMM to generate daily rainfall/runoff statistics.

National Stormwater Calculator

Overview | Location | Soil Type | Soil Drainage | Topography | Precipitation | Evaporation | Climate Change | Land Cover | LID Controls | Results

Options

Years to Analyze: 20

Event Threshold (inches): 0.10

Ignore Consecutive Days ☐

Actions

Refresh Results

Use as Baseline Scenario

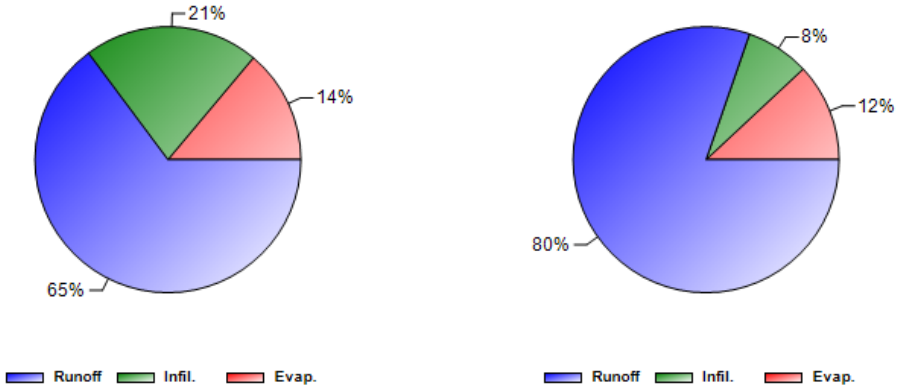
Remove Baseline Scenario

Print Results to PDF File

Reports

- ○ Site Description
- ◉ Summary Results
- ○ Rainfall / Runoff Events
- ○ Rainfall / Runoff Frequency
- ○ Rainfall Retention Frequency
- ○ Runoff By Rainfall Percentile
- ○ Extreme Event Rainfall / Runoff
- ○ Cost Summary

Help



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*

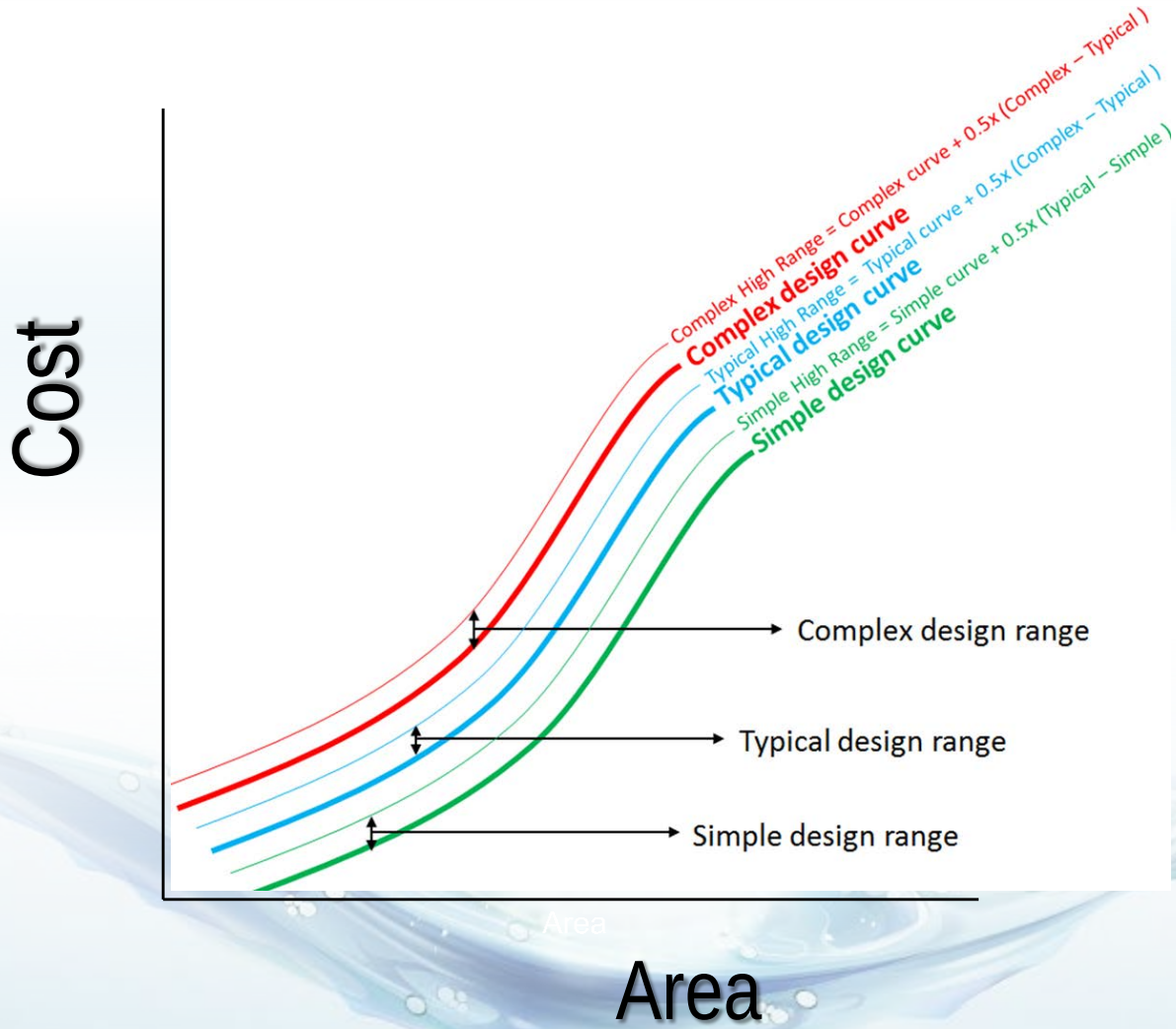
Help

Runoff results are up to date.

Analyze a New Site | Save Current Site | Exit

EPA United States Environmental Protection Agency

LID Cost Estimation Module:



Questions?

EPA's Other GI Tools

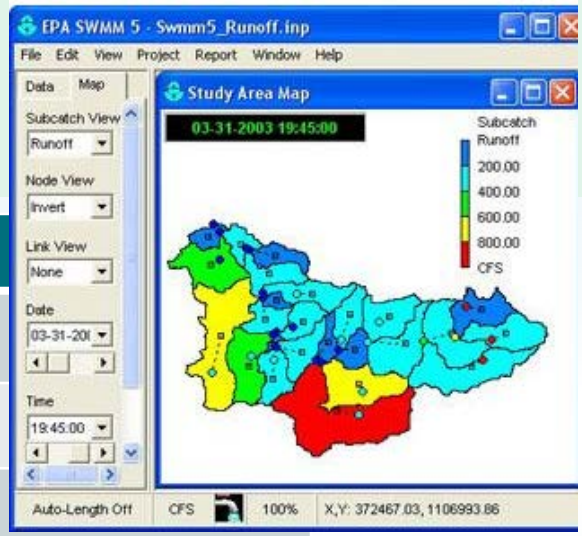
Green Infrastructure Modeling Toolkit

Toolkit website: https://www.epa.gov/water-research/green-infrastructure-modeling-toolkit

***Toolkit video:** https://www.youtube.com/watch?time_continue=2&v=xHp-OeUneqQ

SWMM GI AND Waste Water Infrastructure

SWMM dynamic hydrologic - hydraulic - water quality runoff model for urban environments



Version	Year	Model Enhancements
SWMM 5	2005	Complete re-write of SWMM
SWMM 5.1	2010	Added LID Modules
SWMM 5.1.011	2016	Added Climate Adjustment Tool
SWMM 5.1.013	2018	Most Recent Release, currently reviewing SWMM 5.1.013 and debugging new GUI + bug fixes

Michael Tryby, Michelle Simon, Colleen Barr, Anne Mikelonis, Katherine Ratliff, Xuanyi Lin, Lew Rossman Retired

National Stormwater Calculator

Software application that estimates the annual amount of rainwater and frequency of runoff from a specific site

Developed, added Cost Module to Desktop 2017 SWC 1.2.01

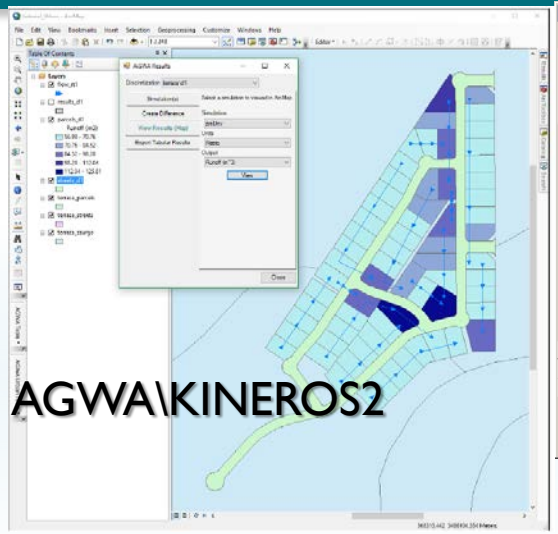
Beta Testing Mobile App 2018

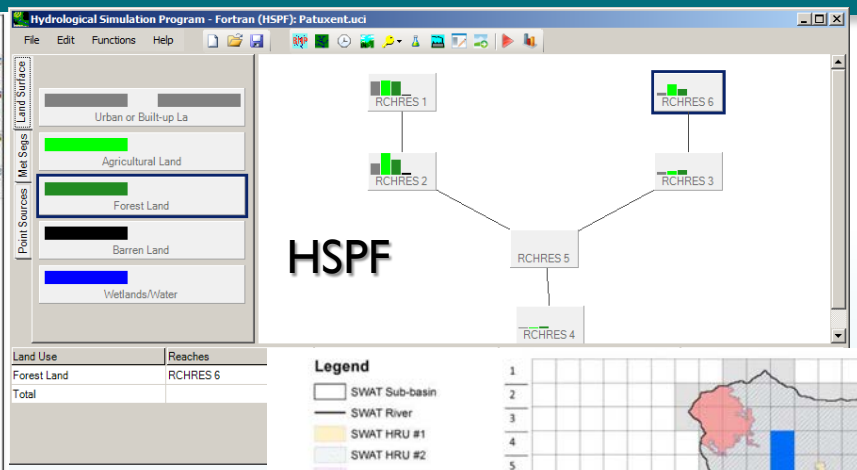
Interfaces with

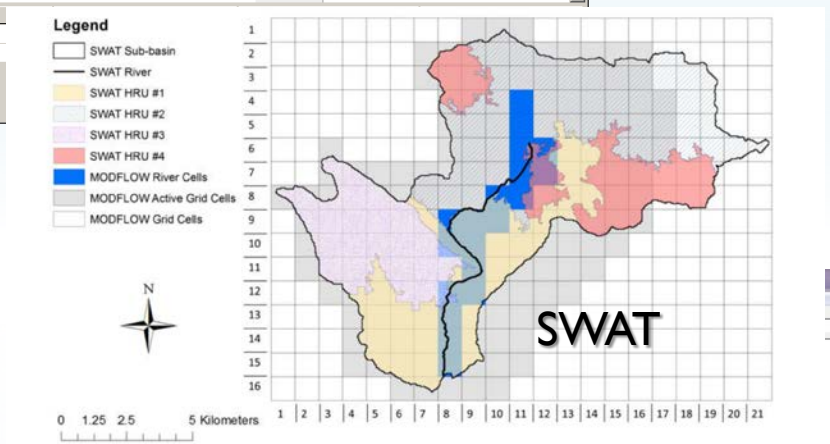
- NRCS SSURGO
- Bureau of Labor Statistics
- BASINS dll

Jason Bernagros, Michelle Simon, Michael Tryby, Colleen Barr,

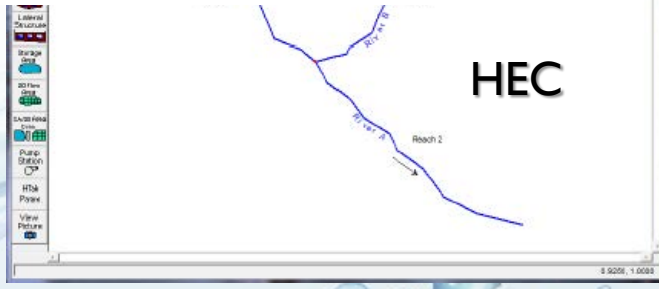
Possible Coupling to Other Models and Data





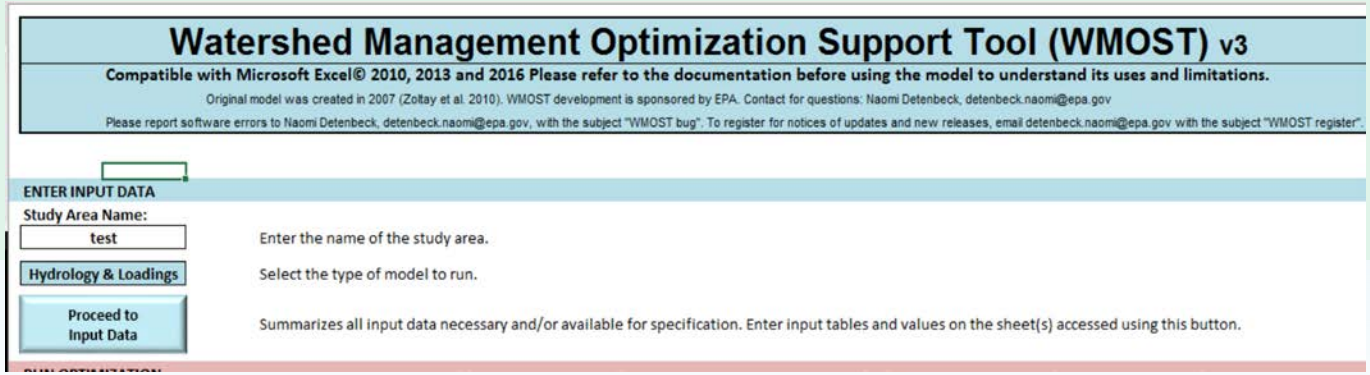


Plus MODFLOW
HYDRUS, GSSHA,
others



Watershed Management Optimization Support Tool (WMOST):

Decision Support tool for integrated water management at the small watershed/community scale



Version	Year	Model Enhancements
WMOST (v1)	2013	
WMOST (v2)	2016	Baseline Hydrology Module Stormwater Hydrology Module
WMOST (v3)	2018	Baseline Hydrology and Loadings Module Stormwater Hydrology and Loadings Module Water Quality Module, CSO Module, Calibration

Naomi Detenbeck, Marilyn ten Brink, Amy Piscopo

Visualizing Ecosystems for Land Management Assessment (VELMA) Model

Identify green infrastructure (GI) best management practices for enhancing water quality & ecosystem service co-benefits.

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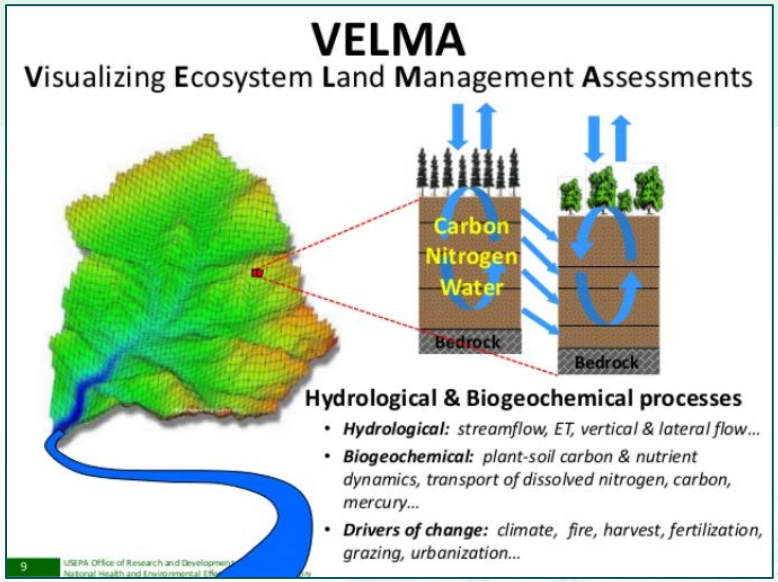


VELMA is a gridded watershed model that can explicitly target green infrastructure

Future Research

- Alternate forms of media (Bollman et al. [in prep])
- Simulation of nutrients, toxics

Bob McKane, Allen Brookes, Kevin Djang, Brad Barnhart, Jonathan Halama, Paul Pettus, Don Phillips, Marc Stieglitz, Feifei Pan, Alex Abdelnour

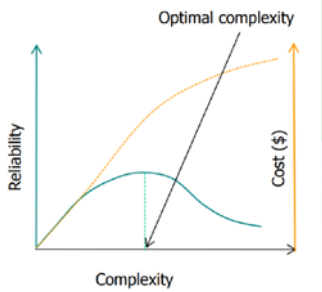
WetQUAL

Relates nitrification, denitrification, and phosphorus precipitation and release oxygen dynamics
and describes wetland free-water and soil processes.

World Environmental and Water Resources Congress 2014 Downloaded 21 times

Identifying Dominant Biogeochemical Processes Regarding theNitrogen Cycle in Active and Passive Zones of a Restored Wetland through WetQual Model

A. Sharifi ; L. Kalin ; M. M. Hantush ; J. J. Maynard



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Development and application of WetQual-C, a mechanistic model for simulating carbon dynamics, GHG gas emissions and carbon export from wetlands

http://aaes.auburn.edu/wrc/wp-content/uploads/sites/108/2015/10/Kalin-2015ALWRC.pdf

Mohammed Hantush, A. Sharif, L. Kalin, J.J. Maynard

Green Infrastructure Wizard (GIWiz)

Interactive web application that provides users with customized reports containing the EPA tools and resources they select, direct links, and overview information about each.

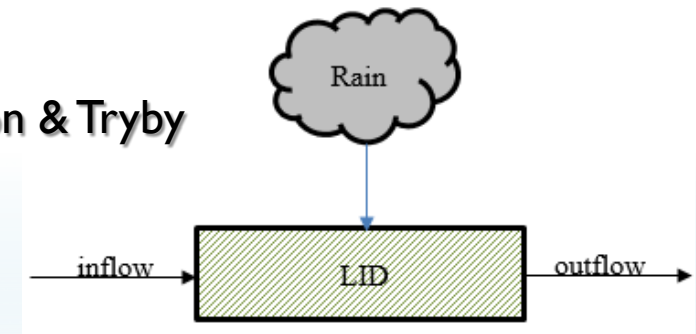
Accomplishments for GITAR Interface

Completion of Case Studies Report

Michael Nye, Marilyn ten Brink

Compare Model Results to Empirical Data

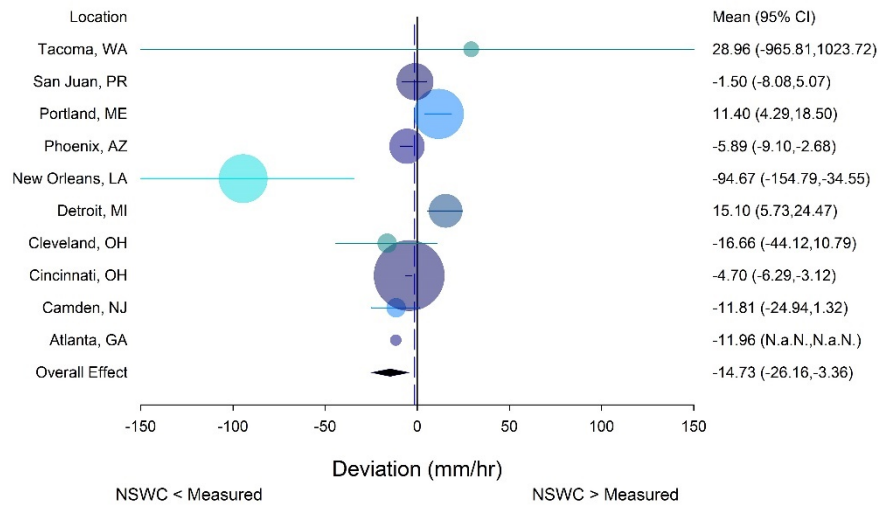
Simon & Tryby



Platz et al. Journal of Hydrologic Engineering, for submittal

Schifman et al. *Journal of the American Water Resources Association* 2017
Stewart et al. *Hydrological Processes* 2017
Schifman et al. *JHE* 2018

Bill Shuster



JOURNALS BOOKS MAGAZINE AUTHOR

Journal of Sustainable Water in the Built Environment / Volume 3 Issue 2 - Ma

Technical Papers Downloaded 1,501 times

Storm Water Management Model: Performance Review and Gap Analysis

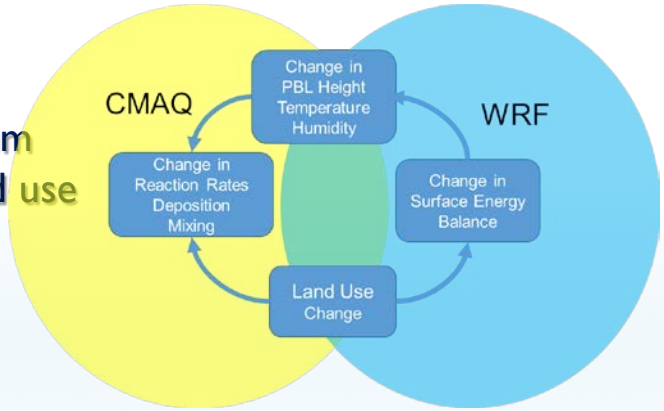
Mehran Niazi; Chris Nietch; Mahdi Maghrebi, A.M.ASCE; Nicole Jackson Show all authors

FULL TEXT DOWNLOAD TOOLS SHARE

Chris Nietch

Modeling Air Quality Impacts of Green Infrastructure: A Case Study in Kansas City

- Kansas City land use and land cover provided by Mid-America Regional Council
  - Included current land use scenario and a hypothetical maximum feasible green infrastructure scenario built on the current land use (urban forestry, riparian buffers, etc.)
  - Land use categories were mapped to meteorological and air quality model inputs
- Model simulations
  - 4 km grid resolution modeling domain over Kansas City, extending approximately 400 km from the city center
  - Simulations used the Weather Research and Forecast model (WRF) coupled with the Community Multiscale Air Quality model (CMAQ)
    - Additional sensitivity tests using different land-surface schemes



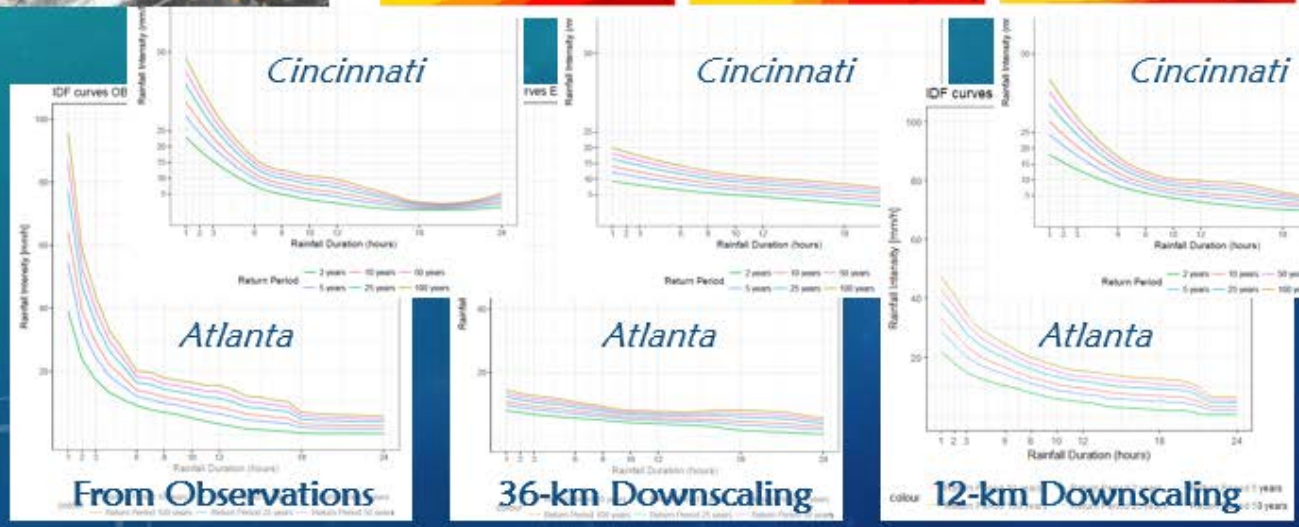
Reduced UHI lowers Blowfish reduces mixing zone and increases pollutant deposition

Jesse Bash, Yuqiang Zhang, Shawn Roselle, Angie Shatas, Robin Deyoung

Developing IDF Curves from Dynamically Downscaled Data

Developing IDF Curves from Dynamically Downscaled Data

Future directions: Develop higher-resolution weather scenarios in partnership with A-E AIMS-2.3 to support generating intensity, duration, and frequency curves under future scenarios. Include in SWMM and CREAT.



- New historical simulations were created at 12-km.
- New simulations improved representation of weather and IDF curves.

~~~ *Moving forward…*

- Need to consider:
  - Is 12-km fine enough?
  - Do we have resources to generate future scenarios at 12-km or finer?
- Discuss steps required to include these data in SWMM and CREAT.

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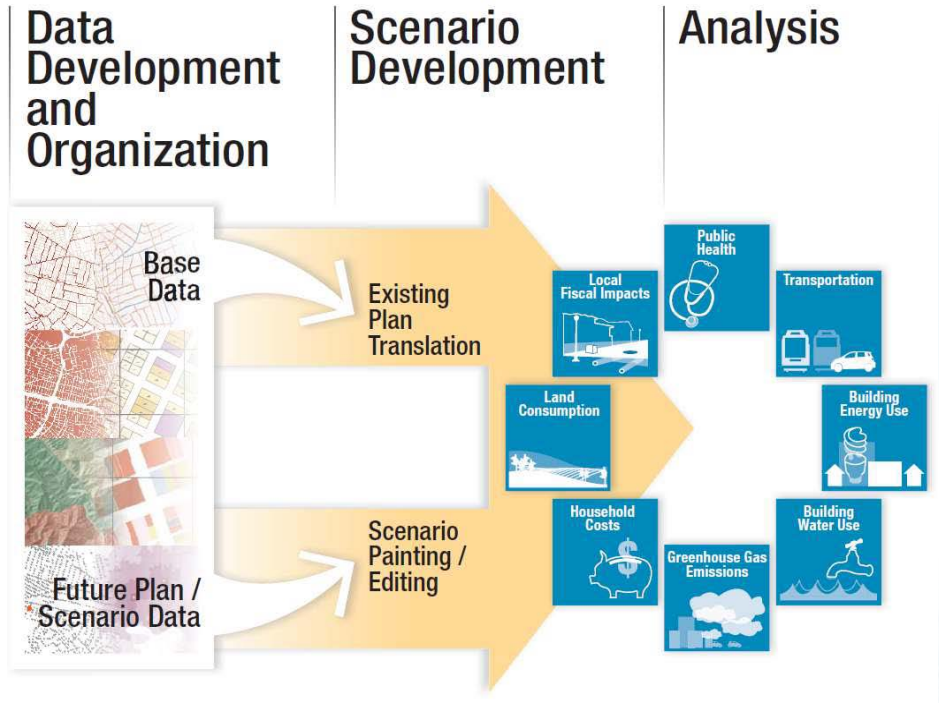
Integrate in Open Scenario Planning Tools

URBAN FOOTPRINT

https://urbanfootprint.com/



Allan Brooks, Colleen Barr

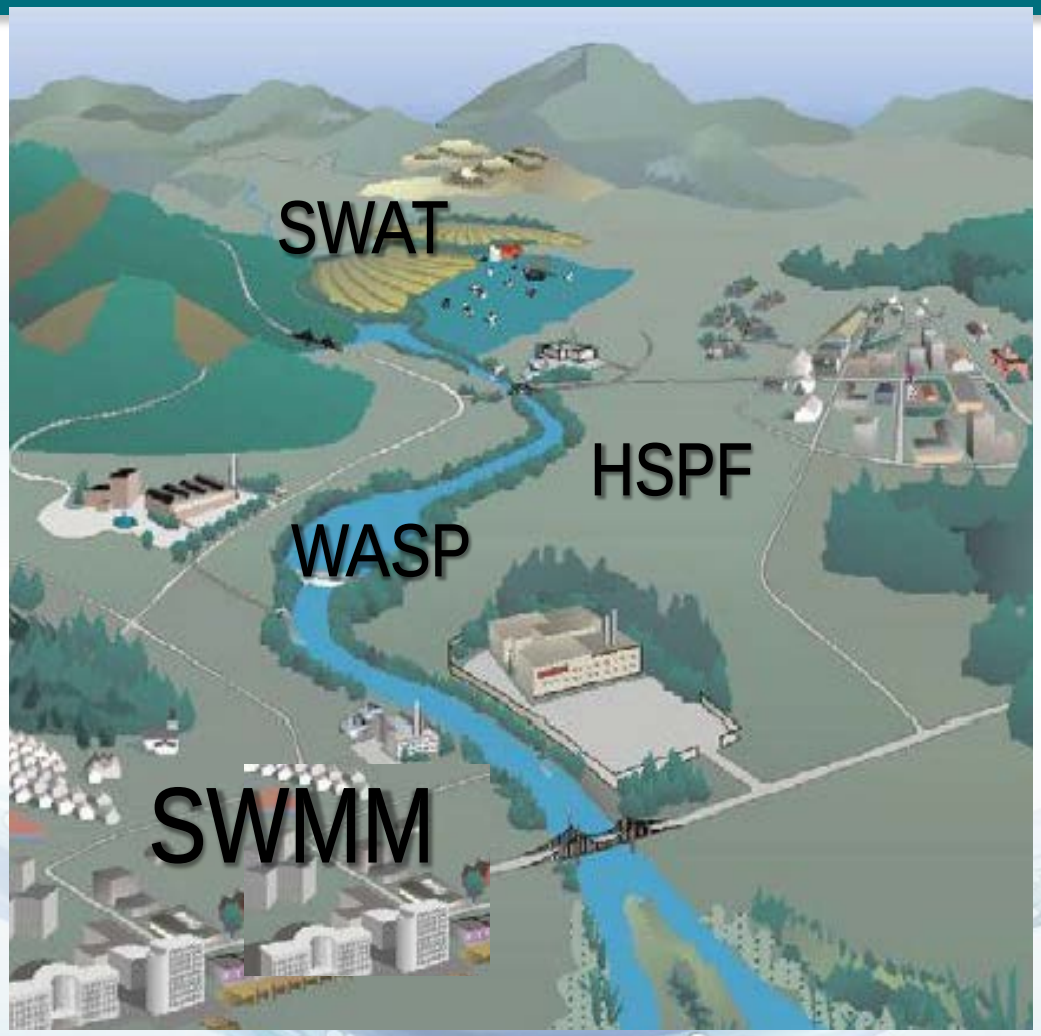
FINAL ASSESSMENT SURFACE WATER MODEL MAINTENANCE AND SUPPORT STATUS

AGNPS	Aquatox	BASINS
BATHTUB	CE-QUAL-ICM	CE-QUAL-W2
CORMIX	EFDC	HAWQS
HSPF	LSPC	QUAL2KW
SPARROW	SWAT	SWMM
SWTOOLBOX	VISUAL PLUMES	WASP

and AGWA, HEC, HYDRUS, KINEROS2, MODFLOW, iTree, etc.

EPA Report EPA/600/R-18/270

How SWMM, HSPF, SWAT, and WASP Relate

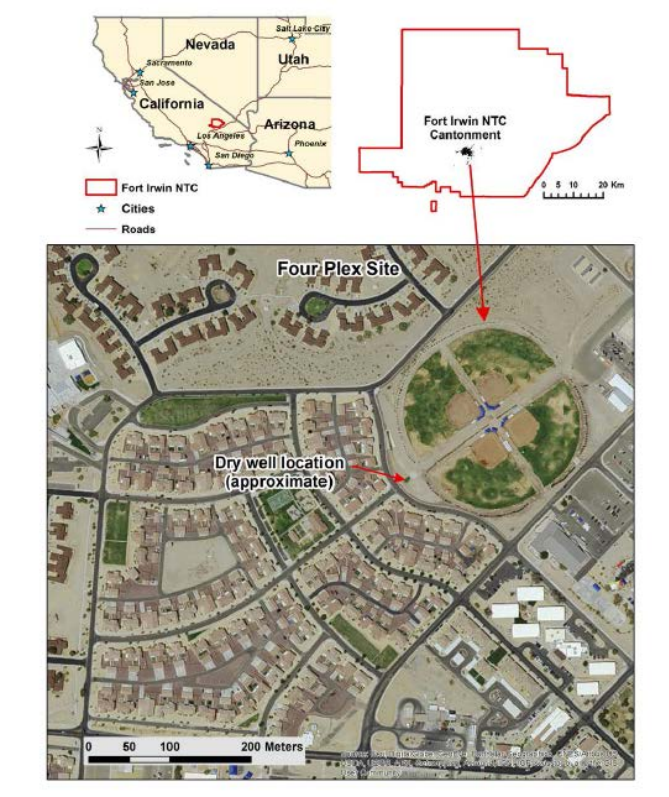


https://cfpub.epa.gov/watertrain/pdf/modules/WshedModTools.pdf

https://www.aquaterra.com/resources/pubs/fiftyyearwatershedconferencePrograms.php

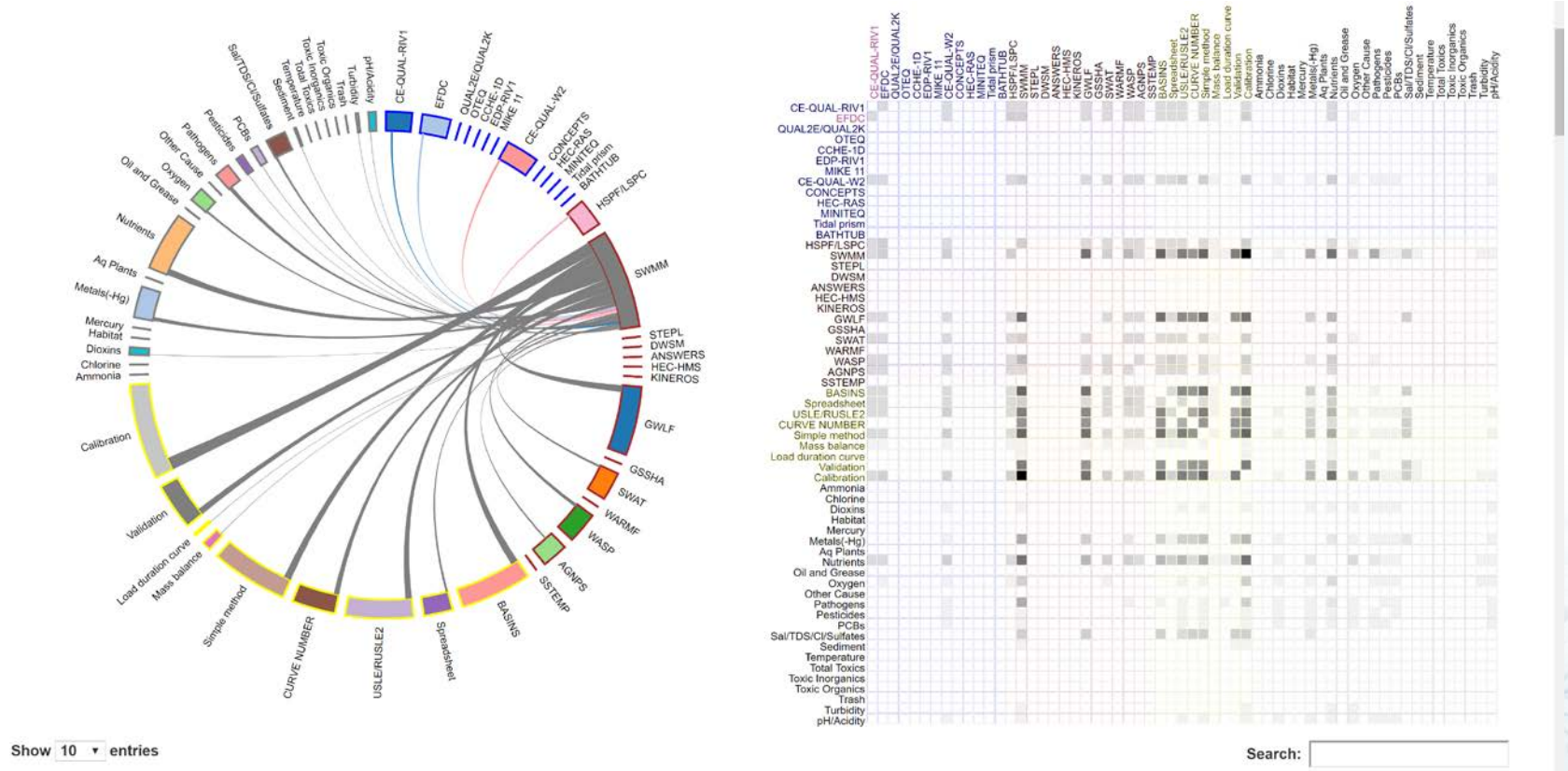
Fort Irwin Study- Compare PD Models

- NERL Steve Kraemer Lead
- USEPA – SWMM (Michelle Simon)
- UC-Riverside – HYDRUS
- USDA/The University of Arizona KINEROS2
- USGS – MODFLOW



Total Maximum Daily Loads Tool

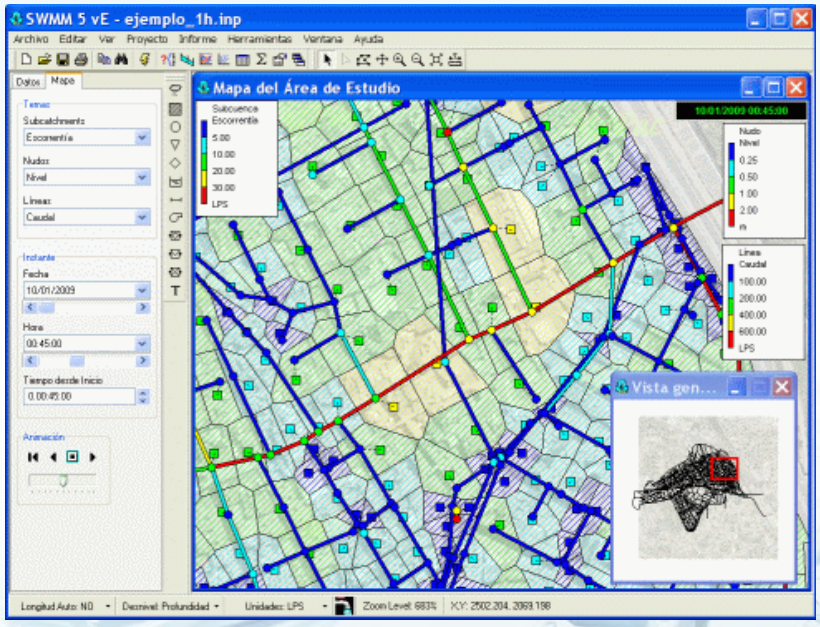
https://owml.vt.edu/tmdl/



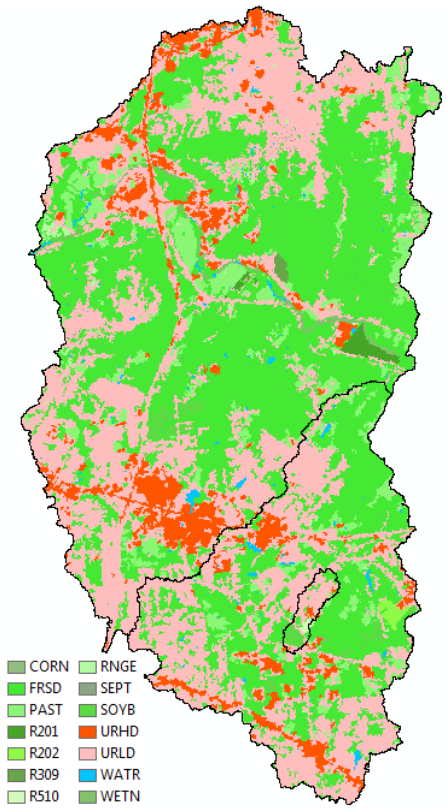
EPA Research

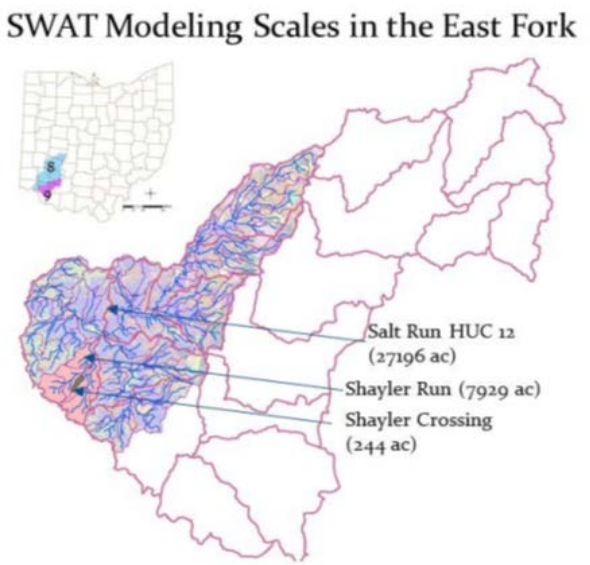
Current Work on SWMM - SWC

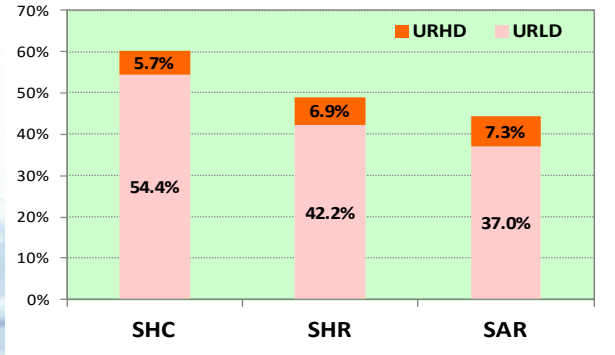
- SWMM – GUI User Interface GIS Capabilities
- Improve Data Access of National Databases
- Interface with KINEROS2 -
  future with BASINS, HSPF,
  further into future SWAT, WASP
- Ground Truth SWMM with project
  at The Stevens Institute



SWMM-SWAT Integration for GI effectiveness





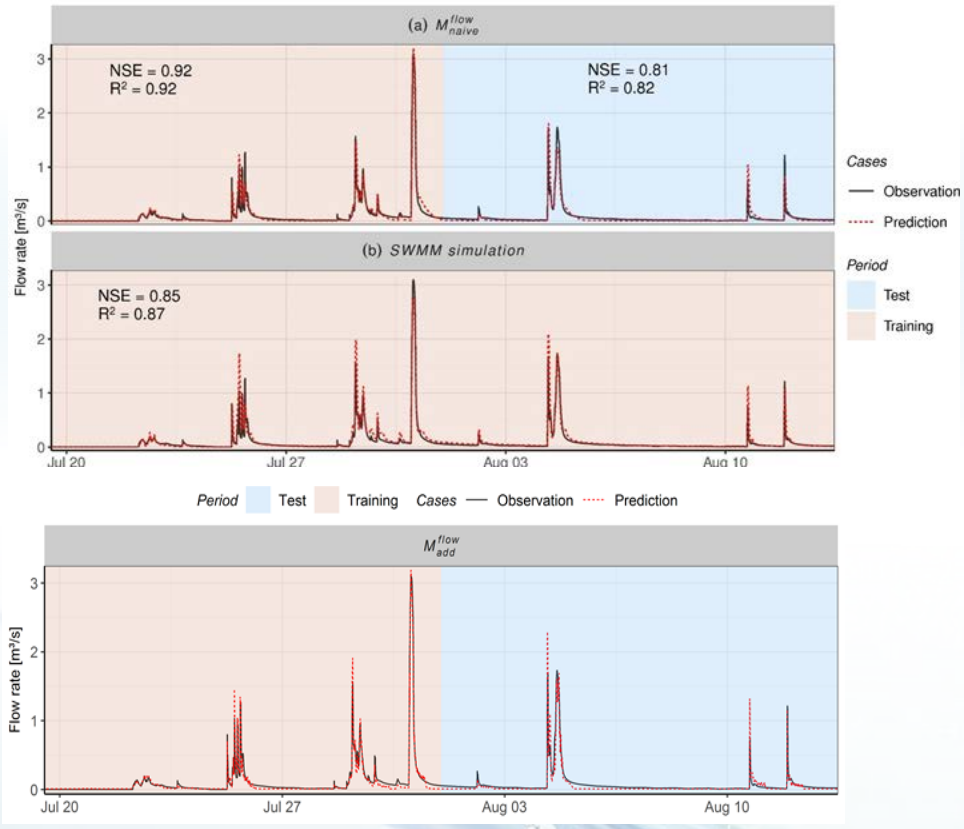


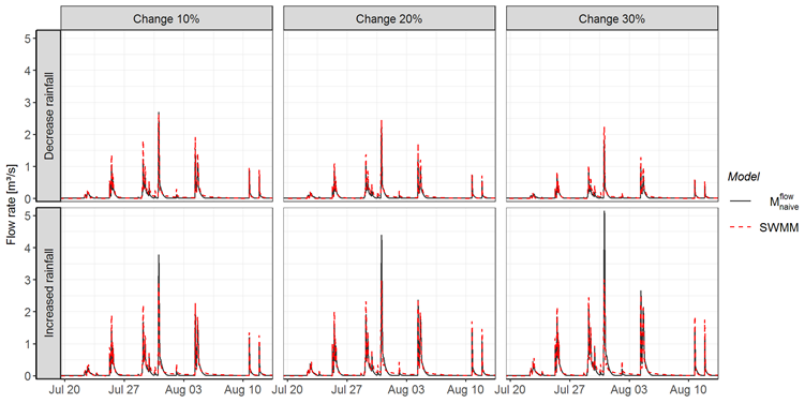
The East Fork of the Little Miami River Watershed serves as a test bed for EPA ORD research

Symposia Papers - UC Computer Science

- Testing
- Xuanyi Lin, Michelle Simon, Nan Niu (2018). "Exploratory Metamorphic Testing for Scientific Software" *Computing in Science and Engineering*. DOI: 10.1109/MCSE.2018.2880577
- Coupling
- Kamble, Suraj; Xiaoyu Jin; Nan Niu, Michelle Simon (2017) "A novel Coupling Pattern in Computational Science and Engineering Software." DOI: 10.1109/SE4Science.2017.10
- Computer Science and Environmental Engineering – June 2019
- 18th International Conference on Software and Systems Reuse (ICSR) https://www.uc.edu/eventservices/ICSR2019
- Machine Learning Analyses
- Yang Yang Dissertation – University of Hong Kong

HK Yang Yang's Machine Learning Results





Most Recent ORD Publications

- Niazi, M., C. Nietch; Mahdi Maghrebi; N. Jackson; B. R. Bennett; M. Tryby; and A. Massoudieh (2017). "Storm Water Management Model: Performance Review and Gap Analysis."

  Journal of Sustainable Water in the Built Environment

- Platz, M.; M. Simon; and M. Tryby (2018). "Testing of the SWMM Model's LID Modules."

  Submitted to *Journal of Sustainable Water in the Built Environment*

- Brad Barnhart, Heather Golden, Joseph Kasprzyk, James Pauer, Chas Jones, Keith Sawicz, Nahal Hoghooghi, Michelle Simon, Robert McKane, Paul Mayer, Amy Piscopo, Darren Ficklin, Jonathan Halama, Paul Pettus, Brenda Rashleigh.

  "Embedding co-production and addressing uncertainty in watershed modeling decision- support tools: successes and challenges"

  Journal of Environmental Modelling and Software 109 368-379

Thank You!

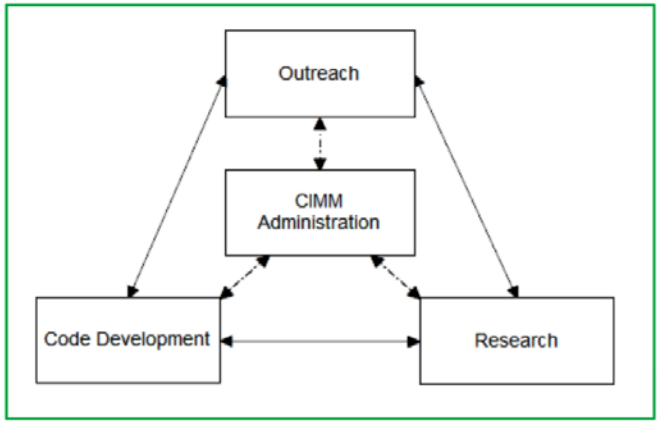
Michelle Simon
U.S. EPA Office of Research and Development (ORD)
513-569-7469 Simon.michelle@epa.gov

Extra slides

NCIMM – Cooperative Agreement UT Austin ($4M August 2016 – August 2021)

Center for Infrastructure Modeling and Management

Organized toward three major efforts



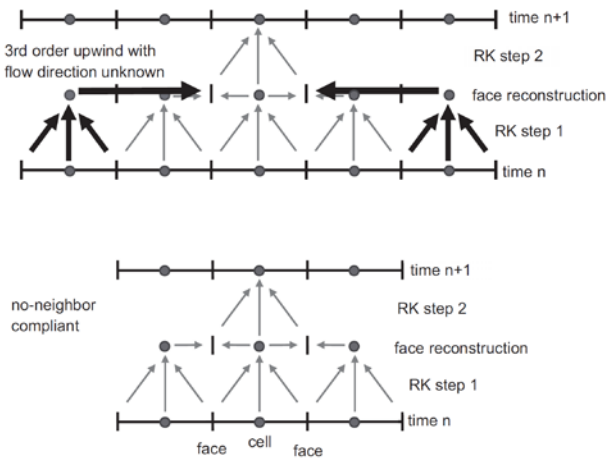
CIMM

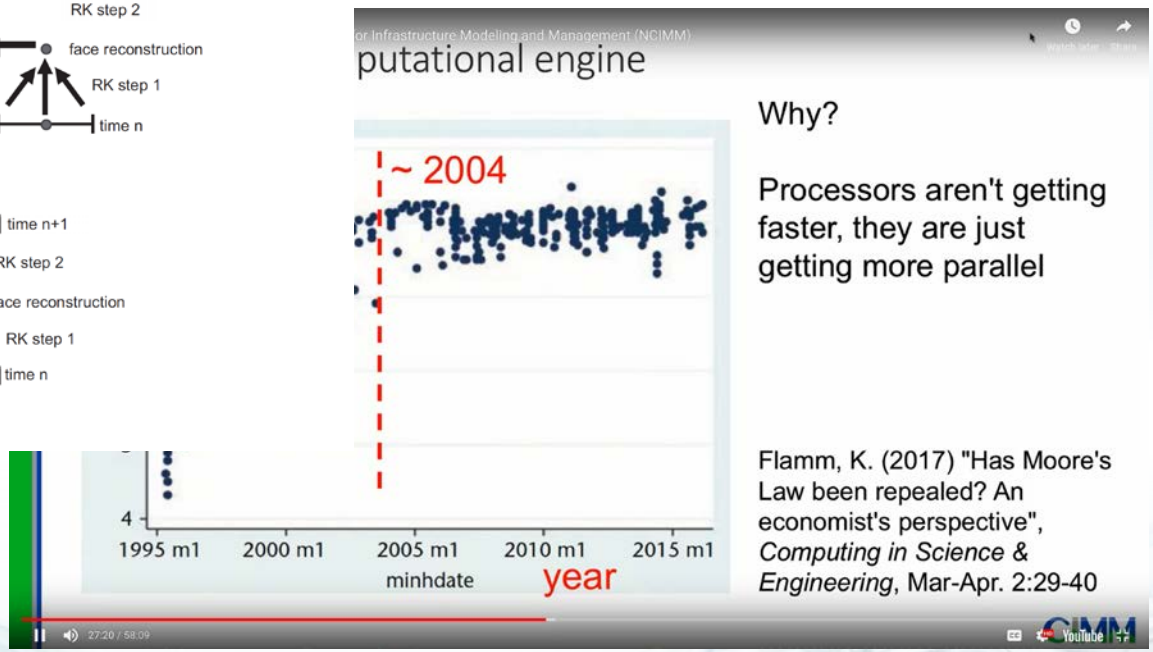
http://www.ncimm.org/

Figure from Ben Hodges's 2/21/2018 CUASHI Talk

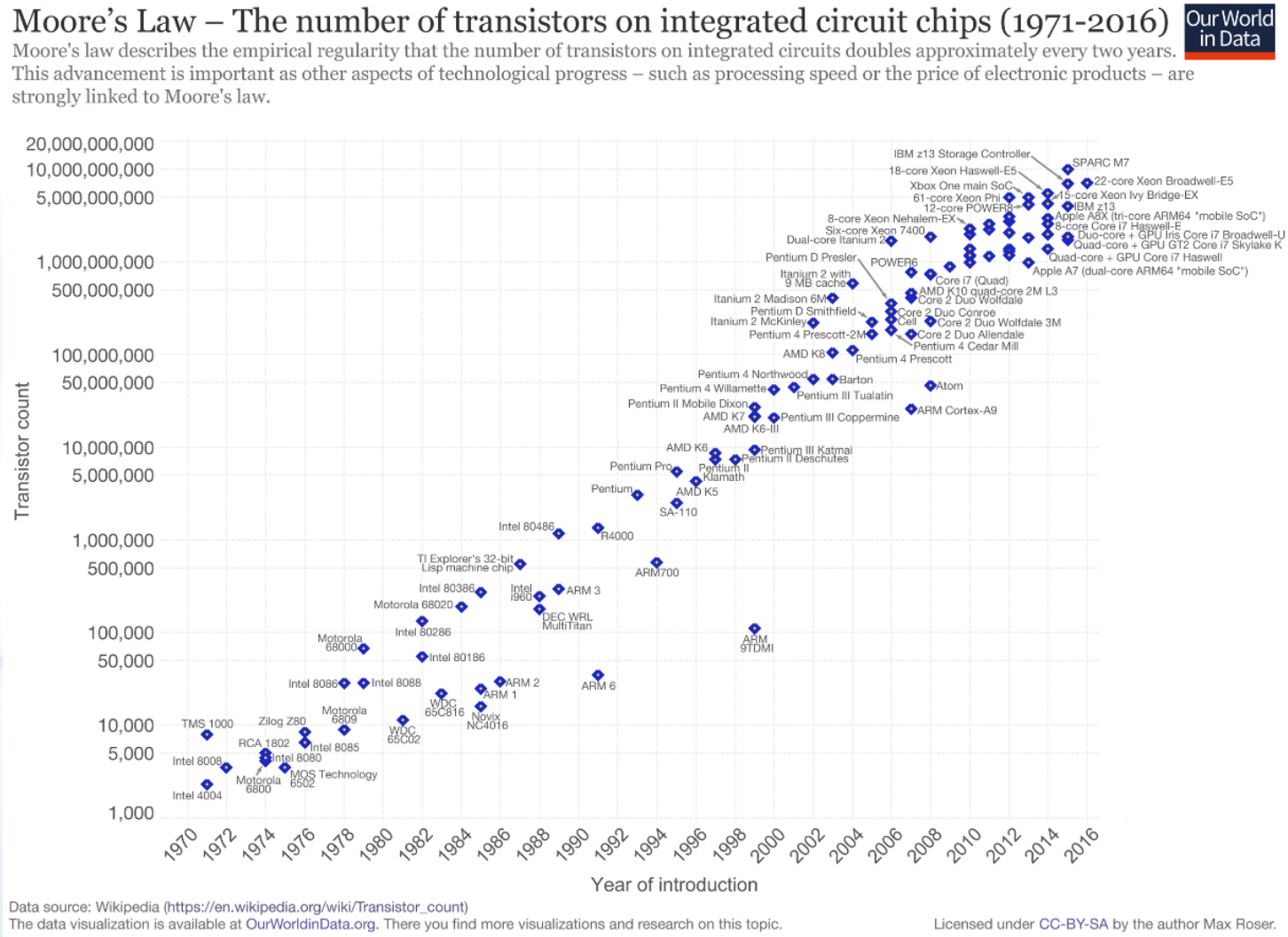
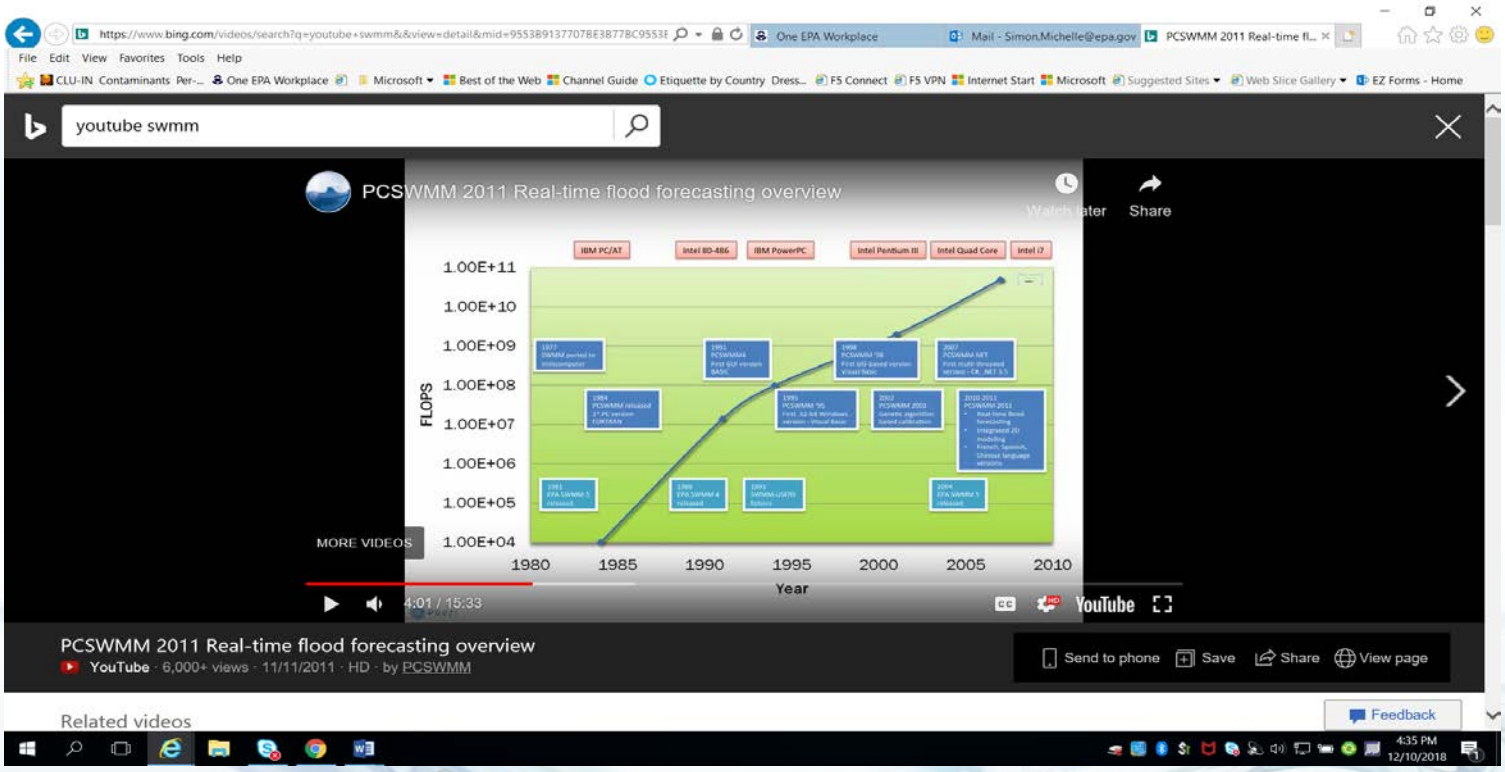
https://www.cuahsi.org/education/cyberseminars/urban-hydrology-and-the-national-center-for-infrastructure-modeling-and-management-ncimm

NCIMM Research – New Solver





Wikipedia


Moore's Law – The number of transistors on integrated circuit chips (1971-2016)
Our World in Data
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.
Transistor count
Year of introduction
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.
Licensed under CC-BY-SA by the author Max Roser.

PCSWMM Thoughts