An Introduction to the Storm Water Management Model (SWMM)

Michelle Simon

February 20, 2018

https://www.epa.gov/waterdata/surface-water-quality-modeling-training

Speaker Introduction

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20 Years Superfund Site Technical Support

Working with SWMM since 2010

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

Disclaimer

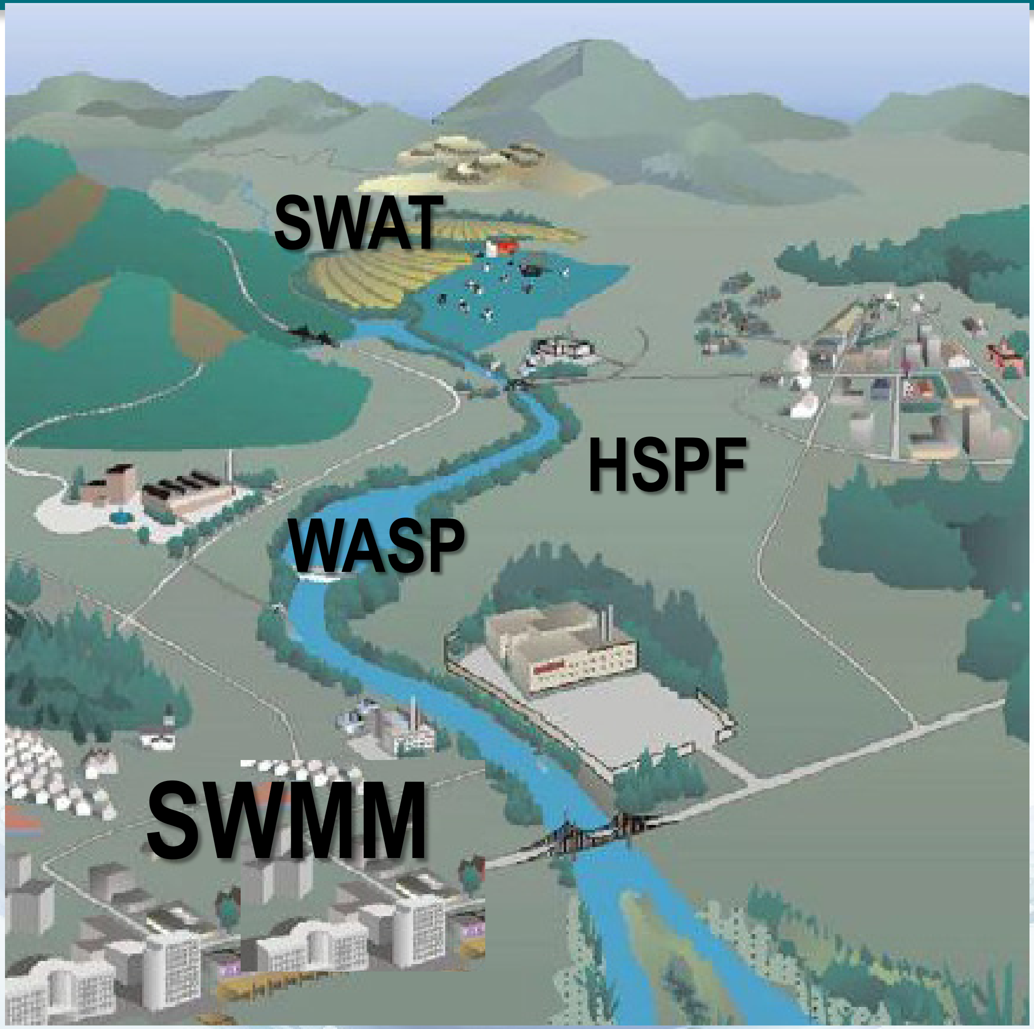
Any opinions expressed in this presentation are those of the author and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. But it has been through USEPA's official clearance process. **Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.**

Outline

Storm Water Management Model

- What is SWMM?
- Processes Modeled by SWMM
- Demonstration of SWMM
- Low Impact Development (LID)
- National Stormwater Calculator
- Location of Data
- Technical Support
- Discussion & Questions

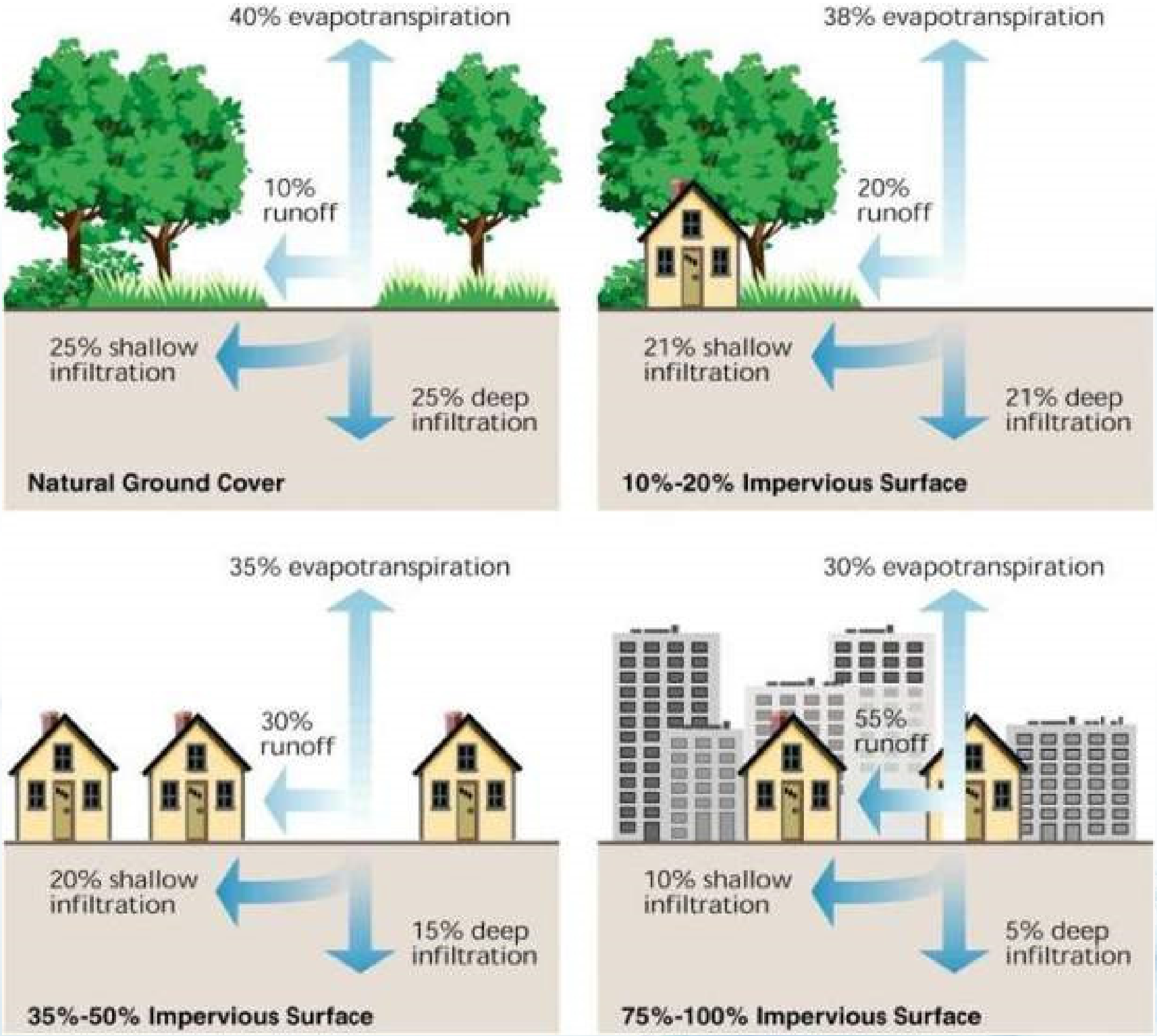
How SWMM, HSPF, SWAT, and WASP Relate



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

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

Urbanization Changes the Hydrologic Cycle

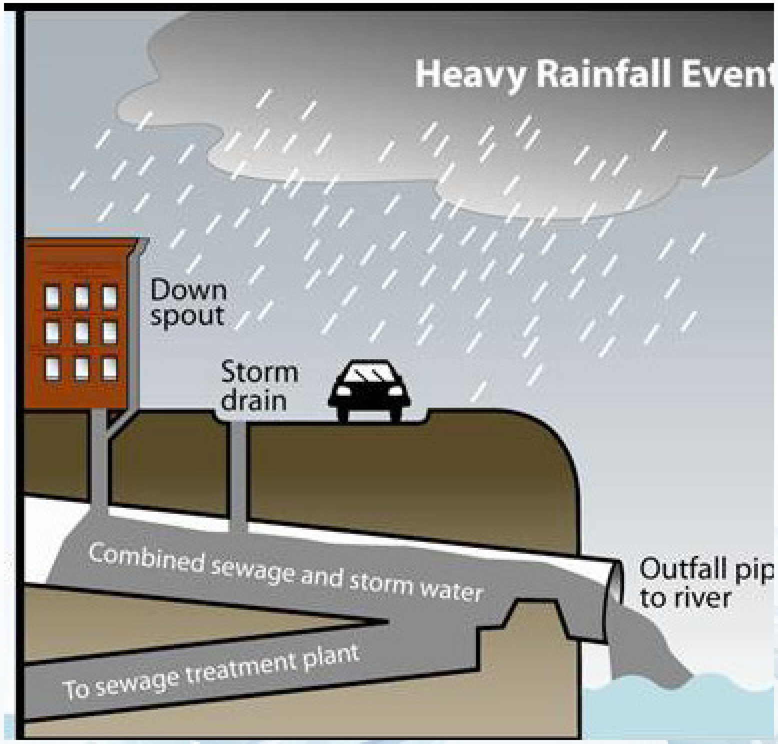


- Soils and vegetation are replaced with impervious surfaces
- Impervious surfaces are connected to dense drainage networks
- Runoff drains directly into streams, lakes, wetlands, and coastal waters
- Even small storms generate significant runoff

Urban Stormwater Impacts

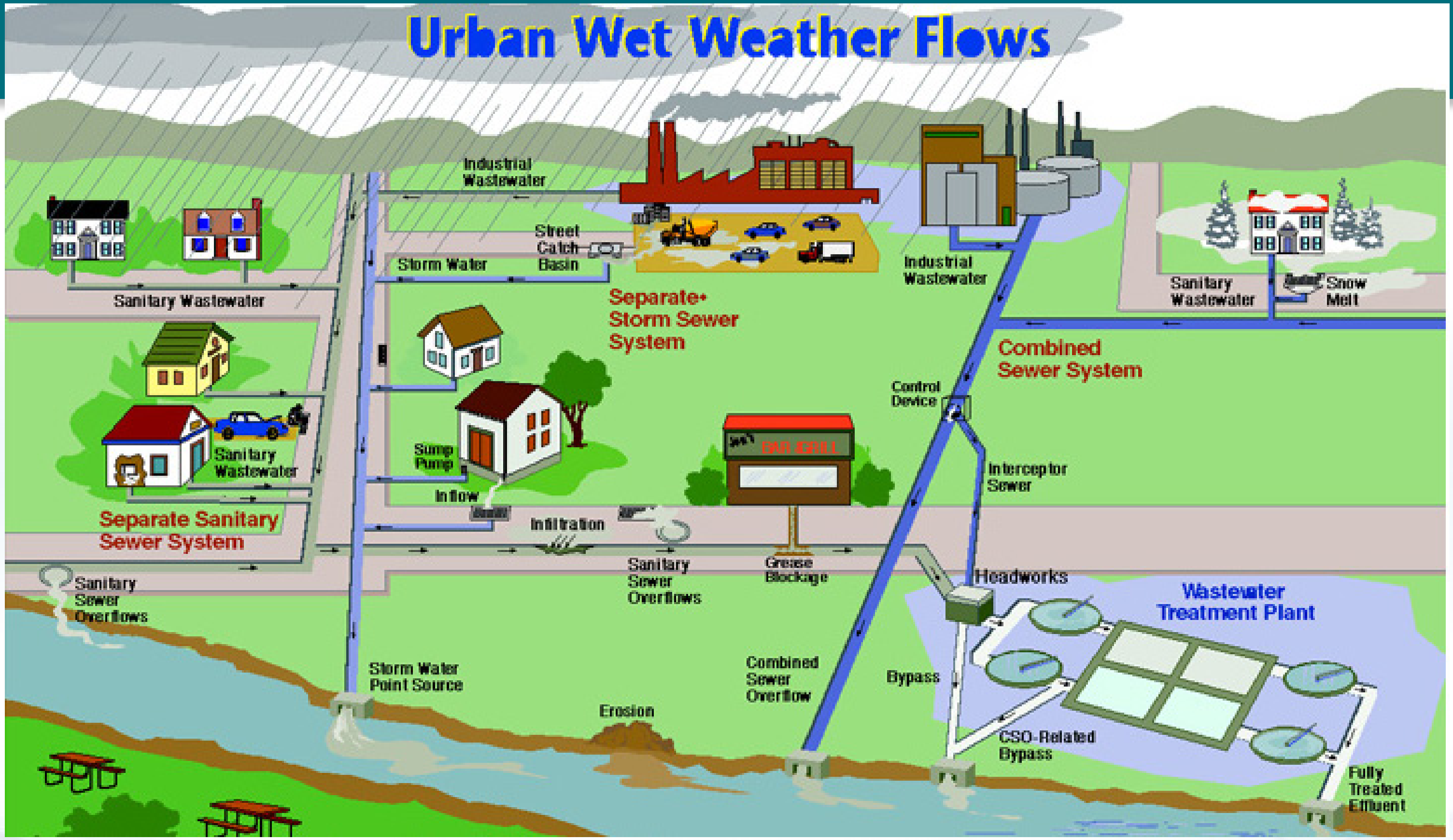
Hydrologic, Geomorphic, and Biological Impacts:

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



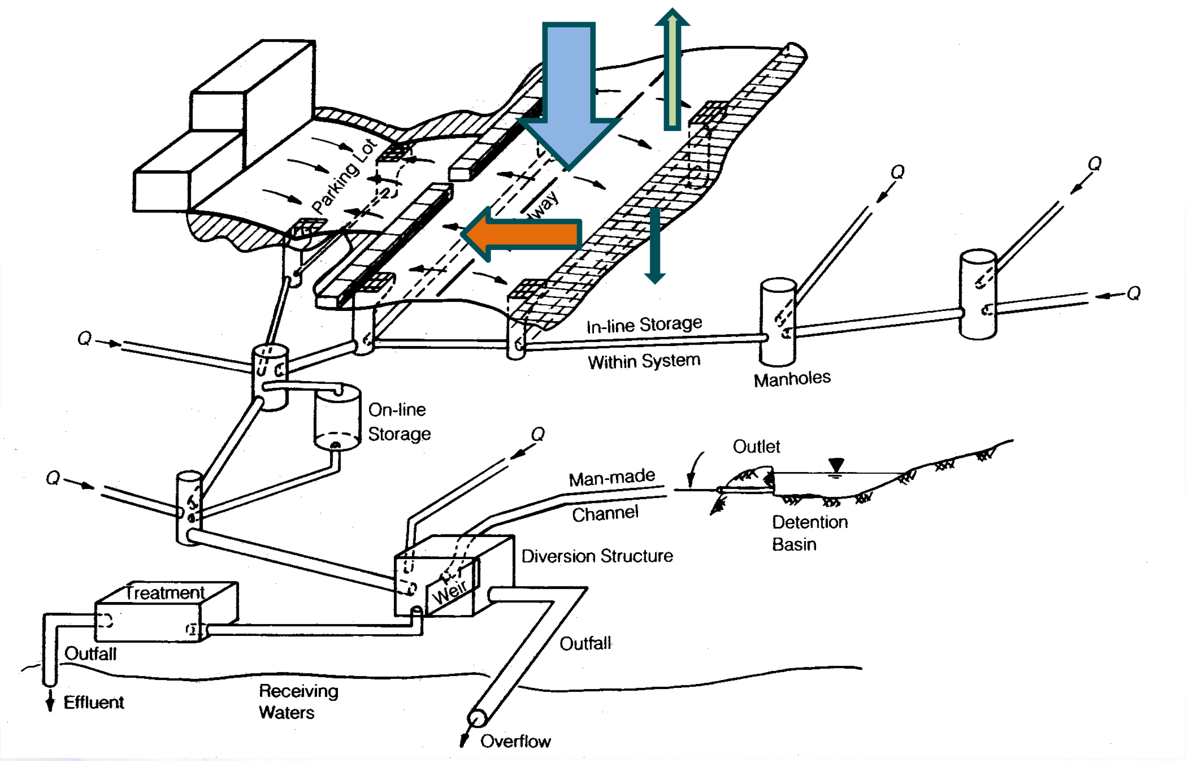
- Impaired habitat and water quality impact fisheries and shellfish harvesting due to e coli, metals, PAHs, and other pollutants.
- Reduced groundwater recharge impacts water supplies.

What is SWMM?



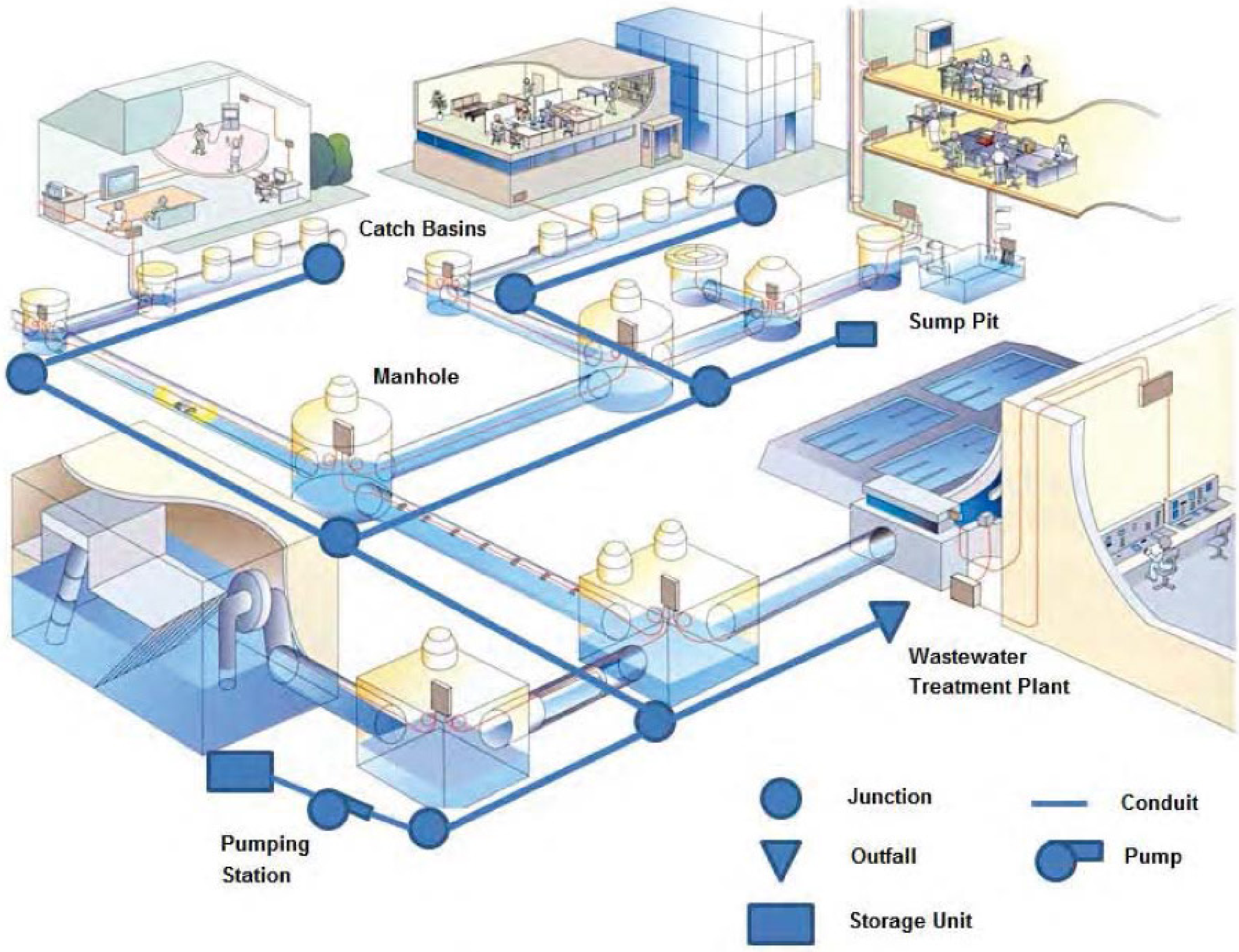
SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

How does SWMM Model?



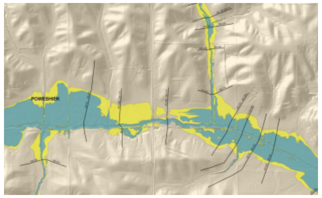
SWMM is a **distributed**, **dynamic rainfall-runoff** simulation model used for **single event** or long-term (**continuous**) simulation of runoff quantity and quality from **primarily urban** areas.

Hydraulic Model



United States Environmental Protection Agency

What is SWMM Used For?



Design and sizing of drainage system components.

Control of combined and sanitary sewer overflows.

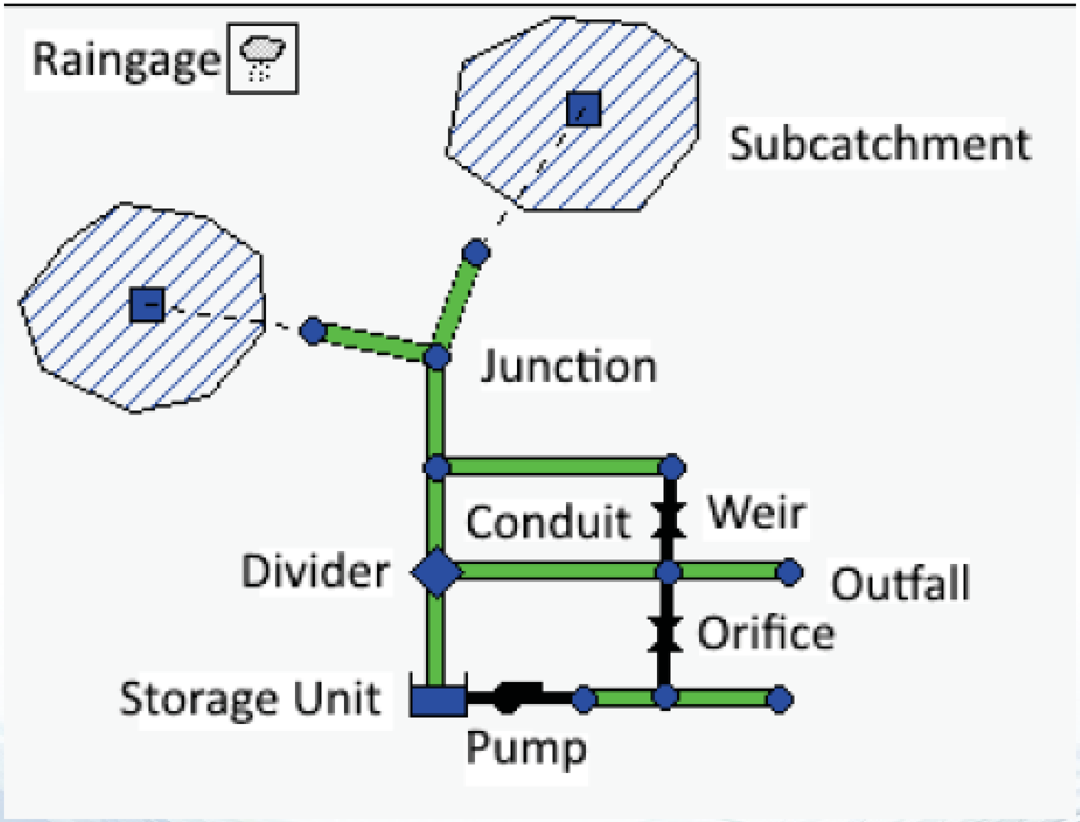
Modeling Inflow & Infiltration in sanitary sewer systems.

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

Evaluating green infrastructure for sustainability goals.

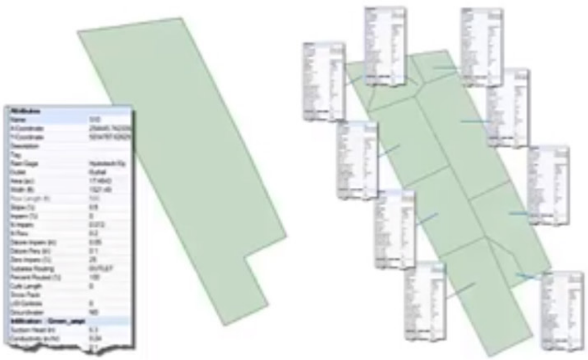
Flood plain mapping of natural channel systems.

SWMM's Conceptual Model



Idealized Subcatchment (Courtesy of Rob James, CHI Water)

Subcatchment parameters



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

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

Hydrology – Governing equations

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

where:

i = rate of rainfall + snowmelt (ft/s)

e = surface evaporation rate (ft/s)

f = infiltration rate (ft/s)

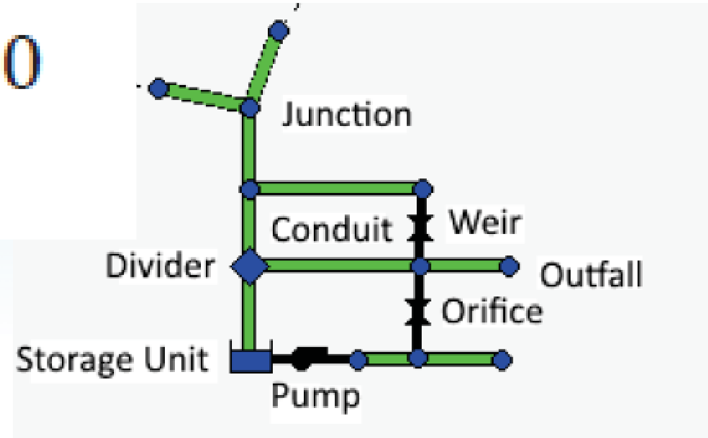
q = runoff rate (ft/s).

Hydrology Reference Manual Equation 3-1

Hydraulic Governing Equations

- Continuity

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



where

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

Governing Equations

- Momentum

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

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

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

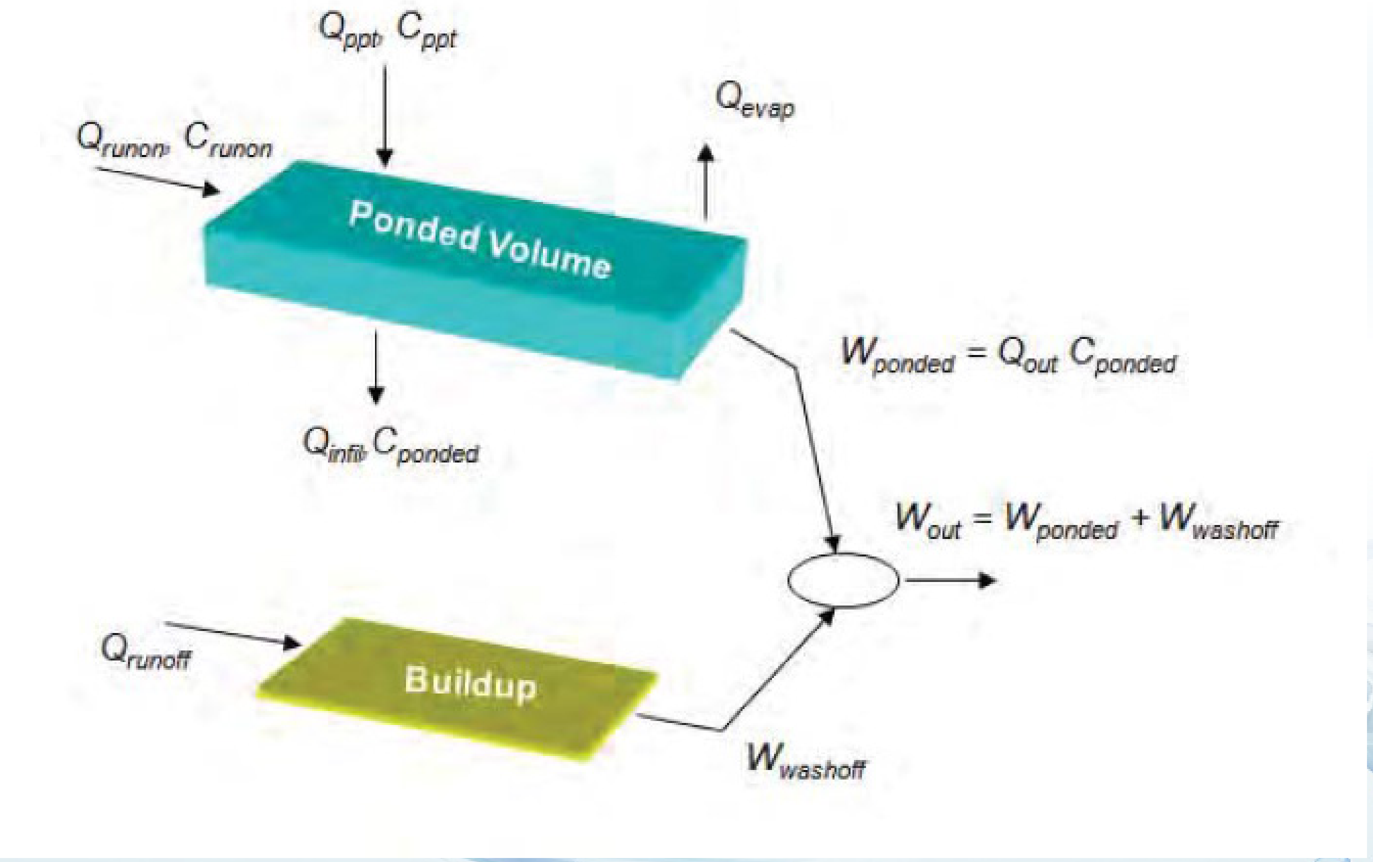
Kinematic Wave

Cannot have

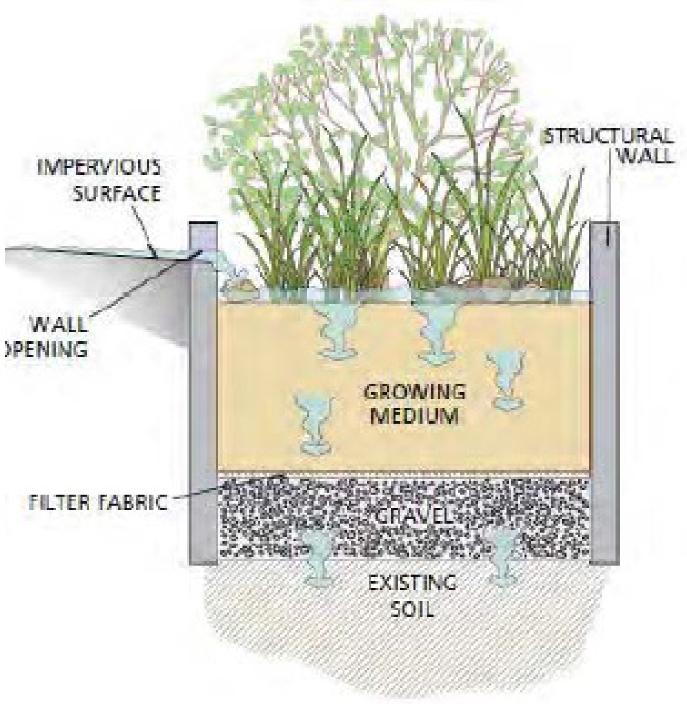
- Looped networks
- Backwater effects
- Pressure-flow conditions

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

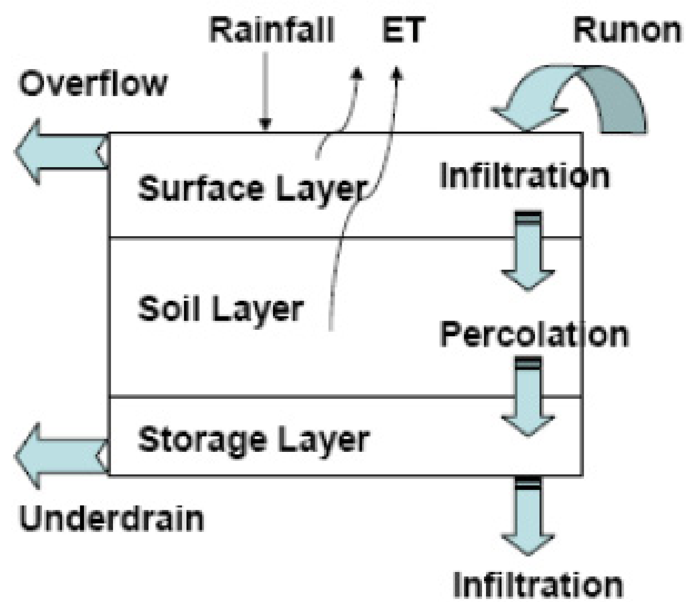
Pollutant Buildup and Washoff



Green Infrastructure Subcatchment



(A)



(B)

Questions?

Demonstration of SWMM

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

- Calibration of SWMM

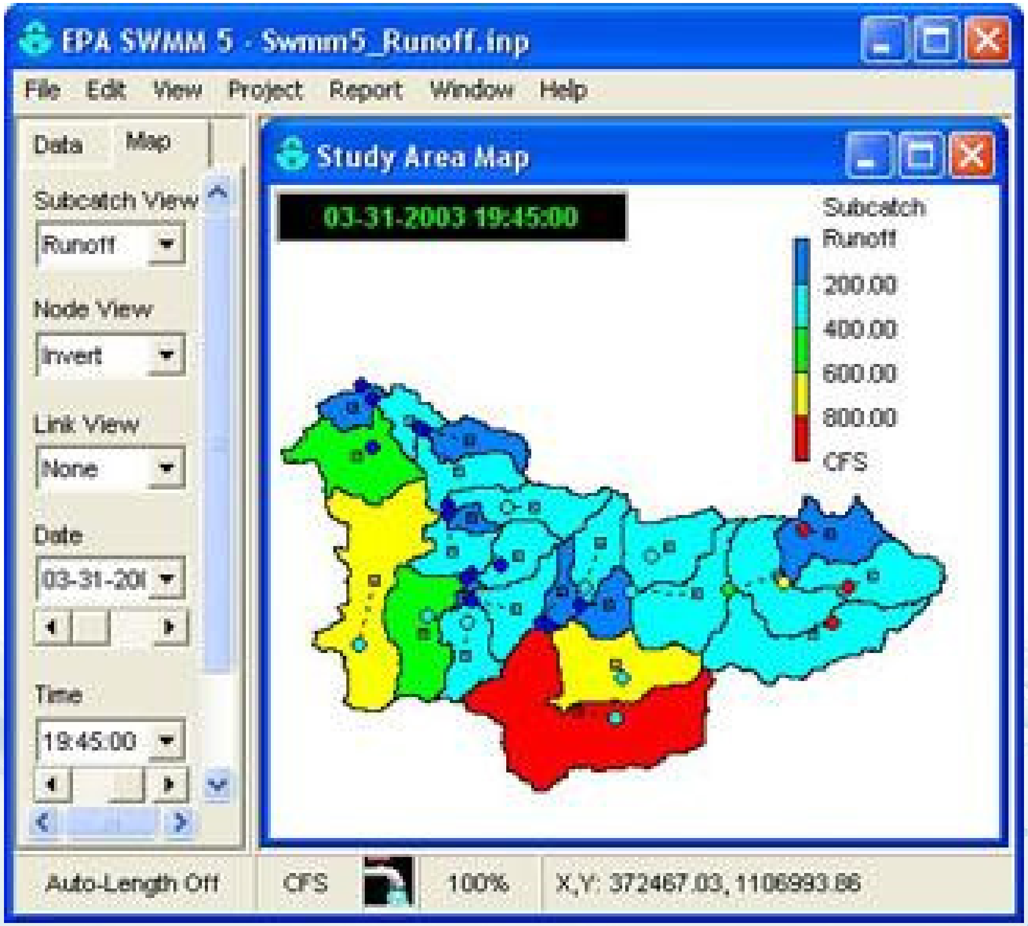
SWMM Demonstration

- Go to Desktop SWMM

Hydraulic Animation
(Courtesy of Robert Dickinson, Innovyze)

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)

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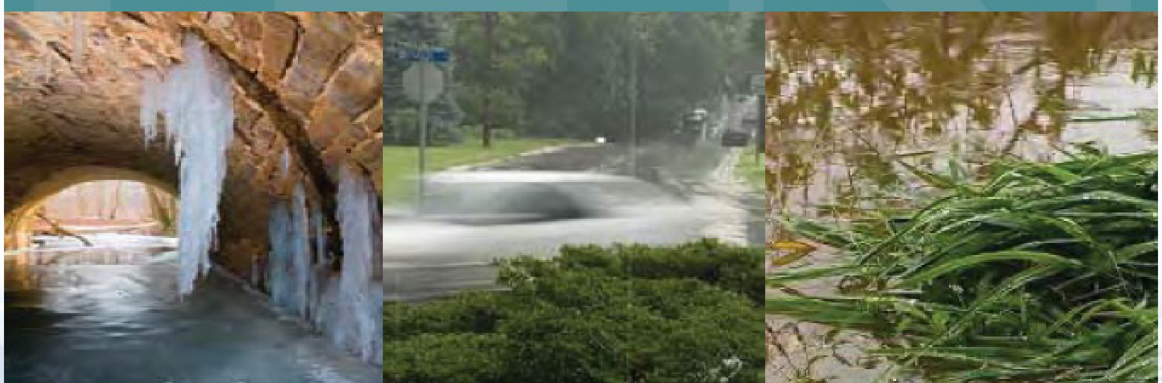
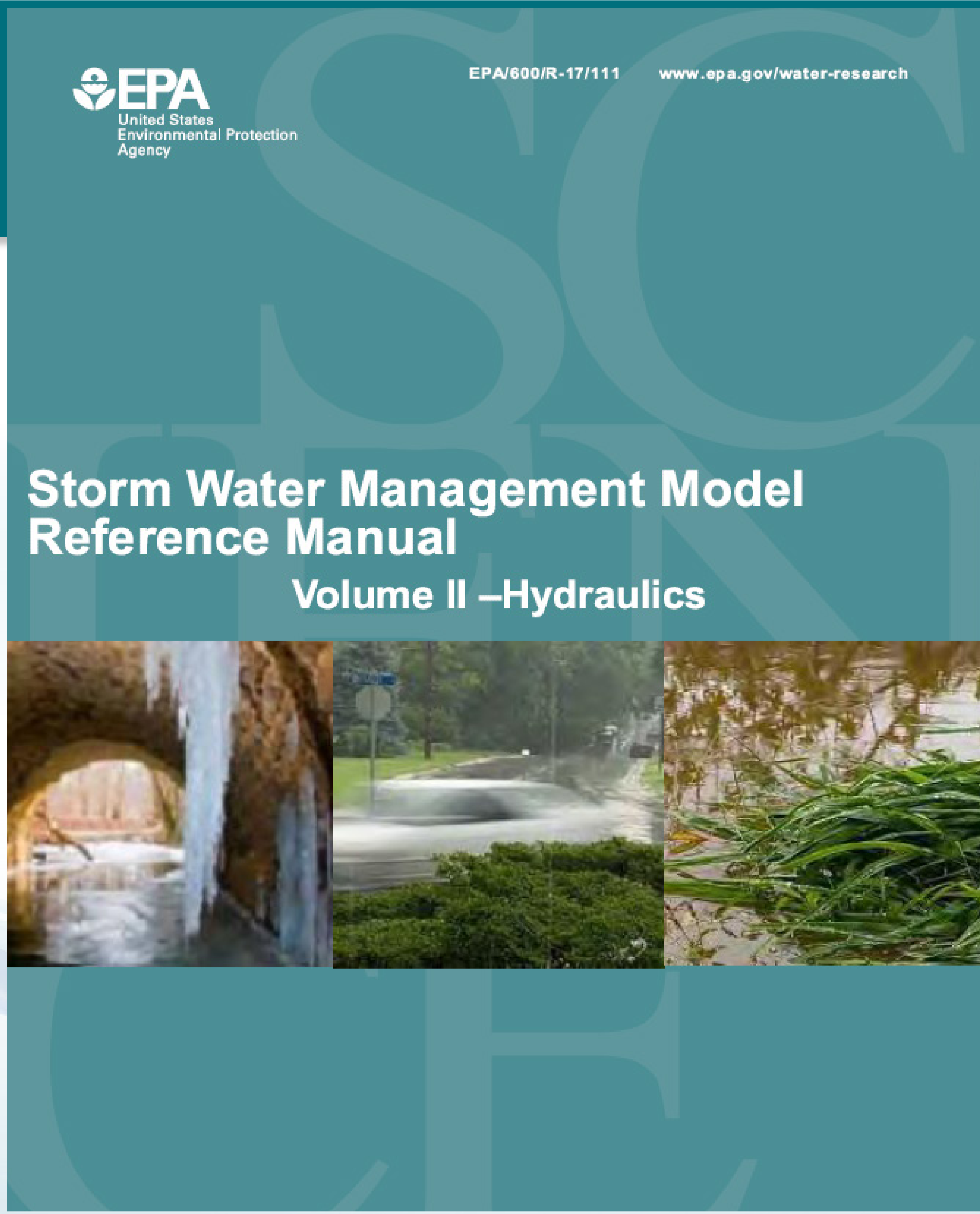
Agency

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

Storm Water Management Model Reference Manual

Volume I – Hydrology (Revised)




EPA United States Environmental Protection Agency

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

Storm Water Management Model Reference Manual

Volume II –Hydraulics

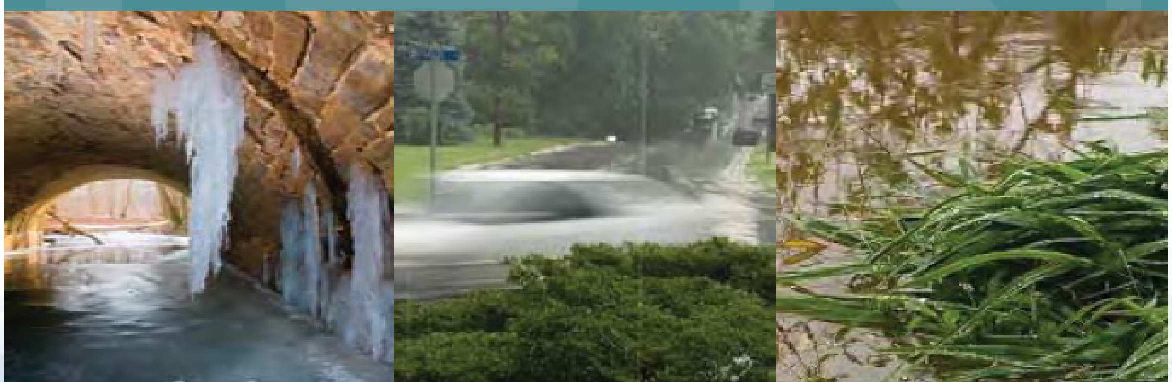
EPA

United States
Environmental 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

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.

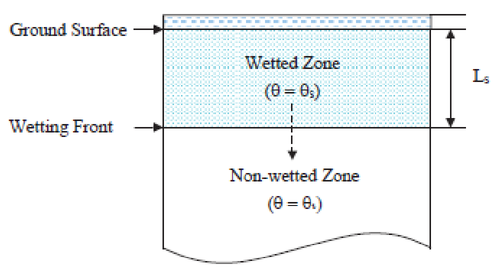


Figure 4-5 Two-zone representation of the Green-Ampt infiltration model (after Nicklow et al., 2006).

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:

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)

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

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 $i \le K_s$, 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, ψ_s = 6.5 in, and θ_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 Tutorial's

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.

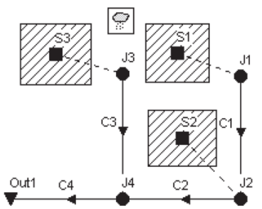


Figure 2-1 Example study area

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
08/07/2017	SWMM Reference Manual Volume II—Hydraulics
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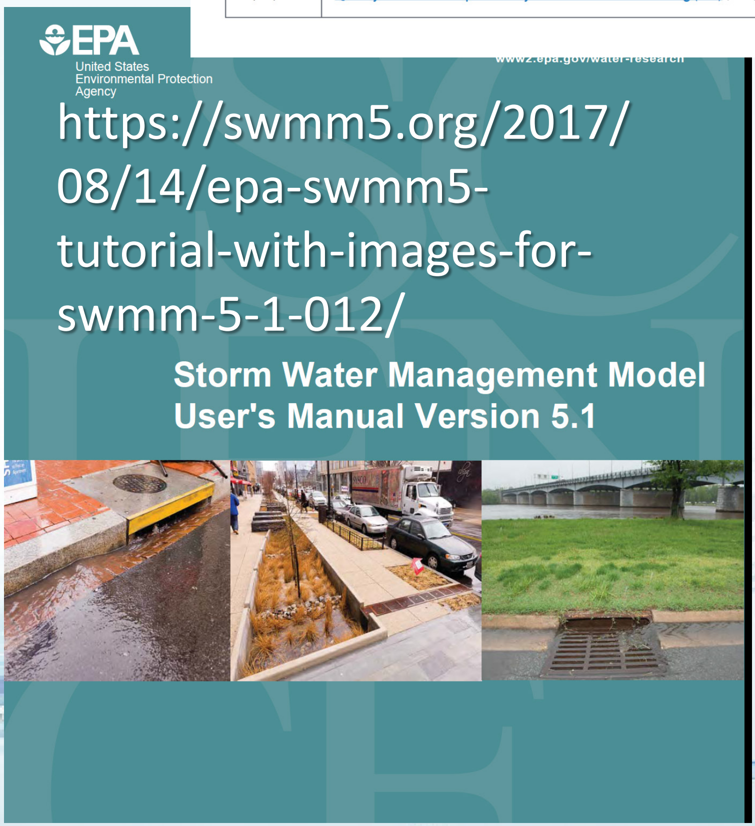
https://swmm5.org/2017/08/14/epa-swmm5-tutorial-with-images-for-swmm-5-1-012/



LID Modeling in SWMM

Types of LIDs Modeled

Disconnection

Infiltration Basin

Rain Garden

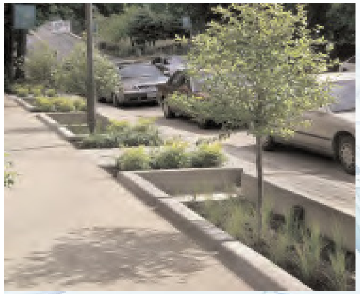
Cistern

Infiltration Trench

Green Roof

Porous Pavement

Vegetative Swale



Street Planter

Testing of SWMM Model's LID Modules

Michelle Platz, Michelle Simon, and Michael Tryby

United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory

Introduction

- Municipalities rely heavily on software such as the EPA's **Storm Water Management Model (SWMM)** to design storm water and wastewater infrastructure, a multi-billion dollar, multi-decade effort.
- **Study Main Objective**: quantify SWMM v5.1.10 accuracy in simulating hydrologic activity of previously monitored low impact development storm water control measures.
- This study's results and parameter sensitivity analysis led to several SWMM LID module improvements.

Methodology

- Model performance was evaluated by mathematically comparing multi-event storm empirical data to modeled results.
- The calibration methodology utilized **PEST** software to determine the valuation of unmeasured hydrologic parameters.

U.S. Environmental Protection Agency
Office of Research and Development

Results

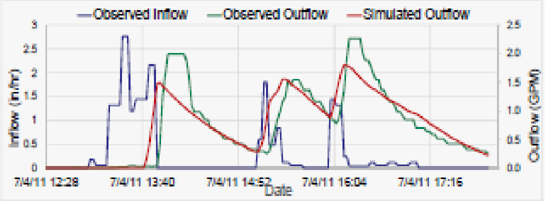


Figure: Boone Porous Pavement hydrograph depicting early outflow start-time

Table 1: Sensitivity analysis summary

	First Most Sensitive Parameter		Second Most Sensitive Parameter		Third Most Sensitive Parameter	
LID Name	**Layer**	**Parameter**	**Layer**	**Parameter**	**Layer**	**Parameter**
Graham Bio-Retention	Drainage	Flow Coefficient	Soil	Wilting Point	Soil	Field Capacity
Villanova BTI Rain Garden	Surface	Surface Roughness	Surface	Vegetation Volume	LID Usage	Surface Width
Villanova Infiltration Trench	Drainage	Flow Coefficient	Drainage	Flow Exponent	Storage	Void Ratio
UMD BioSwale	Roadway	Road Roughness	Surface	Side Slope	Surface	Surface Roughness
Washington DOT BioSwale	Surface	Surface Roughness	Surface	Vegetation Volume	Infiltration	Suction Head
Hamilton Ecoroof	Soil	Wilting Point	Soil	Porosity	Soil	Thickness
EOC Green Roof	Soil	Wilting Point	Soil	Field Capacity	Drainage Mat	Void Ratio
FS10 Green Roof	Soil	Field Capacity	Soil	Wilting Point	Drainage Mat	Void Ratio
Boone Porous Pavement	Storage	Conductivity	Storage	Void Ratio	Drainage	Drain Coefficient

Table 2: N-S Efficiency Value and R^2 Value results summary

LID Name	Average N-S Efficiency Value	Average R^2 Value
Graham Bio-Retention	0.67	0.91
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

Discussion and Conclusions

- The most significant discovery made in this analysis was that given proper instrumentation, **site specific parameter measurement, and calibration, SWMM can accurately reproduce hydrologic response of enhanced infiltration-based** LID storm water controls.
- **SWMM does not model lateral exfiltration**, severely limiting its accuracy in predicting hydrologic performance for narrow low impact development controls LIDs such as infiltration trenches.

Acknowledgements

The authors heavily relied upon the information supplied by The Cadmus Group, Inc., in collaboration with Michael Baker Corporation, Inc. via Contract No. EP-C-11-03 who performed a thorough study of the literature, identifying the Low Impact Development data sets, wrote the project descriptions, and formatting the SWMM input files for that we used for this work. Any opinions expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

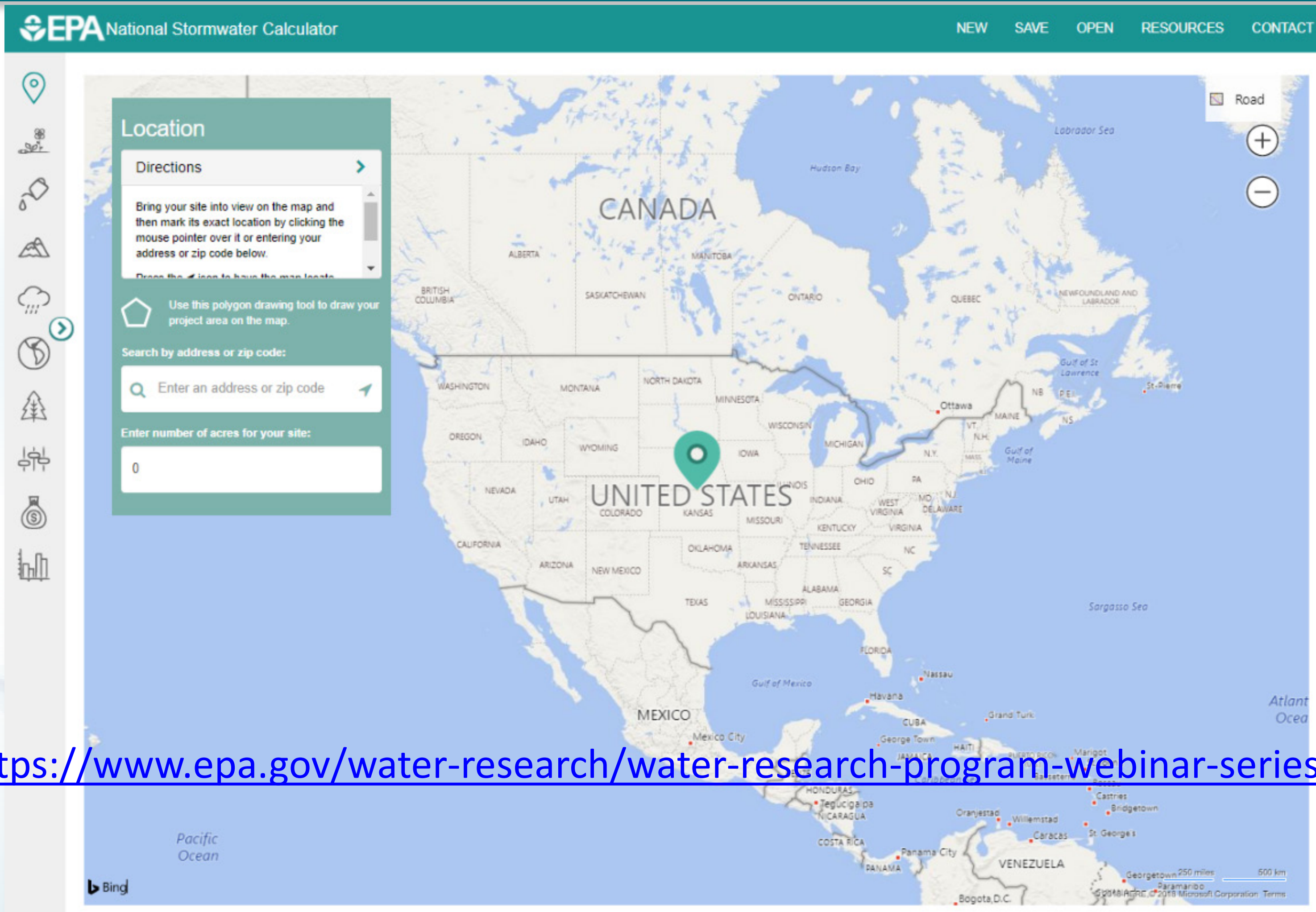
Rossman, L. A. and W. C. Huber (2016b). Storm Water Management Model Reference Manual Volume III - Water Quality. EPA/600/R-16/093.

Doherty, J. (2005). "PEST Model-Independent Parameter Estimation User Manual: 5th Edition.": 333.

United States Environmental Protection Agency

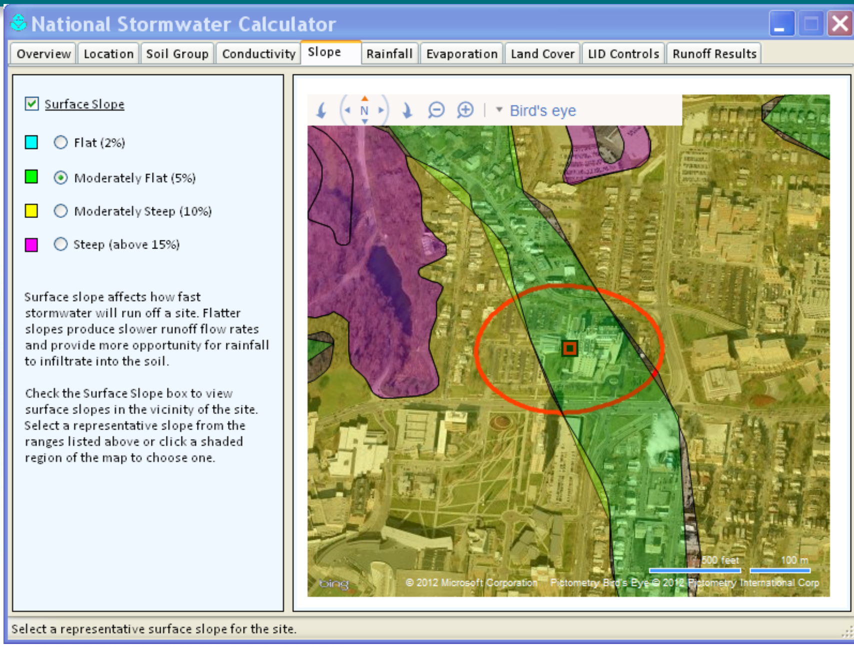
National Stormwater Calculator

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

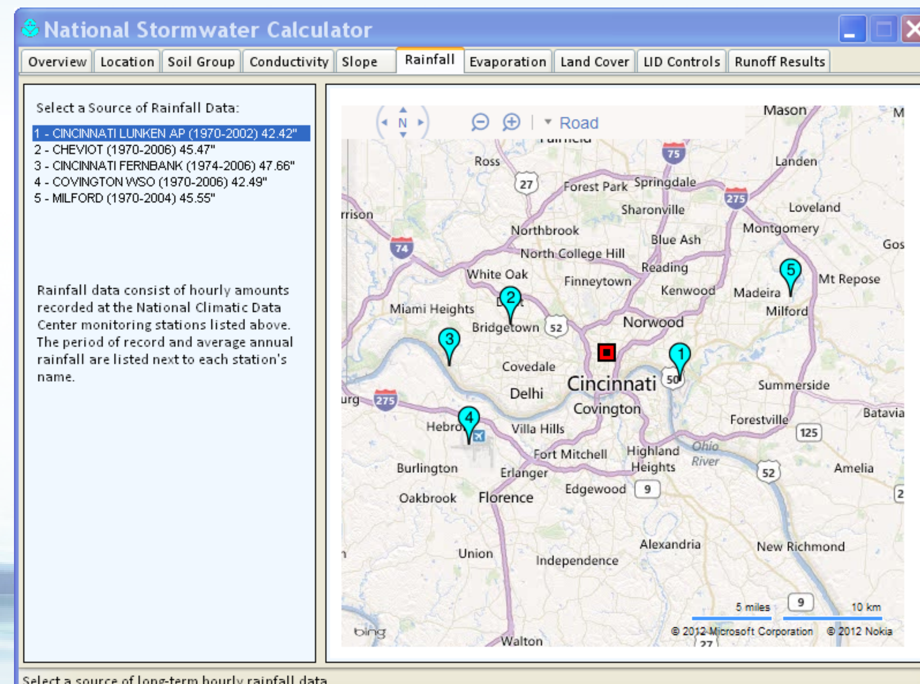


: https://www.epa.gov/water-research/water-research-program-webinar-series .

National Stormwater Calculator



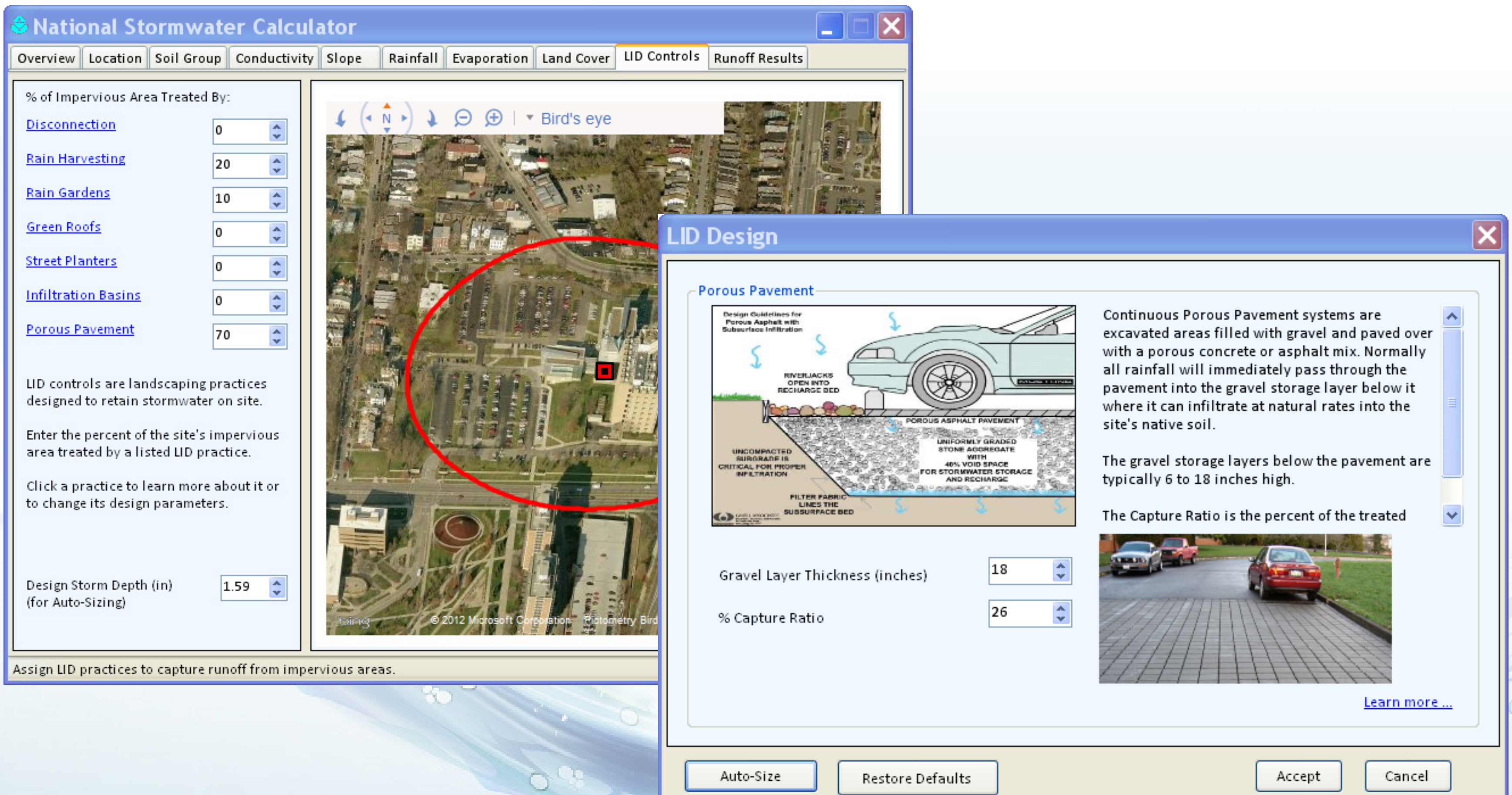
Displays soil properties obtained from querying the NRCS SSURGO database



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

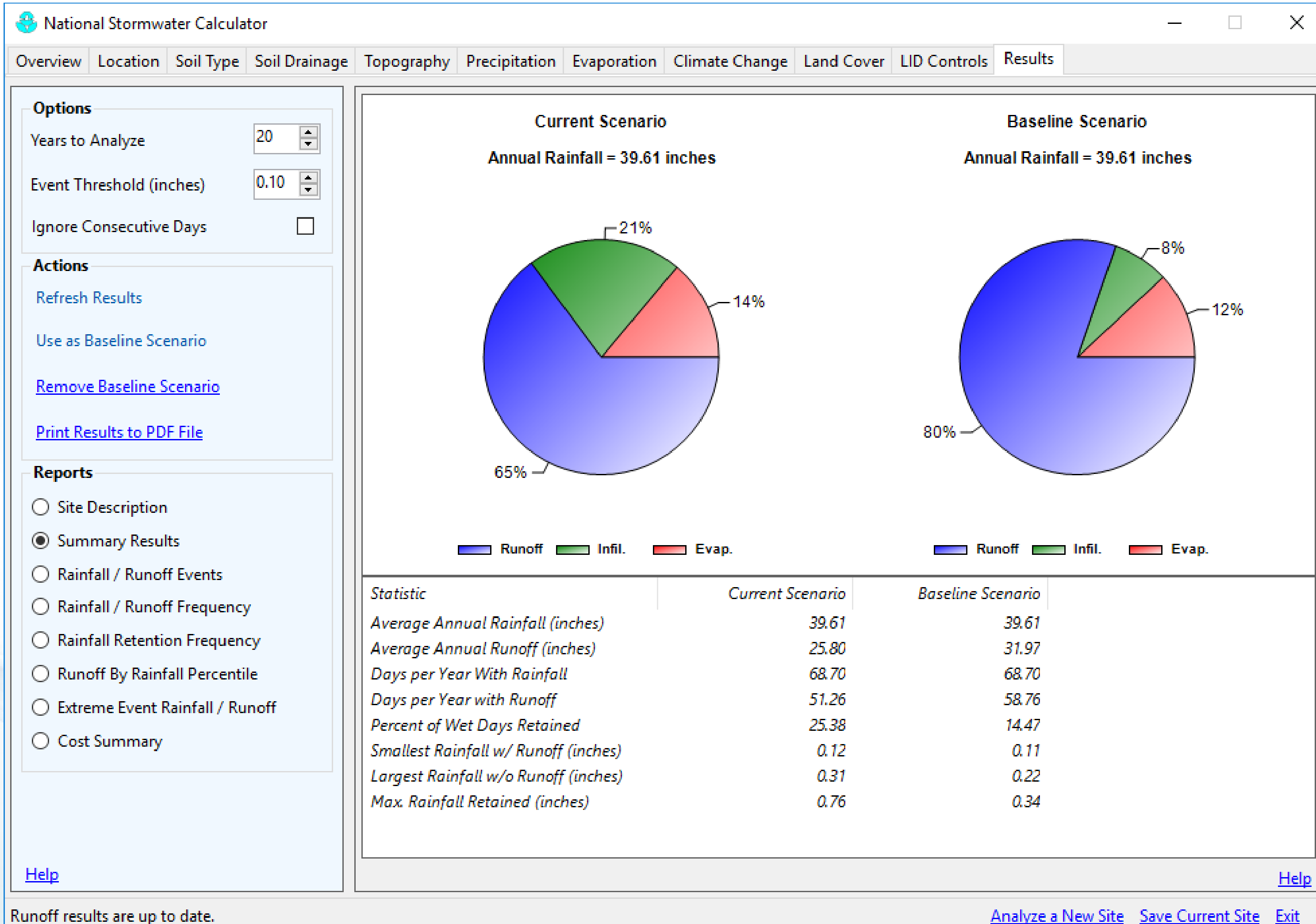
National Stormwater Calculator

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



National Stormwater Calculator

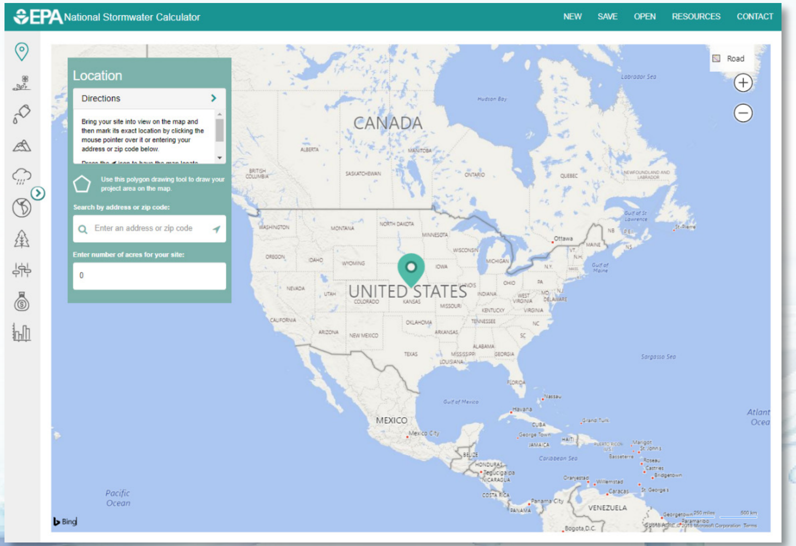
The Calculator runs SWMM to generate daily rainfall/runoff statistics.



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



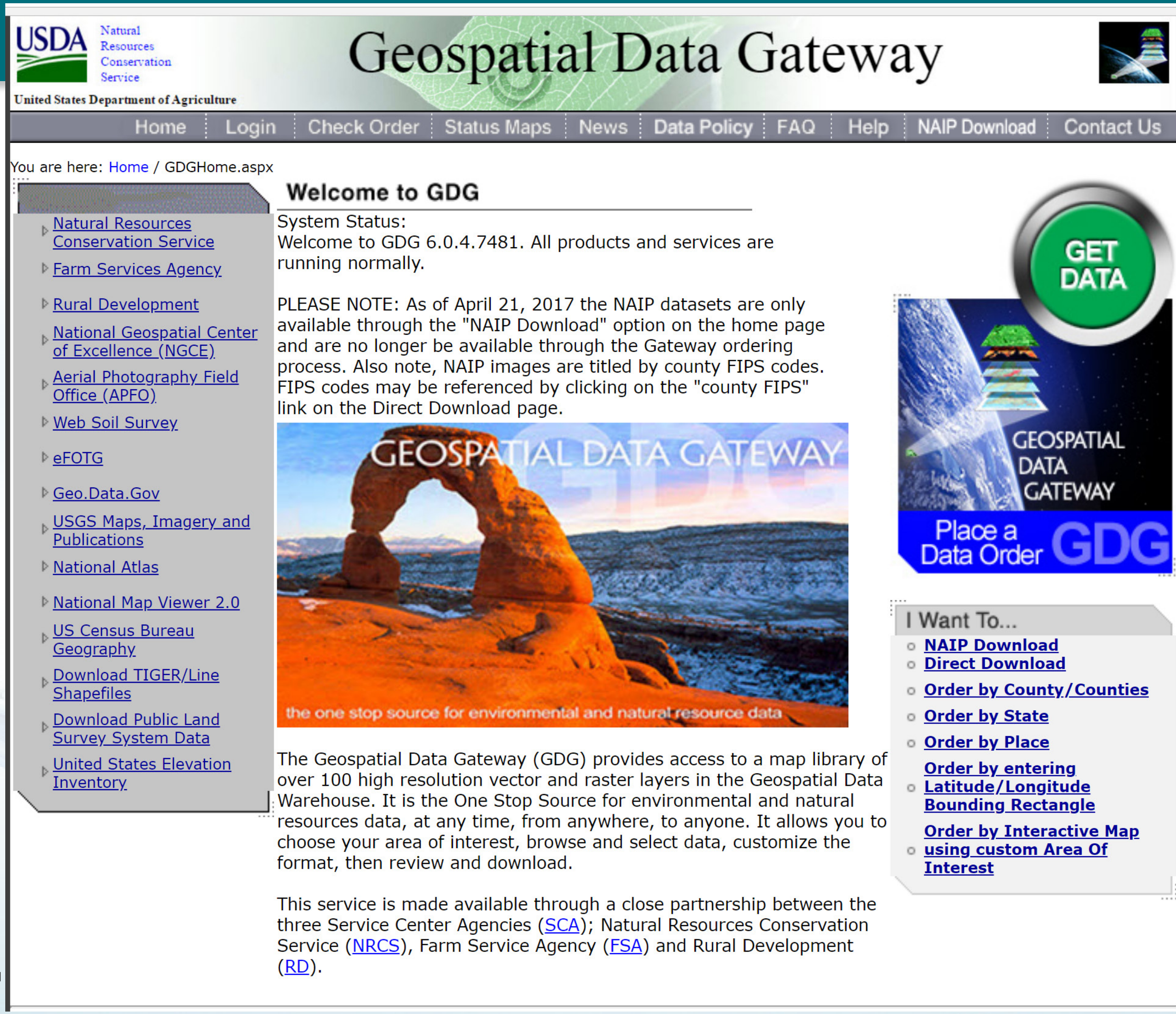
Where to get information

https://www.epa.gov/exposure-assessment-models
https://www.nrcs.usda.gov
https://www.usgs.gov/science/mission-areas/water-resources

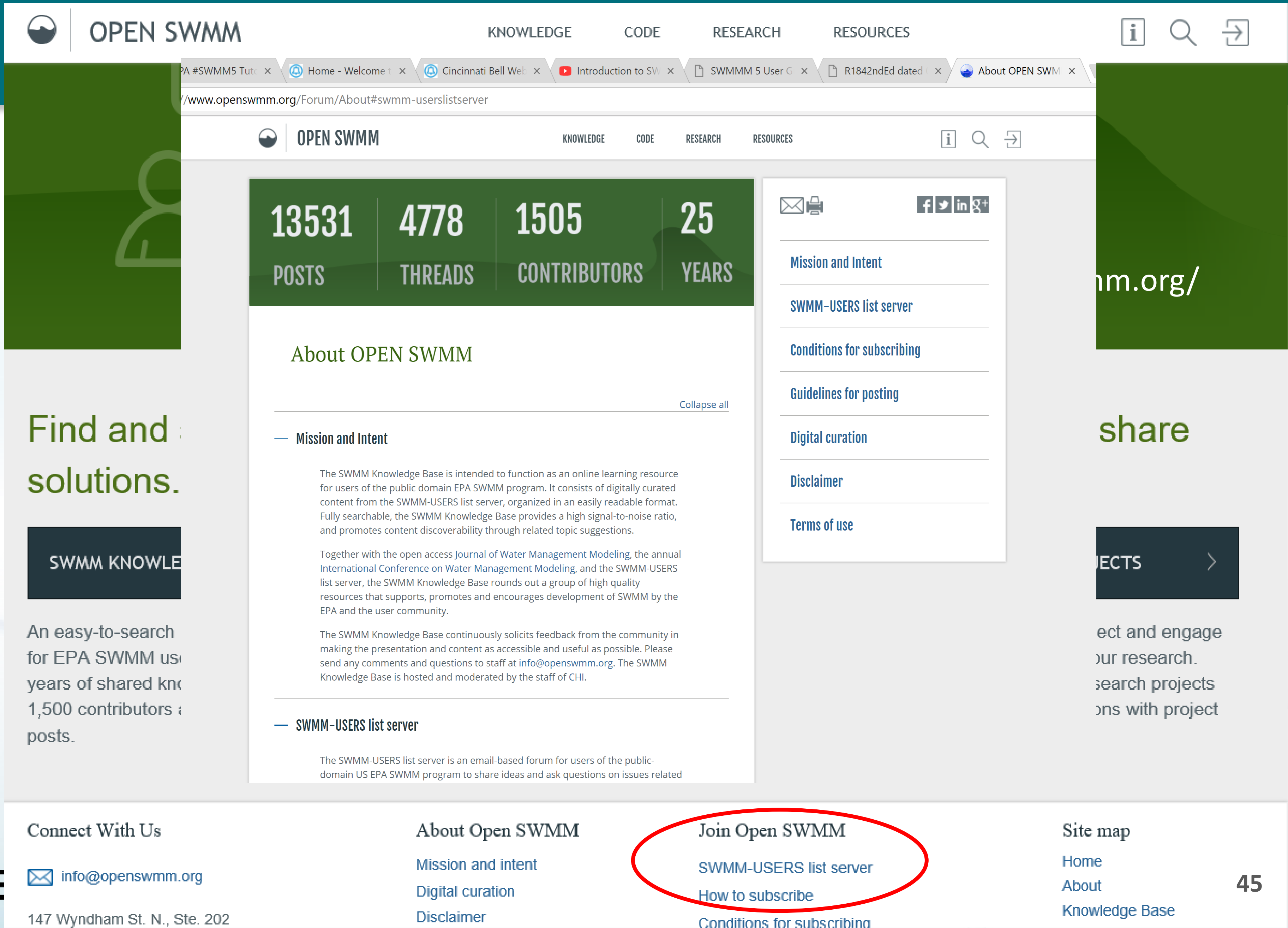
Gather Data
- DEM and NLCD https://viewer.nationalmap.gov/basic/
- Soils - https://www.nrcs.usda.gov
  - SSURGO
  - STATGO
- Climate - NOAA National Centers for Environmental Information (www.ncdc.noaa.gov)

Hydrologic Unit Maps (HUC)
- NRCS http://www.usda.gov/wps/portal/nrcs/main/national/water/watersheds

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



Technical Support - OPEN SWMM



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/

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.“
Under Division Review

Thank You!

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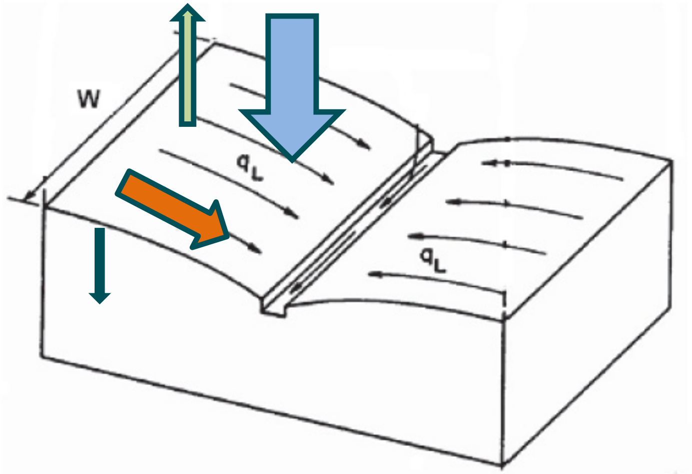
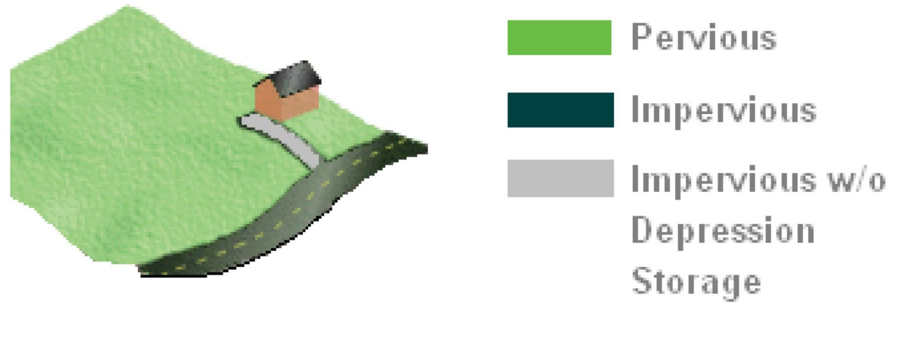
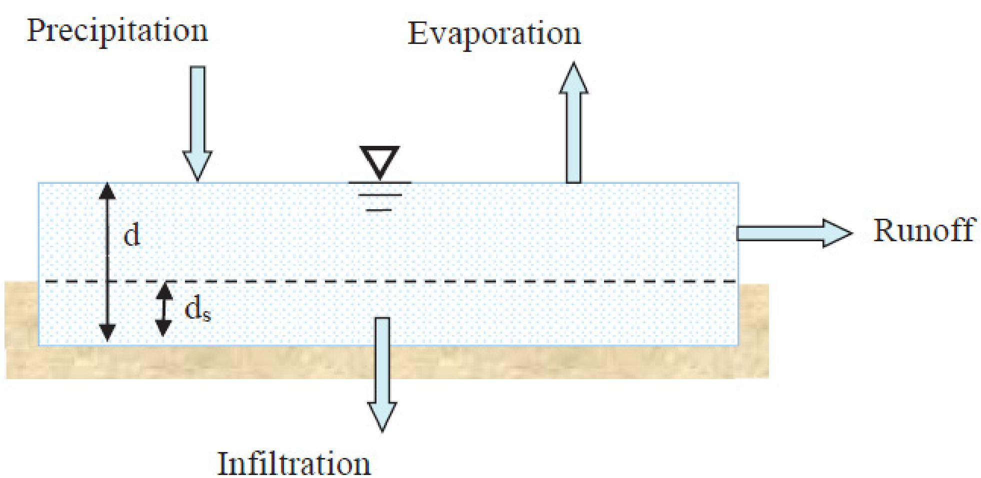
Questions?

Extra Slides

Idealized Subcatchment







SWMM - Manning Equation

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

Q = flow rate

A = cross sectional area

R = hydraulic radius

S = slope

n = Manning roughness coefficient

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