Phase II MS4 Permits and EPA Watershed Models

Michelle Simon, Ph.D., P.E.
United States Environmental Protection Agency

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Introduction

Michelle Simon

BS Chemical Engineering, University of Notre Dame
MS Chemical Engineering, Colorado School of Mines
PhD Environmental Science,
Minor Chemical Engineering, University of Arizona

Went to US EPA in 1990 - worked on Superfund Site Cleanup mostly in the vadose zone and groundwater

Since 2010, I worked on Storm Water Runoff

Questions

Are you a

- Hydrologist
- Engineer
- Other?

Do you

- Use the rational method
- Use surface water models
- Other?

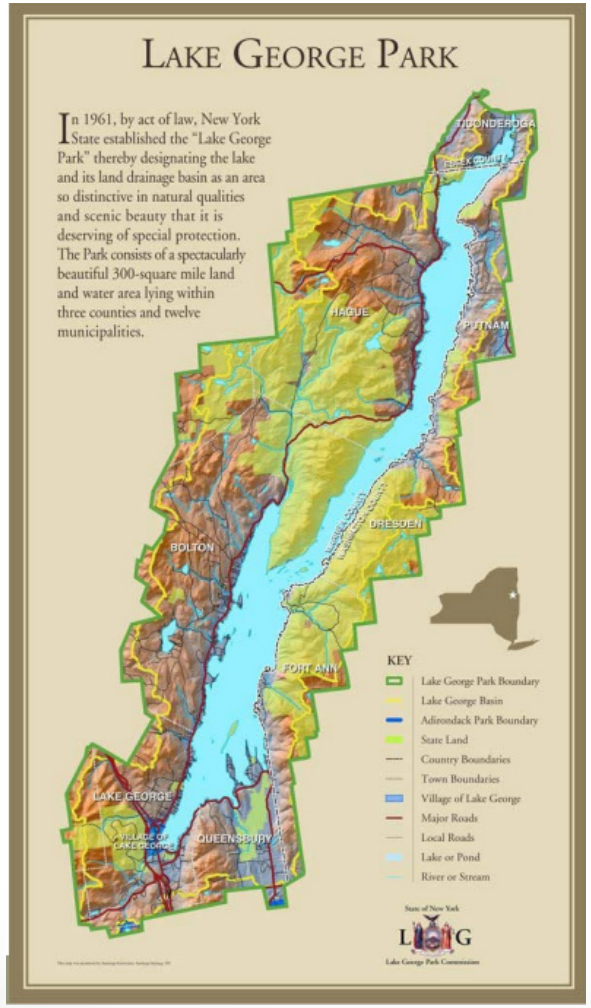
Do you

- Write permits
- Execute permits
- Other?

Are you

- Government
- Consultant
- Operator
- Other?

Outline



Introduction

TMDL, MS4, CSO Processes

Tools

- Water Surface Toolbox
- Training for Surface Water Models

EPA SWMM – Storm and Waste Water

- Data Needs and where to get Data
- Models and Results

EPA Stormwater Calculator

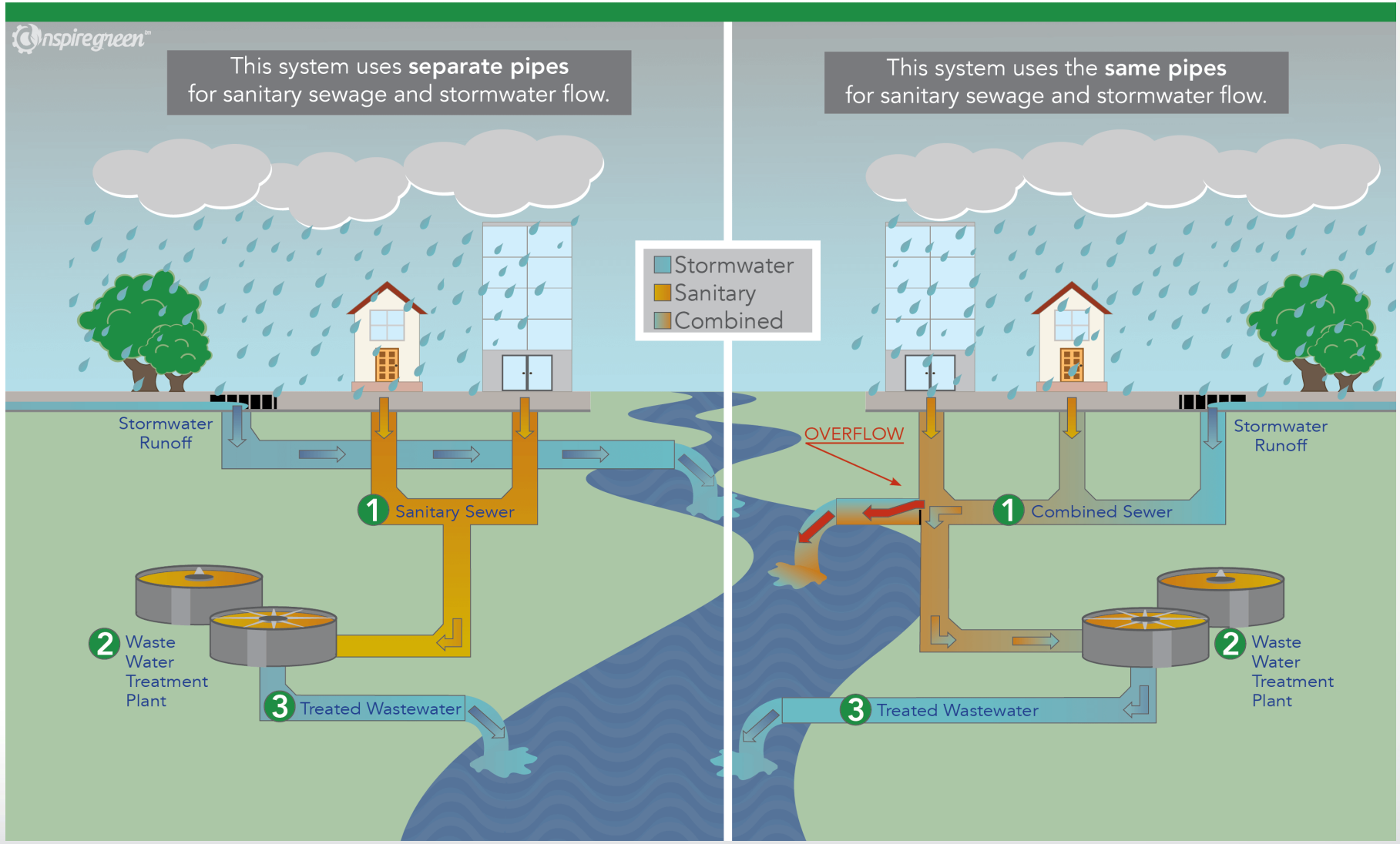
Discussions

https://lgpc.ny.gov/system/files/documents/2018/08/stormwater-background-and-proposed-changes.pdf

EPA

MS4 MUNICIPAL SEPARATE STORM SEWER SYSTEM

CSS COMBINED SEWER SYSTEM



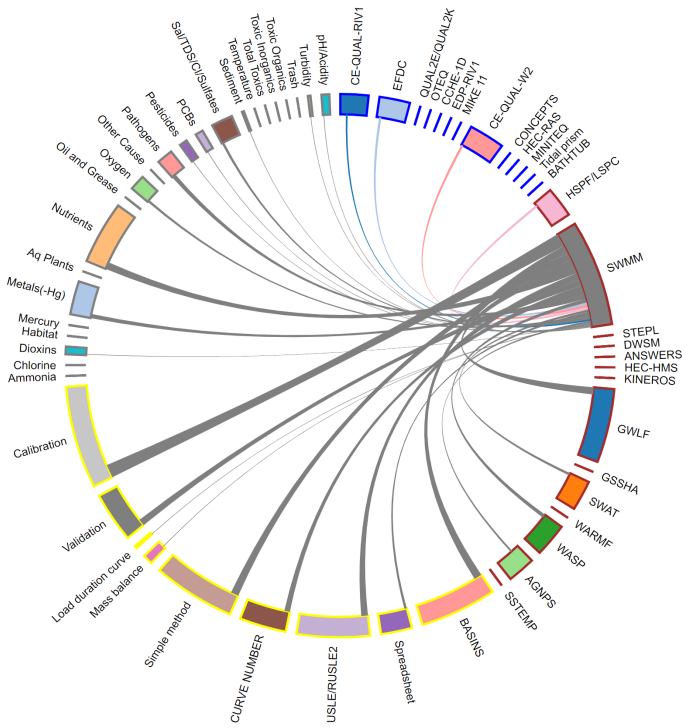
https://www.limno.com/portfolio-posts/ms4-tmdl-implementation-planning-and-monitoring-for-washington-dc/

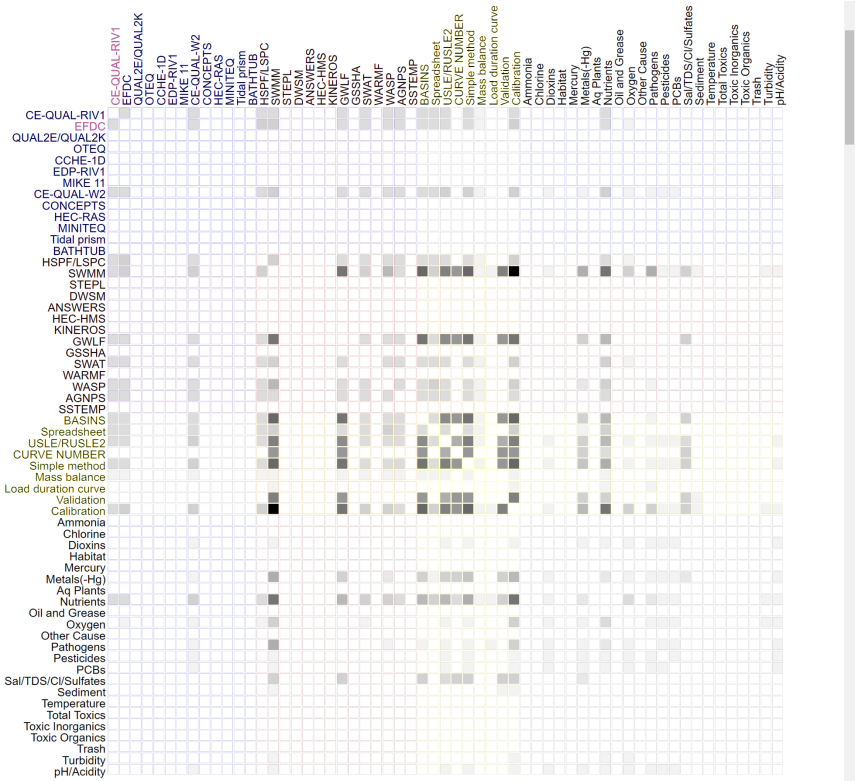
US Map of Regulated MS4

https://www.epa.gov/npdes/stormwater-discharges-municipal-sources

Total Maximum Daily Load Tool

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





Show 10 entries

Search:

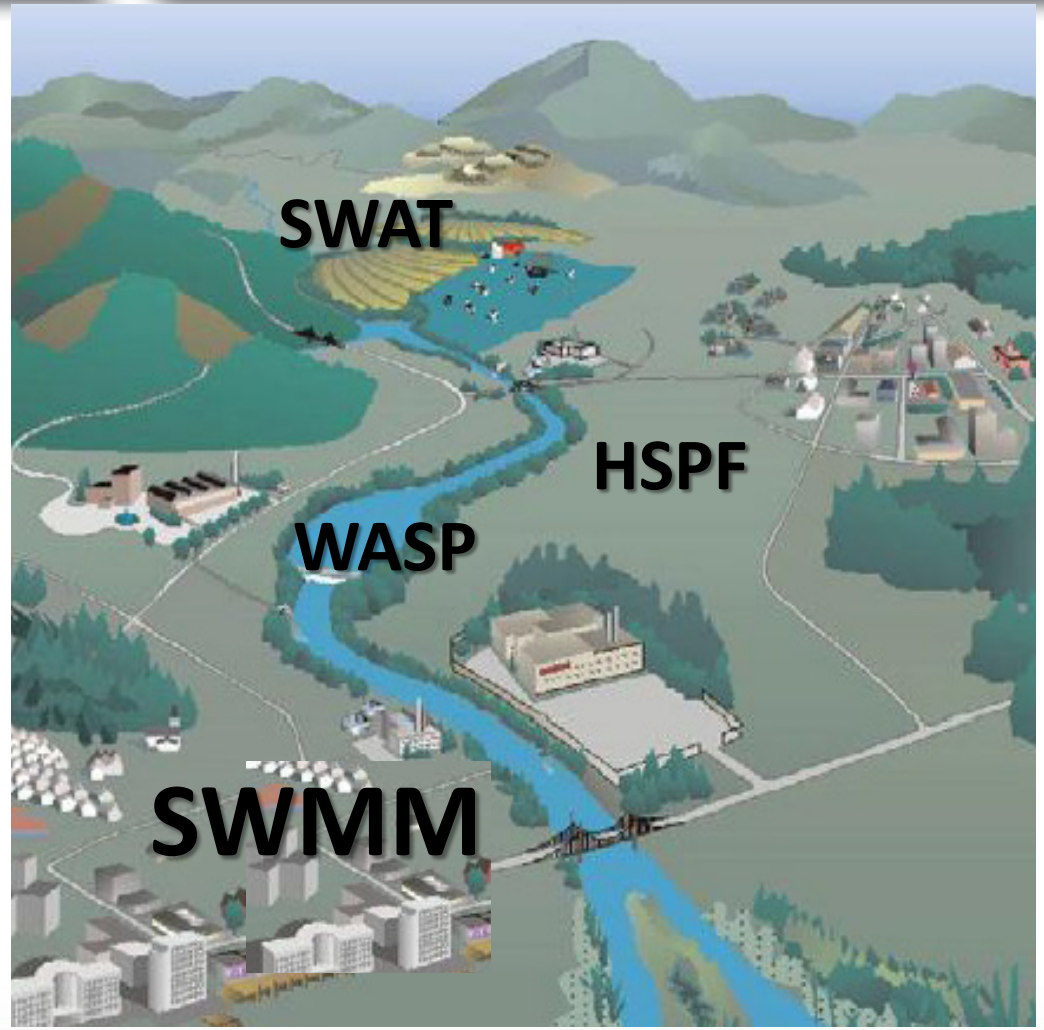
FINAL ASSESSMENT SURFACE WATER MODEL MAINTENANCE AND SUPPORT STATUS

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

EPA Training on these Models

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

EPA United States Environmental Protection Agency

Environmental Topics | Laws & Regulations | About EPA | Search EPA.gov

Related Topics: Water Data and Tools

CONTACT US SHARE

Surface Water Quality Modeling Training

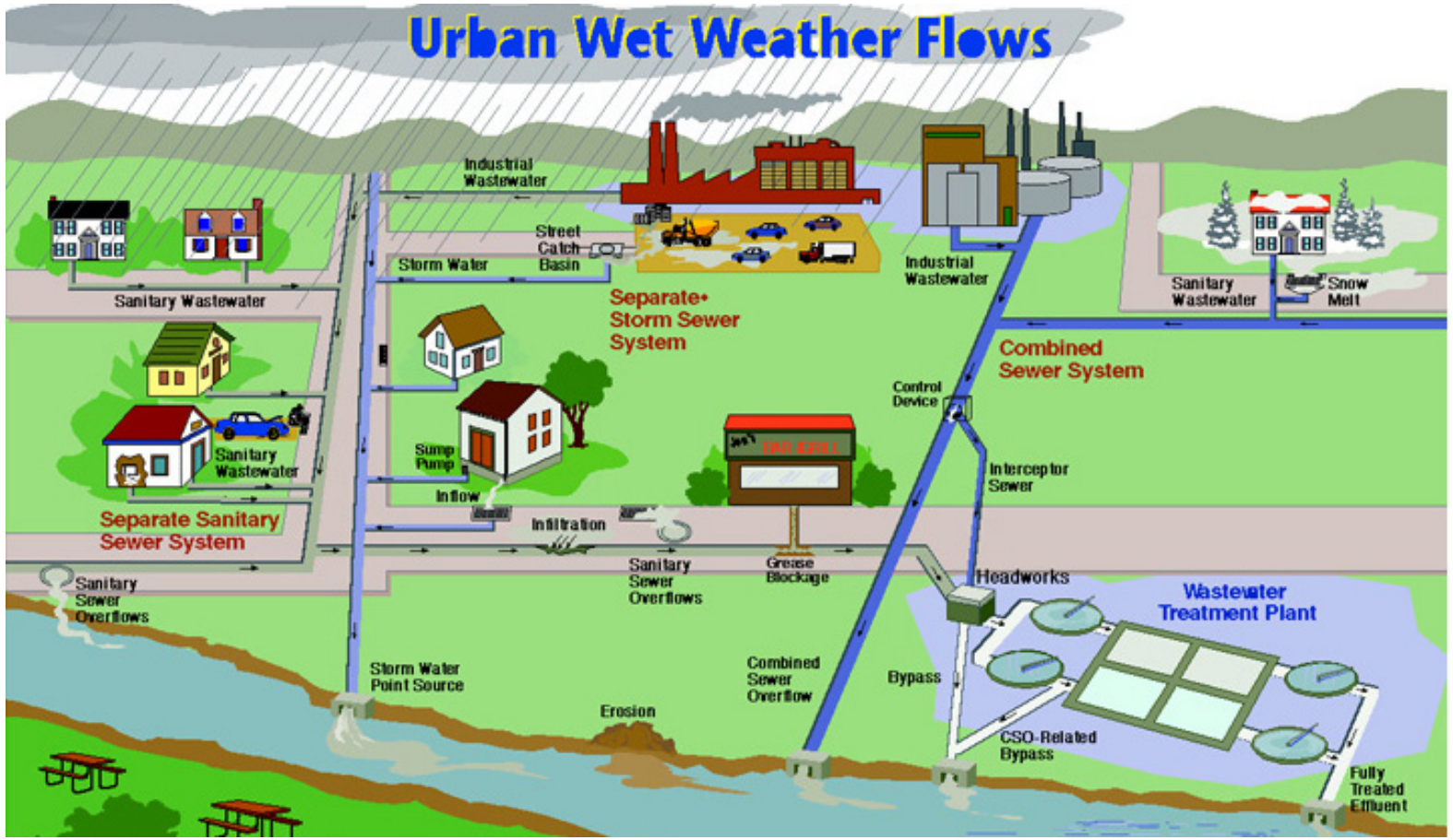
EPA's Water Modeling Workgroup (WMW) sponsors training to facilitate use of surface water quality models. Both webinars and workshops are available at this time.

Webinars

EPA's WMW sponsors an ongoing series of two-hour webinars to help water quality professionals better understand surface water quality models and how they can be used to address water quality problems. WMW posts introductory flyers and video recordings for the webinars to this website. Webinars 1 through 3 in the table below cover modeling basics such as selecting, developing, and running hydrology and water quality models. Subsequent webinars focus on modeling specific pollutants and parameters (e.g., nutrients, sediment, metals), specific types of models, and emerging issues in water quality modeling. If you want to receive updates on the webinars, please sign up here and select the Training and Webinars email list.

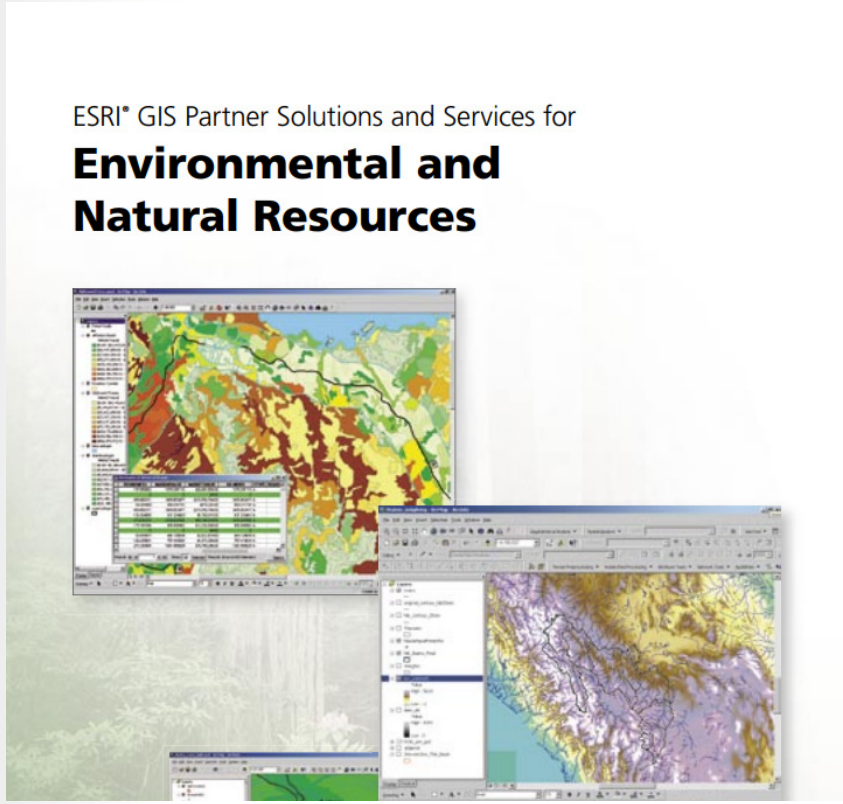
Webinar	Time	Documents
1. "Water Quality Models 101—What Are These Things?"	Thursday, March 26, 2015, 1:00 pm – 3:00 pm Eastern	Flyer Archived Video (YouTube)
2. "Brick by Brick: How Water Quality Models are Developed"	Thursday, April 23, 2015, 1:00 pm – 3:00 pm Eastern	Flyer Archived Video (YouTube)

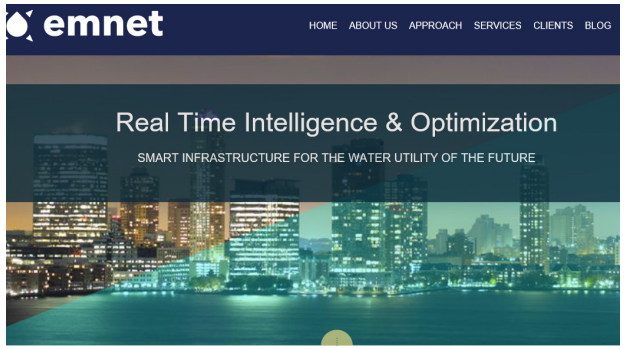
What is SWMM?

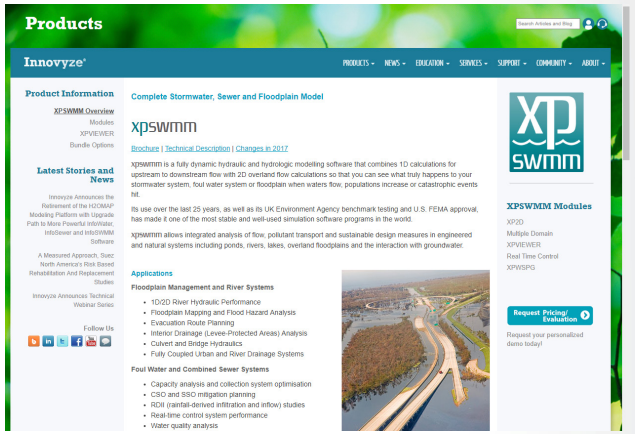


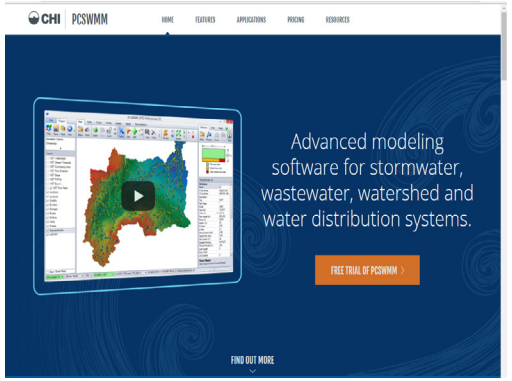
SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

Stakeholders - >30,000 2018 downloads





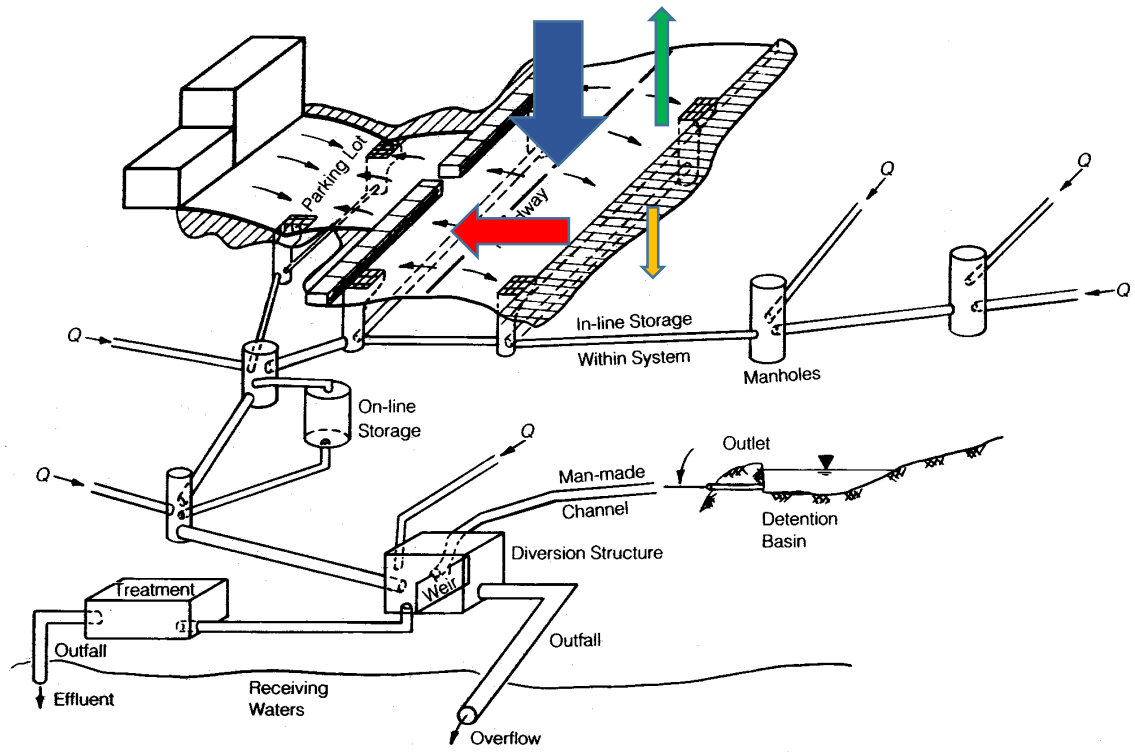




Regulators,
Communities,
Utilities,
Private industry,
Consultants,
Academia

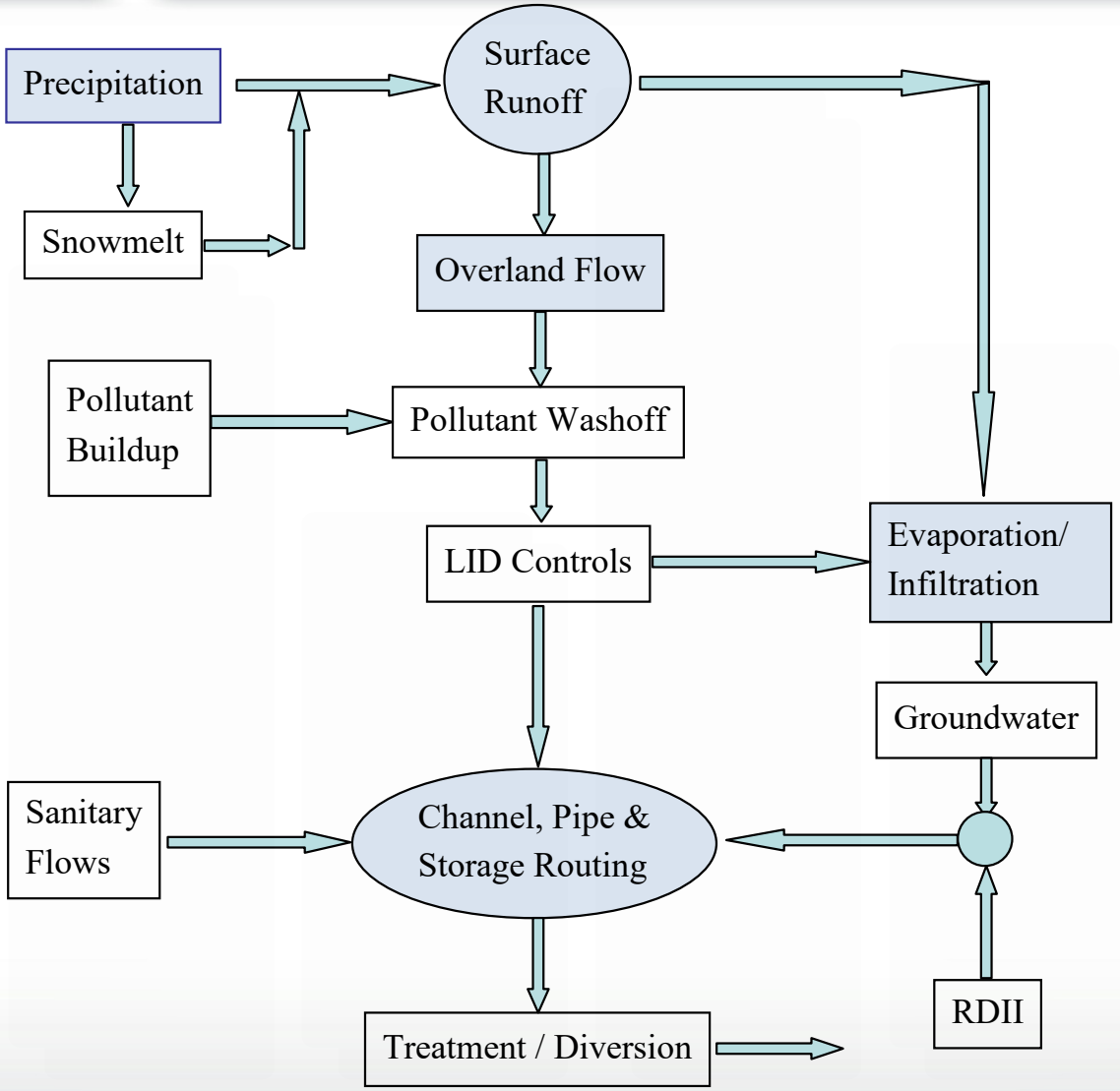
https://github.com/USEPA/Stormwater-Management-Model

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.

SWMM's Process Models



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)

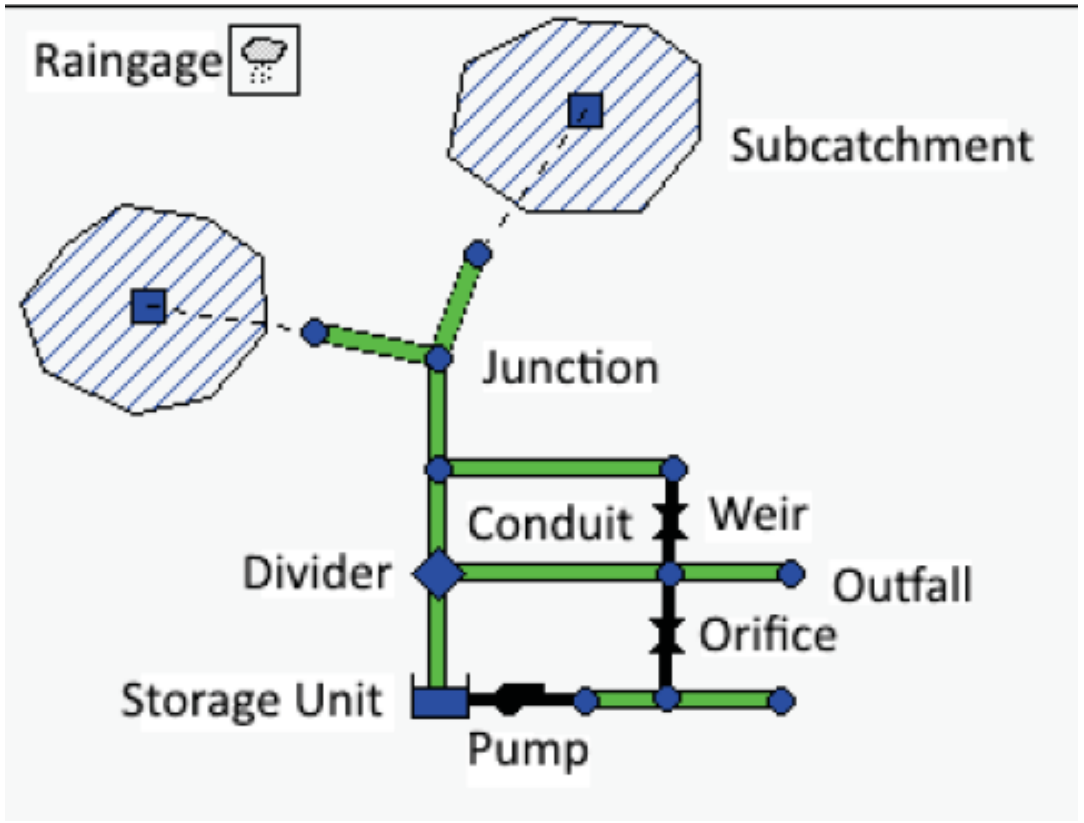
q = runoff rate (ft/s).

d = depth (ft)

t = time (s)

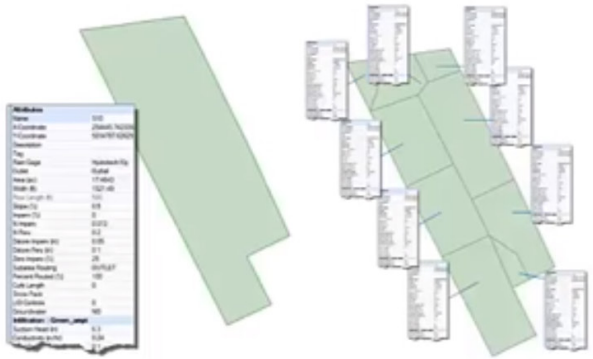
SWMM Hydrology Reference Manual Equation 3-1

SWMM's Conceptual Model



Idealized Subcatchment
(Courtesy of Rob James, CHI Water, www.openswmm.org)

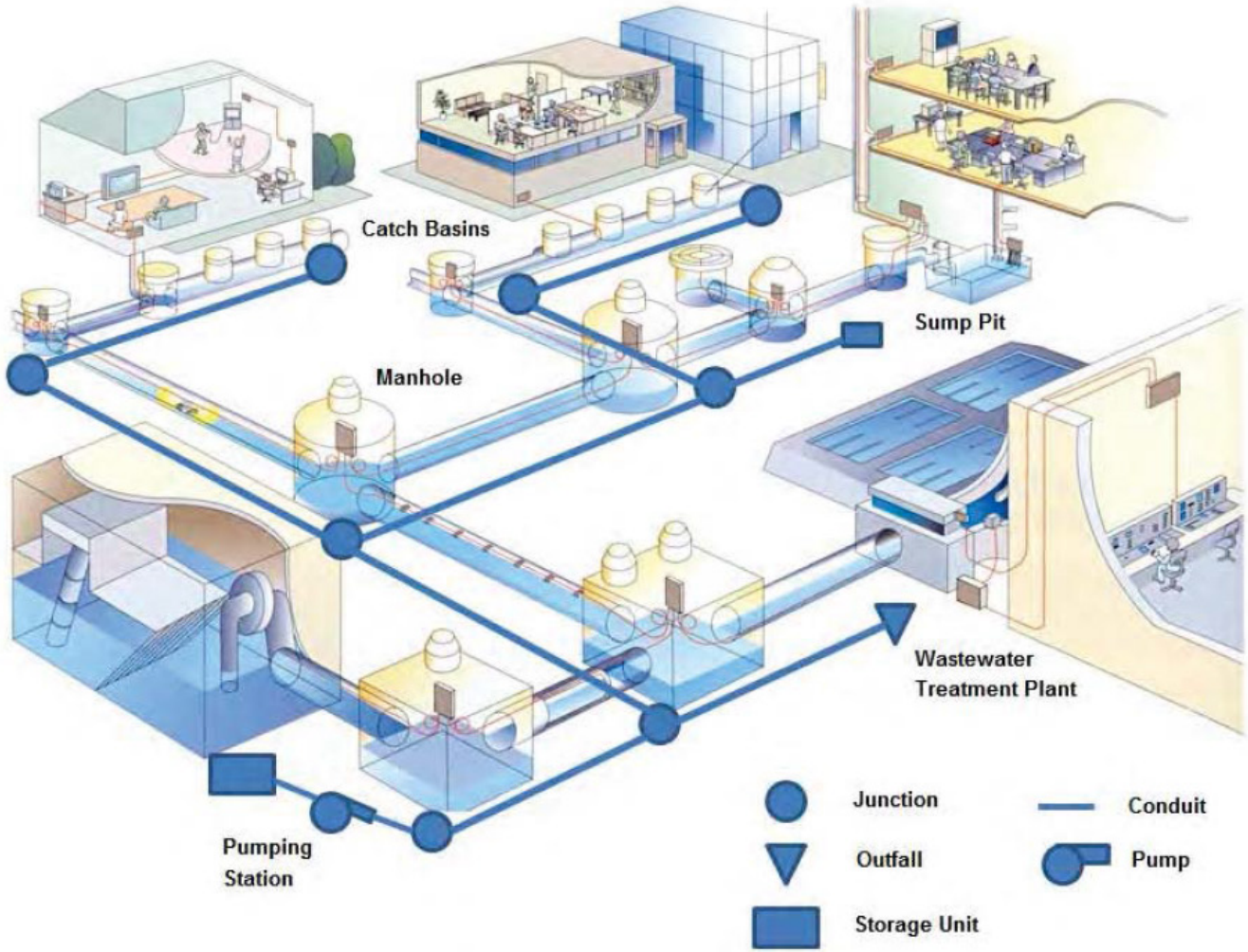
Subcatchment parameters



- 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

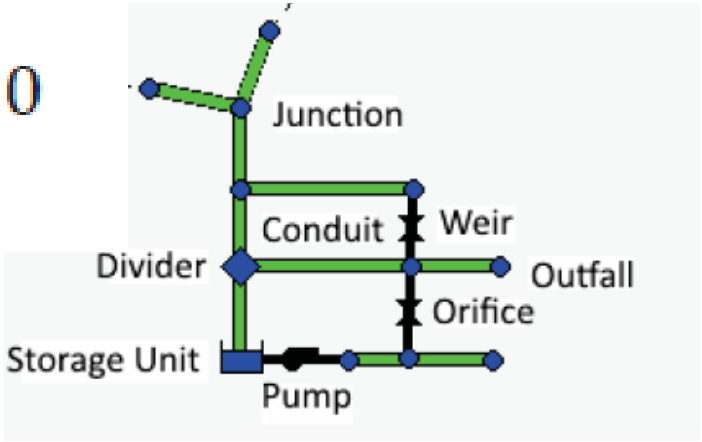
Hydraulic Model



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

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)

SWMM Hydraulics Reference Manual Equation 3 - 1

Hydraulic 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)

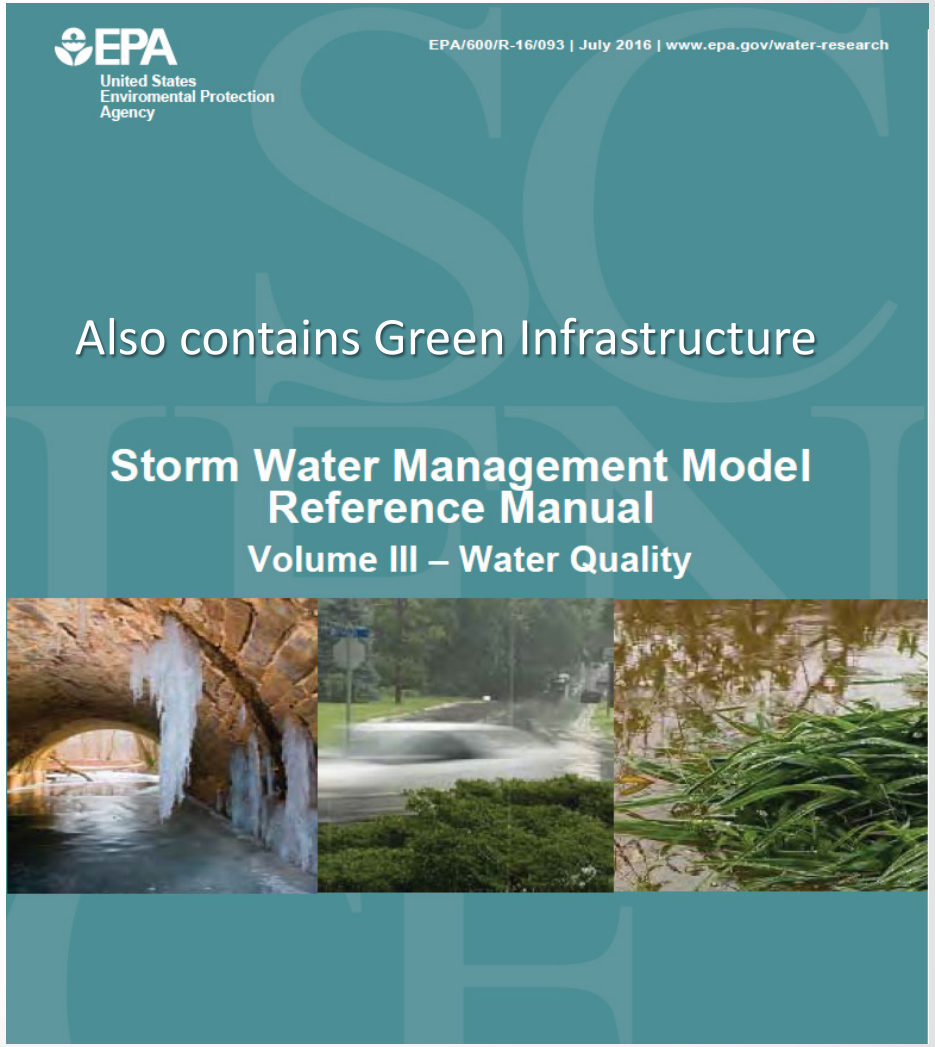
SWMM Hydraulics Reference Manual Equation 3 - 2

Level of sophistication

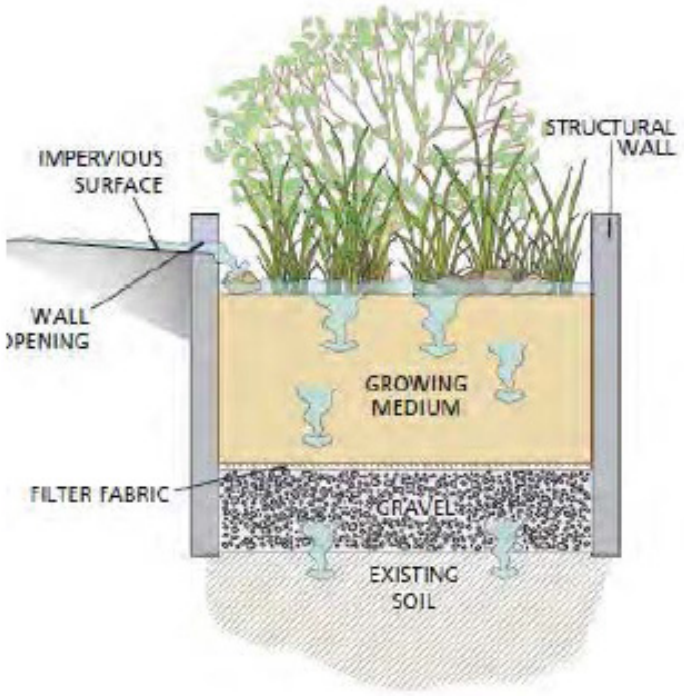
1. Steady Flow Routing
2. Kinematics Wave Routing
3. Dynamic Wave Routing

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

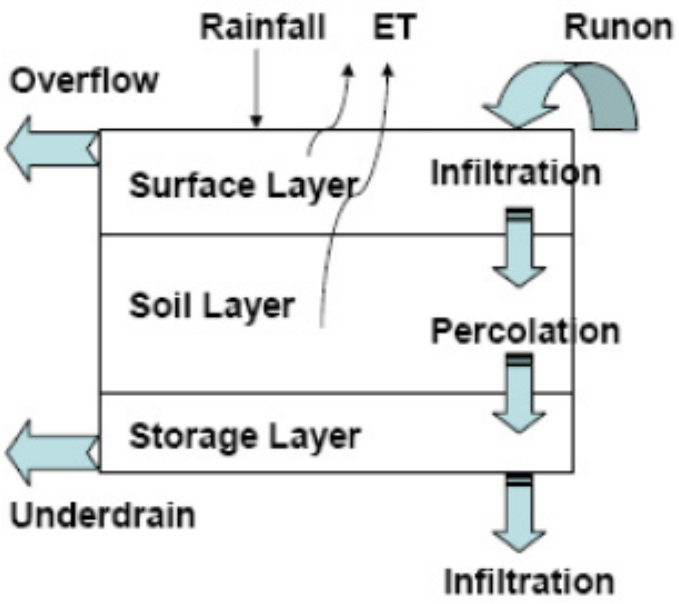
SWMM Hydraulics Reference Manual Equation 3-1



Green Infrastructure Subcatchment



(A)



(B)

Types of Low Impact Development Storm Control Measures that SWMM can model

Disconnection

Infiltration Basin

Rain Garden

Cistern

Infiltration Trench

Green Roof

Porous Pavement

Vegetative Swale

Street Planter

Infiltration

- **Ho**

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

- **Modified Horton**

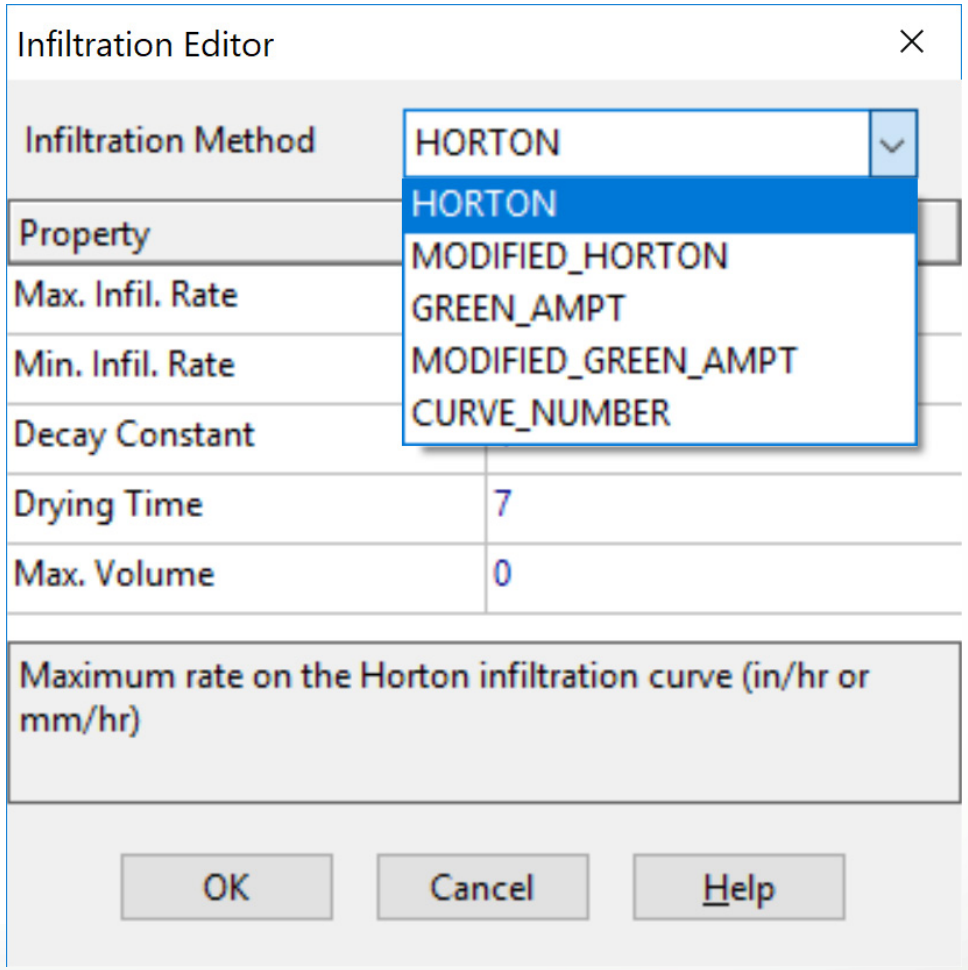
$$f_p = f_\infty + (f_0 - f_\infty)e^{-k_d t}$$

- **Green_Ampt, Modified Green_Ampt**

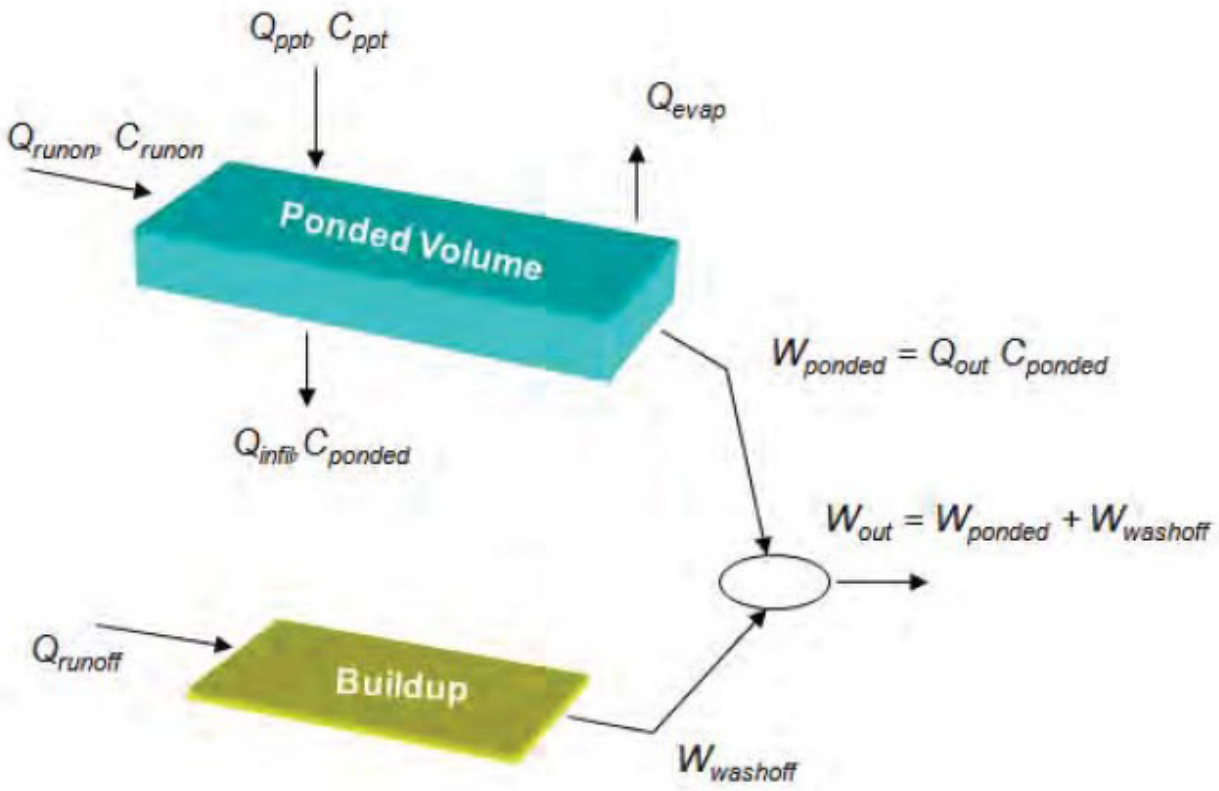
$$F = K_s + \psi_s \theta_d ln\left(1 + \frac{F}{\psi_s \theta_d}\right)$$

- **Curve_Number**

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



Water Quality - Pollutant Buildup and Wash-off



SWMM Reference Manuals

EPA/600/R-15/162A | January

United States Enviromental Protection Agency

Storm Water Management Reference Manual

Volume I – Hydrology (Revi

EPA/600/R-17/111 www.e

United States Environmental Protection Agency

Storm Water Management Mo Reference Manual

Volume II –Hydraulics

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

United States Enviromental Protection Agency

Also contains Green Infrastructure

Storm Water Management Model Reference Manual

Volume III – Water Quality

SWMM Webpage

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)

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.

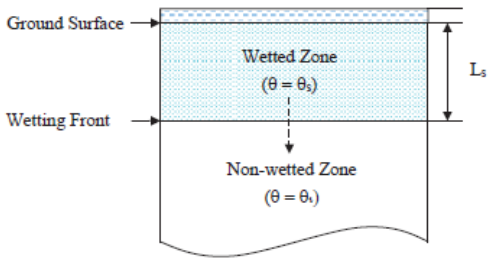


Figure 4-5 Two-zone representation of the Green-Ampt infiltration model (after Nicklow et al., 2006).

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:

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

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

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

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

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

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

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

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

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

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

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
	SWMM Technical Fact Sheet
	SWMM Applications Manual (ZIP) (7 MB)
	Quality Assurance Report for Dynamic Wave Flow Routing (ZIP) (3 MB)

How to Use SWMM Tutorials

CHAPTER 2 – QUICK START TUTORIAL

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

2.1 Example Study Area

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

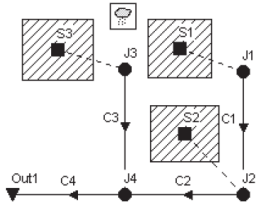


Figure 2-1 Example study area

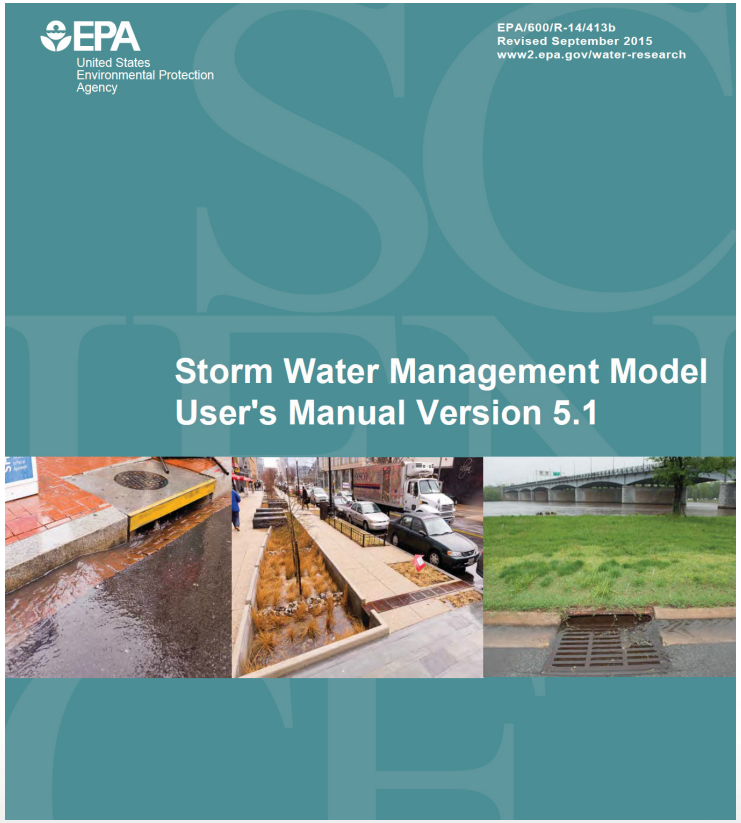
2.2 Project Setup

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

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

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

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



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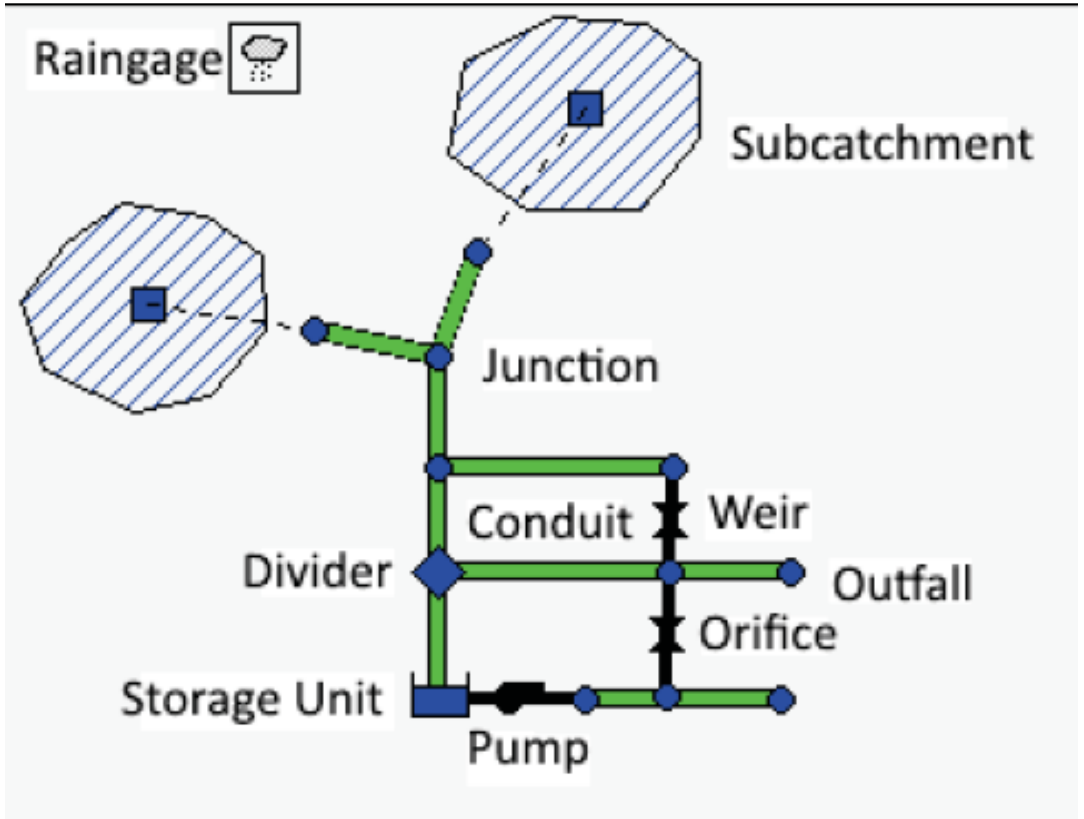
01/31/2017	SWMM Technical Fact Sheet
07/06/2010	SWMM Applications Manual (ZIP) (7 MB)
09/19/2006	Quality Assurance Report for Dynamic Wave Flow Routing (ZIP) (3 MB)

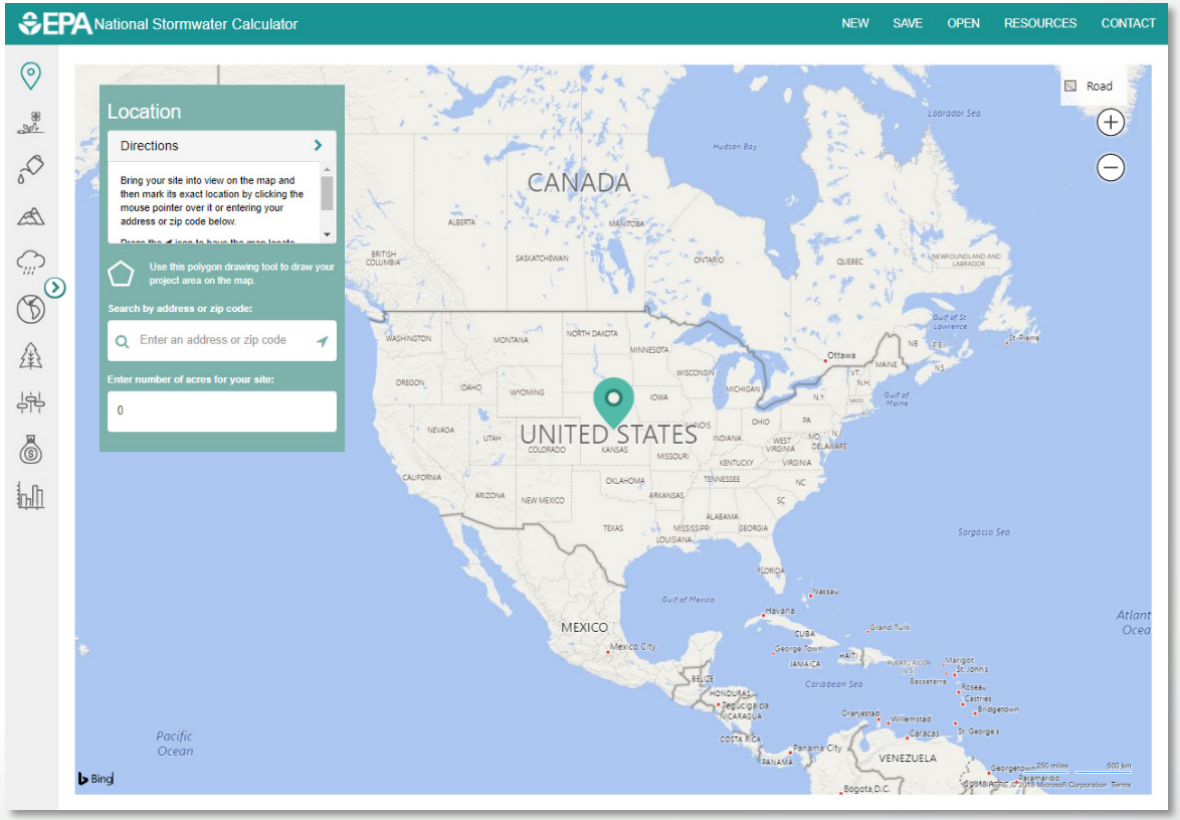
Quick Demontration of SWMM



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

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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.

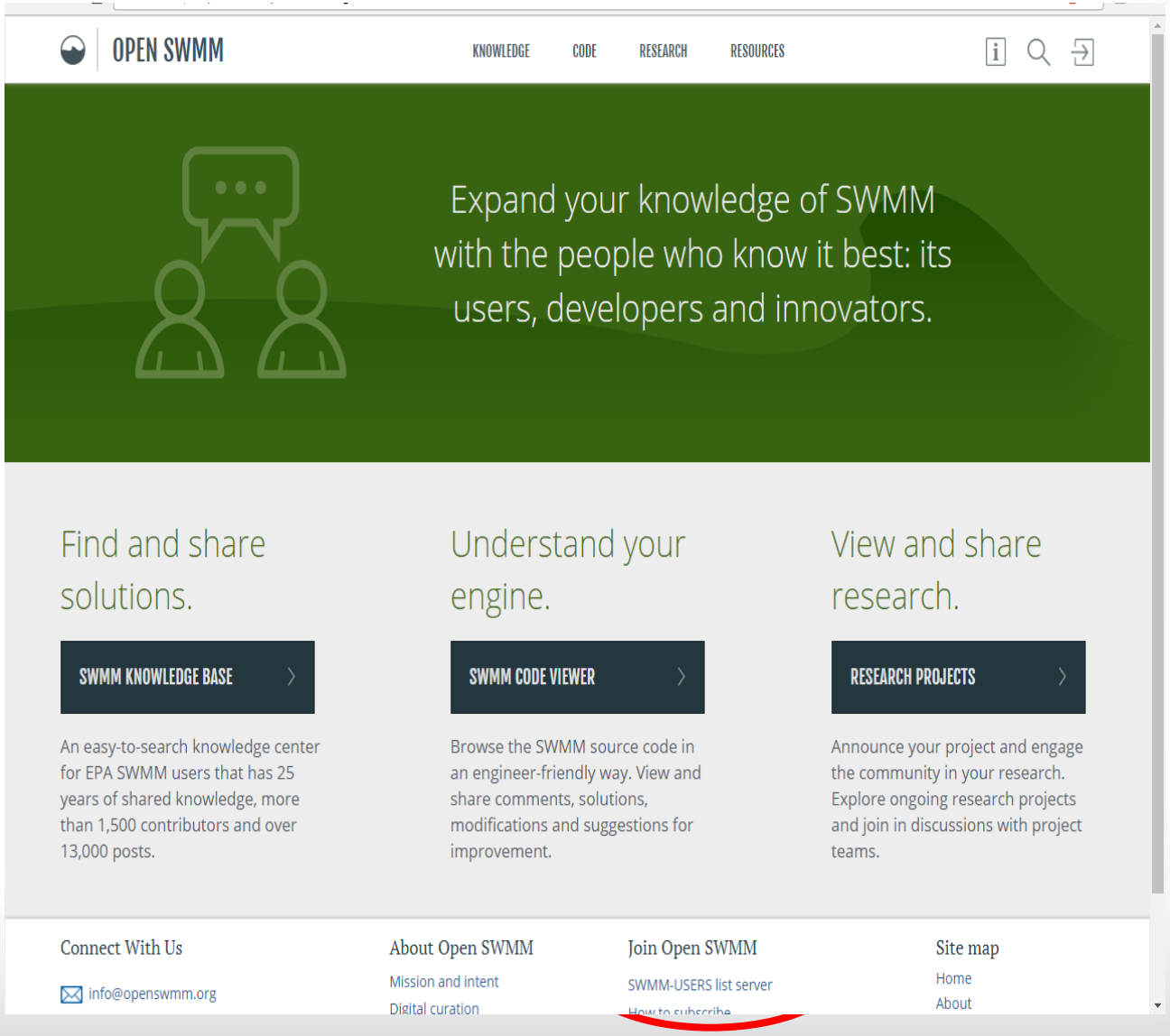
This service is made available through a close partnership between the three Service Center Agencies (SCA); Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA) and Rural Development (RD).

I Want To...

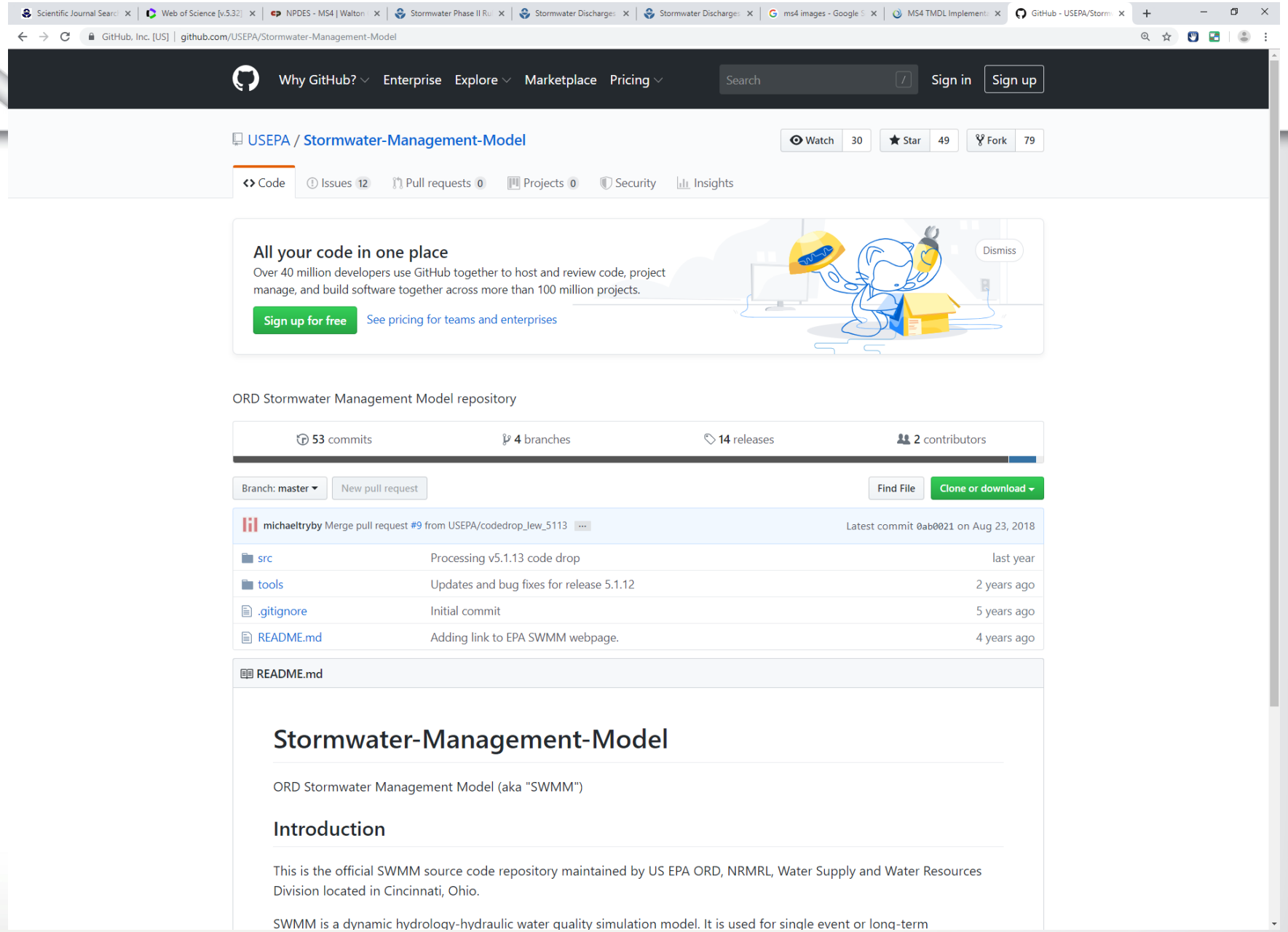
- NAIP Download
- Direct Download
- Order by County/Counties
- Order by State
- Order by Place
- Order by entering Latitude/Longitude Bounding Rectangle
- Order by Interactive Map using custom Area Of Interest

Open SWMM

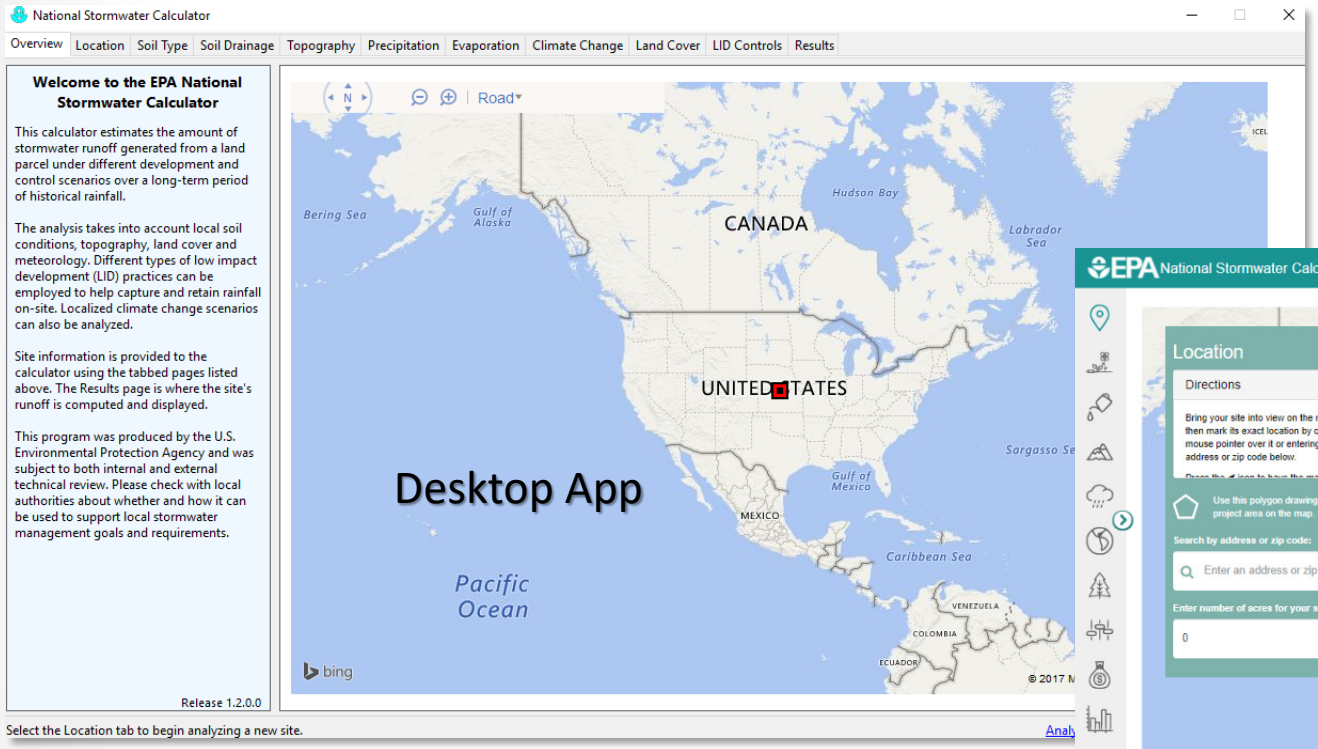
https://www.openswmm.org/

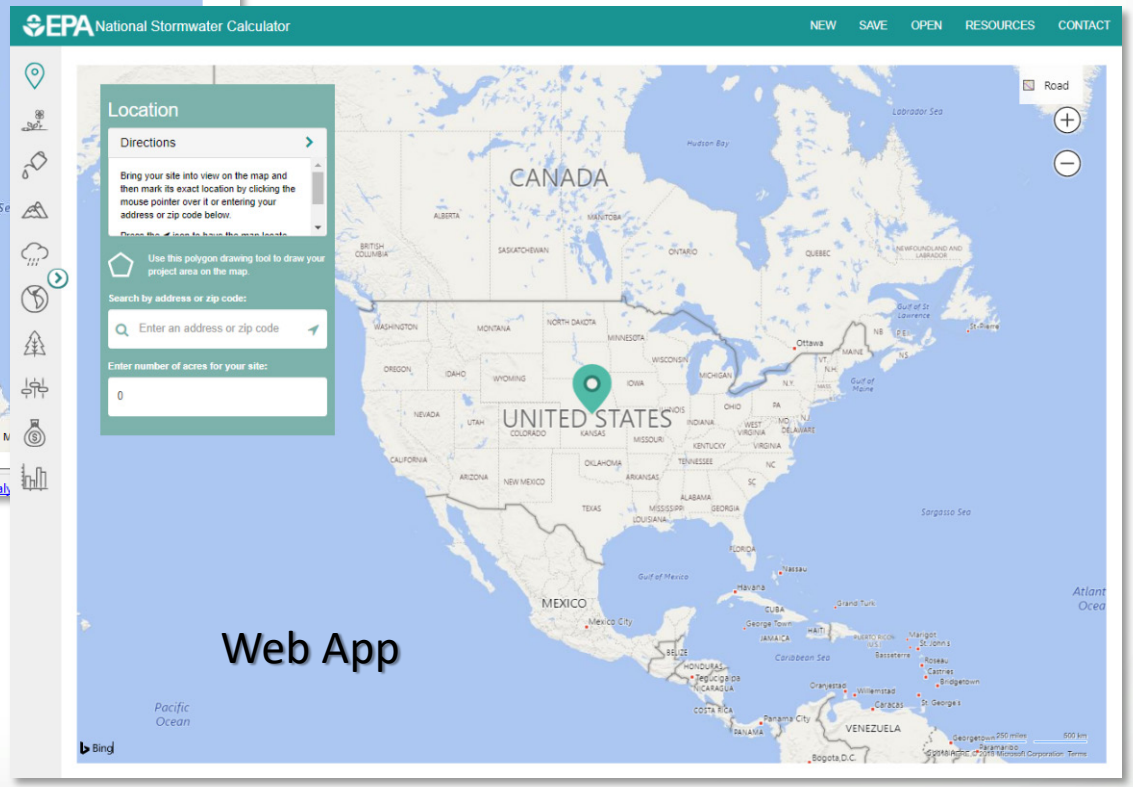


Open Source
Community Developed



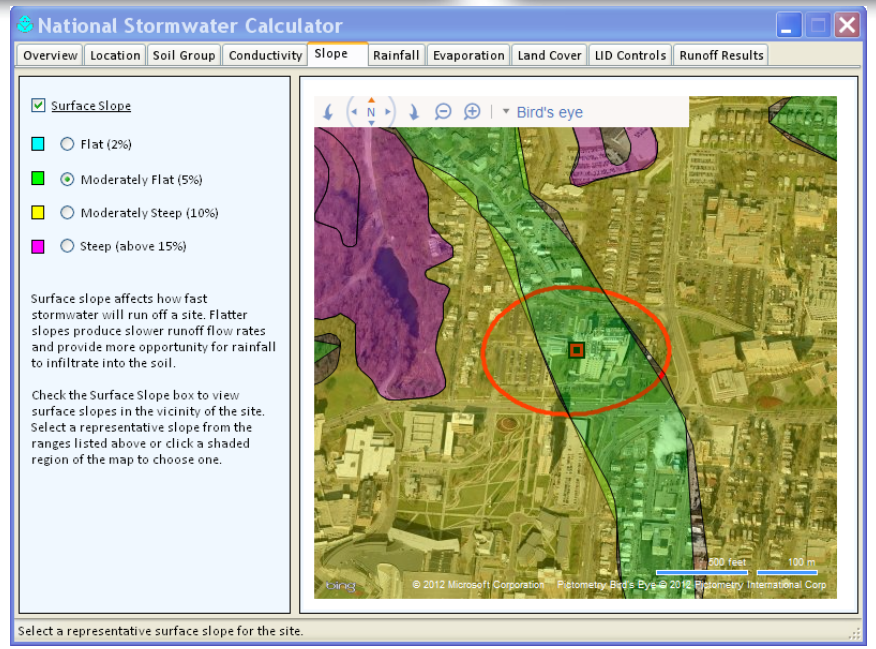
National Storm Water Calculator (SWC)



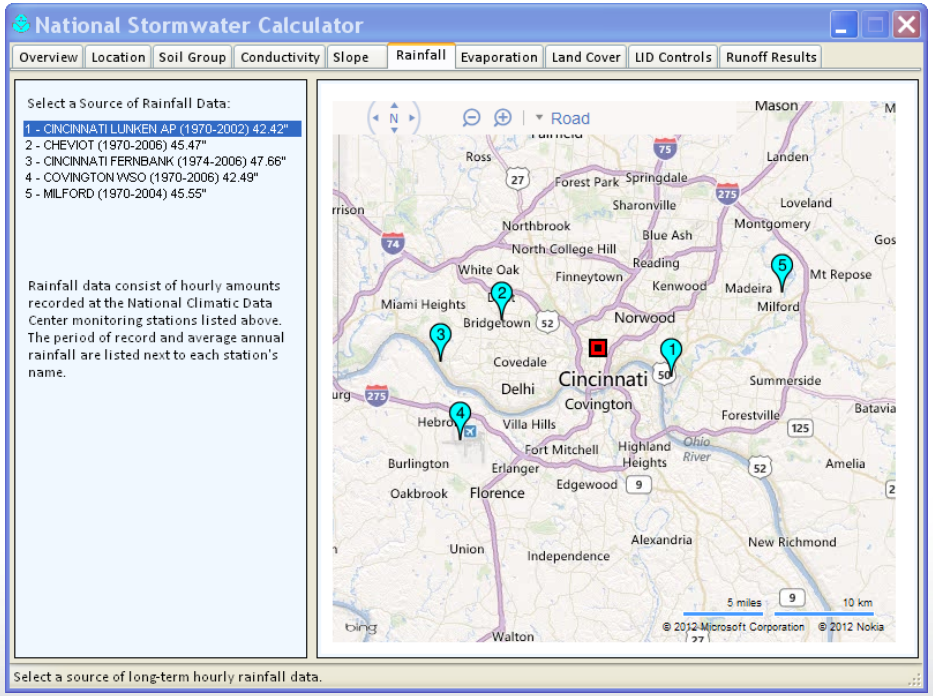


https://www.epa.gov/water-research/water-research-program-webinar-series .

National Stormwater Calculator



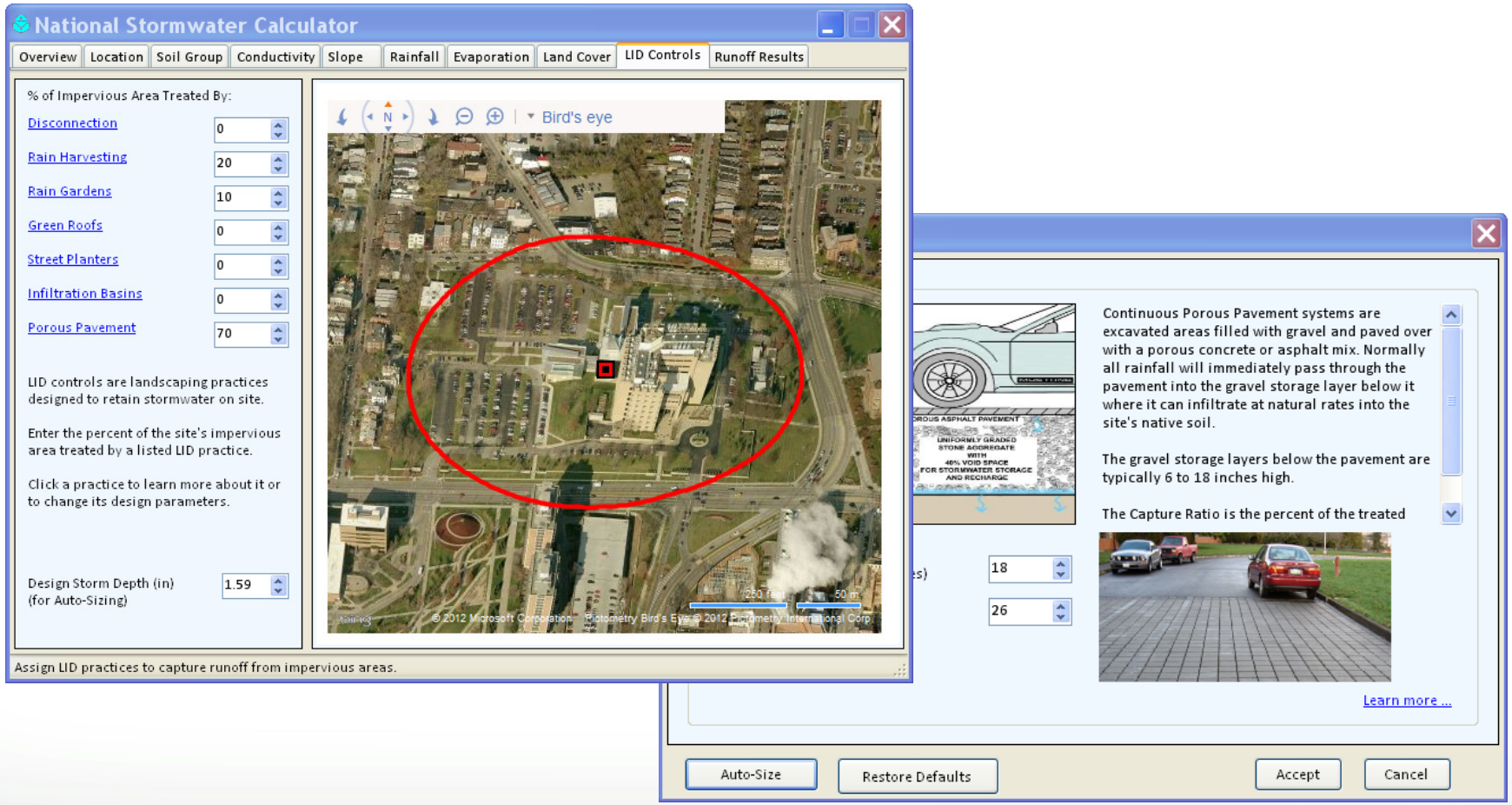
Displays soil properties obtained from querying the NRCS SSURGO database



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

National Stormwater Calculator

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



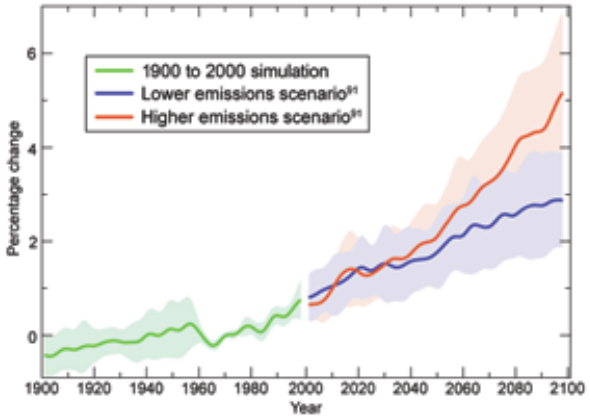
Climate Component Added to Calculator

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

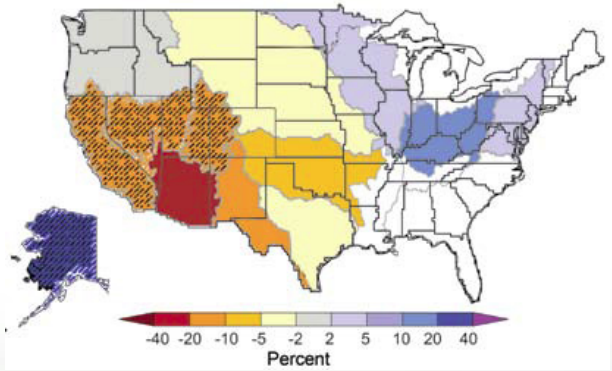
Impacts on small-scale hydrology:

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

Global Increase in Heavy Ppt. Events

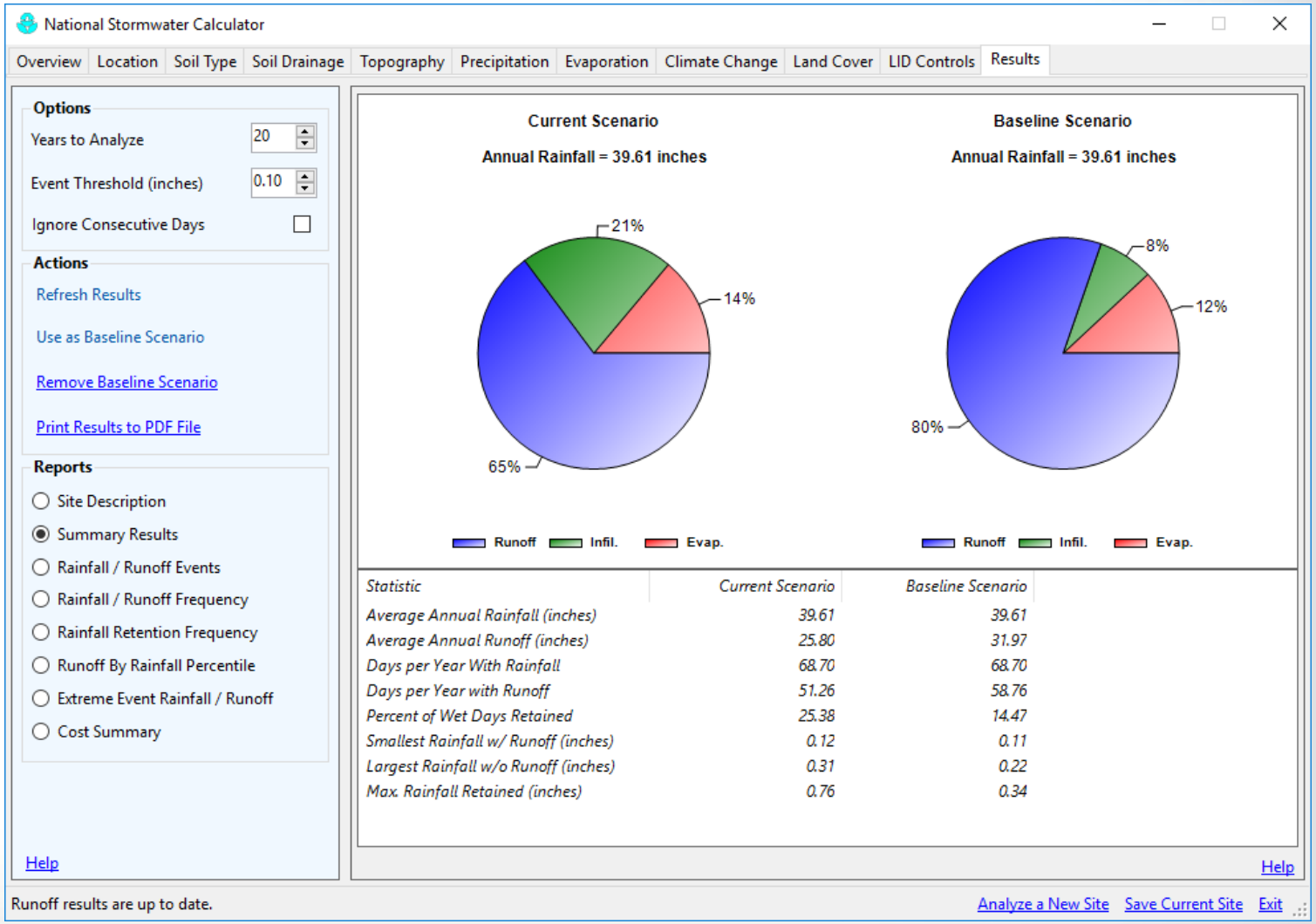


Projected Changes in Annual Runoff



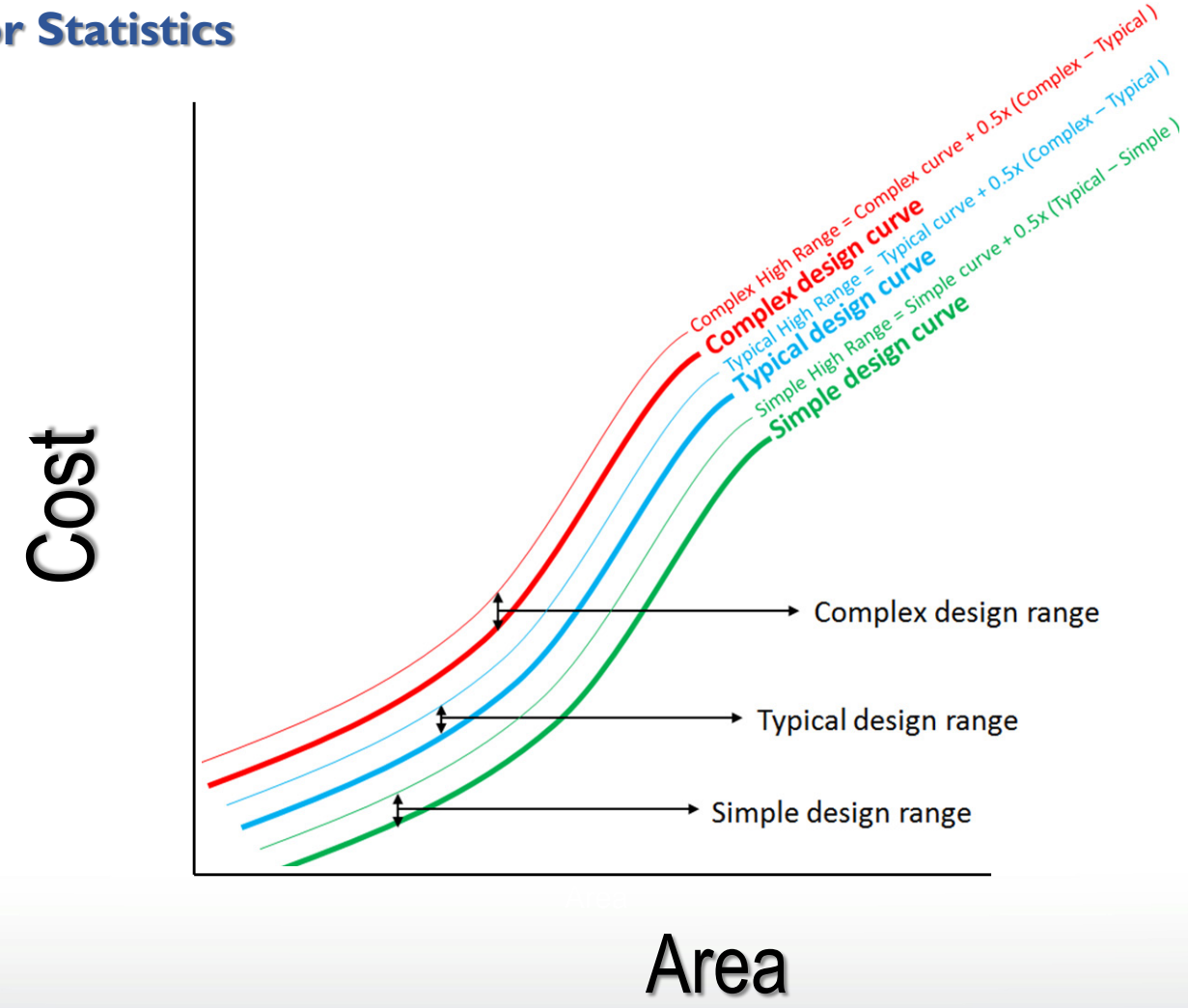
National Stormwater Calculator

The Calculator runs SWMM to generate daily rainfall/runoff statistics



LID Cost Estimation Module

Data from the Bureau of Labor Statistics



Conclusions

1. SWMM can calculate stormwater runoff volumes from an urban water shed
2. SWMM can calculate stormwater runoff water quality from an urban watershed
3. SWMM can aid in the design of hydraulic upgrades to stormwater and waste water systems.
4. In addition to the rational method, EPA has other surface water models for natural, agricultural, and other types of watersheds for MS4 permitting.
5. There are several national databases for obtaining the data necessary for modeling stormwater runoff.

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Questions?

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Thank You!

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Extra Slides