

Permeable Pavement Hydrologic Modeling

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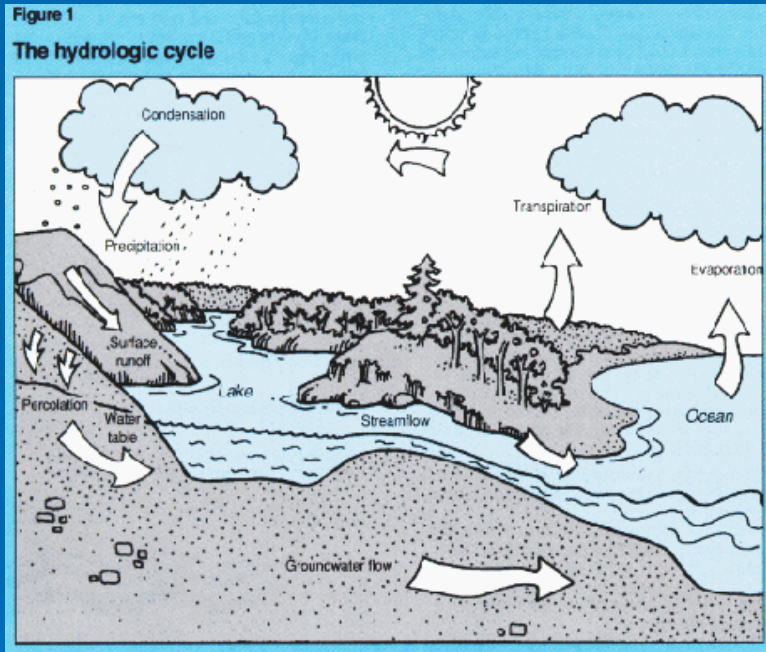
September 24, 2014

Presentation Overview

- Overview of Hydrologic Modeling
- Performance Standards
- Modeling Guidelines, Tools, Concepts
- Permeable Pavement Types
- Applications
 - Flow Control
 - Water Quality Treatment
 - Slope Considerations
 - Peak Flow Reduction
- Advanced Tools



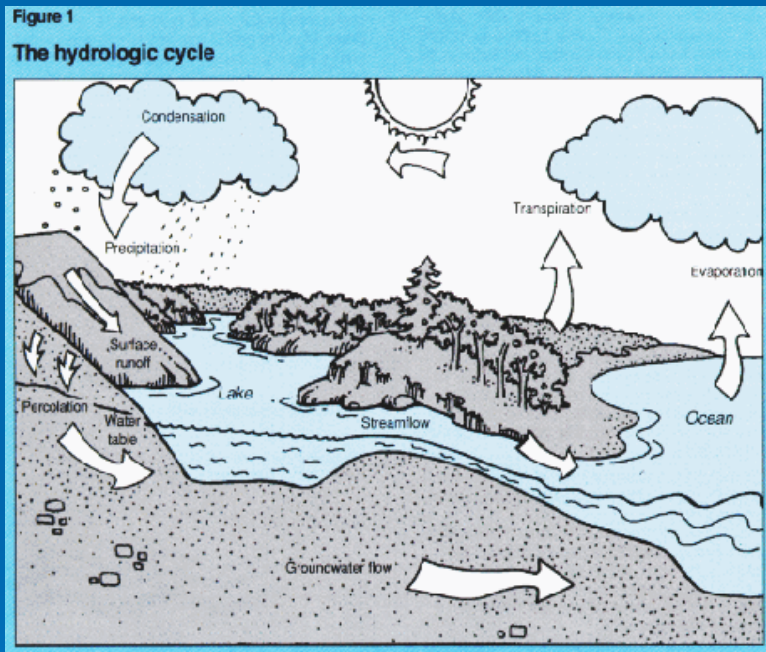
Hydrologic Modeling



Source: <http://www.und.nodak.edu/>

- Q: What is hydrologic modeling?
- A: Use of mathematical equations to estimate runoff based on:
 - weather patterns
 - landuse
 - soil
 - topography

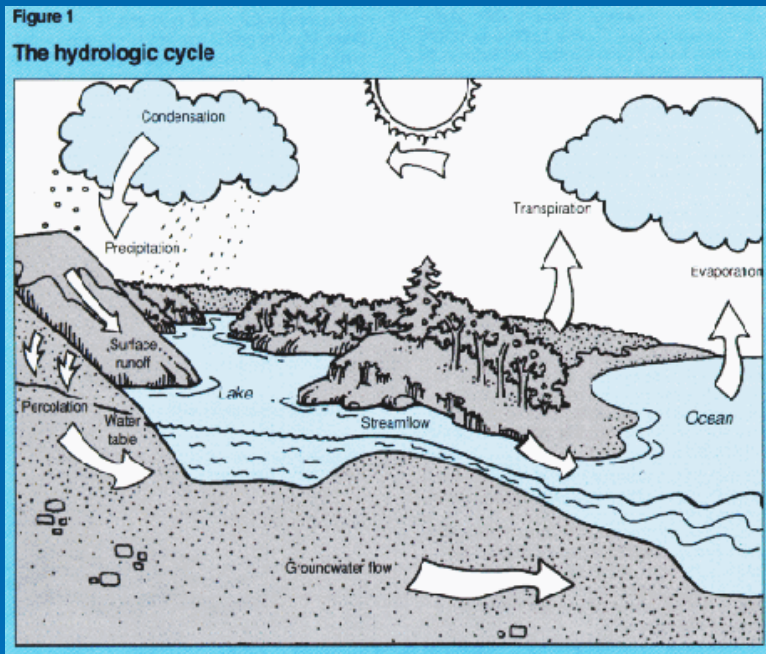
Hydrologic Modeling



Source: <http://www.und.nodak.edu/>

- Q: Why do we use hydrologic models?
- A1: Characterize hydrologic conditions
 - Predeveloped
 - Current
 - Post-project
- A2: Design mitigation
- A3: It's fun!

Hydrologic Modeling



Source: <http://www.und.nodak.edu/>

- Q: When does hydrologic modeling enter into your project?
- A: Start to finish
 - preliminary design (sizing)
 - final design (optimization)
 - demonstrate requirements met (permit submittals)

Performance Standards

- On-site Stormwater Management (MR #5) (NEW 2012)
 - Use BMP List (rain garden)
 - or
 - Meet LID Performance Standard (match flow durations to pre-developed condition from 8% to 50% of the 2-year peak flow)
- Runoff Treatment (MR #6)
 - Infiltrate 91 percent of the total runoff volume through soil meeting Ecology treatment criteria (for infiltration BMPs)
- Flow Control (MR #7)
 - Match flow durations to pre-developed condition from 50% of the 2-year to the 50-year peak flow
- Other Flow Control Standards
 - Combined Sewer or Capacity Constrained Basins (peak-based standards)

Modeling Tools

➤ Single-event models

- May be appropriate for conveyance sizing

➤ Continuous models

- Required for sizing flow control (MR7) and treatment (MR6) BMPs

➤ Simplified sizing tools

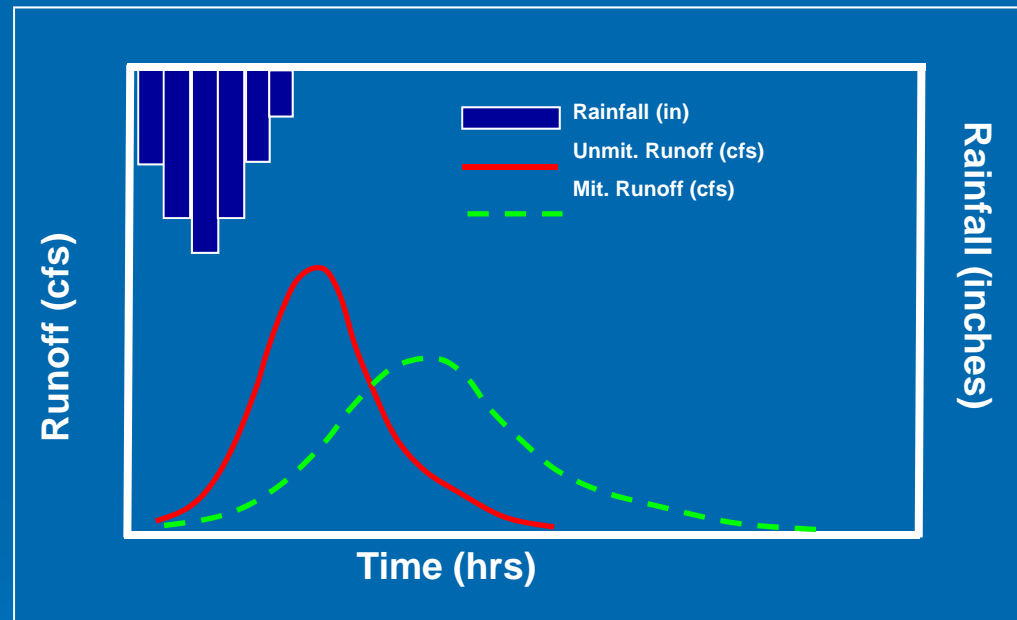
- Allow sizing without hydrologic modeling



Modeling Tools

Single-Event Methods

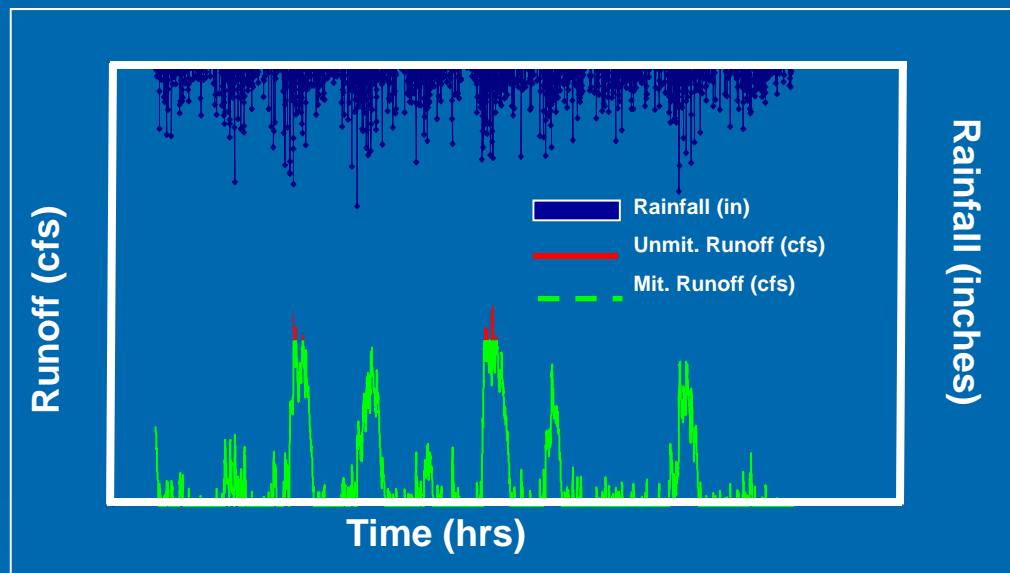
- Input single storm event
- Output peak flow rates
- Typical methods
 - SCS
 - SBUH
 - StormShed
 - SWMM
 - HEC-HMS
 - SUSTAIN



Modeling Tools

Continuous Models

- Input long-term rain and evaporation
- Output continuous runoff, peak flow, & duration
- Typical programs
 - HSPF
 - WWHM
 - MGS Flood
 - KCRTS
 - SWMM
 - SUSTAIN
 - InfoWorks



Modeling Tools

Simplified Sizing Tools

- Represent BMP footprint area as % Imp. Area (“sizing factor”)
- Prescribed design criteria
- Engineer not needed for small projects (e.g., <10,000sf imp.)
- GSI-Calc available for western WA Lowlands
- Jurisdiction-specific sizing tools also available (e.g., Seattle, Bellevue, Edmonds, Kitsap County, Pierce County)

Modeling Tools

Simplified Sizing Tools

Kitsap County: Pavement sized as function of contributing impervious area and precipitation

BMP	Design Infiltration Rate (in/hr)	Forest Standard		Sizing Equation
		M	B	
Permeable Pavement Facility				
6 inch ponding depth	0.25	0.1100	- 1.0536	Area (sf) = Impervious Area (sf) x [M x Precip. (in) + B]
	0.5	0.0187	+ 0.4945	
	1.0	0.0048	+ 0.3531	
Permeable Pavement Surface				
Slope <= 2%	0.13 – 0.249	0.005	0	Aggregate Depth (in) = M x Precip. (in)
	≥ 0.25	0.01	0	

Modeling Tools

Simplified Sizing Tools

Kitsap County Pre-Sized Calculator

GSI-Calc

Kitsap County BMP Sizing Calculator for Flow Control

Site Mean Annual Precipitation in

New and Replaced Impervious Area

Flow Control Standard Achieved?

LID Runoff Reduction Methods		Facility Size		Credit	
Retained Trees					
Existing Evergreen	# Trees <input type="text"/>	Total Canopy Area of Trees	<input type="text"/> sf	x	40% (or min 10% if trees are dead)
Existing Deciduous	# Trees <input type="text"/>	Total Canopy Area of Trees	<input type="text"/> sf	x	10% (or min 50 sf/tree)
New Trees					
New Evergreen	# Trees <input type="text"/>		<input type="text"/> sf	x	50 sf
New Deciduous	# Trees <input type="text"/>		<input type="text"/> sf	x	20 sf
				Total Area Mitigated by Trees =	
Dispersion					
Downspout or Sheet Flow		Dispersed Impervious Area	<input type="text"/> sf	x	74%
Permeable Pavement Surface					
Subgrade slope < 2%		Permeable Pavement Area	<input type="text"/> sf	x	100%
Subgrade slope 2-5%		Permeable Pavement Area	<input type="text"/> sf	x	40%
Vegetated Roof					
4" Growth Medium		Vegetated Roof Area	<input type="text"/> sf	x	42%
8" Growth Medium		Vegetated Roof Area	<input type="text"/> sf	x	45%
				Area Mitigated by LID Runoff Reduction Methods =	
LID Infiltration Facilities		Facility Size		Equation	
Bioretention Cell (without Underdrain)				Enter Site	
Ponding Depth	<input type="text"/> in	Bioretention Bottom Area	<input type="text"/> sf	+ (Precip <input type="text"/> x <input type="text"/>) =	
Design Infiltration Rate	<input type="text"/> in/hr				
Permeable Pavement Facility				Enter Site	
Ponding Depth (1)	<input type="text"/> in	Permeable Pavement Area	<input type="text"/> sf	+ (Precip <input type="text"/> x <input type="text"/>) =	
Design Infiltration Rate	<input type="text"/> in/hr				
				Plus Permeable Pavement Facility Area =	
				Area Mitigated by LID Infiltration Facilities =	
Traditional Infiltration Facilities		Facility Size		Equation	
Rock Trench				Enter Site	
Design Infiltration Rate	<input type="text"/> in/hr	Trench Length	<input type="text"/> ft	+ (Precip <input type="text"/> x <input type="text"/>) =	
Gravelless Chamber				Enter Site	
Design Infiltration Rate	<input type="text"/> in/hr	Chamber Length	<input type="text"/> ft	+ (Precip <input type="text"/> x <input type="text"/>) =	
				Area Mitigated by Traditional Infiltration Facilities =	
				Total Area Mitigated =	
				Flow Control Standard Achieved? =	

Notes:
 LID - low impact development sf - square feet in - inch min - minimum
 precip - precipitation ft - feet in/hr - inch per hour infiltr - infiltration

Herrera Environmental Consultants
 Version: 01-26-10

Permeable Pavement (2 to 5% Slopes with Berms)

Design Infiltration Rate (in/hr) Runon Area (sf) Permeable Pavement Area (sf) Notes

PP #1 0.25 0 3500

PP #2 Select One 0

PP #3 Select One 0

PP #4 Select One 0

Required Ponding Depth (ft) 0.32 Area Mitigated (sf) 3500

OK

Total Area Mitigated 3500

Design Requirements

Requirements

Expand Image

Notes:
 1. The average subsurface ponding depth [(D1 + D2)/2] within the aggregate storage reservoir is the depth required for stormwater management. The minimum aggregate design depth shall be the greater of the depth required to achieve this subsurface ponding and the minimum aggregate required for design loading.
 2. Permeable pavement achieves the water quality treatment standard if native soil meets Ecology treatment soil requirements. Alternatively, a treatment layer may be included.

Notes: sf=square feet, #=Number, ft=feet, in=inch, hr=hour

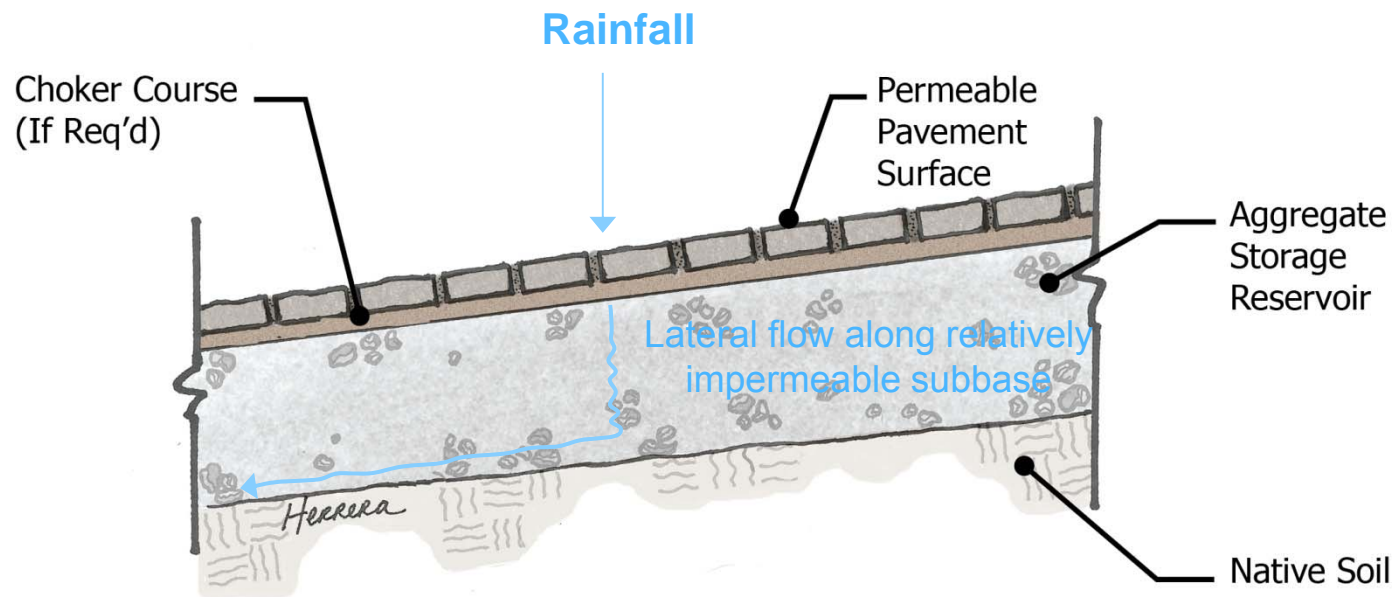
Modeling Guidelines

(General Summary- See 2012 LID Volume 3, Appendix III-C for details)

Base Material	Underdrain	Subgrade Slope	Model Surface as:
Above Surrounding Grade	Yes	Any	Impervious surface
	No	Any	Mix landscape/impervious on underlying soil type
Partially or Below Surrounding Grade	Yes	Any	Impervious surface
	No	0-2%	Impervious surface routed to gravel infiltration trench (same size as the pavement area). Trench depth = aggregate depth below surrounding grade
		>2%	Impervious surface routed to gravel infiltration trench (same size as the pavement area). Trench depth = subsurface storage depth if berms (nominal 1/2-inch if no berms)

Permeable Pavement Types

Subgrade Slope 0 to 2%

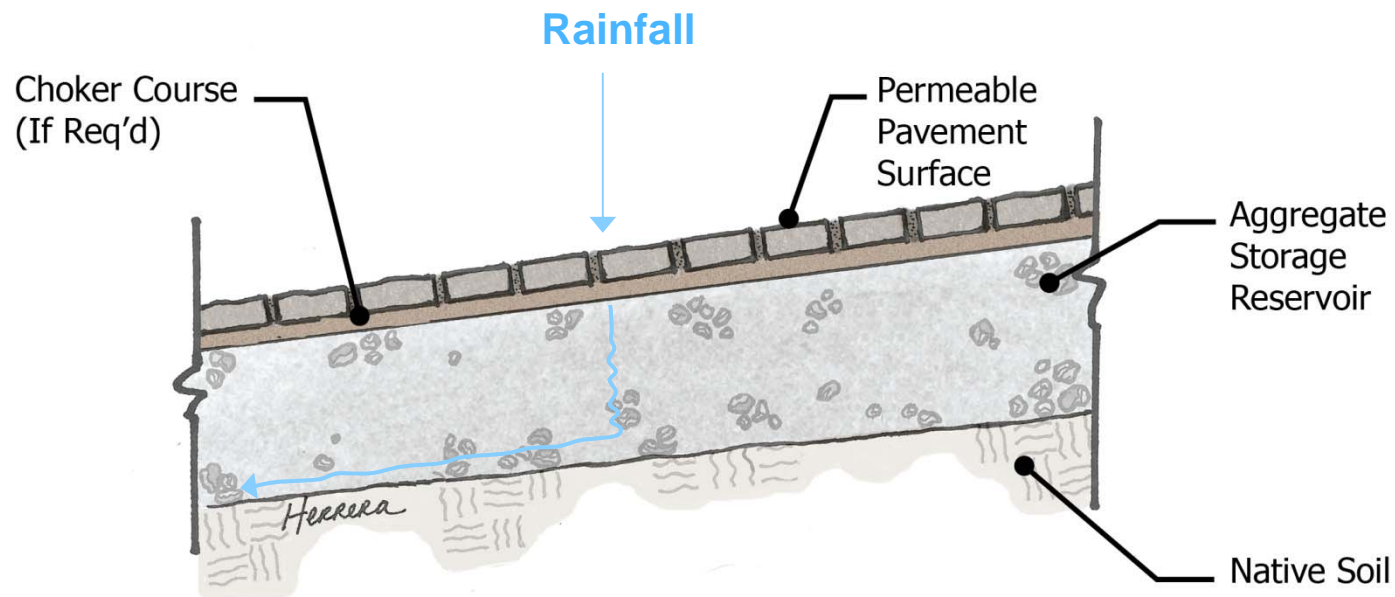


→ can neglect lateral flow

→ subsurface storage depth modeled = aggregate thickness

Permeable Pavement Types

Subgrade Slope >2 to 5% (no berms)

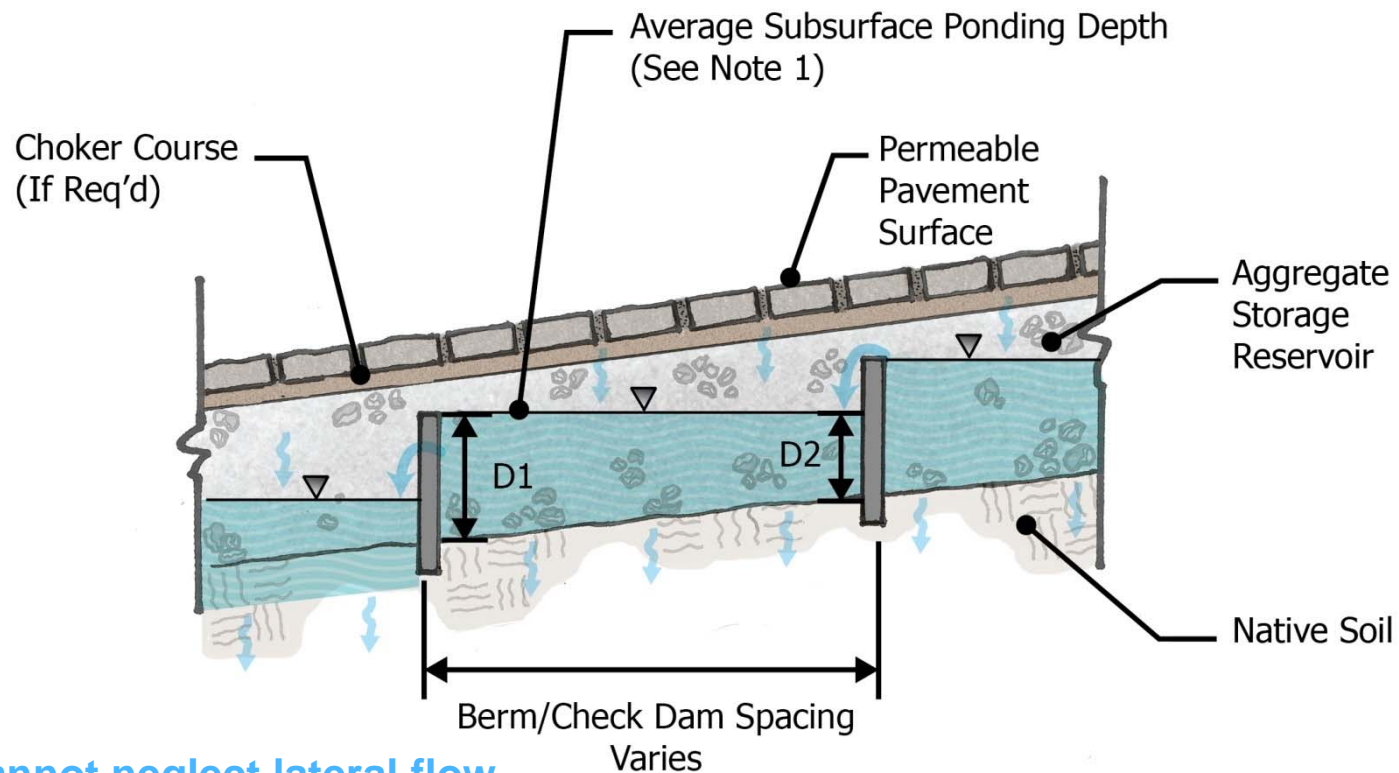


→ cannot neglect lateral flow

→ subsurface storage depth modeled = average subsurface ponding depth
(when no berms, may be estimated as = 1/2")

Permeable Pavement Types

Subgrade Slope >2 to 5% (with berms)



→ cannot neglect lateral flow

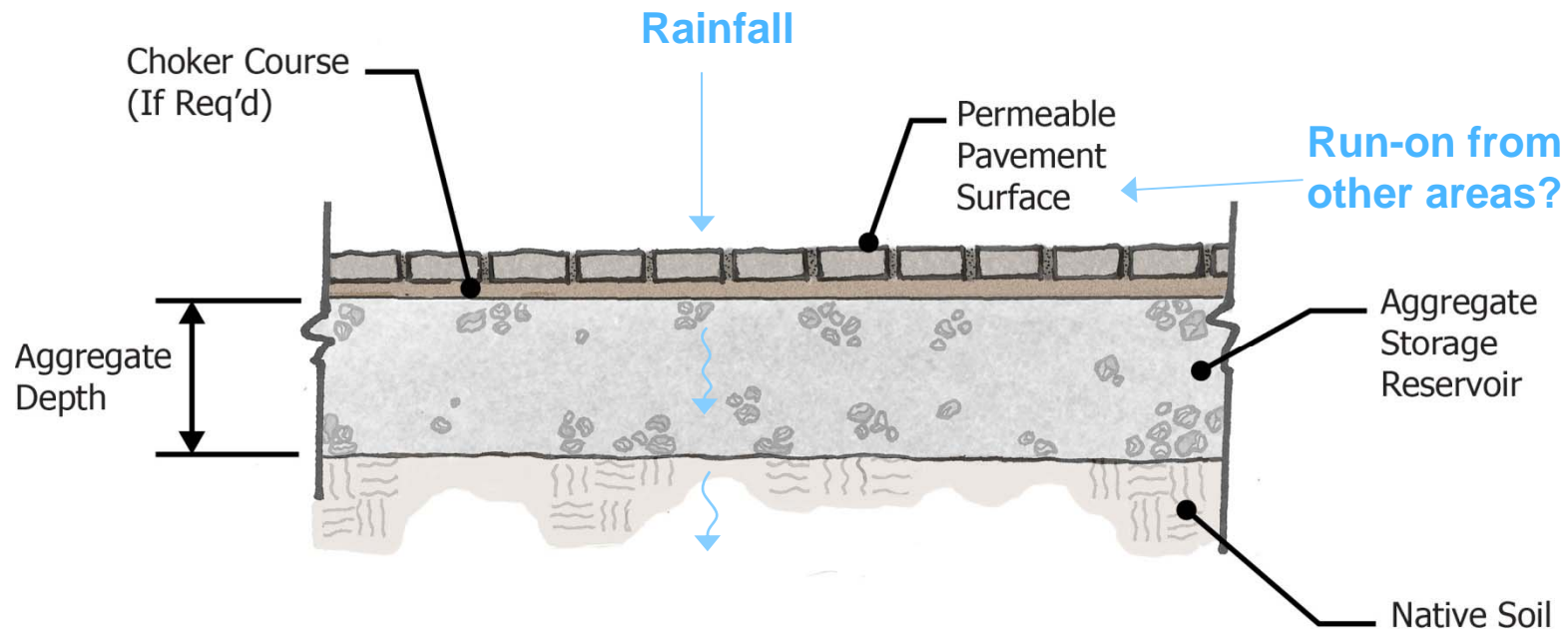
→ subsurface storage depth modeled = average subsurface ponding depth
= water depth before berm overtopping* or overflow

*function of slope, check dam height, and check dam spacing

Permeable Pavement Types

Run-on?:

- Always designed to manage rain falling on the permeable pavement area
- May also be designed to mitigate run-on (flow from other areas)



Modeling Tools

HSPF Basics – Model Inputs

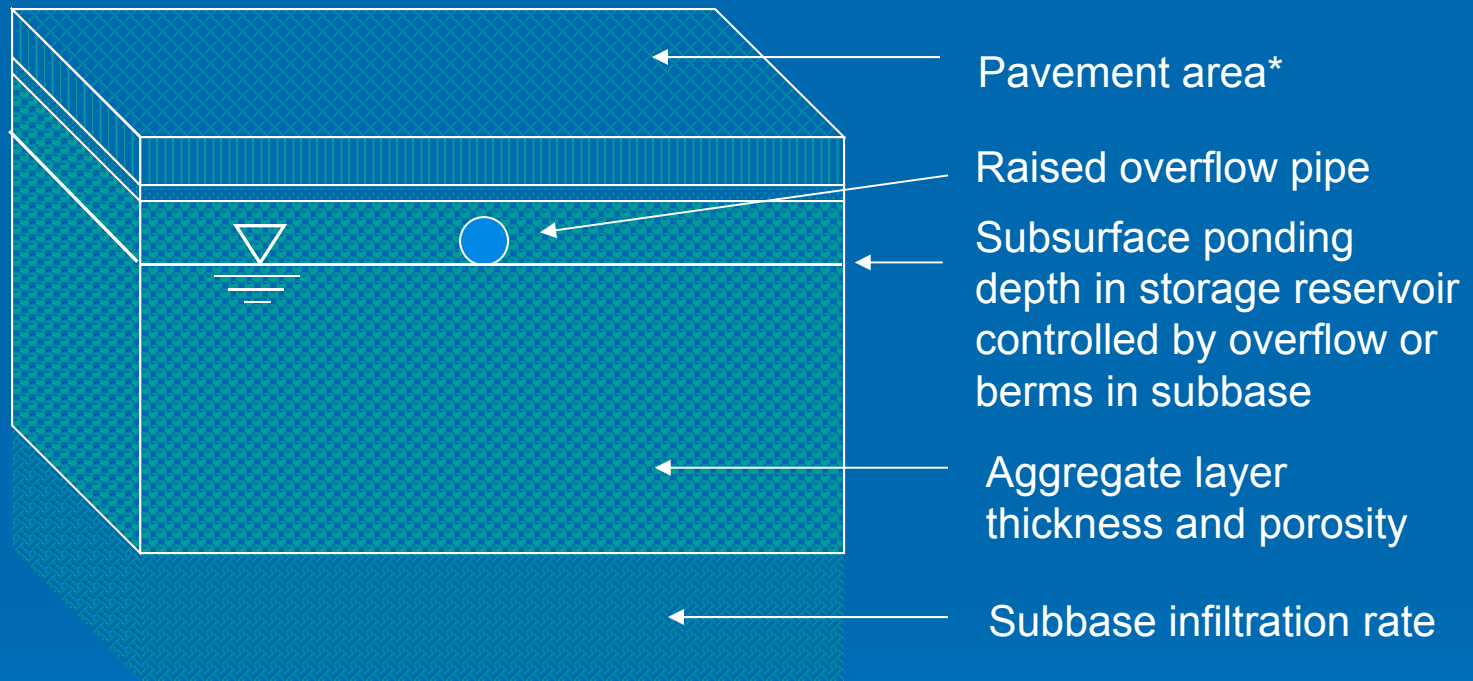
- Meteorological Data
 - Rainfall (5-min, 15-min, hourly)
 - Evaporation (daily)

- Land Cover Types
 - Impervious areas
 - Slope
 - Pervious areas
 - Vegetation
 - Soil type (A, B, C/D)
 - Slope
 - Regional calibrated parameters (Dinicola 1990)

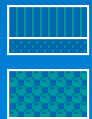
- BMP Configurations

Model Representation

Gravel Trench Parameters



Key :



Wearing Course

Aggregate



Overflow

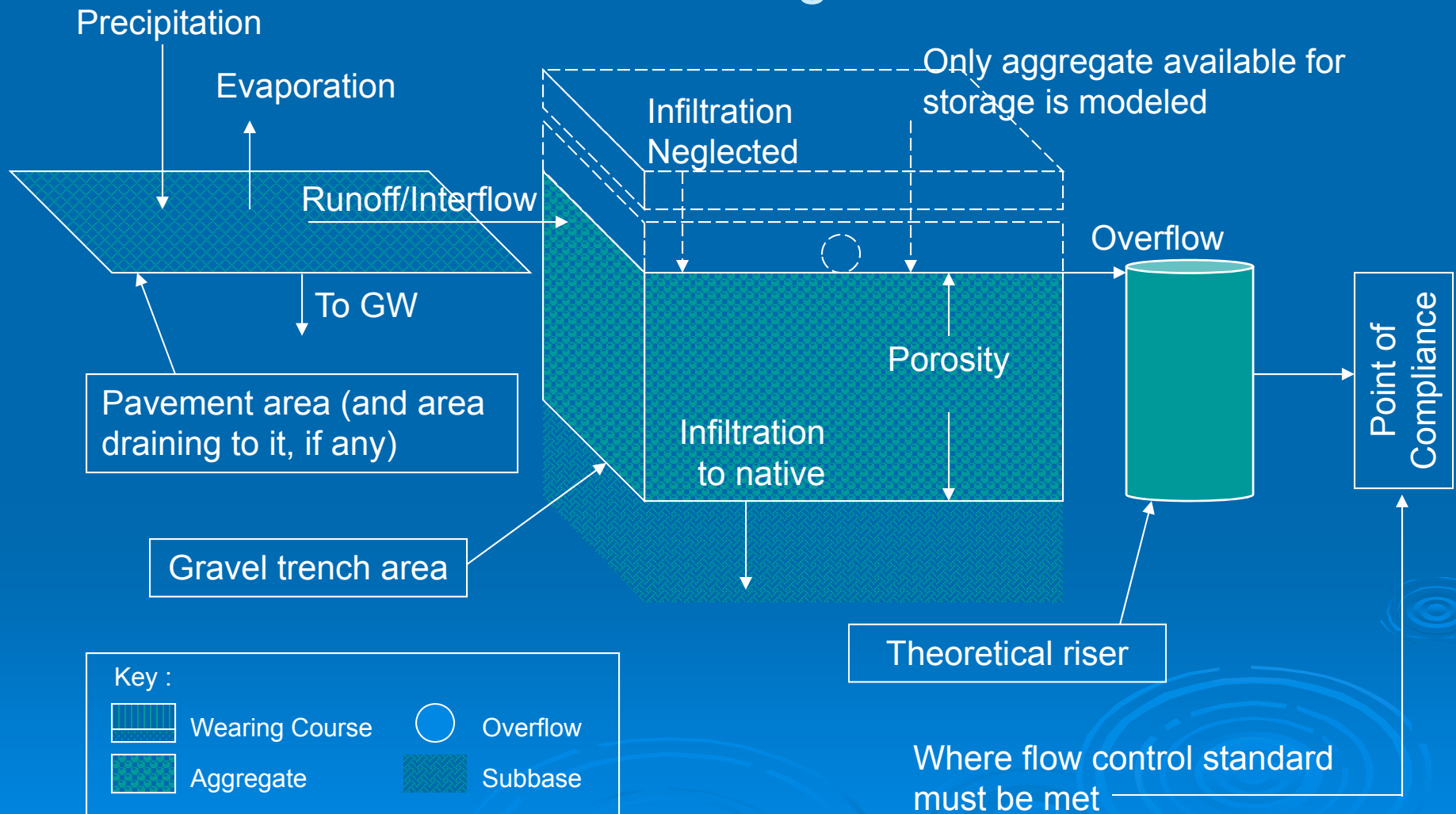


Subbase

* May include additional contributing area

Model Representation

Model Configuration

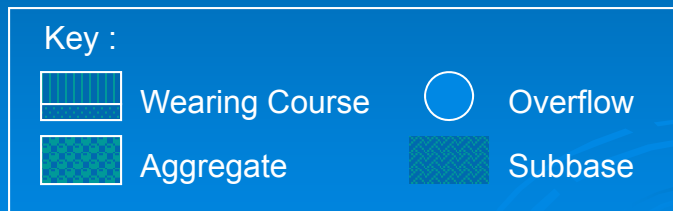
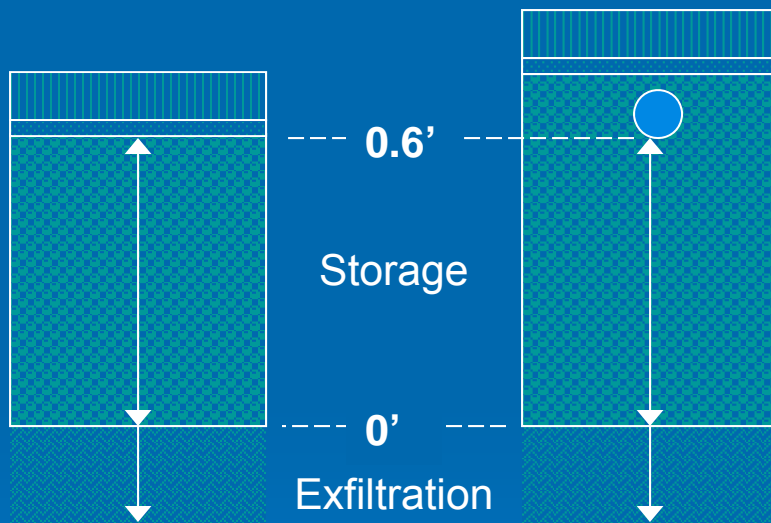


Note: Only aggregate under overflow invert modeled

Model Representation

Gravel Trench Routing

Ex. Cross Sections



Ex. SSD Table

Stage (ft)	Area (sf)	Storage (cf)	Infilt. (cfs)	Overflow (cfs)
0.0	0	0	0	0
0.1	10,000	1,000	0.0579	0
0.2	10,000	2,000	0.0579	0
0.3	10,000	3,000	0.0579	0
0.4	10,000	4,000	0.0579	0
0.5	10,000	5,000	0.0579	0
0.6	10,000	6,000	0.0579	0
0.7	10,000	7,000	0.0579	31.8
0.8	10,000	8,000	0.0579	87.1

Overflow Elevation = top of pavement
or invert of overflow pipe

Permeable Pavement Modeling Examples

- Flow Control in Creek basin (WWHM2012)
- Water Quality Treatment (WWHM2012)
- CSO Reduction (SWMM)



Flow Control in Creek Basin

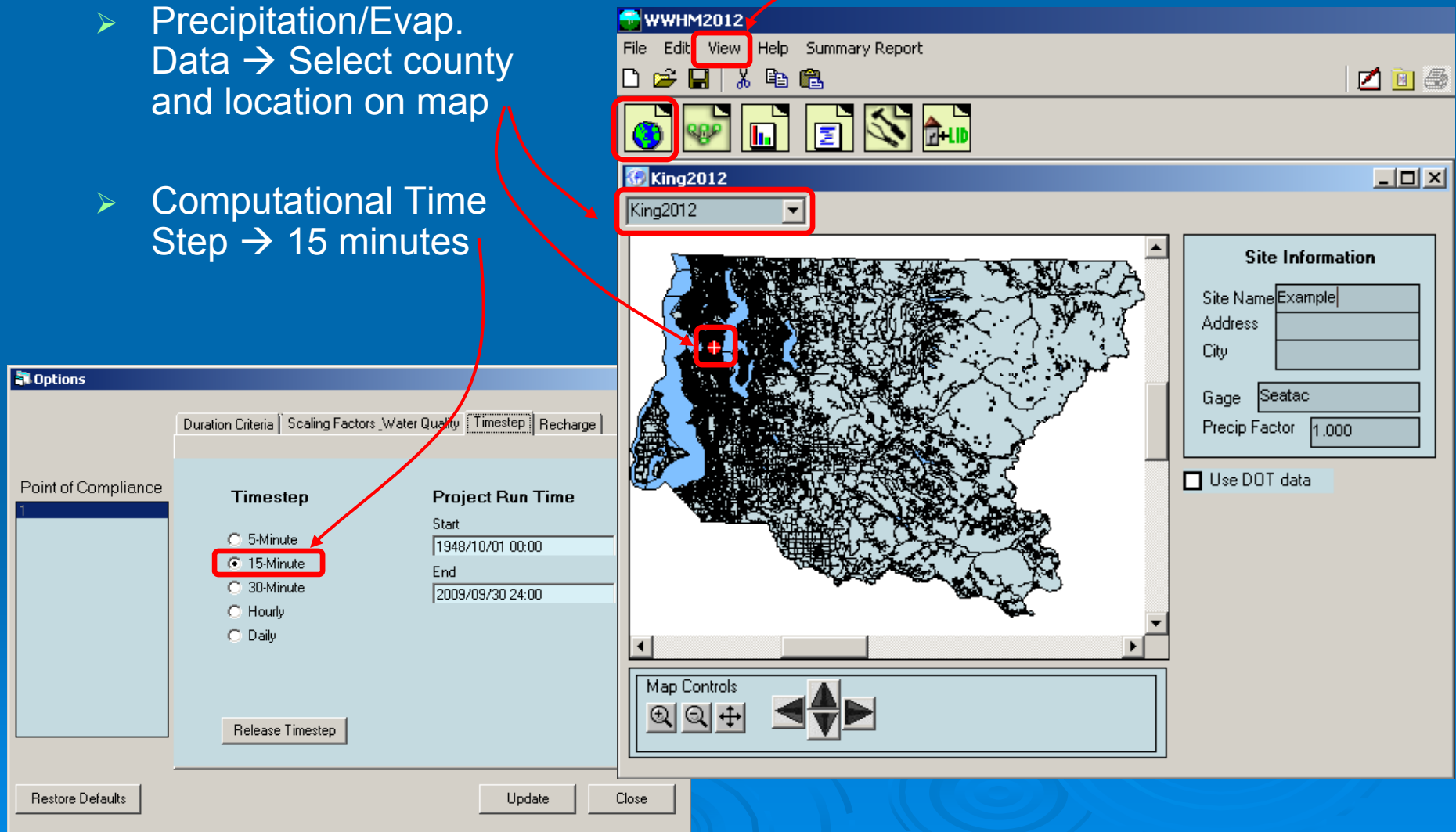
WWHM2012 Example – Explicit Method

- Site in King County
- Soil is till (0.25 inch/hour design infiltration rate)
- Permeable pavement *facility* is 10,000 sf
- Receiving run-on from 5,000 sf of additional area
- Design goal = Ecology Stream Duration standard (assuming a predeveloped forest condition)
- Size aggregate depth (*ave. subsurface ponding depth*)
- SIZING FOR FLOW CONTROL GOAL → MAY NEED TO BE THICKER TO SATISFY OTHER DESIGN GOALS (EX. LOADING)

Sizing for Flow Control

- Precipitation/Evap. Data → Select county and location on map
- Computational Time Step → 15 minutes

Option Menu



Sizing for Flow Control

Predeveloped Basin → Select area, soil type, land cover and slope

The screenshot shows the WWHM2012 software interface. The 'Basin 1 Predeveloped' dialog box is open. The 'Subbasin Name' is 'Predeveloped Forest'. The 'Area in Basin' section shows a list of available pervious and impervious areas. The 'C, Forest, Mod' option is selected, showing 0.3444 acres. A red arrow points to this selection with the text '15,000 sf'.

Basin 1 Predeveloped

Subbasin Name: Predeveloped Forest

Flows To: Surface Interflow Groundwater

Area in Basin

Available Pervious Acres

Available Pervious	Acres
<input type="checkbox"/> A/B, Forest, Flat	0
<input type="checkbox"/> A/B, Forest, Mod	0
<input type="checkbox"/> A/B, Forest, Steep	0
<input type="checkbox"/> A/B, Pasture, Flat	0
<input type="checkbox"/> A/B, Pasture, Mod	0
<input type="checkbox"/> A/B, Pasture, Steep	0
<input type="checkbox"/> A/B, Lawn, Flat	0
<input type="checkbox"/> A/B, Lawn, Mod	0
<input type="checkbox"/> A/B, Lawn, Steep	0
<input type="checkbox"/> C, Forest, Flat	0
<input checked="" type="checkbox"/> C, Forest, Mod	0.3444
<input type="checkbox"/> C, Forest, Steep	0
<input type="checkbox"/> C, Pasture, Flat	0
<input type="checkbox"/> C, Pasture, Mod	0
<input type="checkbox"/> C, Pasture, Steep	0
<input type="checkbox"/> C, Lawn, Flat	0
<input type="checkbox"/> C, Lawn, Mod	0
<input type="checkbox"/> C, Lawn, Steep	0
<input type="checkbox"/> SAT, Forest, Flat	0

Available Impervious Acres

Available Impervious	Acres
<input type="checkbox"/> ROADS/FLAT	0
<input type="checkbox"/> ROADS/MOD	0
<input type="checkbox"/> ROADS/STEEP	0
<input type="checkbox"/> ROOF TOPS/FLAT	0
<input type="checkbox"/> DRIVEWAYS/FLAT	0
<input type="checkbox"/> DRIVEWAYS/MOD	0
<input type="checkbox"/> DRIVEWAYS/STEEP	0
<input type="checkbox"/> SIDEWALKS/FLAT	0
<input type="checkbox"/> SIDEWALKS/MOD	0
<input type="checkbox"/> SIDEWALKS/STEEP	0
<input type="checkbox"/> PARKING/FLAT	0
<input type="checkbox"/> PARKING/MOD	0
<input type="checkbox"/> PARKING/STEEP	0
<input type="checkbox"/> POND	0
<input type="checkbox"/> Porous Pavement	0

PerviousTotal 0.3444 Acres

Impervious Total 0 Acres

Basin Total 0.3444 Acres

15,000 sf

Sizing for Flow Control

Predeveloped Basin → Select area, soil type, land cover and slope

The screenshot displays the WWHM2012 software interface. The main window shows a grid-based schematic of a basin. A red box highlights a green icon labeled '1' on the grid, with a red arrow pointing to it. The 'Basin 1 Predeveloped' dialog box is open, showing the 'Subbasin Name' as 'Predeveloped Forest'. The 'Flows To' section has three empty input fields for Surface, Interflow, and Groundwater. The 'Point Of Compliance' sub-dialog is also open, showing the 'Element' as 'Predeveloped Forest'. The 'POC Outlet' section has three checkboxes: 'Surface Flow' (checked), 'Interflow' (checked), and 'Groundwater' (unchecked). The 'Select POC' list shows '1' as the selected item. The 'Connect' button is visible. The 'Commercial Toolbox' section shows a list of land cover types: 'C, Lawn, Flat', 'C, Lawn, Mod', 'C, Lawn, Steep', and 'SAT, Forest, Flat', each with an 'Acres' input field. The 'Basin Total' is calculated as 0.3444 Acres.

WWHM2012
File Edit View Zoom Help

Schematic
SCENARIOS
☒ Predeveloped
☐ Mitigated
Run Scenario
Basic Elements
Pro Elements
LID Toolbox
Commercial Toolbox
Move Elements
Save x,y Load x,y

Basin 1 Predeveloped
Subbasin Name: Predeveloped Forest
Flows To : Surface Interflow Groundwater
Point Of Compliance
Element: Predeveloped Forest
POC Outlet
☒ Surface Flow
☒ Interflow
☐ Groundwater
Select POC ADD
1
Connect
C, Lawn, Flat 0
C, Lawn, Mod 0
C, Lawn, Steep 0
SAT, Forest, Flat 0
PerviousTotal 0.3444 Acres
Impervious Total 0 Acres
Basin Total 0.3444 Acres
Deselect Zero Select By: GO

Sizing for Flow Control

Developed Mitigated Basin → Area contributing runoff to permeable pavement....

The screenshot displays the WWHM2012 software interface. On the left, the 'SCENARIOS' panel shows 'Mitigated' selected. Below it, the 'Basic Elements' panel contains a grid of icons; a red box highlights a 'Lateral Impervious Basin' icon, with a red arrow pointing to it and the text 'Lateral Impervious Basin'. The main workspace shows a grid with a single 'Lateral Impervious Basin' element. On the right, the 'Lateral I Basin 1 Mitigated' properties panel is open. It shows the 'Element Name' as 'Impervious Runon' (highlighted with a red box). The 'Runoff Type' is 'Surface', 'Interflow' is '0', and 'Groundwater' is '0'. The 'Downstream Connection' is '0'. The 'Element Type' is 'Lateral Impervious Flow Basin'. The 'Impervious (IMPLND) Type' is 'ROADS/MOD LAT'. The 'Lateral Area (ac)' is '0.1148' (highlighted with a red box). A red arrow points from the text '5,000 sf' to this value. The 'Designate as Bypass for F' checkbox is unchecked.

Element Name	Runoff Type	Downstream Connection	Element Type	Impervious (IMPLND) Type	Lateral Area (ac)
Impervious Runon	Surface	0	Lateral Impervious Flow Basin	ROADS/MOD LAT	0.1148

Sizing for Flow Control

Developed Mitigated Basin Continued: Route to Permeable Pavement Module

The screenshot displays the WWHM2012 software interface. The main window is titled "Schematic" and shows a grid-based schematic of a basin. On the left, there is a "SCENARIOS" panel with "Predeveloped" and "Mitigated" options. Below this are "Basic Elements" and "Pro Elements" toolbars. A "LID Toolbox" is also visible. The main grid contains several elements, including a "Permeable Pavement" element (represented by a green icon with a white circle) and a "Gravel Trench" element (represented by a blue icon with a white circle). A red rectangle highlights the "Permeable Pavement" element, and a red arrow points from it to a dialog box titled "From Basin to a Basin".

The dialog box "From Basin to a Basin" has two columns: "Flow From:" and "Flow To:". Under "Flow From:", the "Surface Flow" checkbox is checked. Under "Flow To:", the "Surface Flow" option is selected. The "OK" button is at the bottom.

On the right side of the main window, there is a panel titled "Lateral I Basin 1 Mitigated". It contains the following information:

Element Name	Runoff Type	Surface	Interflow	Groundwater
Impervious Runon	Downstream Connection	Permeable Pavement	0	0

Below this table, the "Element Type" is listed as "Lateral Impervious Flow Basin". Other parameters include "Impervious (IMPLND) Type" (ROADS/MOD LAT), "Lateral Area (ac)" (0.1148), and a "Designate as Bypass for F" checkbox.

Impervious land surface over gravel trench with infiltration

Sizing for Flow Control

Developed Mitigated Basin Continued: Characterize Permeable Pavement

WHM2012
File Edit View Zoom Help

SCHEMATIC

SCENARIOS

- ☐ Predeveloped
- ☒ Mitigated

Run Scenario

Basic Elements

Pro Elements

LID Toolbox

Commercial Toolbox

Move Elements

Save x,y Load x,y

Permeable Pavement 1 Mitigated

Facility Name: Permeable Pavement 1

Outlet 1: 0 Outlet 2: 0 Outlet 3: 0

Downstream Connection: 0

Facility Type: Permeable Pavement

Quick Pavement

Facility Dimension Diagram

Overflow Data

Ponding Depth Above Pavement (ft): 0.1

Diameter Height (in): 0 (ft): 0

Underdrain: 0

Storage Volume at Top of Pavement (ac-ft): .230

Show Pavement Table: Open Table

Initial Stage (ft): 0

Total Volume Through Facility (ac-ft): 0

Percent Infiltrated: 0

Size Pavement

Target %: 100

Facility Dimensions

Pavement Length (ft)	100
Pavement Bottom Width (ft)	100
Effective Total Depth (ft)	2.5
Bottom slope (ft/ft)	0

Layers for Permeable Pavement

Pavement Thickness (ft)	0
Pavement porosity (0-1)	0
Sublayer 1 Thickness (ft)	2
Sublayer 1 porosity (0-1)	0.25
Sublayer 2 Thickness (ft)	0
Sublayer 2 porosity (0-1)	0

Infiltration

Measured Infiltration Rate (in/hr)	0.5
Reduction Factor (infiltr*factor)	0.5
Use Wetted Surface Area (sidewalls)	NO
Total Volume Infiltrated (ac-ft)	0
Total Volume Through Riser (ac-ft)	0

Pavement depth + freeboard above surface

Area

POC

Pavement Section

Infiltration to Native Soil

Name

Depression storage before runoff (weir flow over edge)

SSD Table

Sizing for Flow Control

Stage Storage Discharge Table

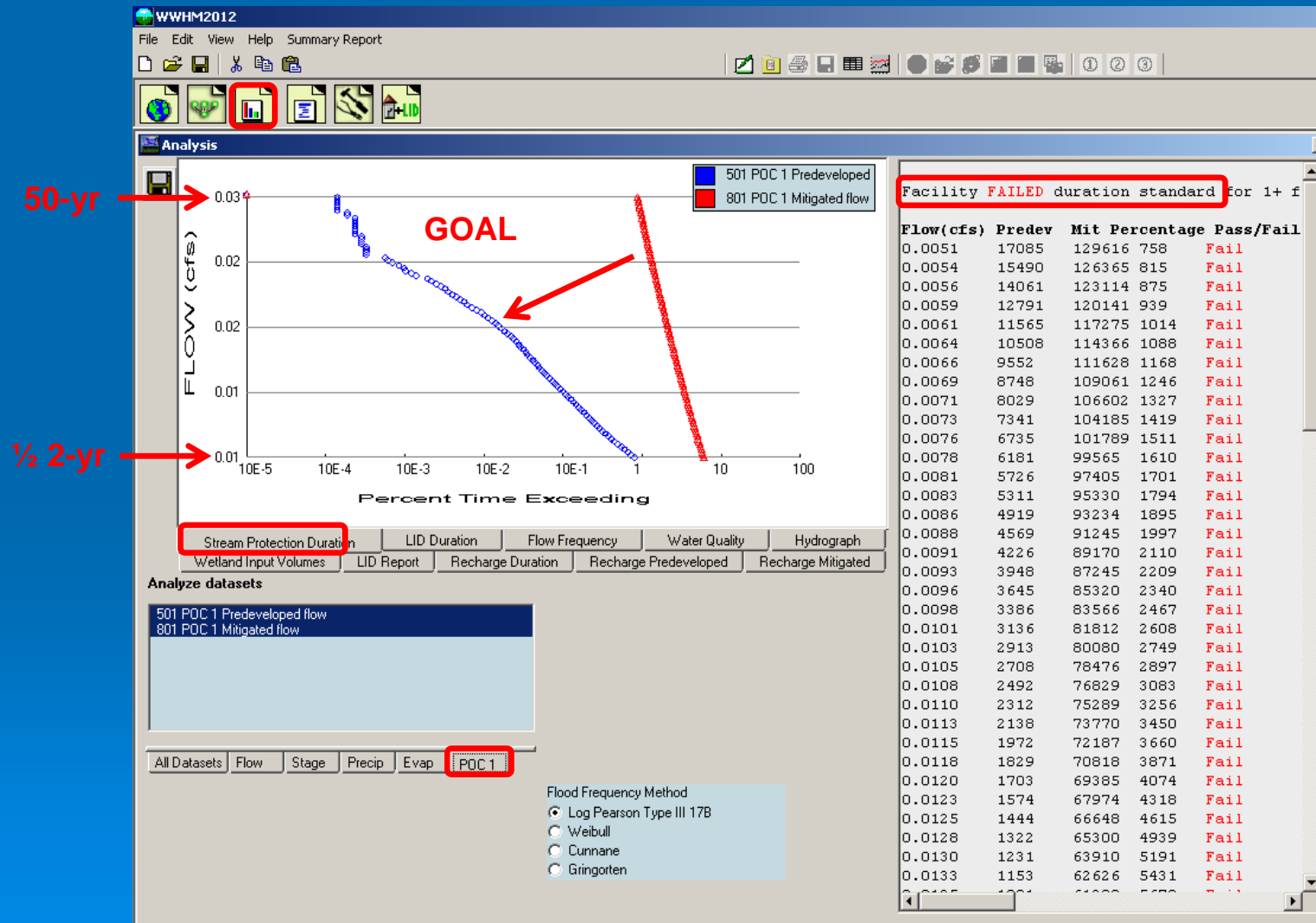
Stage (ft)	Area (acres)	Storage (acre-ft)	Dschrge (cfs)	(cfs)
0.000000	0.229568	0.000000	0.000000	0.000000
0.027778	0.229568	0.001594	0.000000	0.057870
0.055556	0.229568	0.003188	0.000000	0.057870
0.083333	0.229568	0.004783	0.000000	0.057870
0.111111	0.229568	0.006377	0.000000	0.057870
0.138889	0.229568	0.007971	0.000000	0.057870
0.166667	0.229568	0.009565	0.000000	0.057870
0.194444	0.229568	0.011160	0.000000	0.057870
0.222222	0.229568	0.012754	0.000000	0.057870
0.250000	0.229568	0.014348	0.000000	0.057870
0.277778	0.229568	0.015942	0.000000	0.057870
0.305556	0.229568	0.017536	0.000000	0.057870
0.333333	0.229568	0.019131	0.000000	0.057870
0.361111	0.229568	0.020725	0.000000	0.057870
0.388889	0.229568	0.022319	0.000000	0.057870
0.416667	0.229568	0.023913	0.000000	0.057870
0.444444	0.229568	0.025508	0.000000	0.057870
0.472222	0.229568	0.027102	0.000000	0.057870
0.500000	0.229568	0.028696	0.000000	0.057870
0.527778	0.229568	0.030290	0.000000	0.057870
0.555556	0.229568	0.031885	0.000000	0.057870
0.583333	0.229568	0.033479	0.000000	0.057870
0.611111	0.229568	0.035073	0.000000	0.057870
0.638889	0.229568	0.036667	0.000000	0.057870
0.666667	0.229568	0.038261	0.000000	0.057870
0.694444	0.229568	0.039856	0.000000	0.057870
0.722222	0.229568	0.041450	0.000000	0.057870
0.750000	0.229568	0.043044	0.000000	0.057870
0.777778	0.229568	0.044638	0.000000	0.057870
0.805556	0.229568	0.046233	0.000000	0.057870
0.833333	0.229568	0.047827	0.000000	0.057870
0.861111	0.229568	0.049421	0.000000	0.057870
0.888889	0.229568	0.051015	0.000000	0.057870

Stage (ft)	Area (acres)	Storage (acre-ft)	Dschrge (cfs)	(cfs)
1.666667	0.229568	0.095654	0.000000	0.057870
1.694444	0.229568	0.097248	0.000000	0.057870
1.722222	0.229568	0.098842	0.000000	0.057870
1.750000	0.229568	0.100436	0.000000	0.057870
1.777778	0.229568	0.102030	0.000000	0.057870
1.805556	0.229568	0.103625	0.000000	0.057870
1.833333	0.229568	0.105219	0.000000	0.057870
1.861111	0.229568	0.106813	0.000000	0.057870
1.888889	0.229568	0.108407	0.000000	0.057870
1.916667	0.229568	0.110002	0.000000	0.057870
1.944444	0.229568	0.111596	0.000000	0.057870
1.972222	0.229568	0.113190	0.000000	0.057870
2.000000	0.229568	0.114784	0.000000	0.057870
2.027778	0.229568	0.121161	0.154167	0.057870
2.055556	0.229568	0.127538	0.436049	0.057870
2.083333	0.229568	0.133915	0.801073	0.057870
2.111111	0.229568	0.140292	1.233333	0.057870
2.138889	0.229568	0.146669	1.723636	0.057870
2.166667	0.229568	0.153046	2.265778	0.057870
2.194444	0.229568	0.159423	2.855207	0.057870
2.222222	0.229568	0.165799	3.488393	0.057870
2.250000	0.229568	0.172176	4.162500	0.057870
2.277778	0.229568	0.178553	4.875178	0.057870
2.305556	0.229568	0.184930	5.624443	0.057870
2.333333	0.229568	0.191307	6.408588	0.057870
2.361111	0.229568	0.197684	7.226126	0.057870
2.388889	0.229568	0.204061	8.075744	0.057870
2.416667	0.229568	0.210438	8.956274	0.057870
2.444444	0.229568	0.216815	9.866667	0.057870
2.472222	0.229568	0.223192	10.80597	0.057870
2.500000	0.229568	0.229568	11.77333	0.057870

Overflow

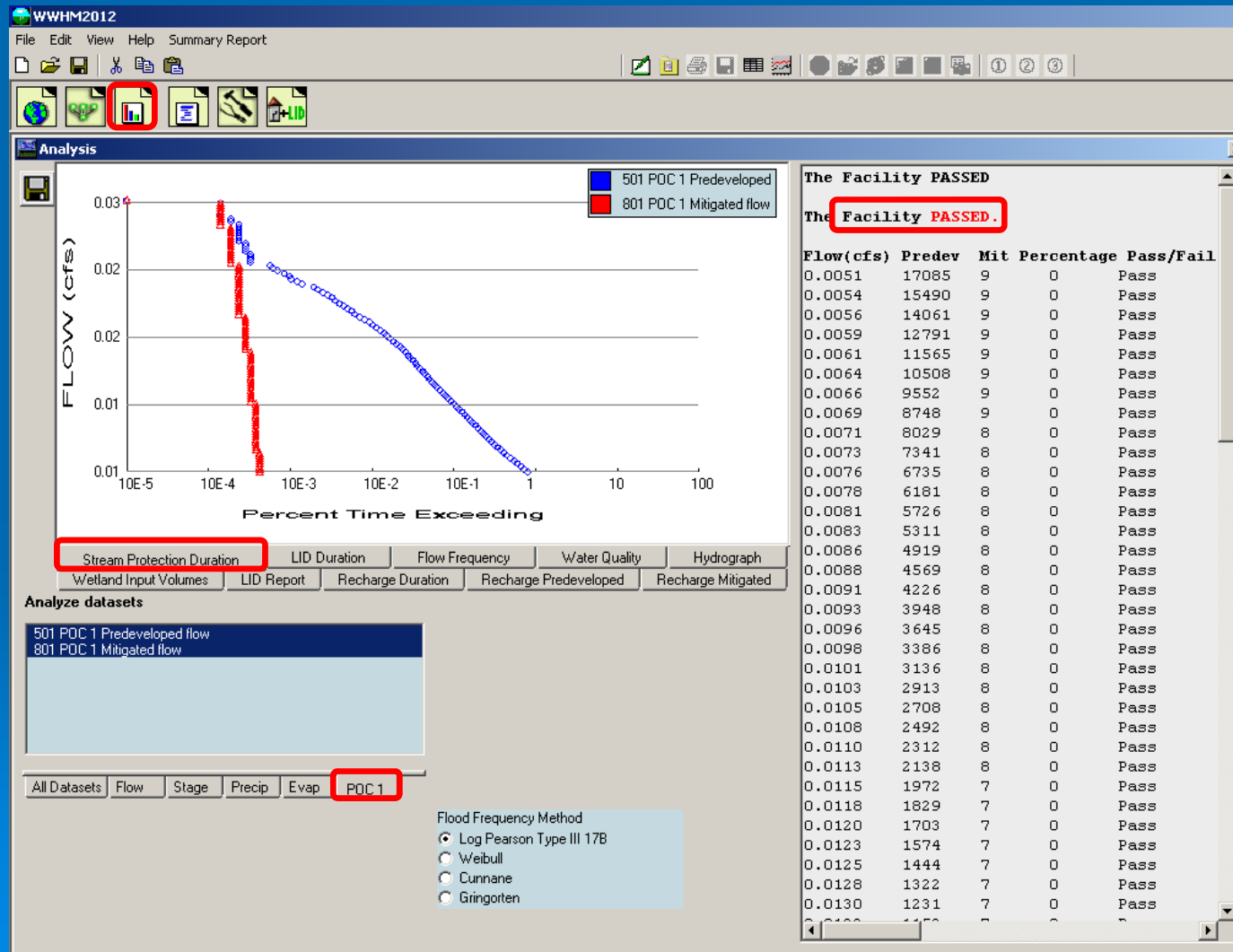
Sizing for Flow Control

Flow Duration Curve- Developed Unmitigated (Impervious)



Sizing for Flow Control

Flow Duration Curve- Developed Mitigated (with Permeable Pavement)



Sizing for Flow Control

Iteratively Sized Storage Aggregate Depth to Meet Duration Standard

The screenshot displays the WWHM2012 software interface. On the left, the 'SCHEMATICS' panel shows a grid with a permeable pavement facility icon. A red arrow points from the text '5.5" required to meet goal' to the facility icon. Another red arrow points from the text 'Infiltrates almost 100% runoff' to the 'Infiltration' section of the facility configuration.

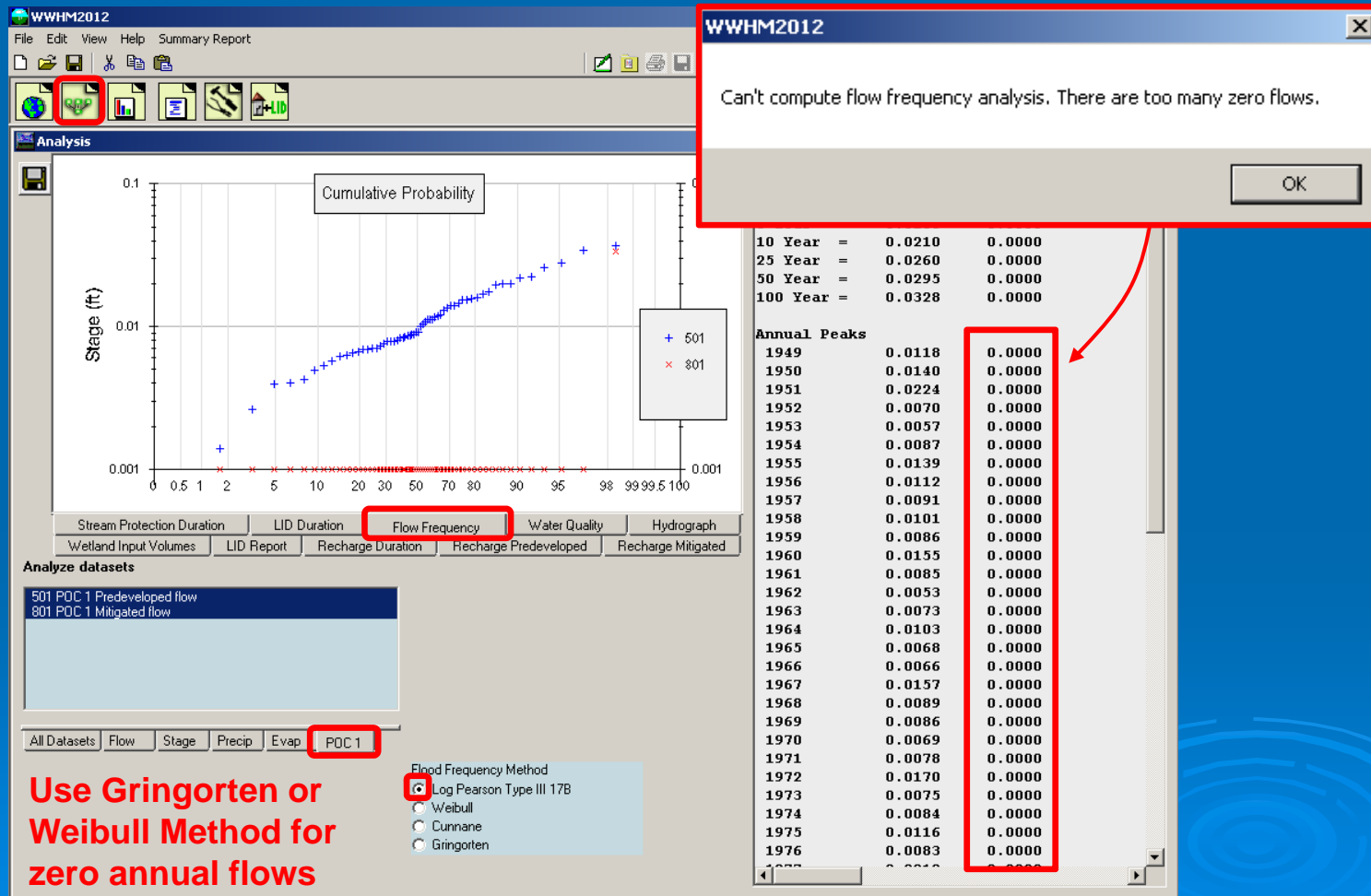
The facility configuration parameters are as follows:

- Facility Name:** Permeable Pavement 1 Mitigated
- Outlet 1:** 0
- Outlet 2:** 0
- Outlet 3:** 0
- Downstream Connection:** 0
- Facility Type:** Permeable Pavement
- Facility Dimensions:**
 - Pavement Length (ft): 100
 - Pavement Bottom Width (ft): 100
 - Effective Total Depth (ft): 1
 - Bottom slope (ft/ft): 0
- Effective Volume Factor:** 0
- Layers for Permeable Pavement:**
 - Pavement Thickness (ft): 0
 - Pavement porosity (0-1): 0
 - Sublayer 1 Thickness (ft): 0.46**
 - Sublayer 1 porosity (0-1): 0.25
 - Sublayer 2 Thickness (ft): 0
 - Sublayer 2 porosity (0-1): 0
- Infiltration:** YES
 - Measured Infiltration Rate (in/hr): 0.5
 - Reduction Factor (infiltration factor): 0.5
 - Use Wetted Surface Area (sidewalls): NO
- Overflow Data:**
 - Ponding Depth Above Pavement (ft): 0.1
- Diameter Height (in):** 0
- Underdrain:** 0
- Storage Volume at Top of Pavement (ac-ft):** .527
- Show Pavement Table:** Open Table
- Initial Stage (ft):** 0
- Total Volume Infiltrated (ac-ft):** 58.672
- Total Volume Through Facility (ac-ft):** 58.676
- Total Volume Through Riser (ac-ft):** 0.004
- Percent Infiltrated:** 99.99

Buttons at the bottom include 'Size Pavement', 'Target %: 100', 'Save x,y', and 'Load x,y'.

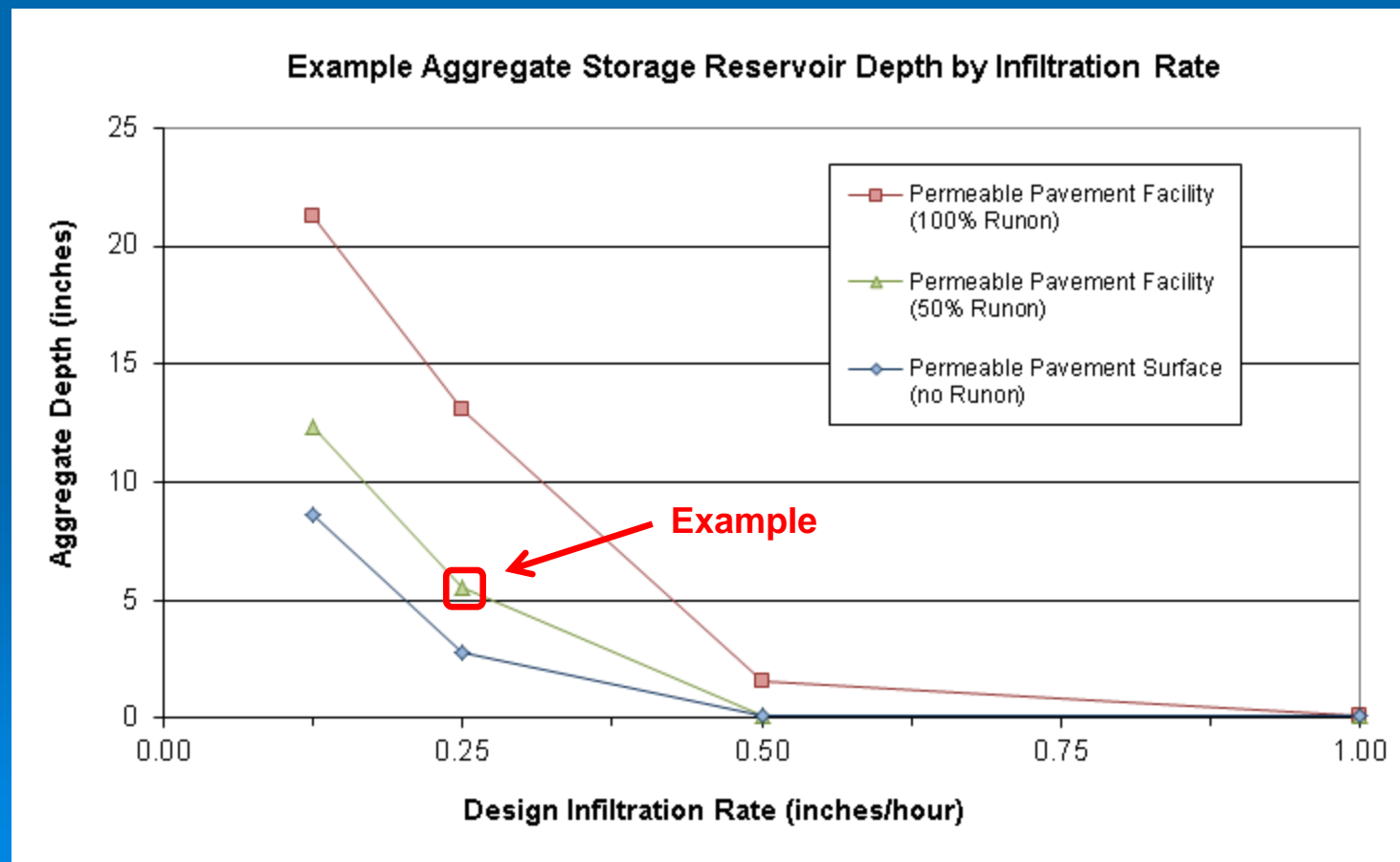
Sizing for Flow Control

Flow Frequency Results



Performance & Infiltration Rate

Example: Permeable Pavement in King County designed to achieve Creek Protection Duration Standard (Forest on Till)



Water Quality Treatment

Same WWHM2012 Example



Sizing for Treatment

Percent Infiltration- at least 91% of entire runoff file
Infiltration through soils meeting Ecology treatment soil requirements

The screenshot displays the WWHM2012 software interface. On the left, the 'SCHEMATICS' panel shows a grid with a permeable pavement facility icon. A red arrow points from the text 'Facility sized for flow control infiltrates much more than 91 percent' to the facility icon. The right panel, titled 'Permeable Pavement 1 Mitigated', contains various configuration options and a table of results.

Facility Name: Permeable Pavement 1

Outlet 1: 0 **Outlet 2:** 0 **Outlet 3:** 0

Downstream Connection: 0

Facility Type: Permeable Pavement

Quick Pavement **Facility Dimension Diagram**

Facility Dimensions

Pavement Length (ft) 100
Pavement Bottom Width (ft) 100
Effective Total Depth (ft) 1
Bottom slope (ft/ft) 0

Effective Volume Factor 0

Layers for Permeable Pavement

Pavement Thickness (ft) 0
Pavement porosity (0-1) 0
Sublayer 1 Thickness (ft) 0.46
Sublayer 1 porosity (0-1) 0.25
Sublayer 2 Thickness (ft) 0
Sublayer 2 porosity (0-1) 0

Overflow Data

Ponding Depth Above Pavement (ft) 0.1

Diameter Height (in) (ft)

Underdrain 0 0

Storage Volume at Top of Pavement (ac-ft) .527

Infiltration YES

Measured Infiltration Rate (in/hr) 0.5
Reduction Factor (infiltrator) 0.5
Use Wetted Surface Area (sidewalls) NO

Show Pavement Table Open Table

Total Volume Infiltrated (ac-ft)	58.672	Total Volume Through Facility (ac-ft)	58.676
Total Volume Through Riser (ac-ft)	0.004	Percent Infiltrated	99.99

Size Pavement

Target %: 100

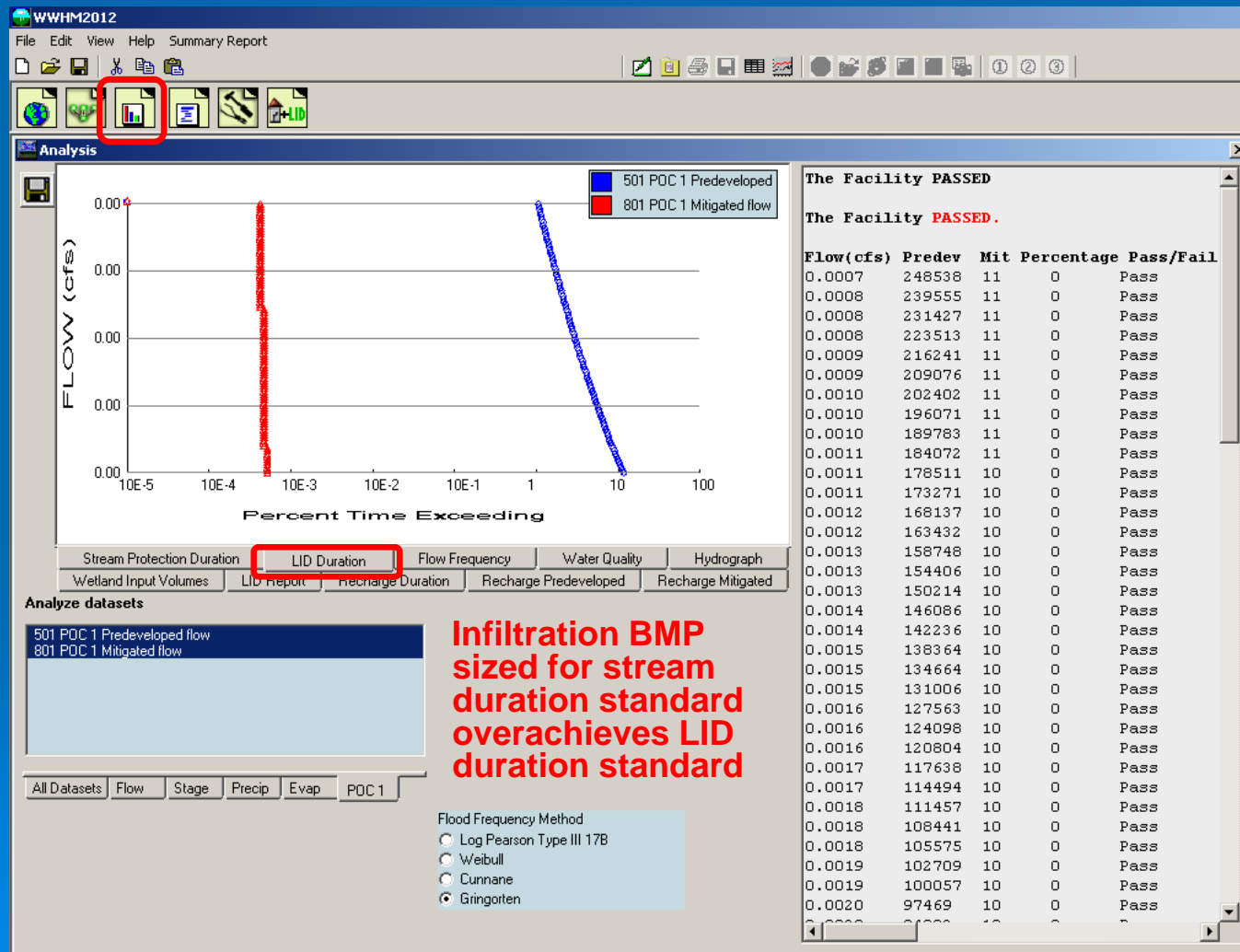
Further Analysis

WWHM2012 Example



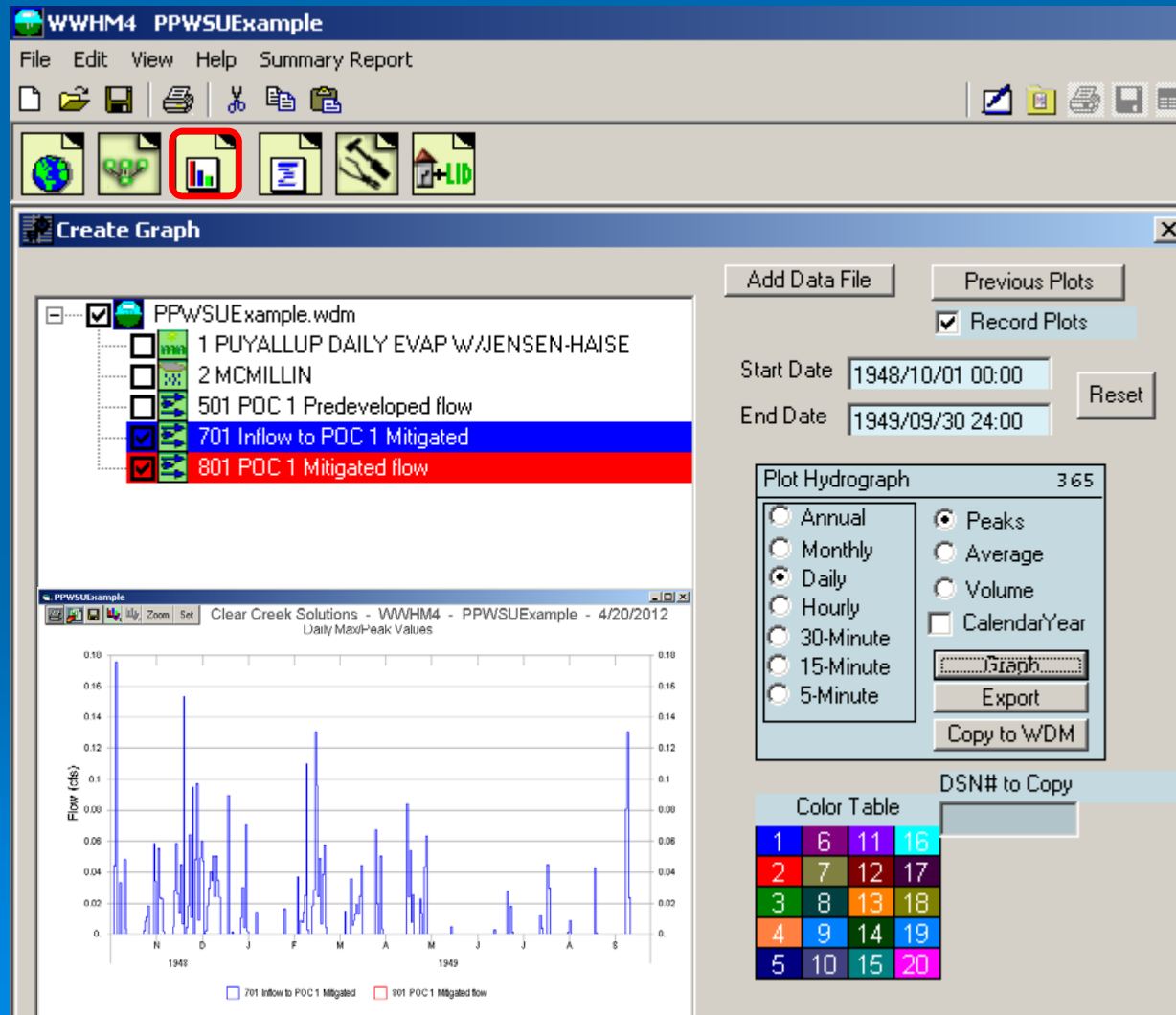
Further Analysis

LID Performance Standard



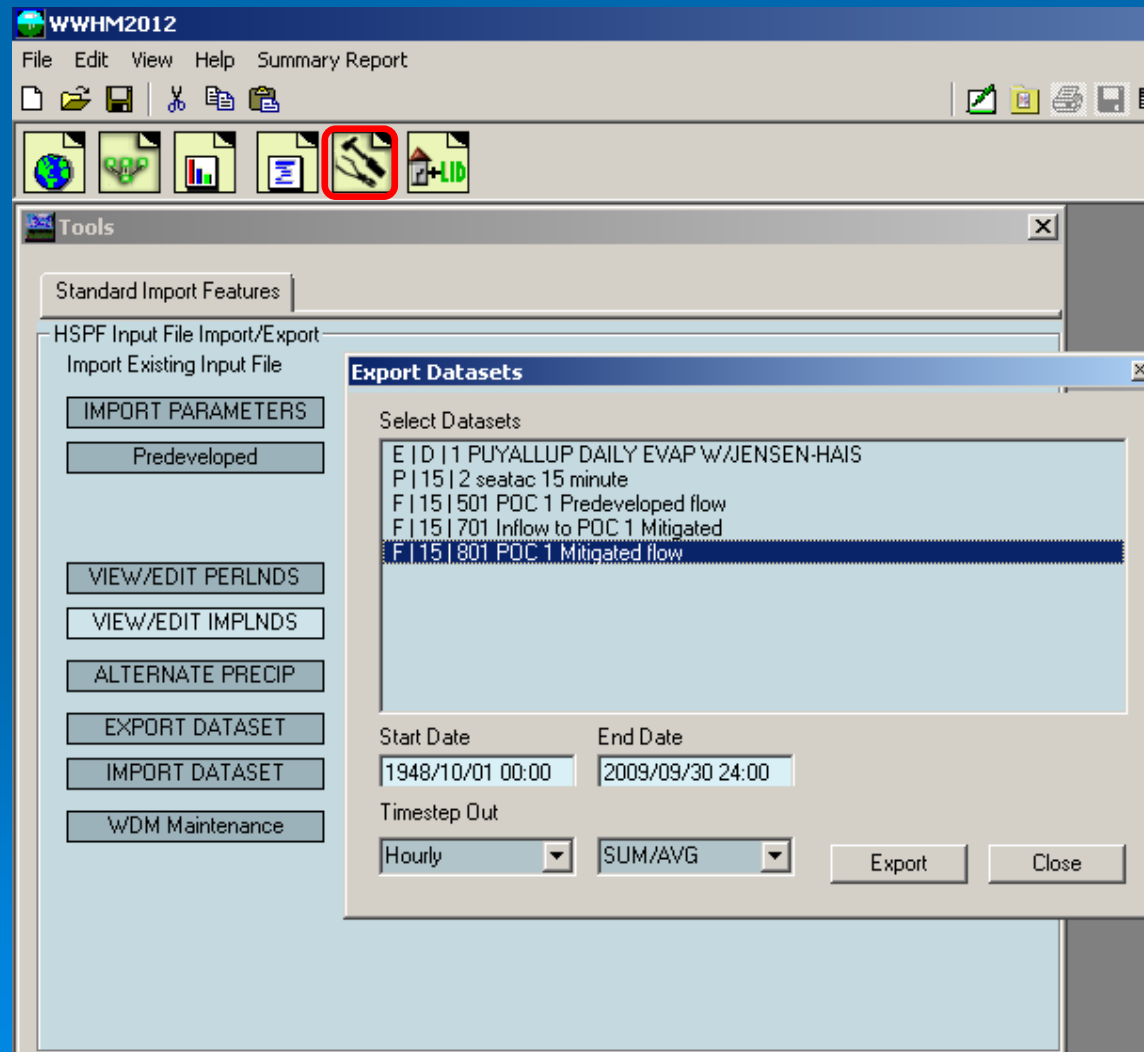
Further Analysis

Hydrograph



Further Analysis

Time Series Export



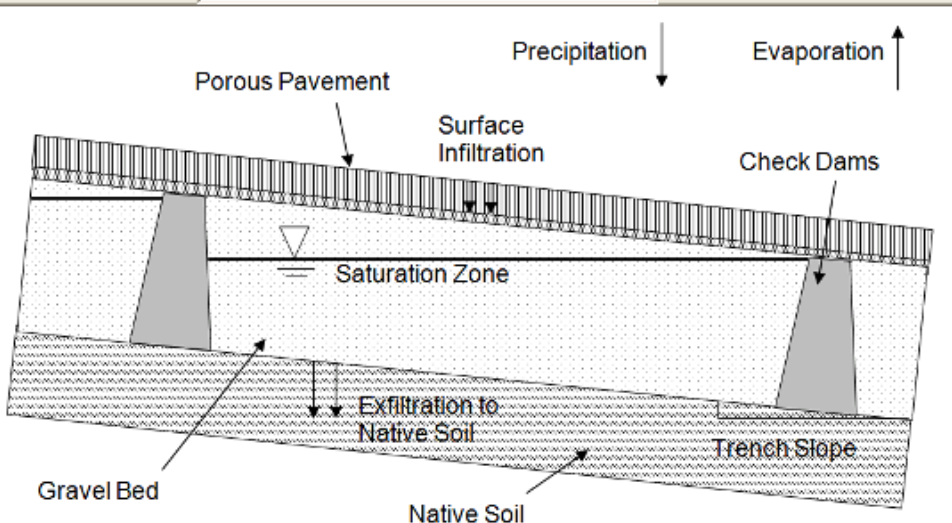
Modeling Tools

MGSFlood Basics

- Similar input as presented for WWHM
- Explicit representation of berms and subsurface ponding

Porous Pavement Structure: Porous Pavement

Structure Name: Porous Pavement



The diagram illustrates a cross-section of a porous pavement structure. It shows a sloped surface with a porous pavement layer. Precipitation is shown as a downward arrow, and evaporation as an upward arrow. Surface infiltration is indicated by downward arrows into the pavement. Check dams are shown as small structures on the surface. A saturation zone is depicted below the pavement, with a water table line. Below the saturation zone is a gravel bed, and at the bottom is the native soil. Arrows indicate exfiltration from the gravel bed into the native soil. The trench slope is also labeled.

Porous Pavement Length (ft)	200.00
Porous Pavement Width (ft)	25.00
Porous Pavement Slope (ft/ft)	0.005
Pavement Infiltration Rate (in/hr)	20.000
Number of Cells Along total Trench length	1
Trench Cell Length (ft)	200.00
Trench Cell Width (ft)	25.00
Trench Cell Depth (ft)	1.00
Gravel Porosity (Percent)	30.00
Trench Slope (ft/ft)	0.005
Native Soil Sat Hydraulic Conductivity (in/hr)	1.000

Ok Cancel

Modeling Tools

SWMM Basics – Model Inputs

- Environmental Protection Agency's (EPA's) Stormwater Management Model (SWMM)
- Meteorological Data Inputs
 - Rainfall and evaporation
- Land Surface Characteristics
- BMPs
 - LID controls allow explicit modeling of GSI

Table 5-1. Estimating Effective Impervious Surface Area

Subcatchment Type	Basis for TIA	Scaling Factor(s) (%)	Effective Impervious Surface (TIA × s)
ROW – informal	GIS or site survey	61	Calculated
ROW – curb and gutter	Site survey	95	Calculated
Parcel – w/existing IMP surface discharges directly to the public drainage system through a pipe or surface channel	Site survey	56	Calculated
Parcel – w/ existing IMP surface discharges to the private pervious surface or private drainage feature (e.g., rock pockets, large vegetated area)	Site survey	28	Calculated

GIS = geographic information system

IMP = impervious

ROW = right-of-way

TIA = total impervious area

SWMM Basics

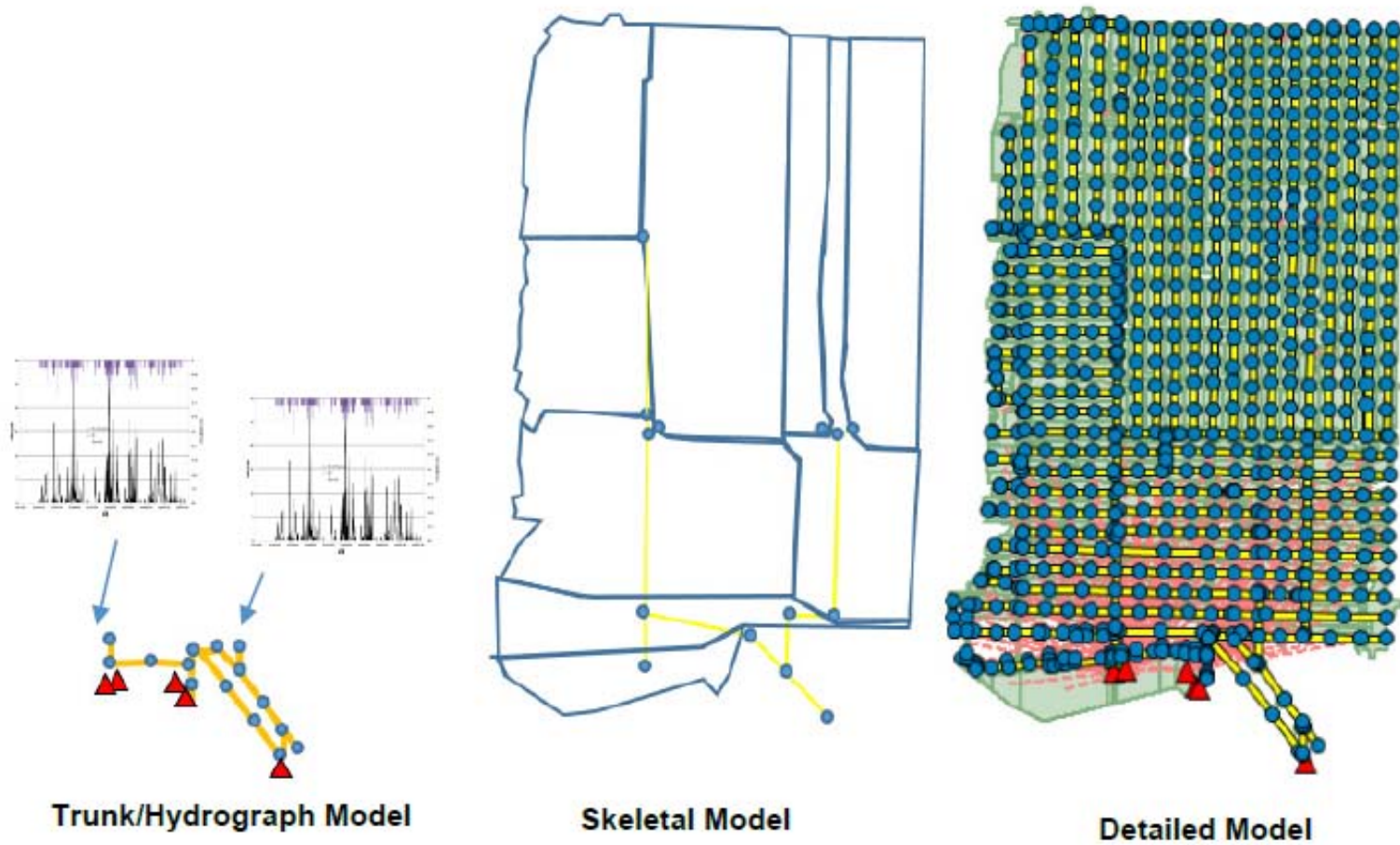
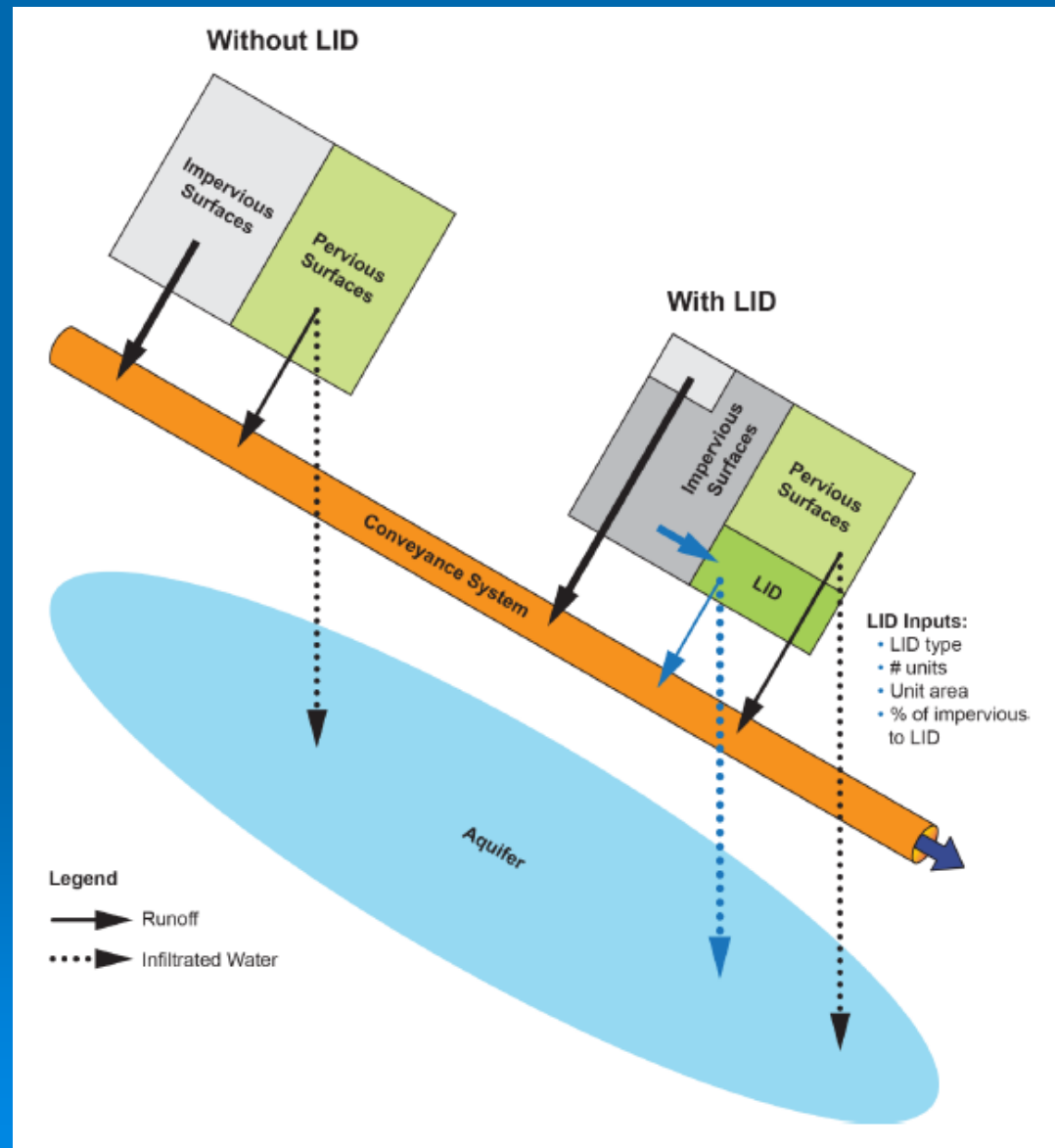


FIGURE 2-1. EXAMPLE MODEL STRUCTURES AND SCALES

SWMM Basics



SWMM Basics

LID Controls

Table 12-1. Composition of Vertical Layers in SWMM5

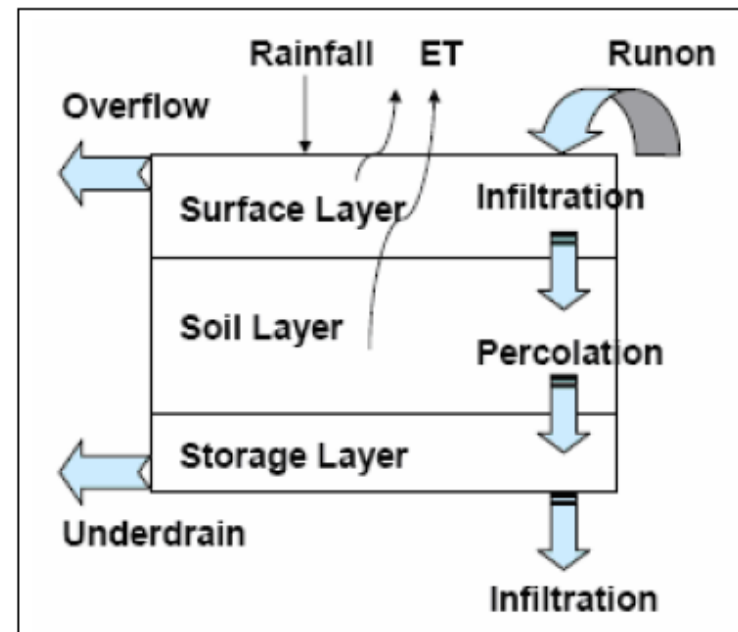
GSI Type	Surface	Pavement	Soil	Storage	Underdrain
Bioretention	√		√	√	o
Porous Pavement	√	√		√	o
Bioswale	√		o	o	o

√ = required

o = optional

GSI = green stormwater infrastructure

SWMM = stormwater management model



Source: SWMM5 User's Guide

FIGURE 12-2. FLOW PATHWAYS BETWEEN VERTICAL LAYERS REPRESENTING BIORETENTION

SWMM Basics

Permeable Pavement Parameters

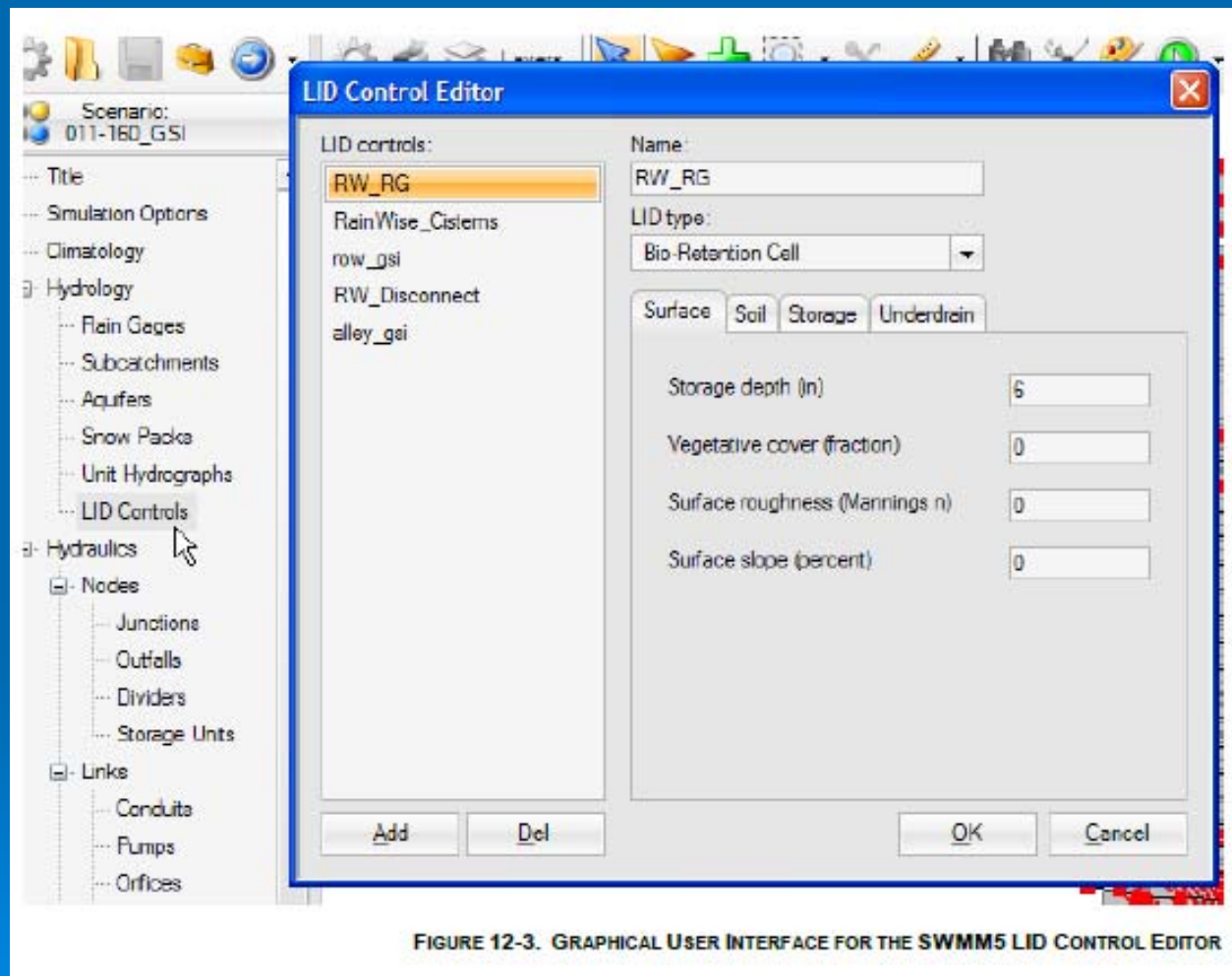


FIGURE 12-3. GRAPHICAL USER INTERFACE FOR THE SWMM5 LID CONTROL EDITOR

SWMM Basics

Permeable Pavement Parameters

Table 12-4. SWMM5 Input Parameters for Permeable Pavement Facility GSI

Vertical Layer	Property	Description	Unit, Field ID, or Data Type	Example Value	Data Source
Surface	Storage depth	Surface depression storage	Inches	0.1	GSI design
	Surface roughness	Manning's n for overland flow	Dimensionless	0.0115	SWMM5 guidance
	Vegetated volume	Proportion of surface that is vegetated	%	0 for pavements	SWMM5 guidance
	Surface slope	Slope of pavement surface	%	<5%	GSI design
Pavement	Thickness	Thickness of the soil layer	Inches	8	GSI design
	Void ratio	Volume of pore space relative to total soil volume	Fraction	0.15	GSI design
	Impervious surface fraction	Ratio of impervious paver material to total area	Fraction	TBD	GSI design
	Permeability	Permeability of the pavement layer	Inches/hour	8	GSI design
	Clogging factor	Number of pavement layer void volumes of runoff treated it takes to completely clog the pavement	Number	0	Not used
Storage	Height	Height of a gravel layer below the soil layer	Inches	24	GSI design

SWMM Basics

Permeable Pavement Parameters

Table 12-4. SWMM5 Input Parameters for Permeable Pavement Facility GSI

Vertical Layer	Property	Description	Unit, Field ID, or Data Type	Example Value	Data Source
	Void ratio	Volume of void space relative to the volume of solids in the layer	Ratio	0.667	LTCP (equivalent to 0.4 porosity)
	Infiltration rate	Rate at which water infiltrates into the native soil below the storage layer	Inches/hour	10	SPU or geotechnical analysis
	Clogging factor	Total volume of treated runoff it takes to completely clog the bottom of the layer divided by the void volume of the layer	Dimensionless	0	Not used

GSI = green stormwater infrastructure

LID = low-impact development

LTCP = long-term control plan

SPU = Seattle Public Utilities

SWMM = stormwater management model

SWMM Basics

LID Usage Editor

LID Usage Editor: ROW_002-082

LID usages:

- alley_gsi
- row_gsi

LID control name: row_gsi

Number of replicate units: 1

☐ LID occupies full subcatchment

Area of each unit (ft²): 2228.5

% of subcatchment occupied: 1.000

Top width of overland flow surface of each unit (ft): 0

% initially saturated: 30

% of impervious area treated: 51.51

☐ Send outflow to pervious area

Detailed report file (optional):

Buttons: Add, Del, OK, Cancel

FIGURE 12-5. LID USAGE EDITOR

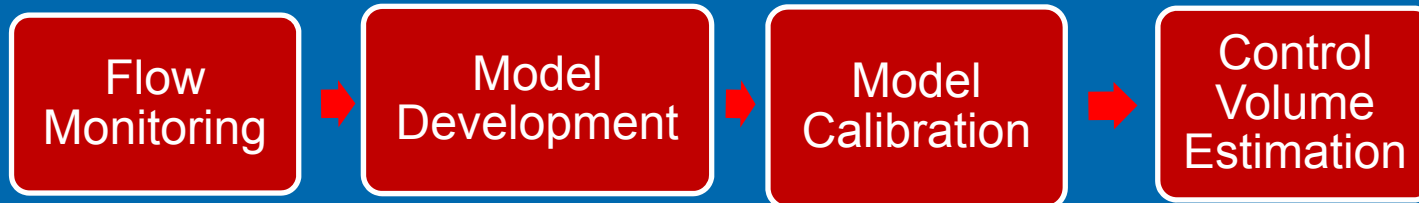
Combined Sewer Overflow Reduction

SWMM Example

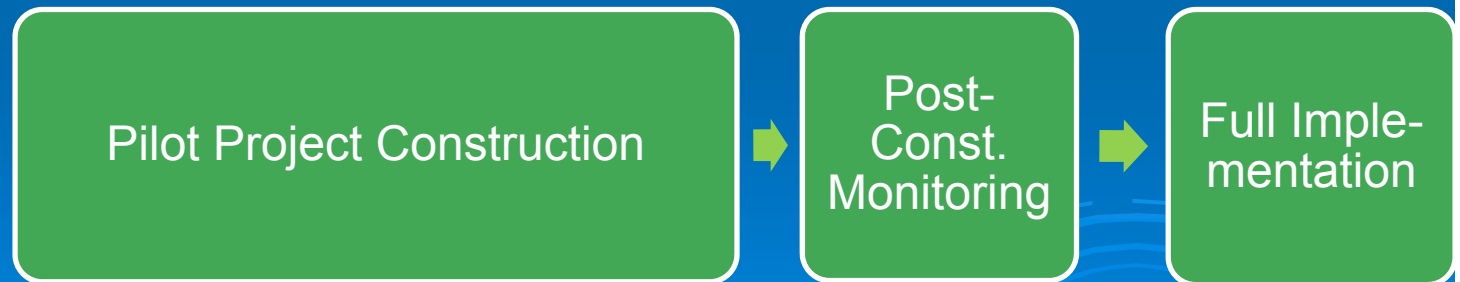
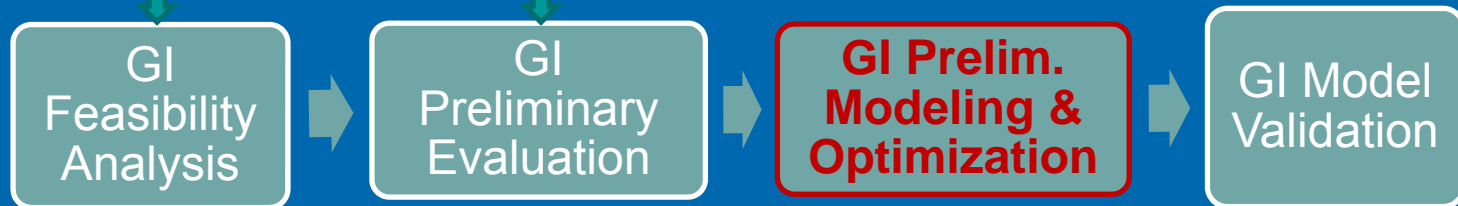


GSI Evaluation Process

System Modeling



GI Analysis and Modeling



GI Project Implementation

GSI Modeling

RainWise Practices

Rain Gardens → **Bio-retention Cell**

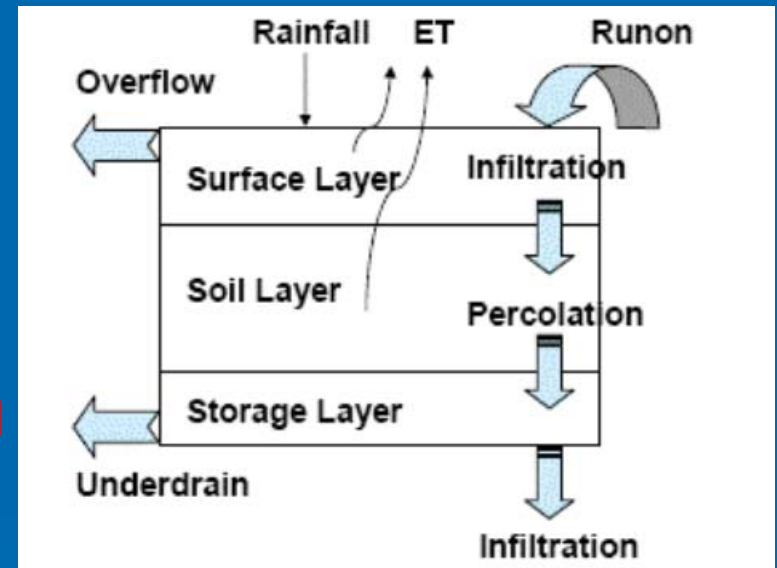
Cisterns → **Bio-retention Cell**

(non-infiltrating with underdrain)

Right-of-way CIP Practices

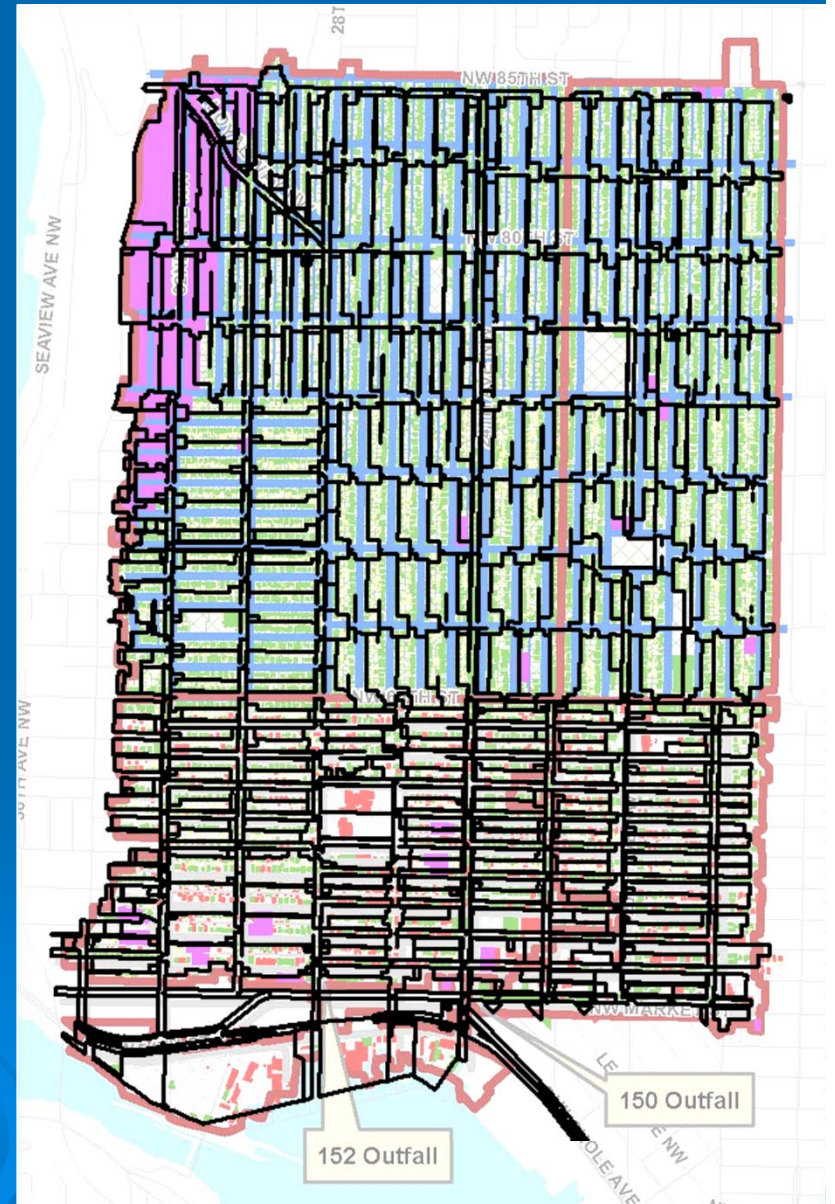
Roadside Rain Gardens → **Bio-retention Cell**

Green Alleys → **Porous Pavement**

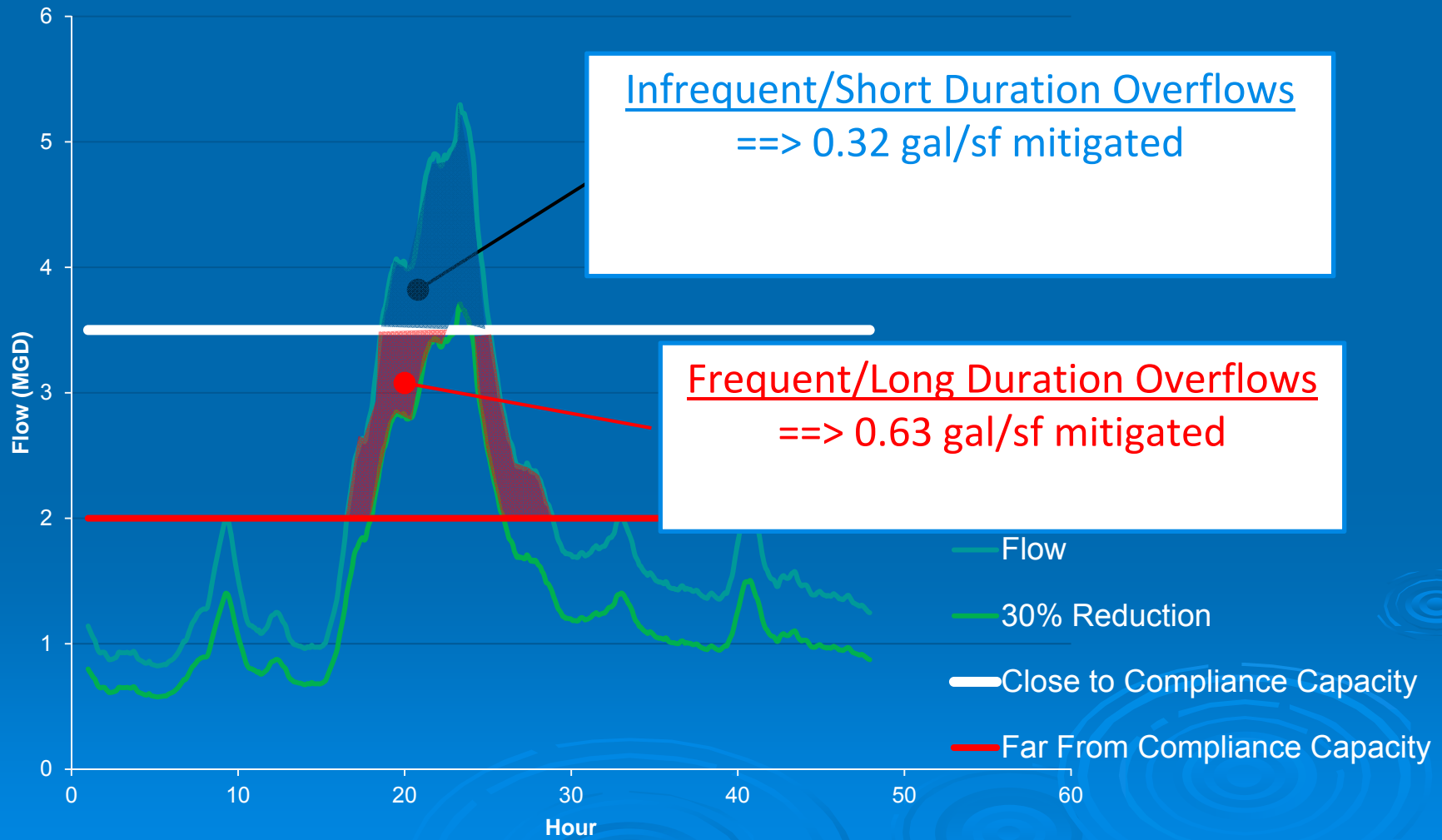


GSI Modeling

- Modeled using EPA SWMM5
- 32-year long term simulations performed
- Feasibility Analysis overlaid with model subcatchment delineation to develop input files



Basin Scale Optimization: Basin-Specific Performance



Other Metrics Besides Control Volume Reduction

Basin 150	Without GI	Reduction	% Reduction
Control Volume (MG)	0.60	0.16	26%
Events/year	12.2	5.0	41%
Annual Overflow Volume (MG/year)	3.52	0.97	28%

Basin 152	Without GI	Reduction	% Reduction
Control Volume (MG)	5.35	1.04	19%
Events/year	37.5	9.8	26%
Annual Overflow Volume (MG/year)	28.75	9.58	33%

Resources

- WWHM
<http://www.clearcreeksolutions.com/>
- MGSFlood
<http://www.mgsengr.com/MGSFlood.html>
- SWMM
<http://www.epa.gov/athens/wwqtsc/html/swmm.html>
- HSPF
<http://water.usgs.gov/software/HSPF/>

Questions and Answers

???



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