Permeable Pavement Hydrologic Modeling

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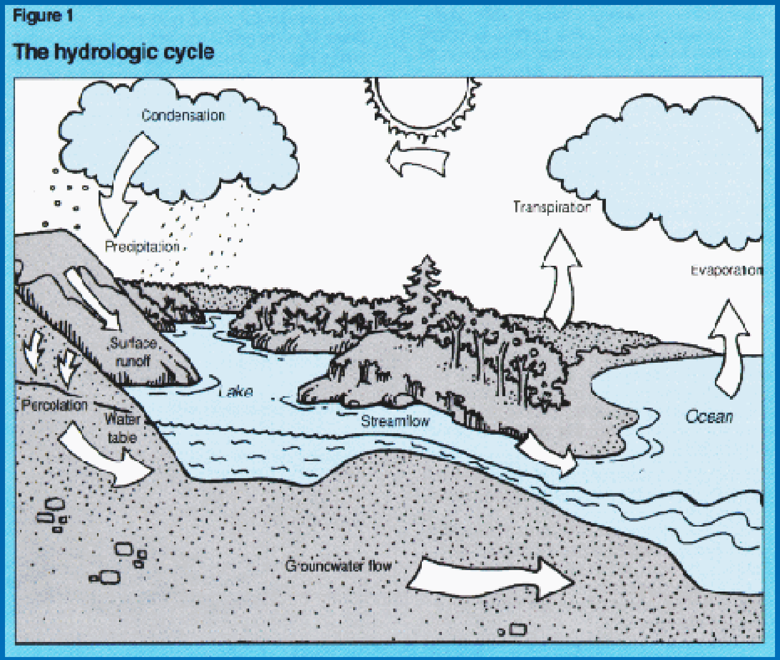
Presentation Overview

- 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

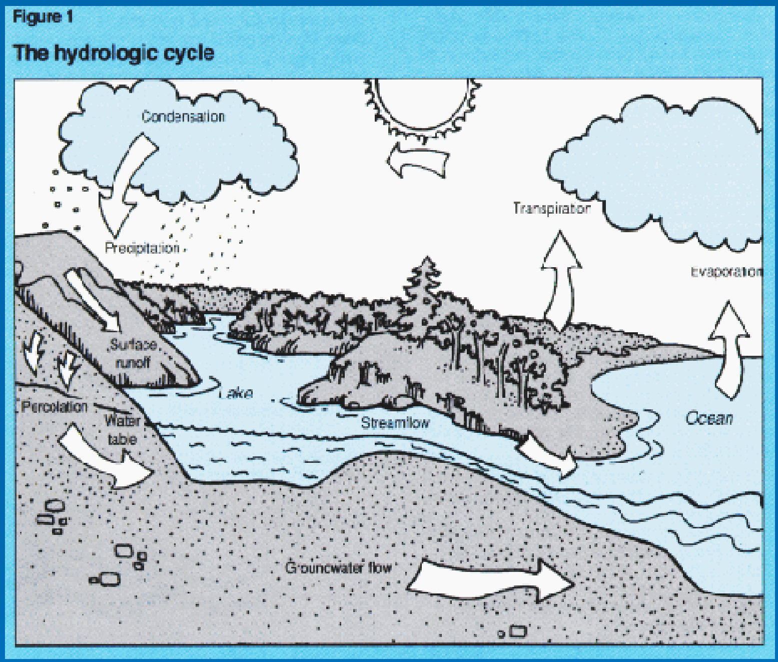
Hydrologic Modeling



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

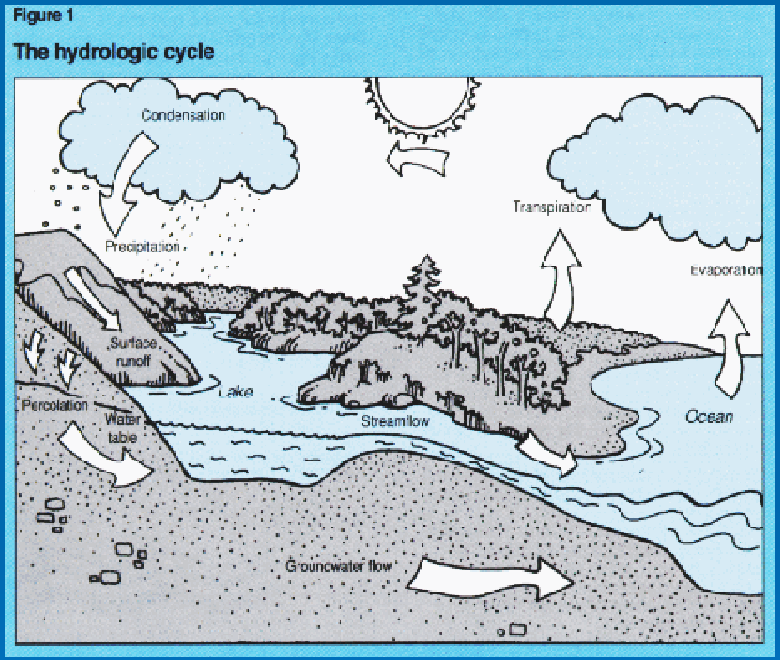
Hydrologic Modeling



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

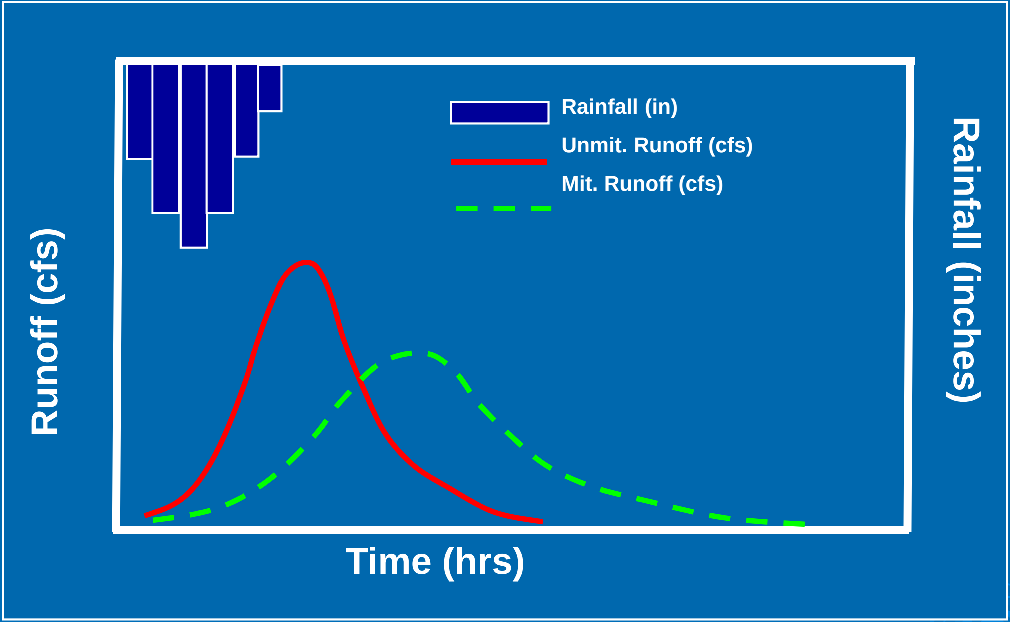
- On-site Stormwater Management (MR #5) (NEW 2012)
  - Use BMP List (rain garden)
  - or
  - Meet LID Performance Standard (match flow durations to pre-developed condition from 8% to 50% of the 2-year peak flow)
- Runoff Treatment (MR #6)
  - Infiltrate 91 percent of the total runoff volume through soil 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

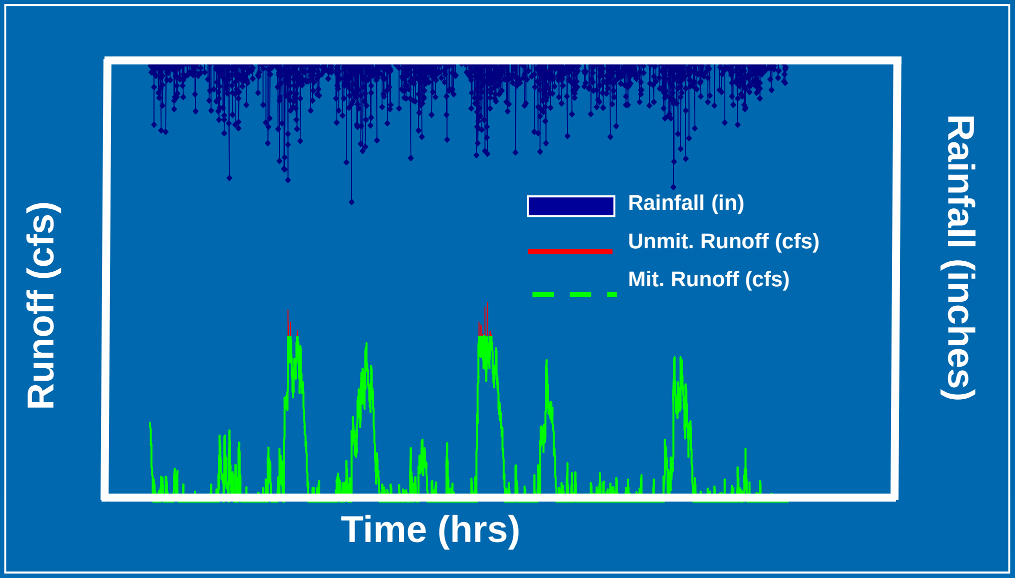
Modeling Tools
Single-Event Methods

- 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)

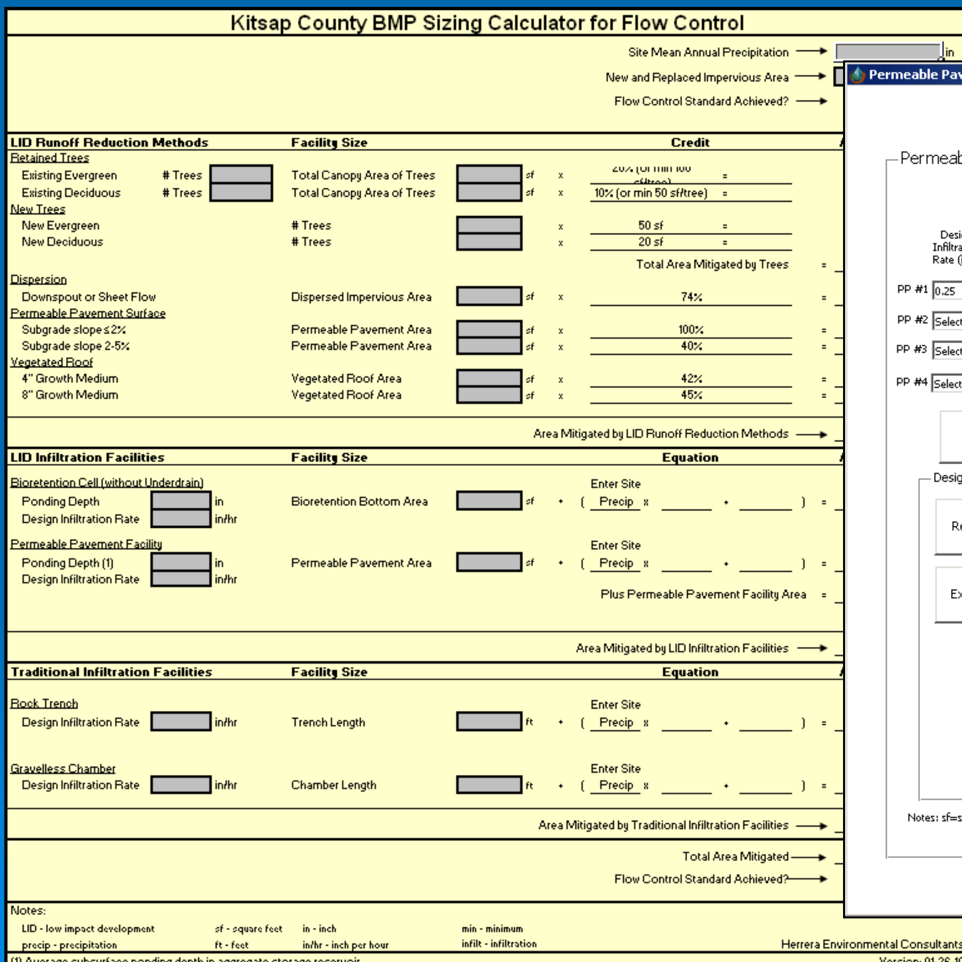
Modeling Tools
Simplified Sizing Tools

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

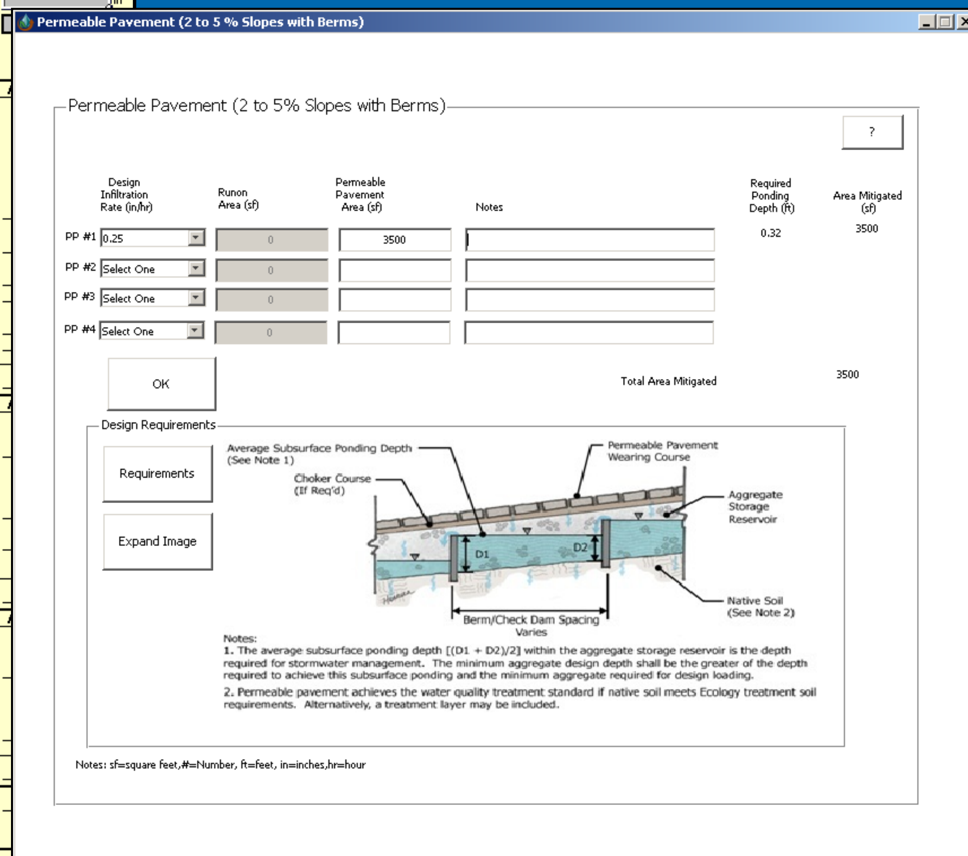
BMP	Design Infilt. Rate (in/hr)	Forest Standard		Sizing Equation
		M	B	
Permeable Pavement Facility				
6 inch ponding depth	0.25	0.1100	- 1.0536	Area (sf) = Impervious Area (sf) x [M x Precip. (in) + B]
	0.5	0.0187	+ 0.4945	
	1.0	0.0048	+ 0.3531	
Permeable Pavement Surface				
Slope <= 2%	0.13 – 0.249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



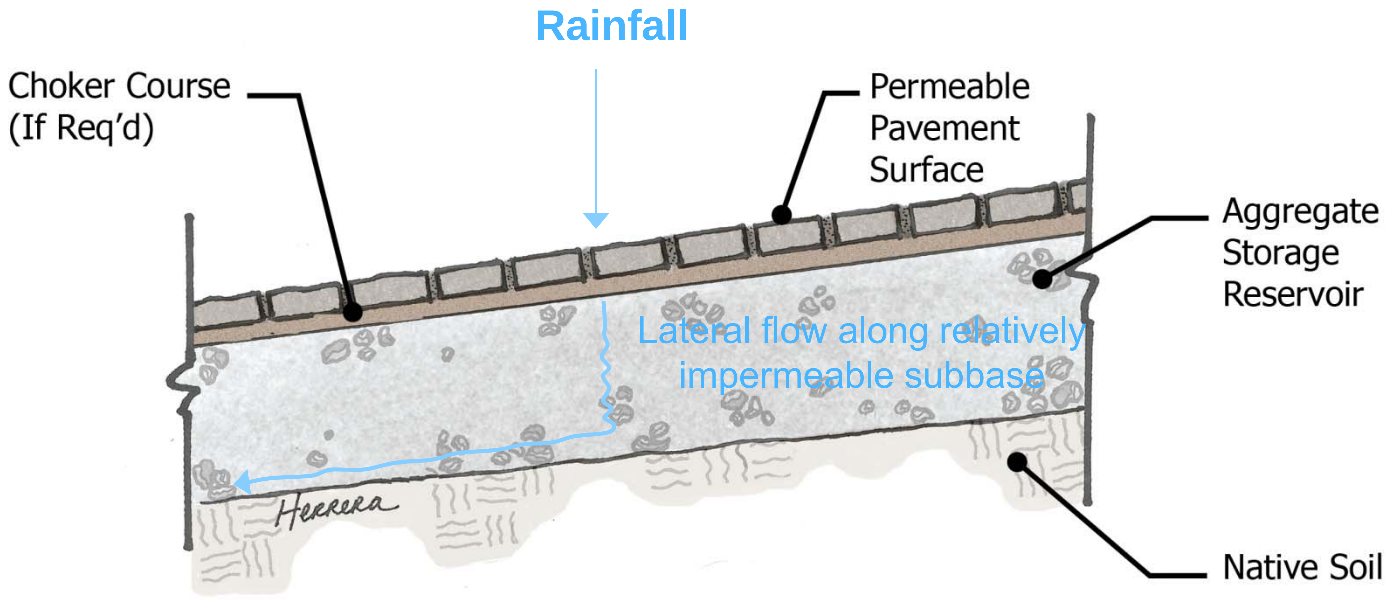
Modeling Guidelines

(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%

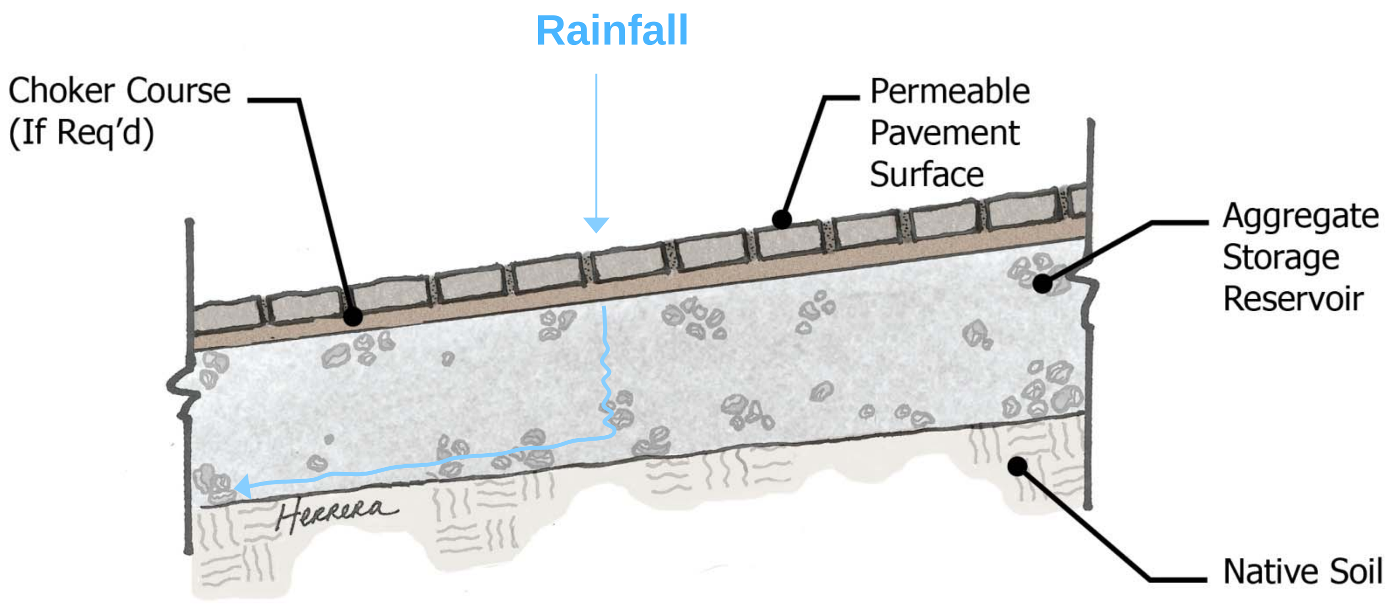


→ **can neglect lateral flow**

→ **subsurface storage depth modeled = aggregate thickness**

Permeable Pavement Types

Subgrade Slope >2 to 5% (no berms)

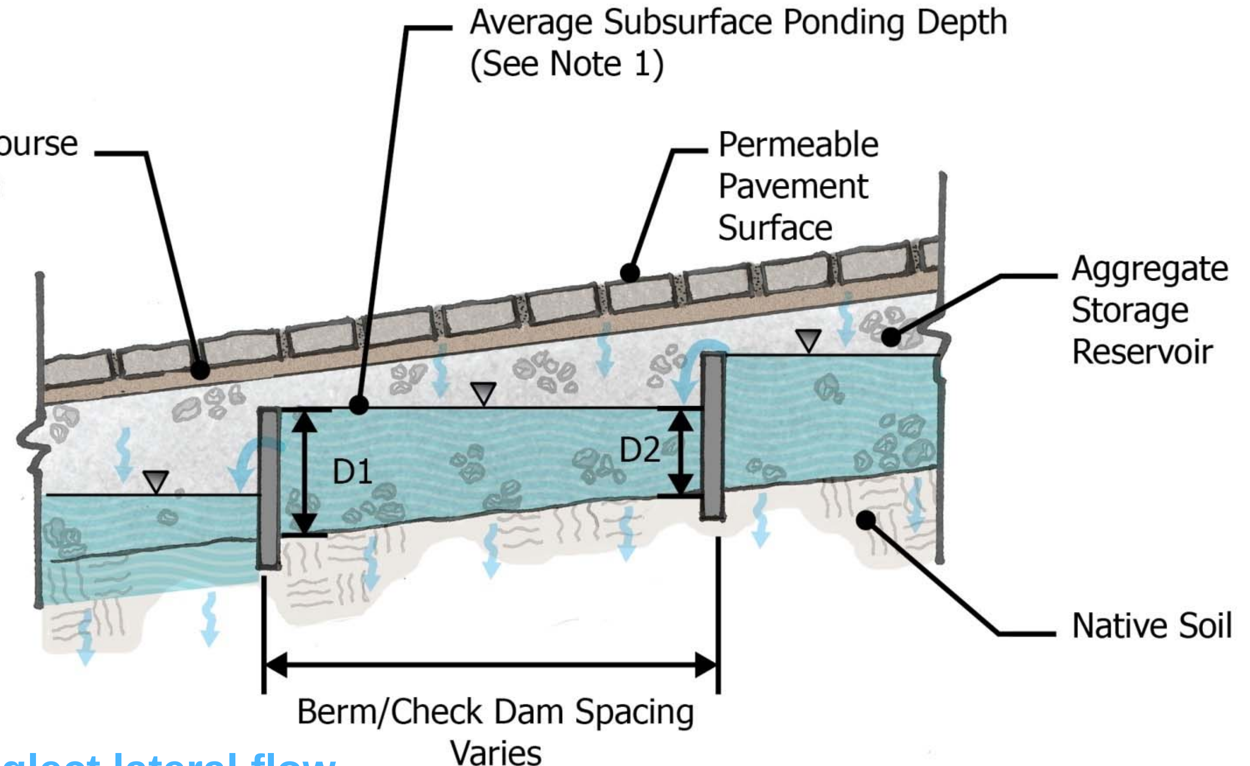


→ **cannot neglect lateral flow**

→ **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**

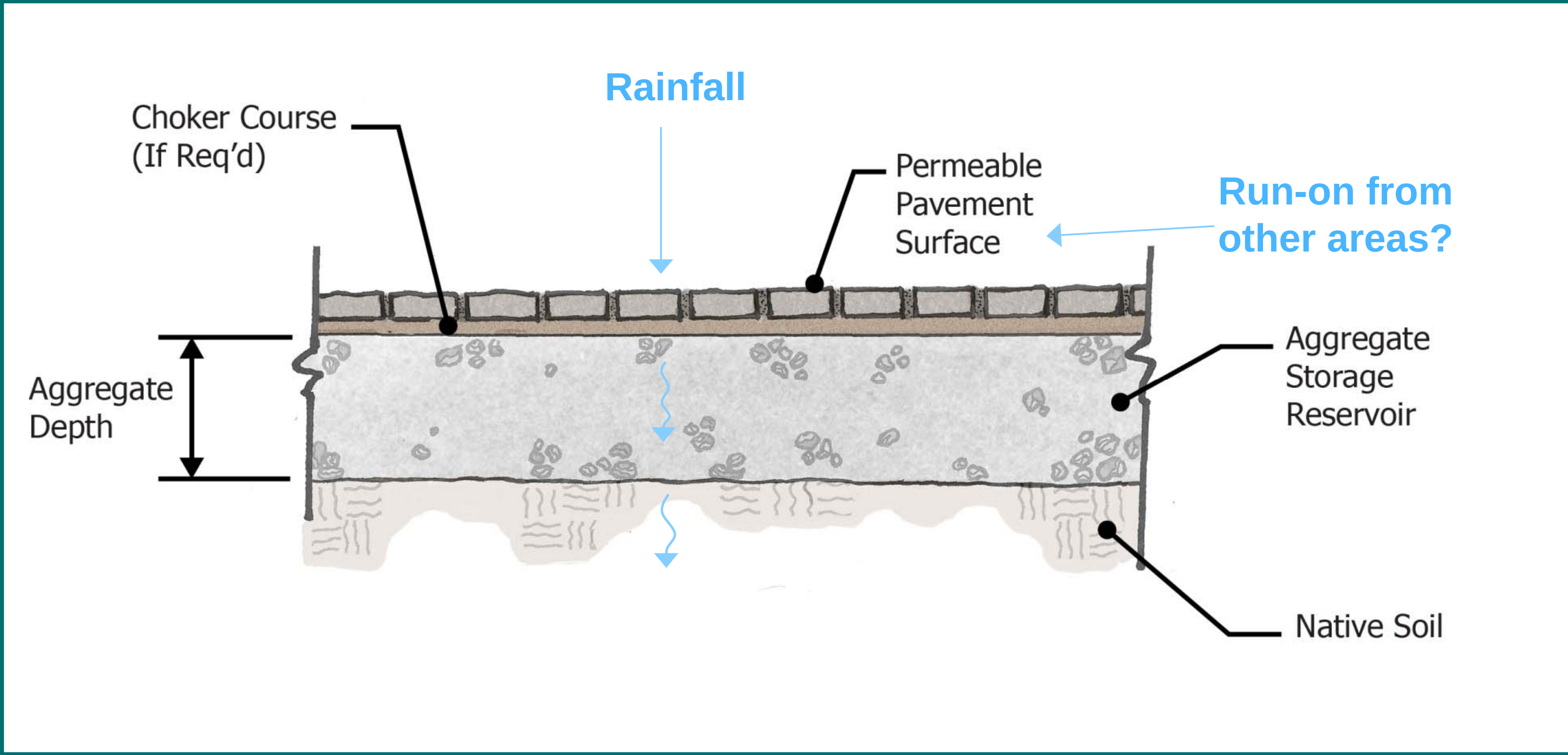
→ **subsurface storage depth modeled = average subsurface ponding depth = water depth before berm overtopping* or overflow**

***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

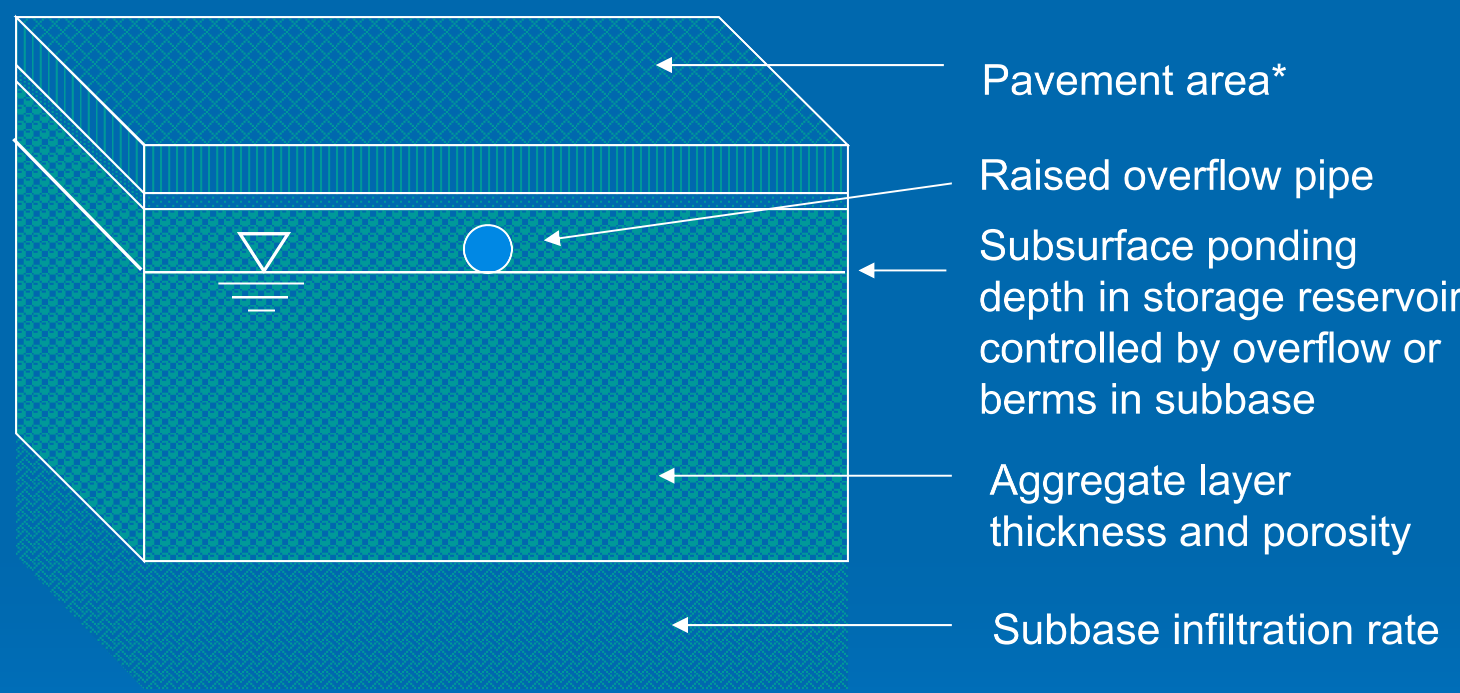
- Meteorological Data
  - Rainfall (5-min, 15-min, hourly)
  - Evaporation (daily)

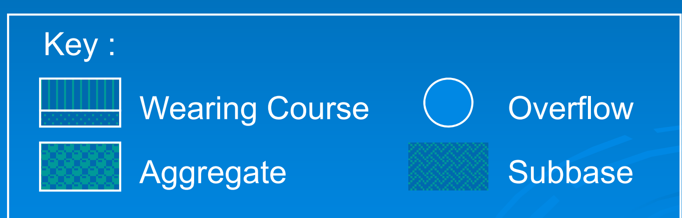
- Land Cover Types
  - Impervious areas
    - Slope
  - Pervious areas
    - Vegetation
    - Soil type (A, B, C/D)
    - Slope
  - Regional calibrated parameters (Dinicola 1990)

- BMP Configurations

Model Representation

Gravel Trench Parameters

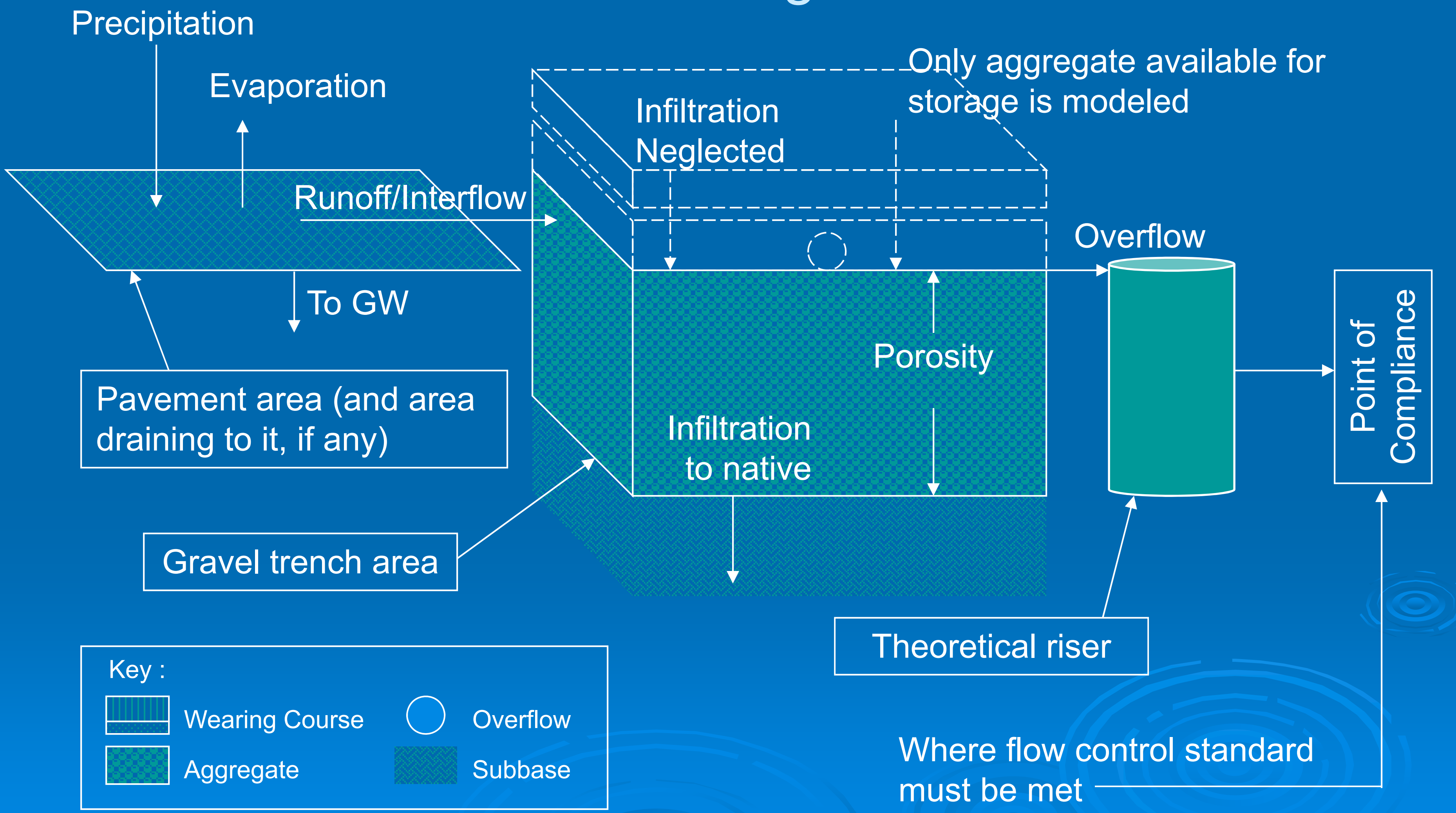




* May include additional contributing area

Model Representation

Model Configuration

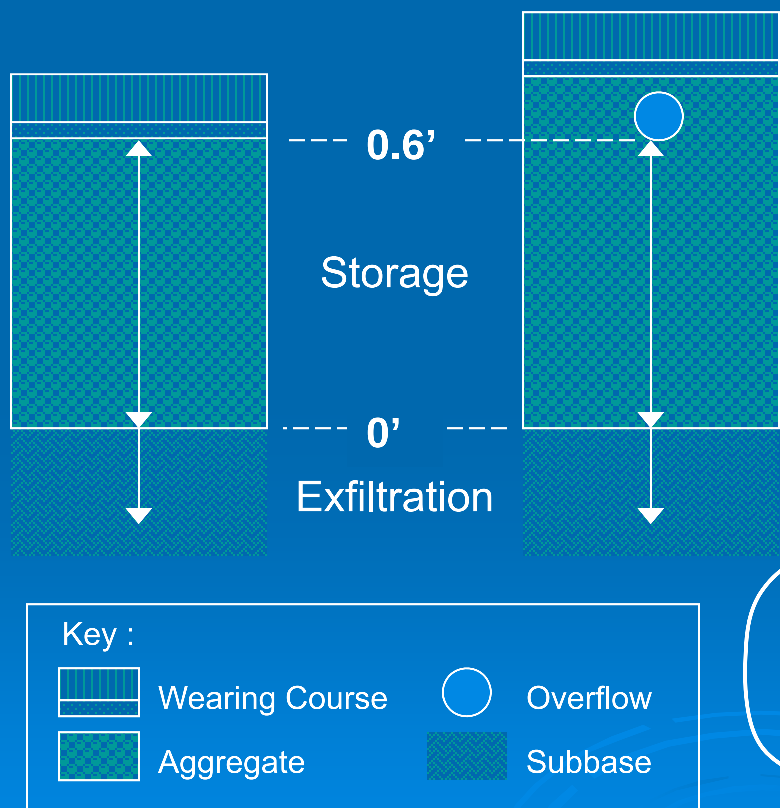


Note: Only aggregate under overflow invert modeled

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)

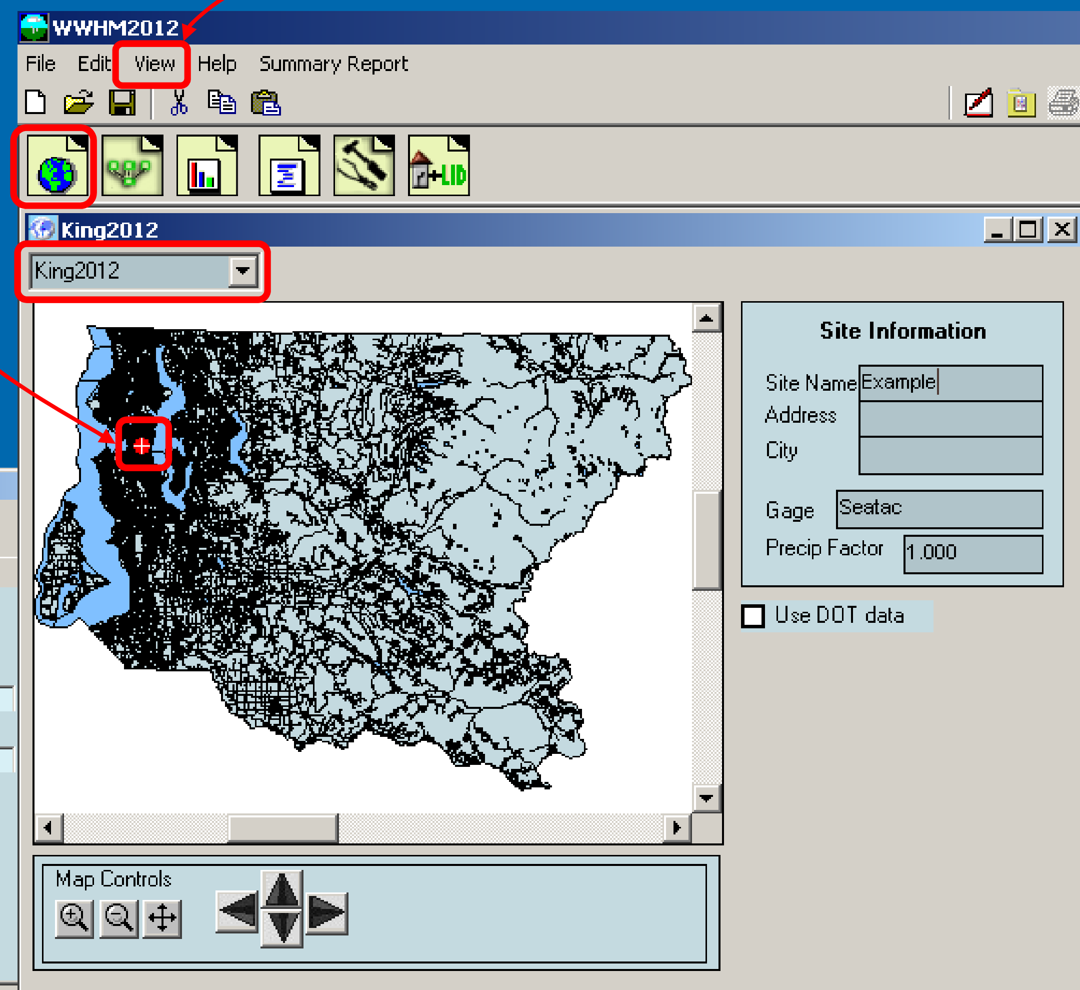
Flow Control in Creek Basin
WWHM2012 Example – Explicit Method

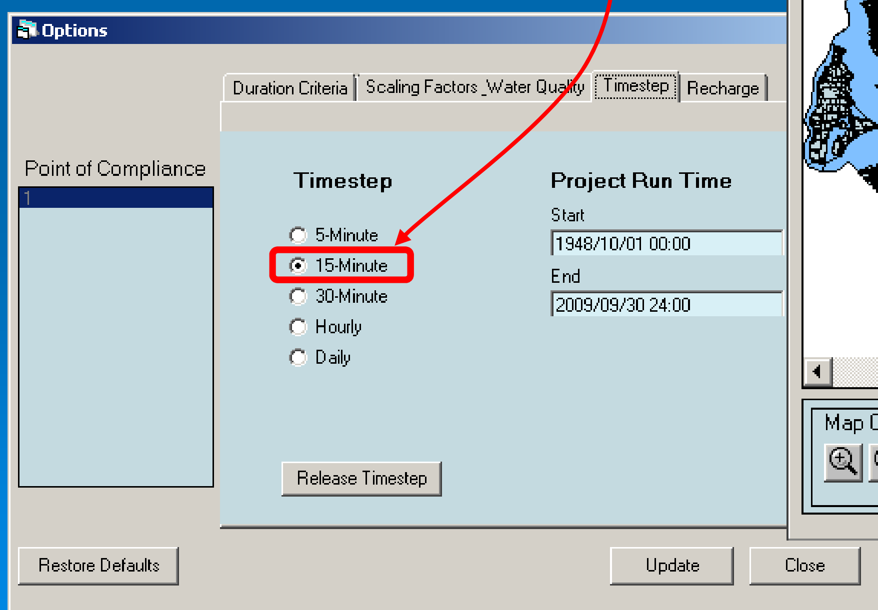
- Site in King County
- Soil is till (0.25 inch/hour design infiltration rate)
- Permeable pavement *facility* is 10,000 sf
- Receiving run-on from 5,000 sf of additional area
- Design goal = Ecology Stream Duration standard (assuming a predeveloped forest condition)
- Size aggregate depth (*ave. subsurface 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

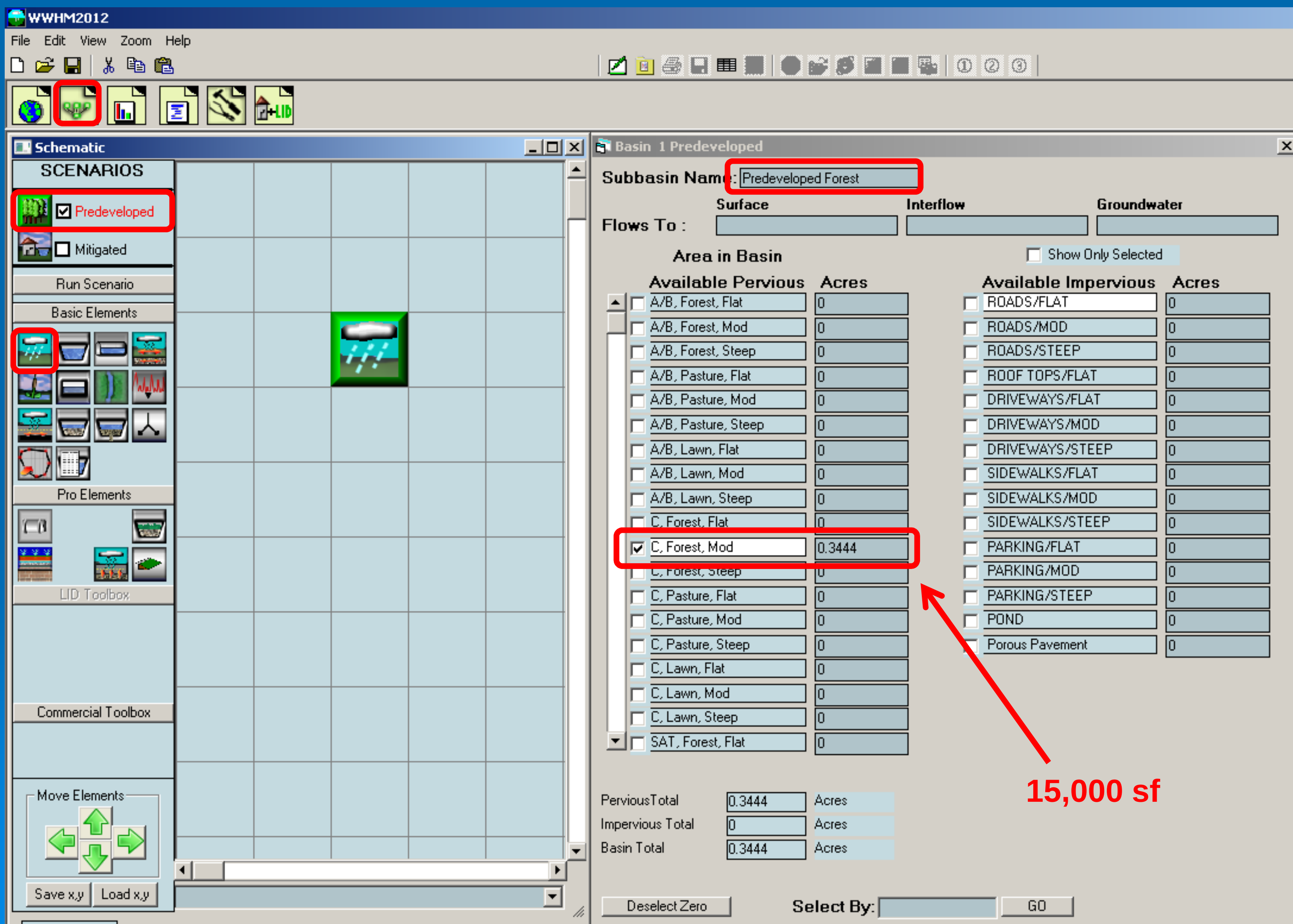
Option Menu





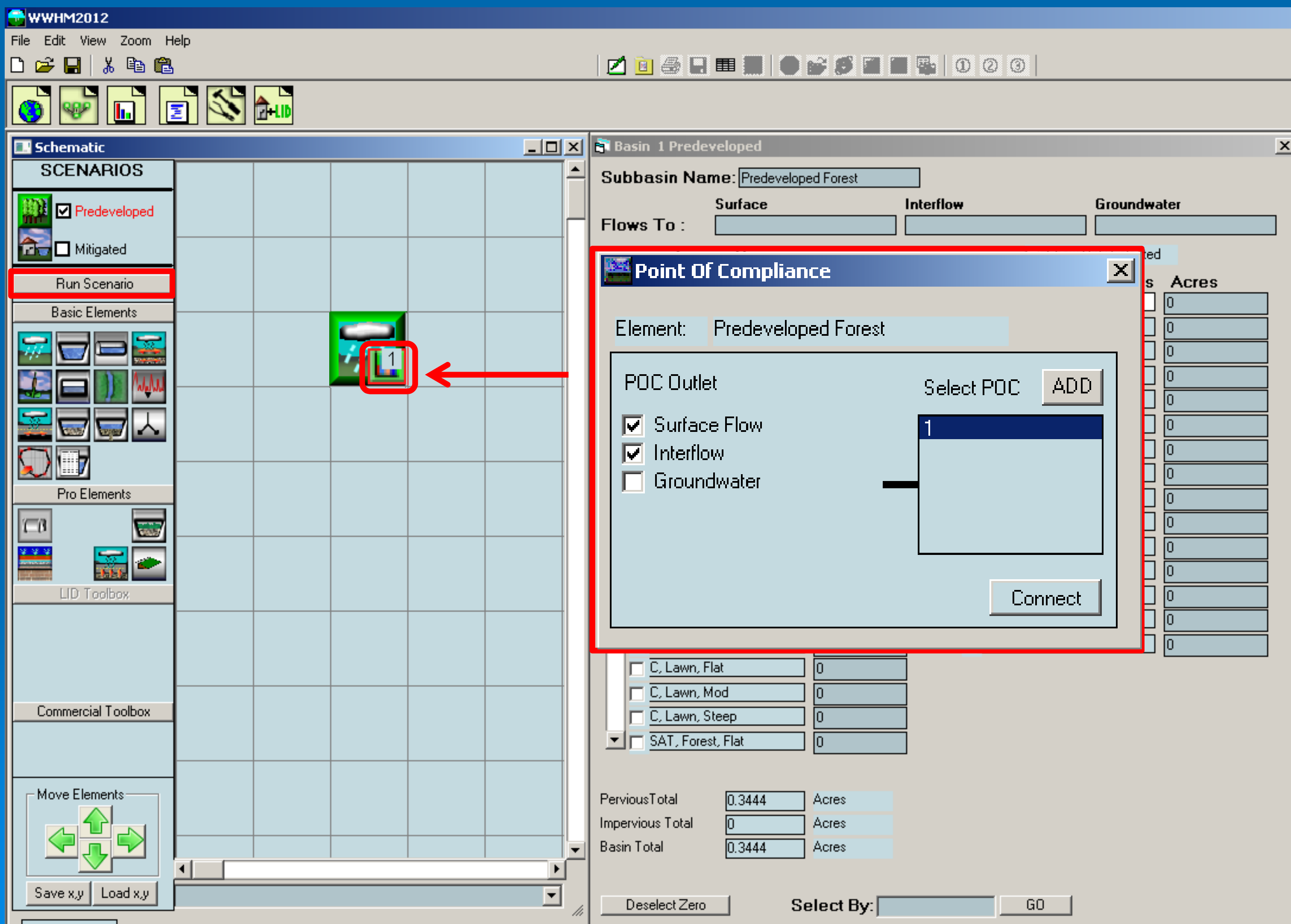
Sizing for Flow Control

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



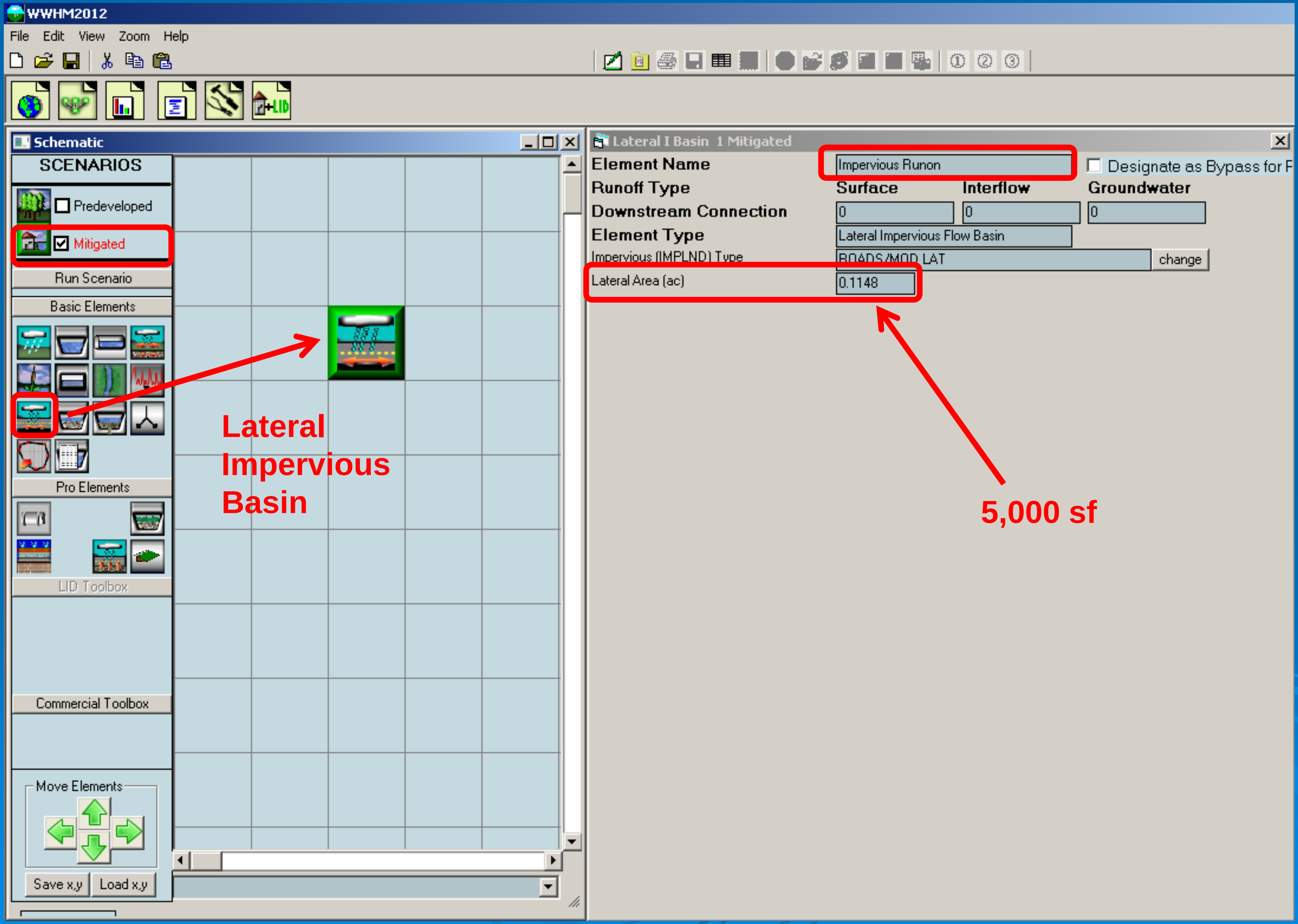
Sizing for Flow Control

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



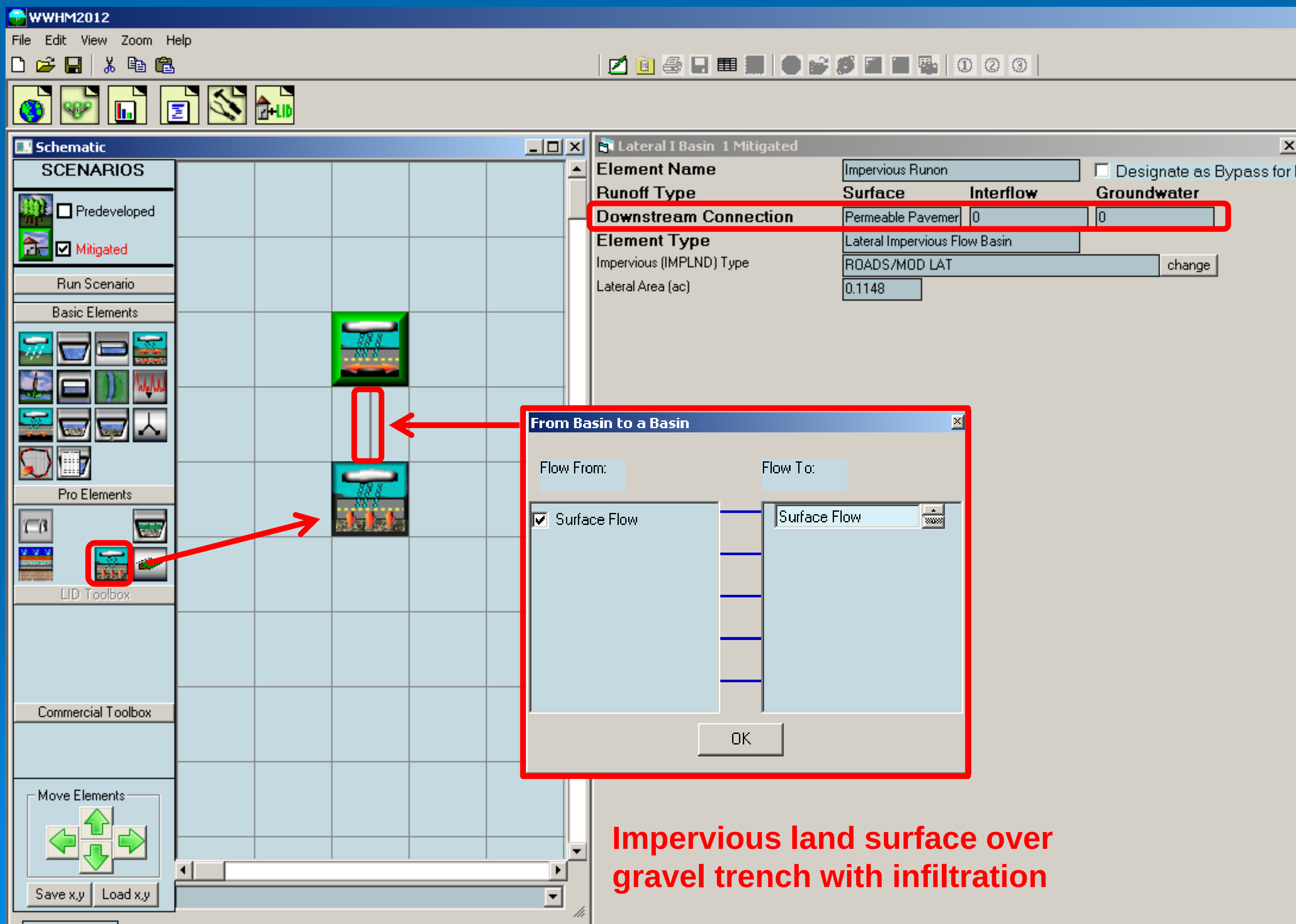
Sizing for Flow Control

Developed Mitigated Basin → Area contributing runon to permeable pavement….



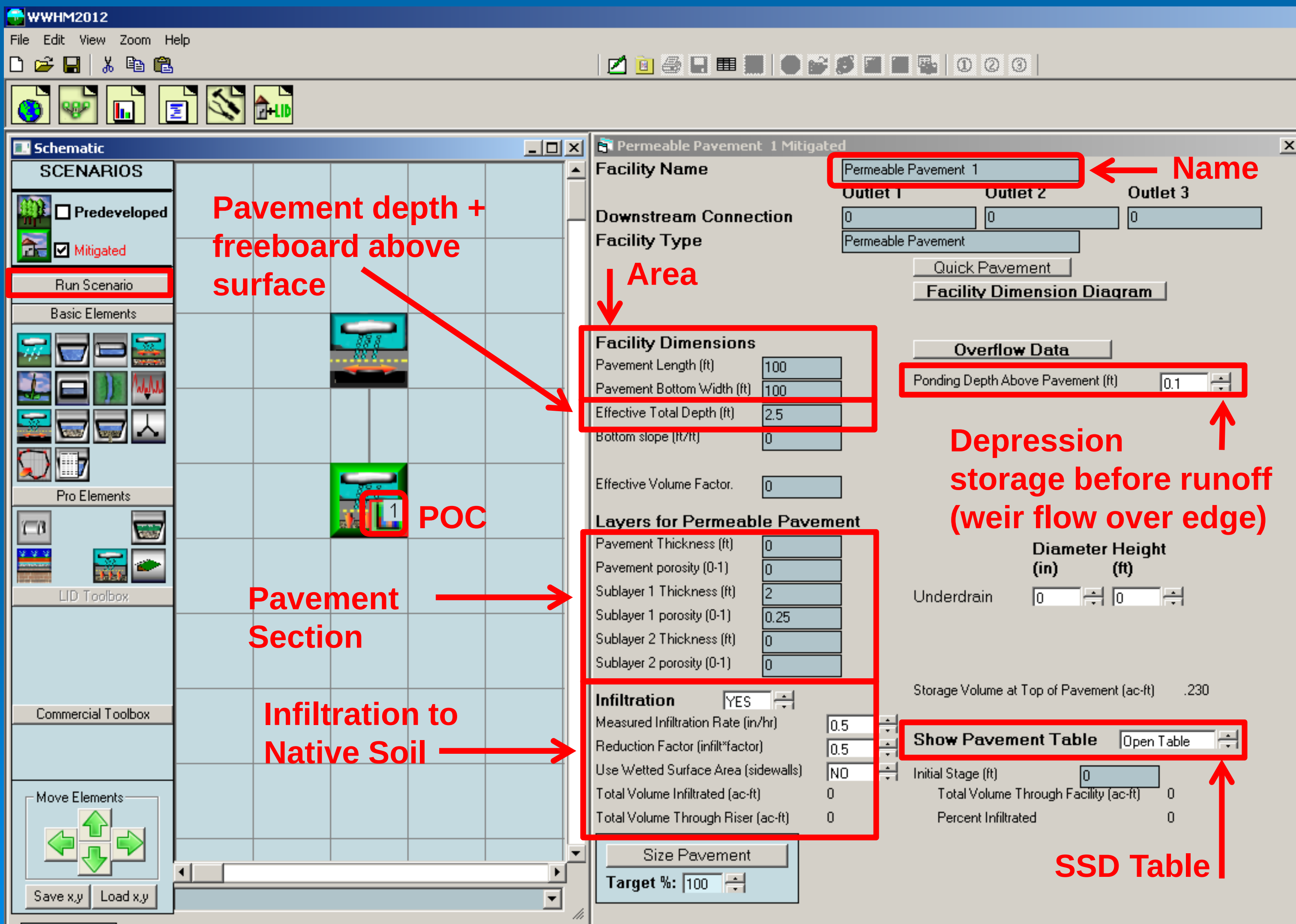
Sizing for Flow Control

Developed Mitigated Basin Continued: Route to Permeable Pavement Module



Sizing for Flow Control

Developed Mitigated Basin Continued: Characterize Permeable Pavement



Sizing for Flow Control

Stage Storage Discharge Table

Permeable Pavement 1

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

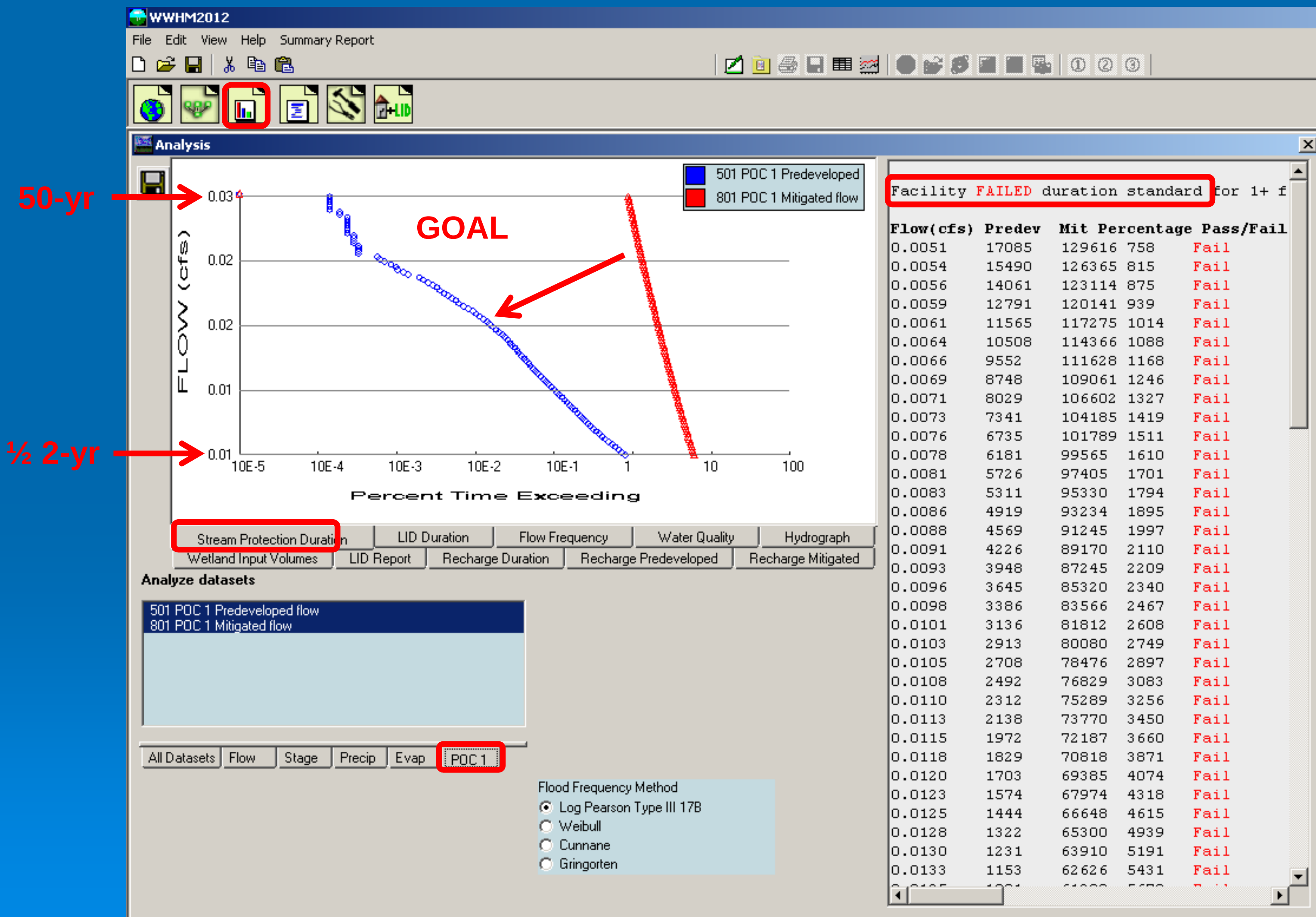
Permeable Pavement 1

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

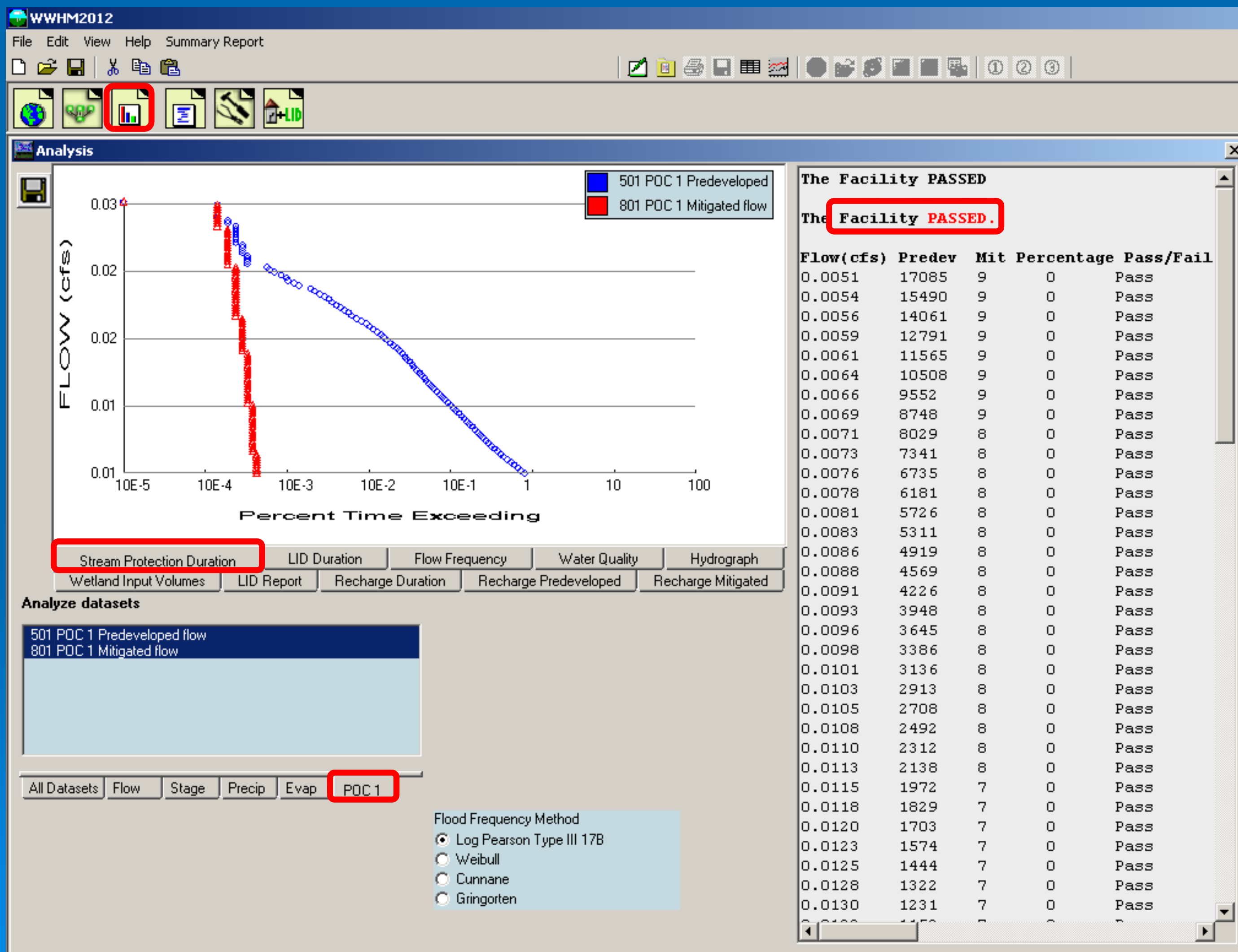
Sizing for Flow Control

Flow Duration Curve- Developed Unmitigated (Impervious)



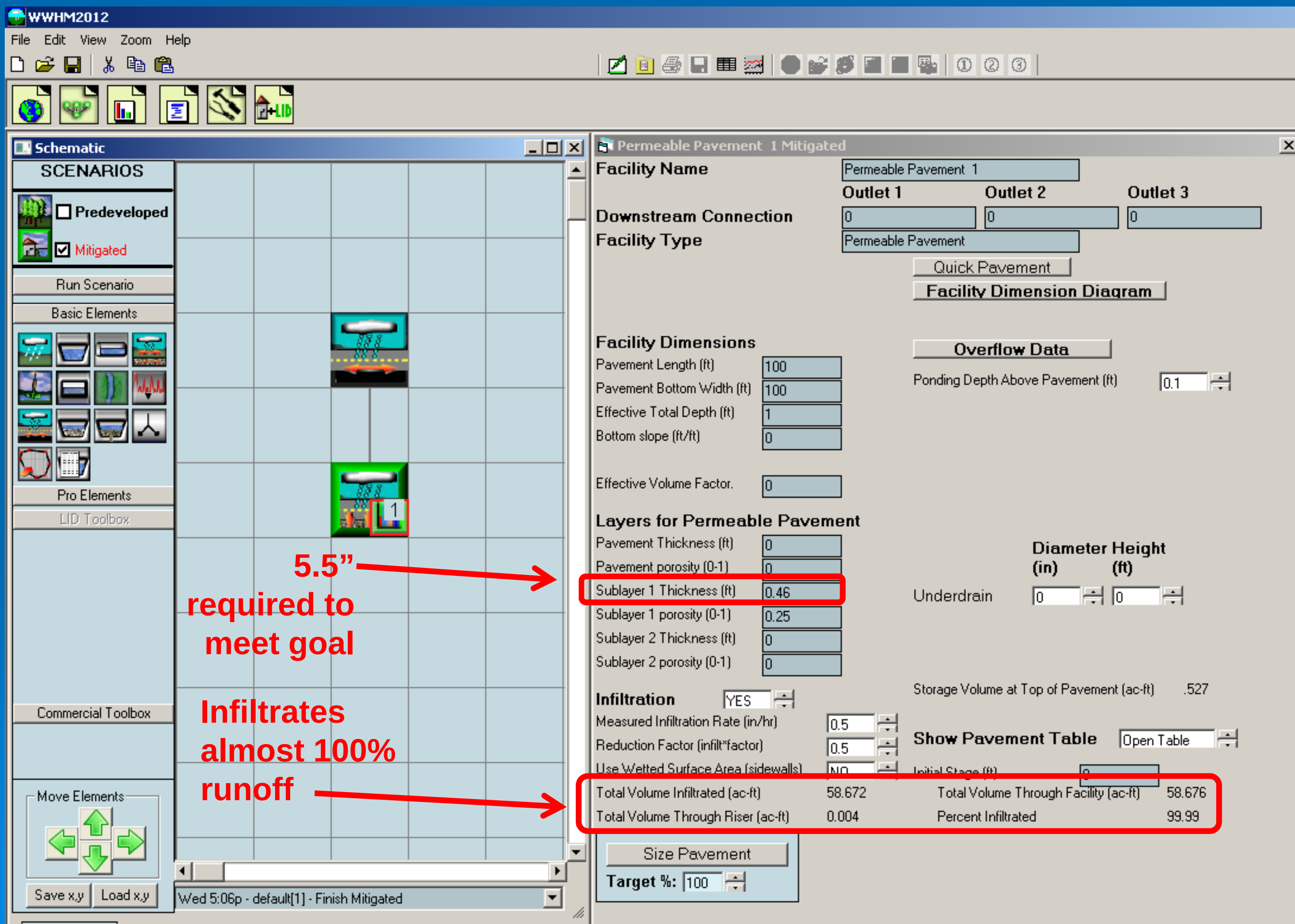
Sizing for Flow Control

Flow Duration Curve- Developed Mitigated (with Permeable Pavement)



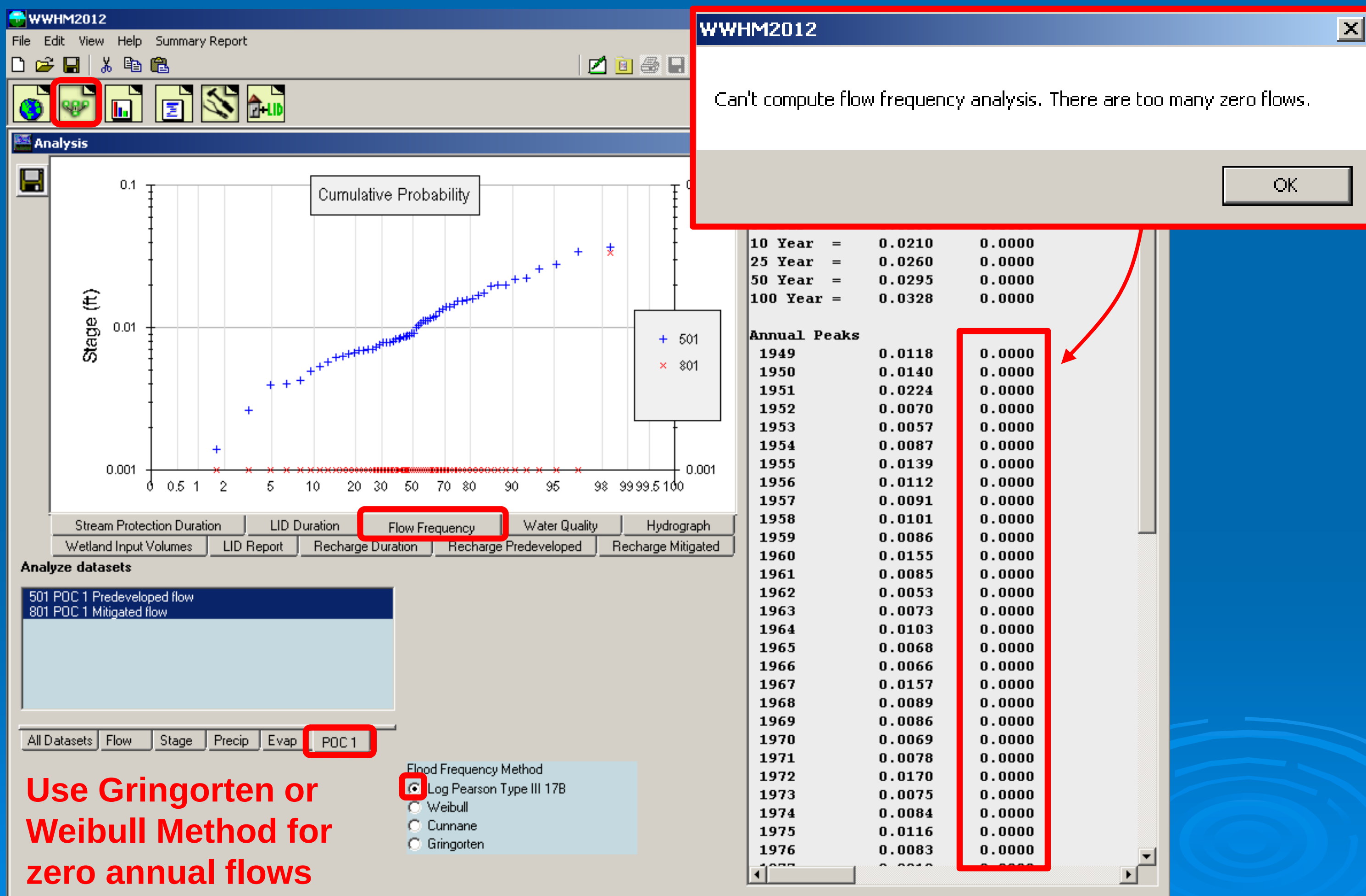
Sizing for Flow Control

Iteratively Sized Storage Aggregate Depth to Meet Duration Standard



Sizing for Flow Control

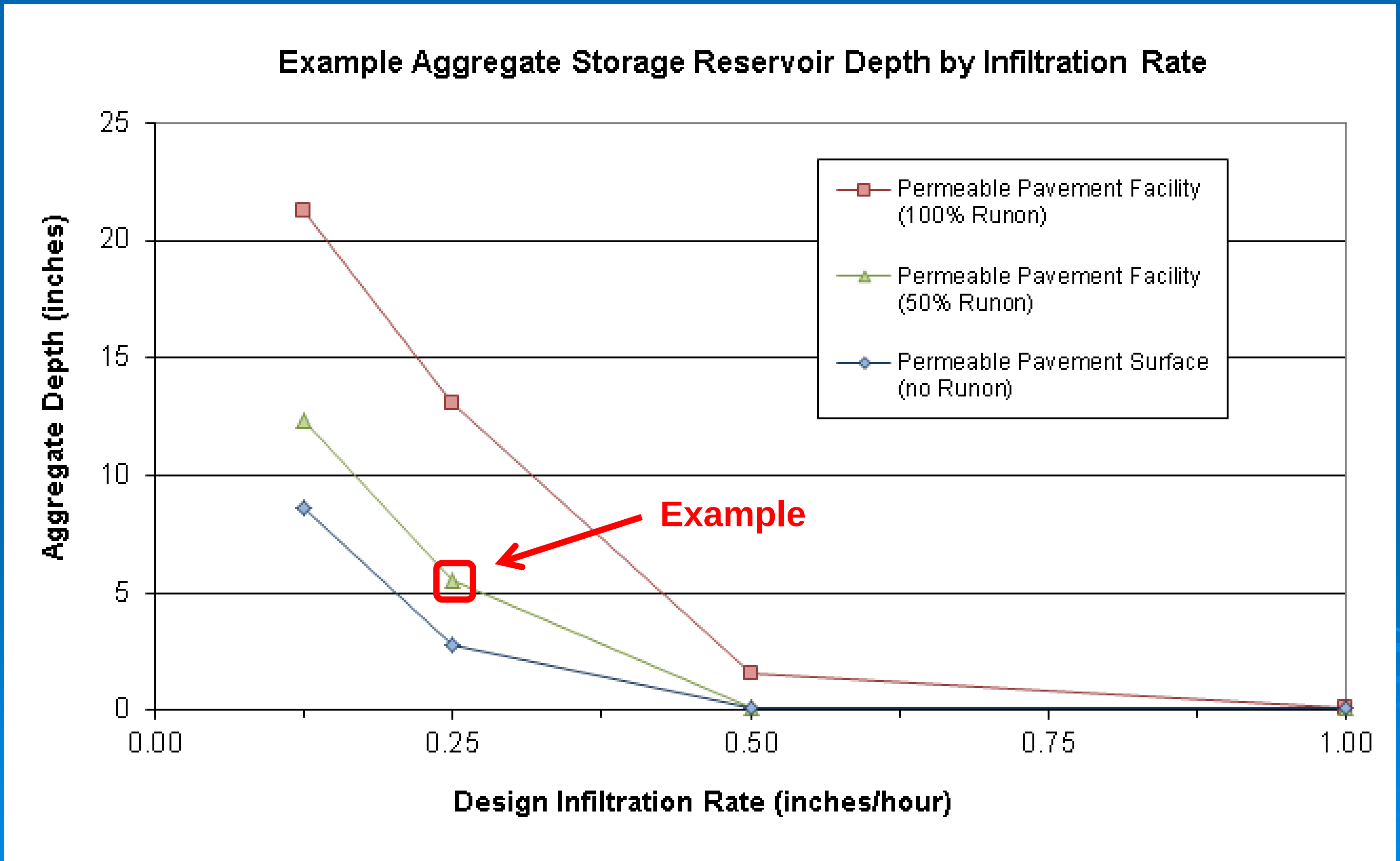
Flow Frequency Results



Use Gringorten or Weibull Method for zero annual flows

Performance & Infiltration Rate

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

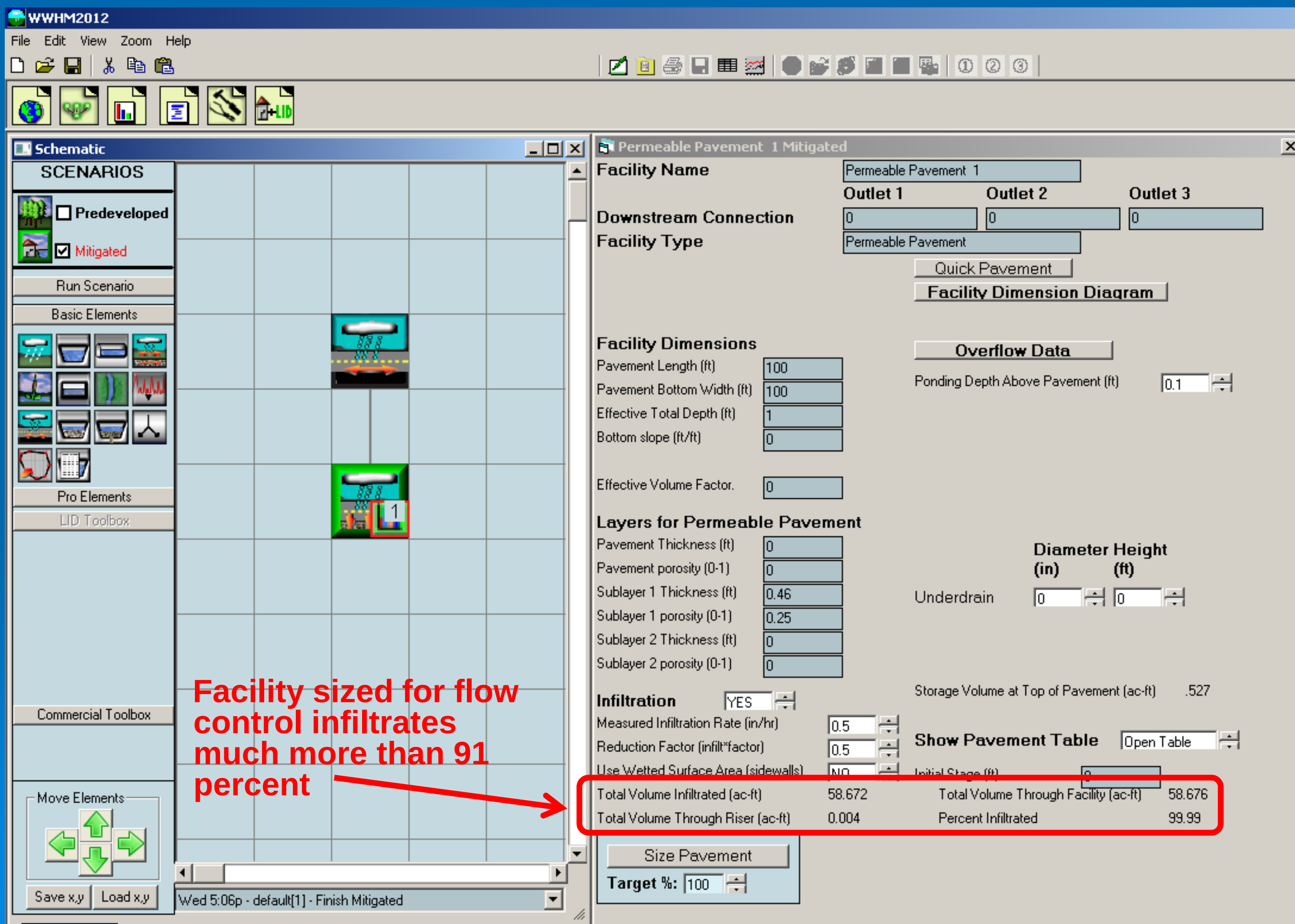


Water Quality Treatment

Same WWHM2012 Example

Sizing for Treatment

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

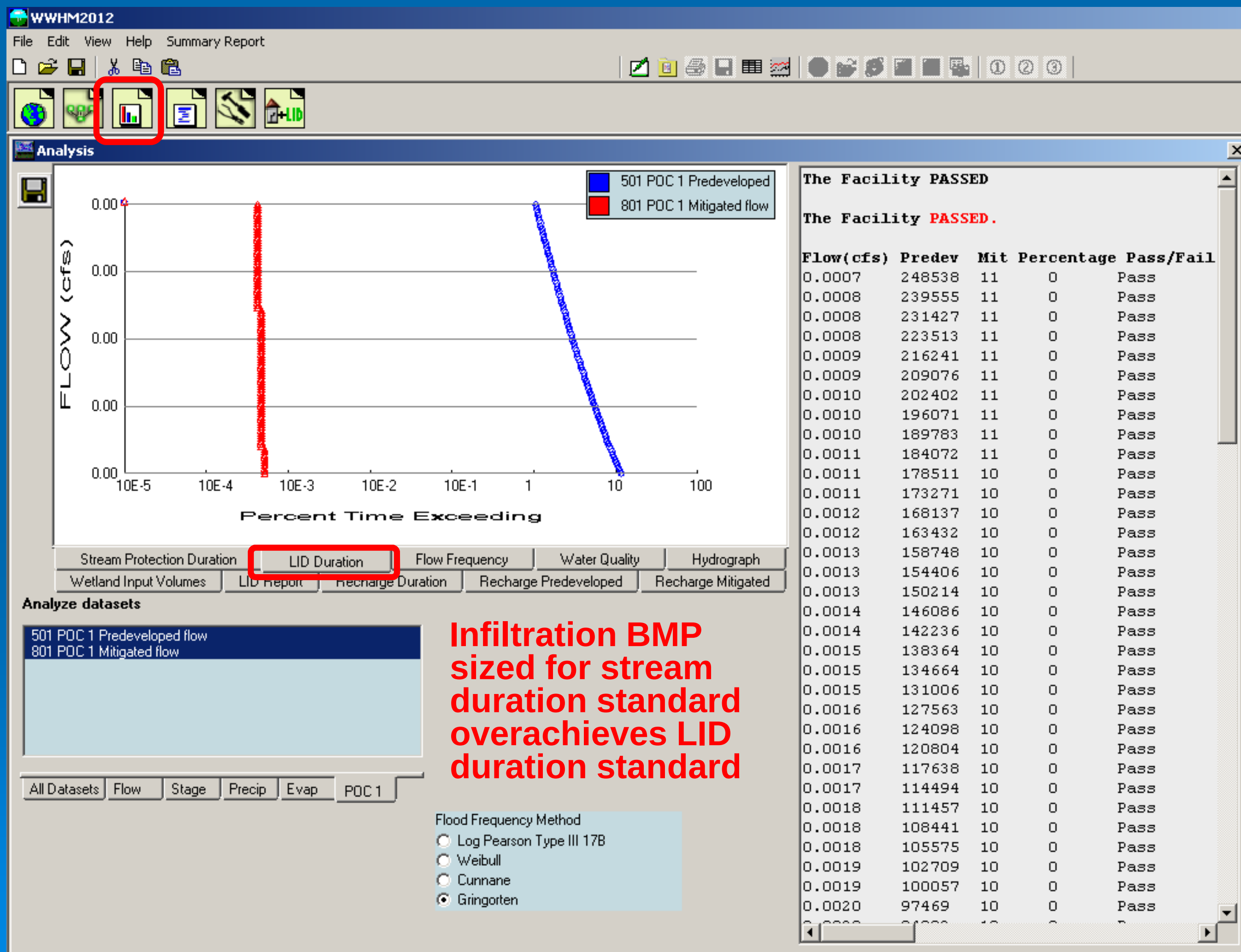


Further Analysis

WWHM2012 Example

Further Analysis

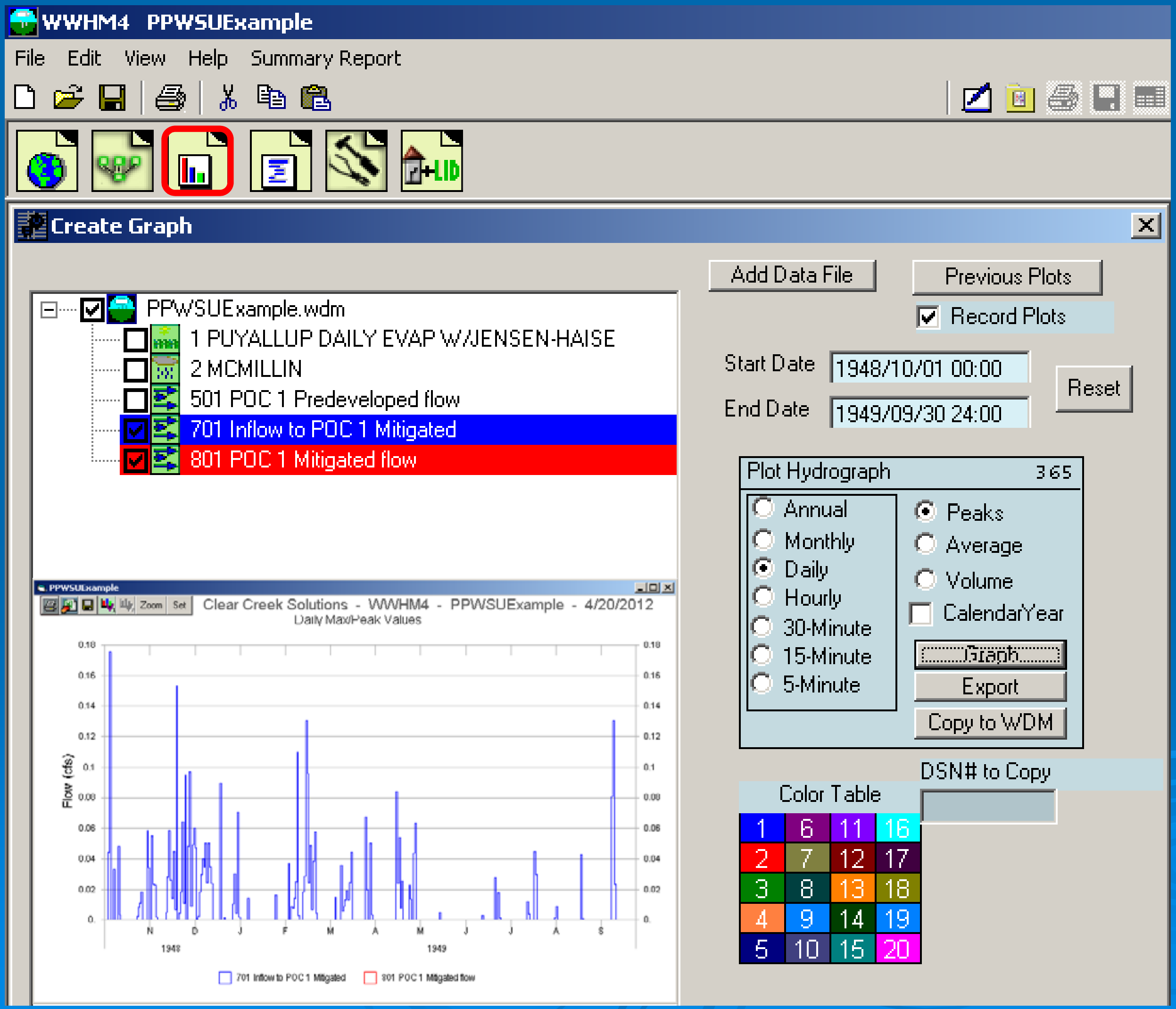
LID Performance Standard



Infiltration BMP sized for stream duration standard overachieves LID duration standard

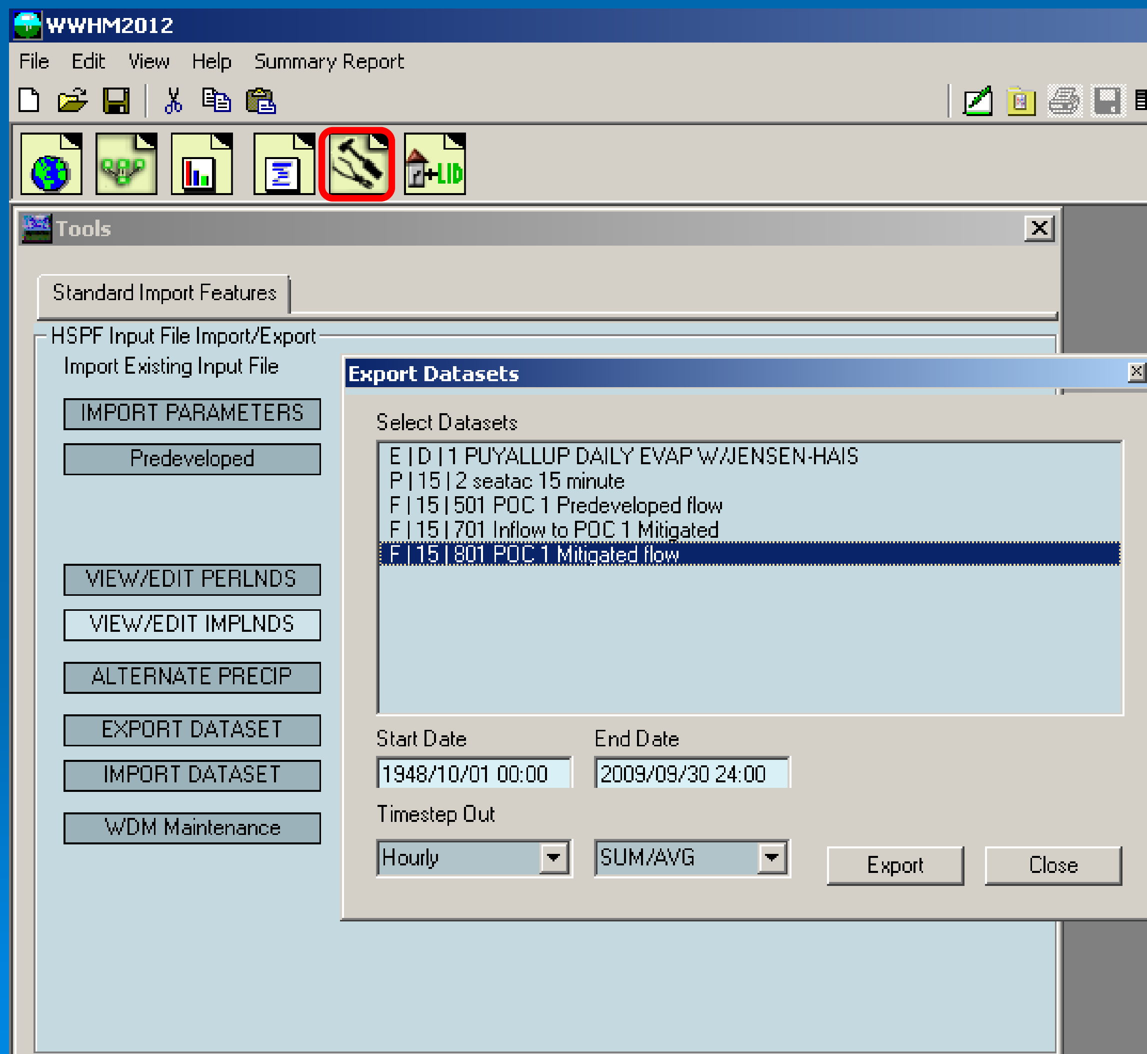
Further Analysis

Hydrograph



Further Analysis

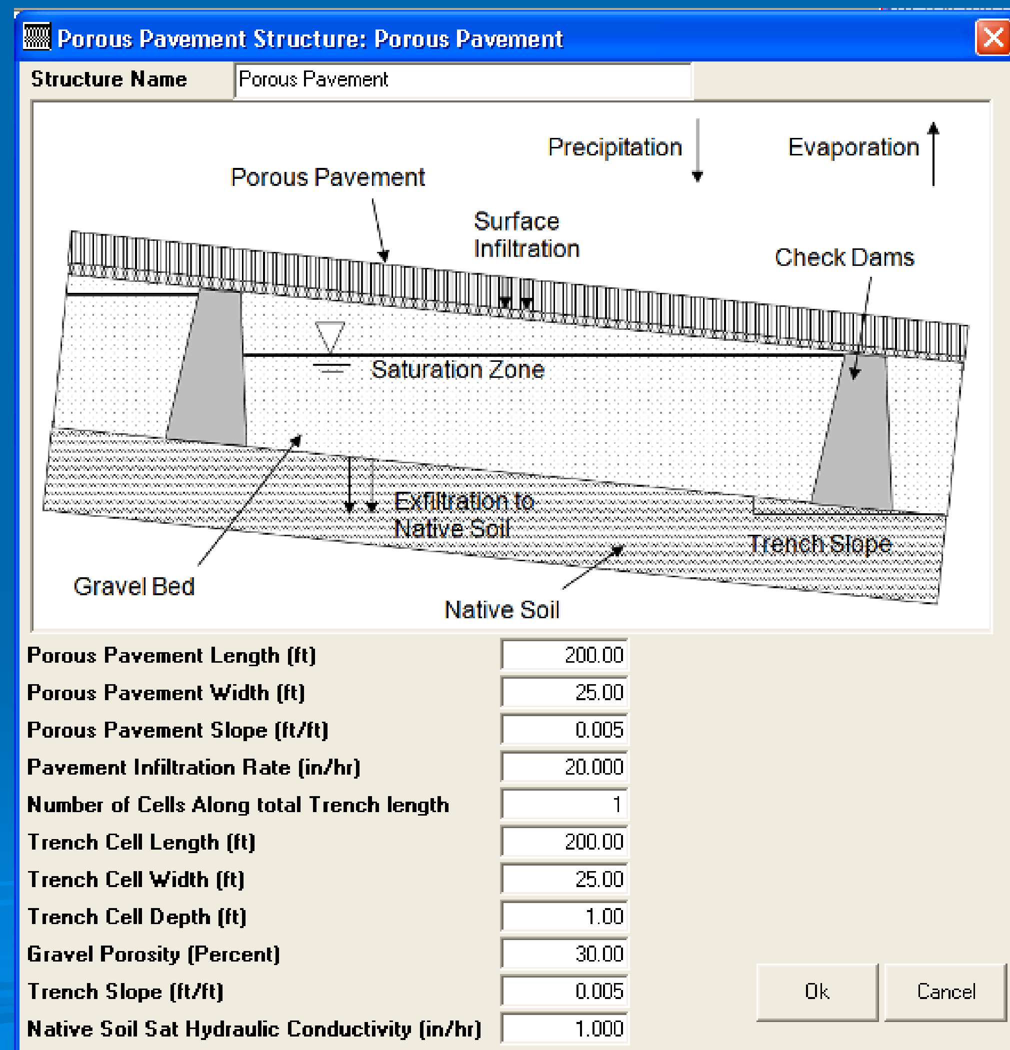
Time Series Export



Modeling Tools

MGSFlood Basics

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



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

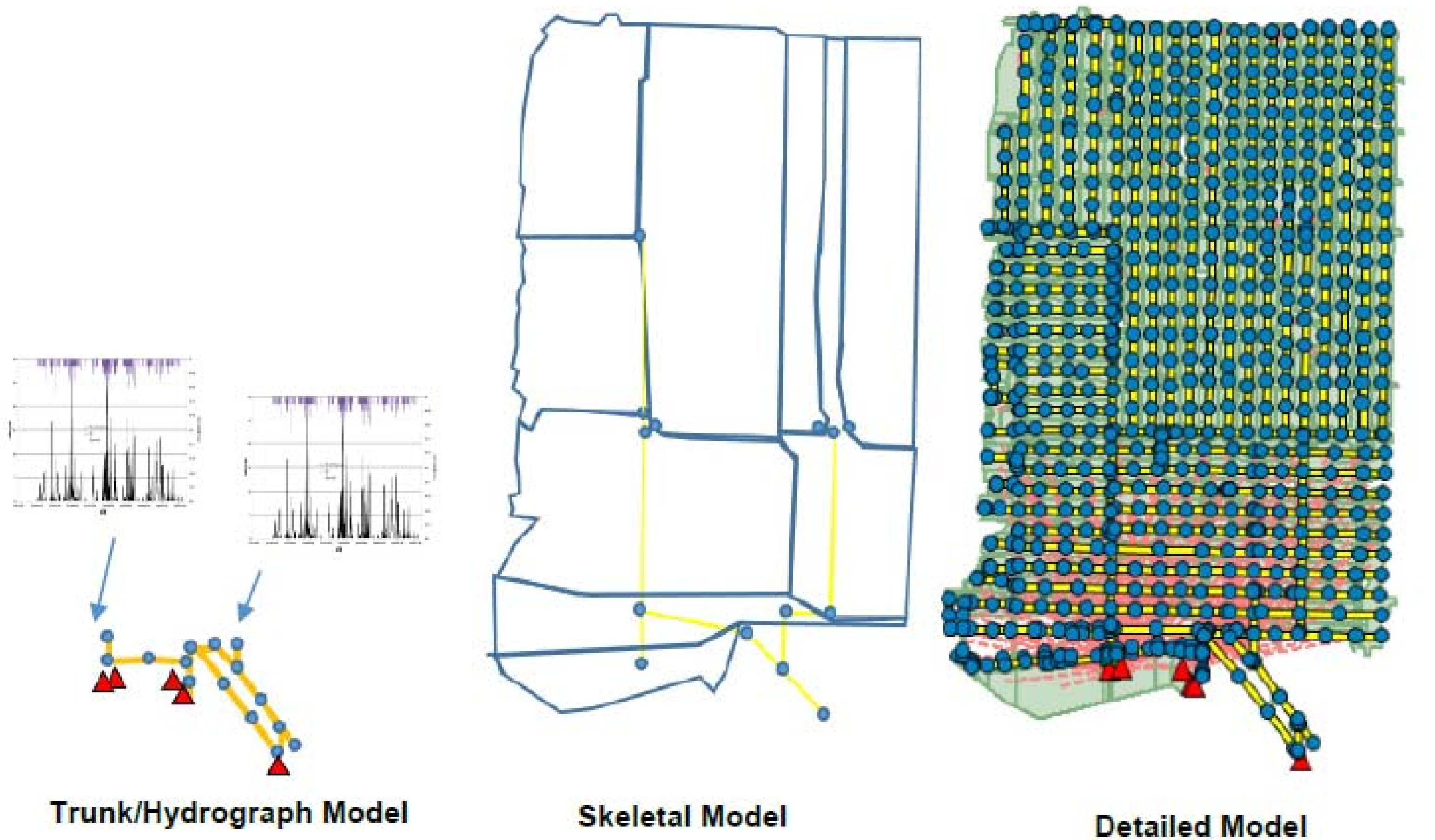
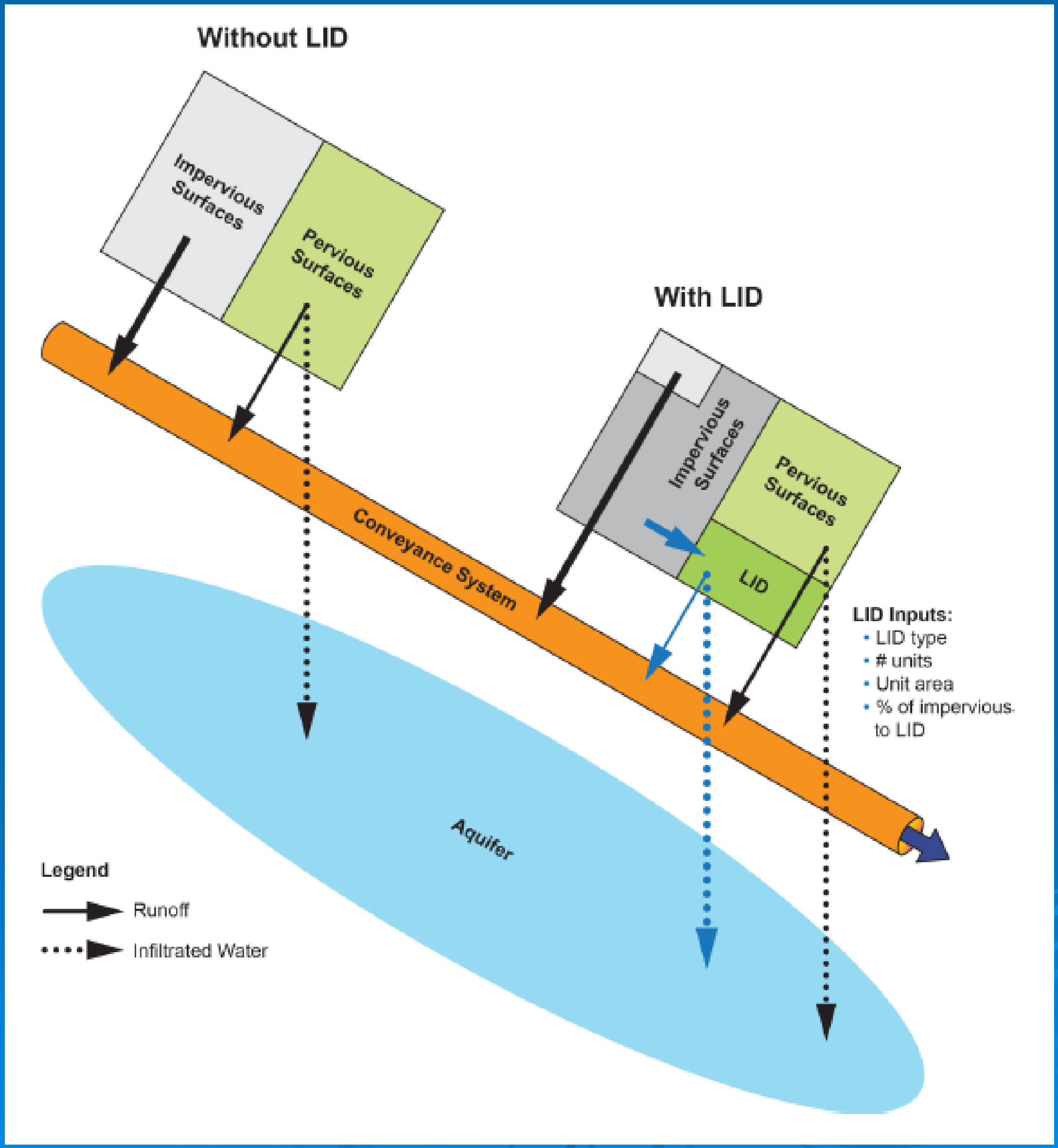


FIGURE 2-1. EXAMPLE MODEL STRUCTURES AND SCALES

SWMM Basics


Without LID
Impervious Surfaces
Pervious Surfaces
With LID
Impervious Surfaces
Pervious Surfaces
LID
Conveyance System
LID Inputs:
• LID type
• # units
• Unit area
• % of impervious to LID
Aquifer
Legend
Runoff
Infiltrated Water

SWMM Basics

LID Controls

Table 12-1. Composition of Vertical Layers in SWMM5

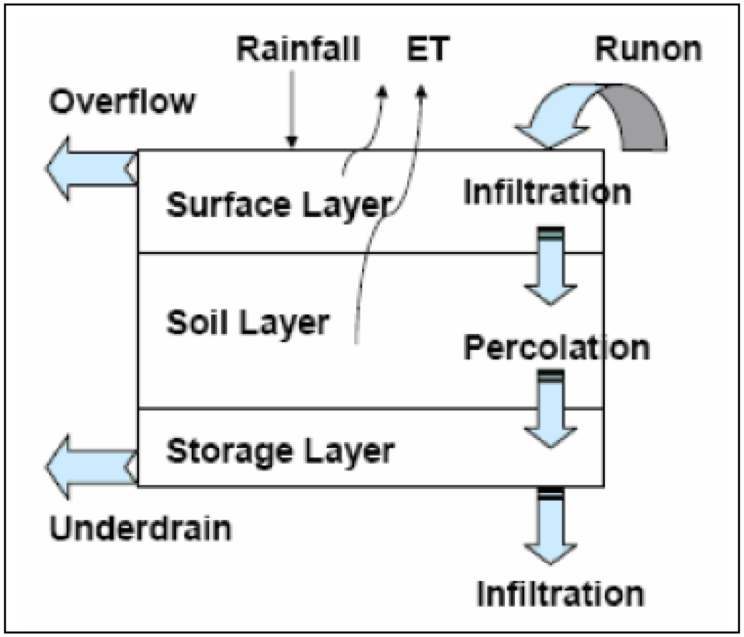
GSI Type	Surface	Pavement	Soil	Storage	Underdrain
Bioretention	√		√	√	o
Porous Pavement	√	√		√	o
Bioswale	√		o	o	o

√ = 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

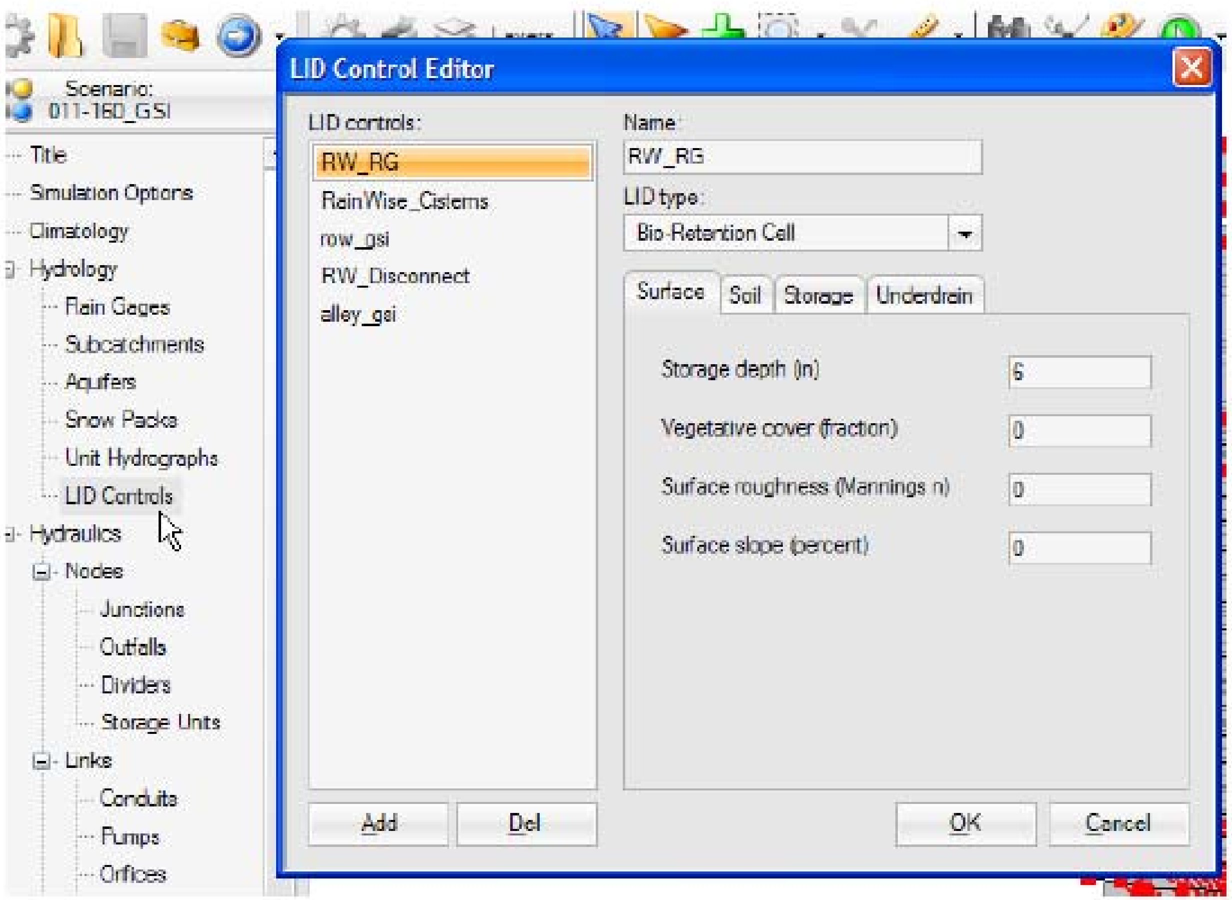


FIGURE 12-3. GRAPHICAL USER INTERFACE FOR THE SWMM5 LID CONTROL EDITOR

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

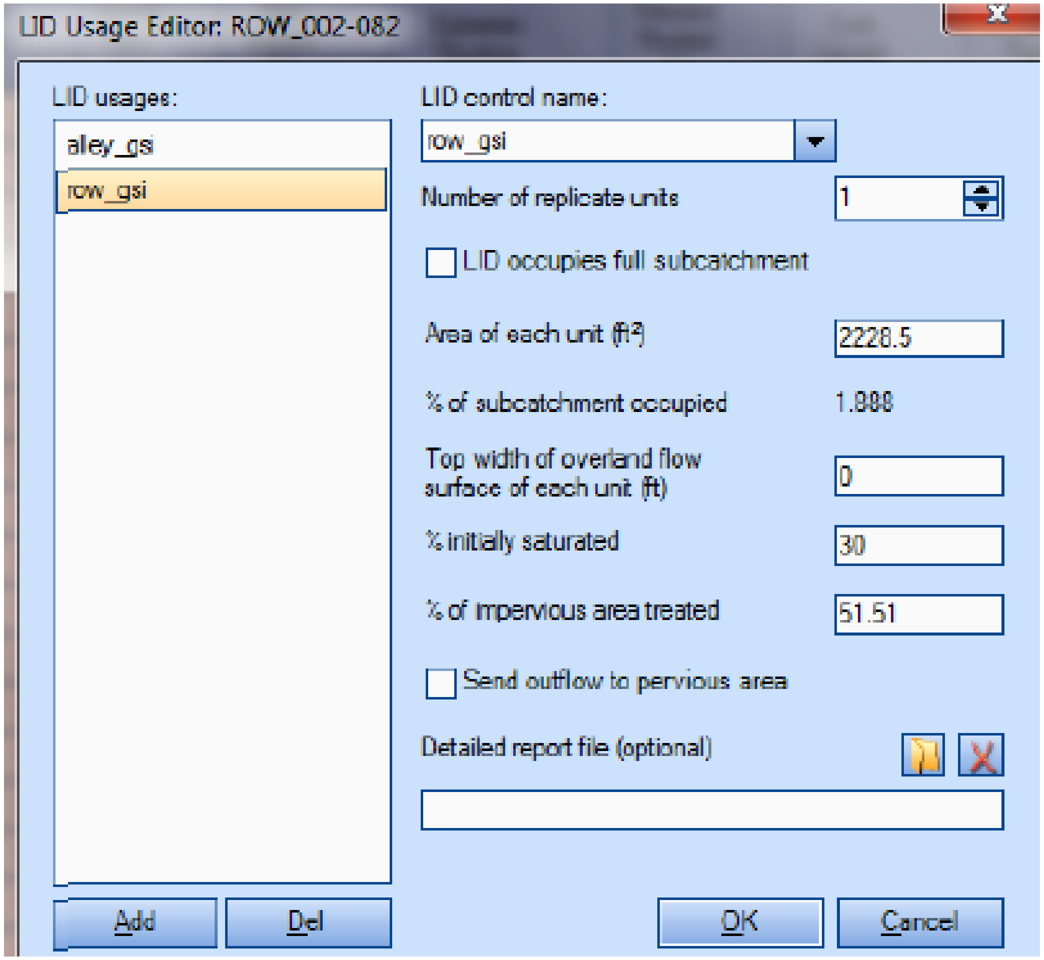
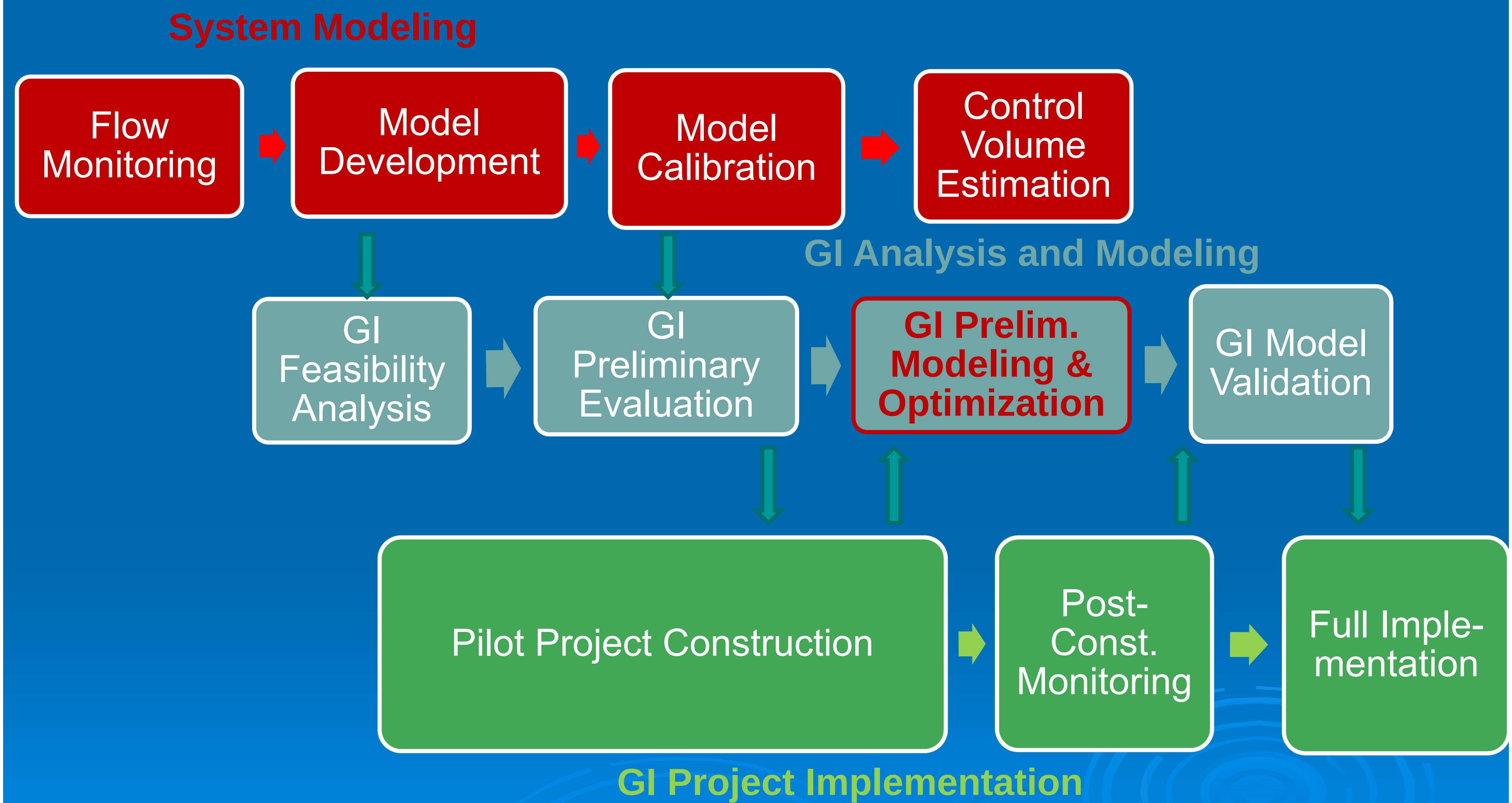


FIGURE 12-5. LID USAGE EDITOR

Combined Sewer Overflow Reduction

SWMM Example

GSI Evaluation Process



GSI Modeling

RainWise Practices

Rain Gardens → Bio-retention Cell

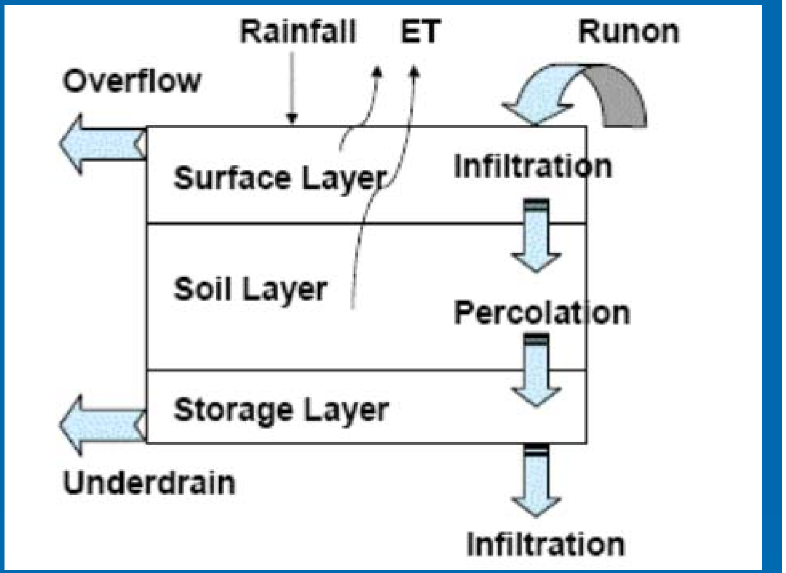
Cisterns → Bio-retention Cell

(non-infiltrating with underdrain)

Right-of-way CIP Practices

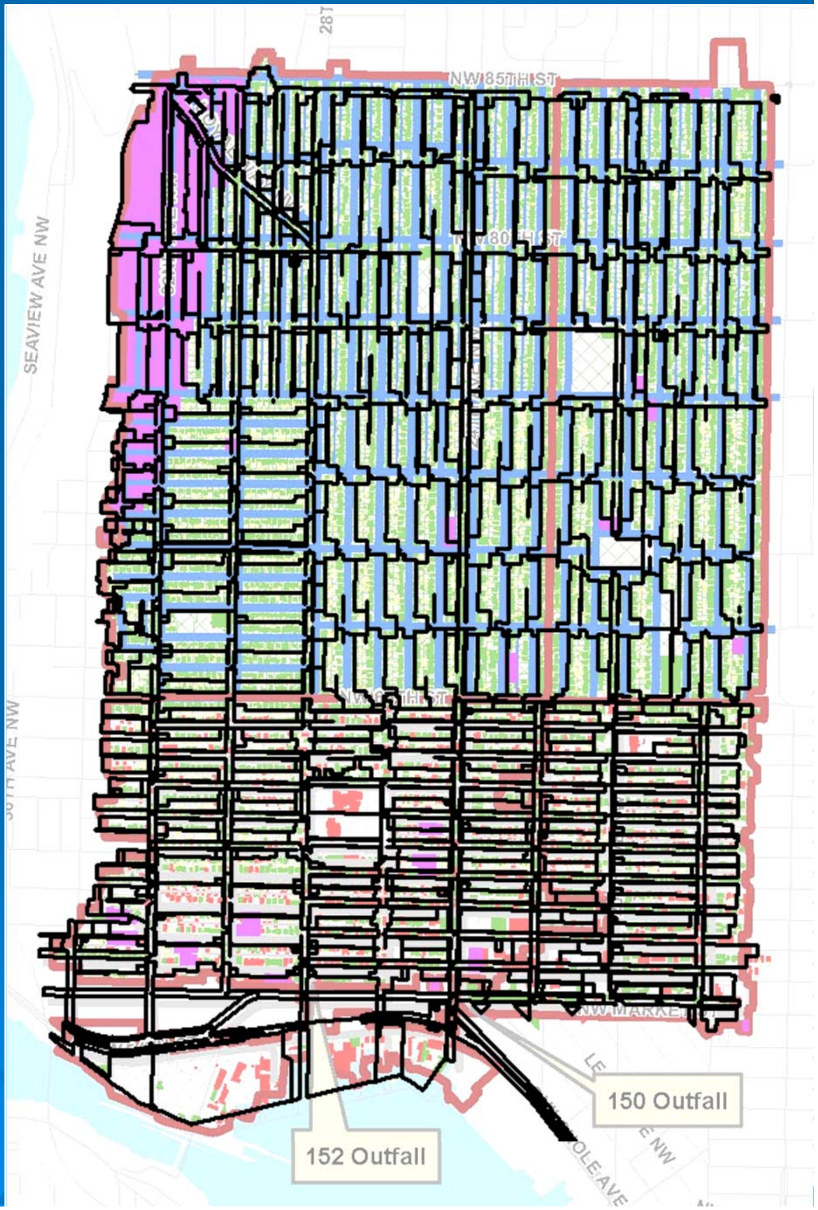
Roadside Rain Gardens → Bio-retention Cell

Green Alleys → Porous Pavement

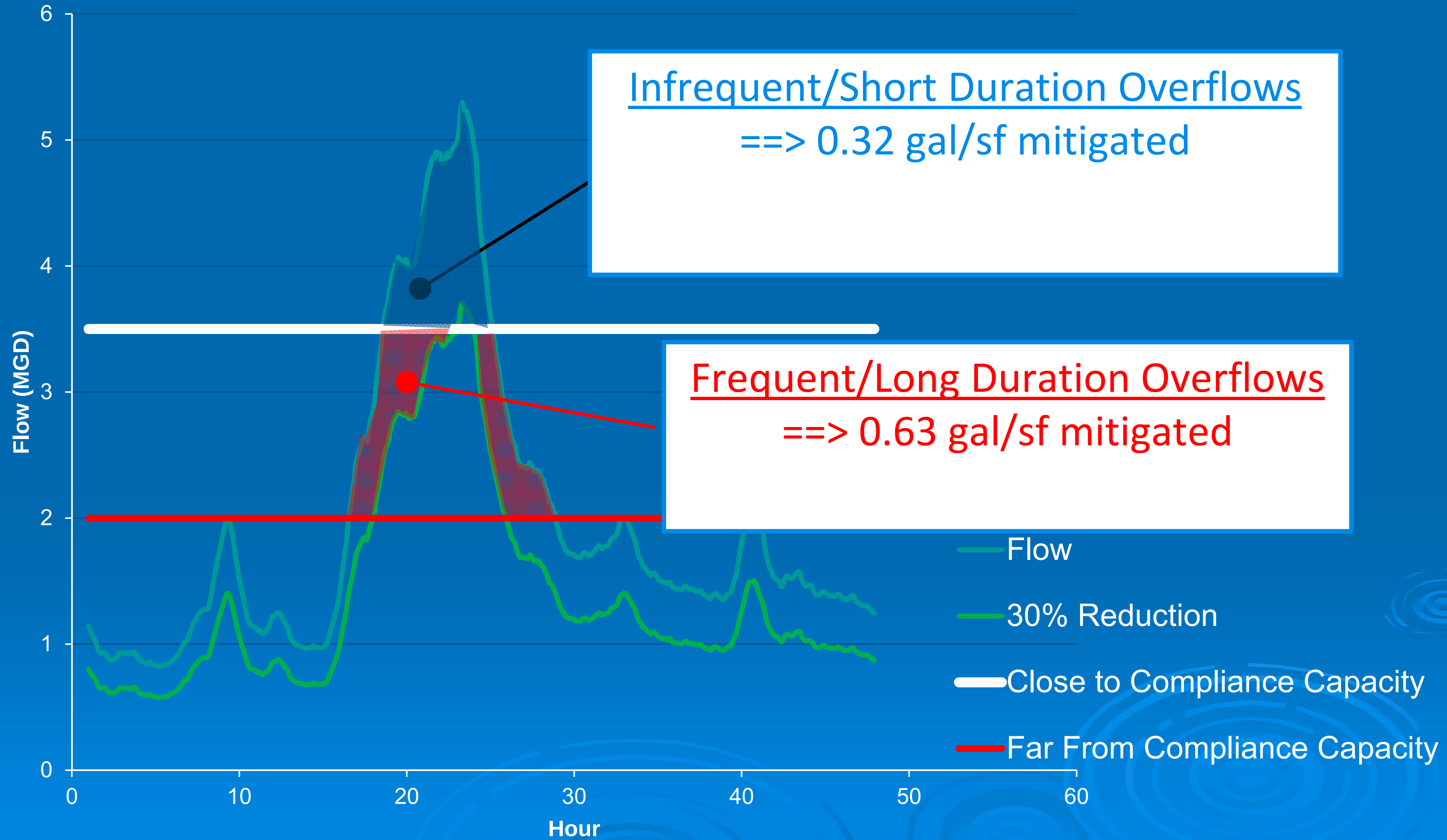


GSI Modeling

- 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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