Hydrologic Modeling for Vegetated Roofs, Rainwater Harvesting and LID Foundations

Robin Kirschbaum, PE, LEED AP HDR

Alice Lancaster, PE HERRERA

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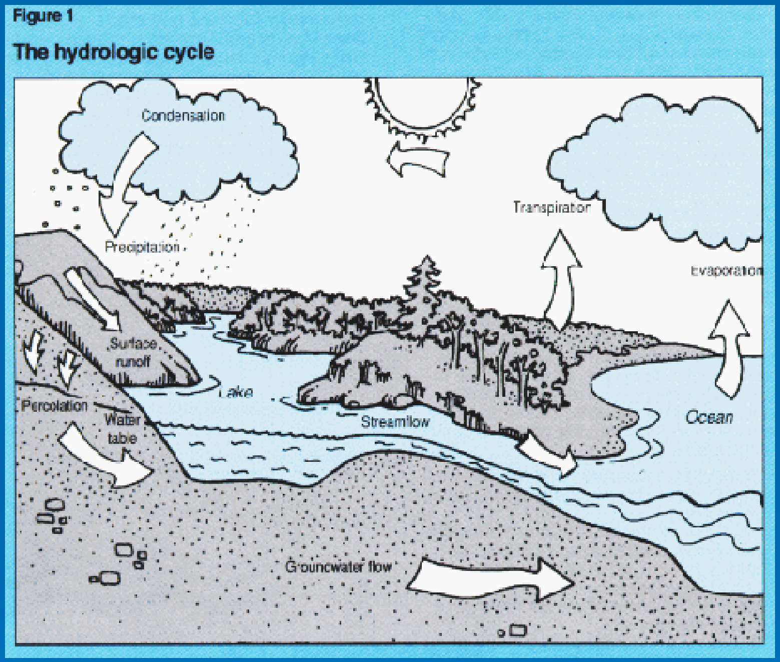
Presentation Outline

- Overview of Hydrologic Modeling
- Performance Standards
- Modeling Guidelines
  - Green Roofs
  - Pin Foundations
  - Detention Cisterns
  - Harvesting Cisterns
- Examples

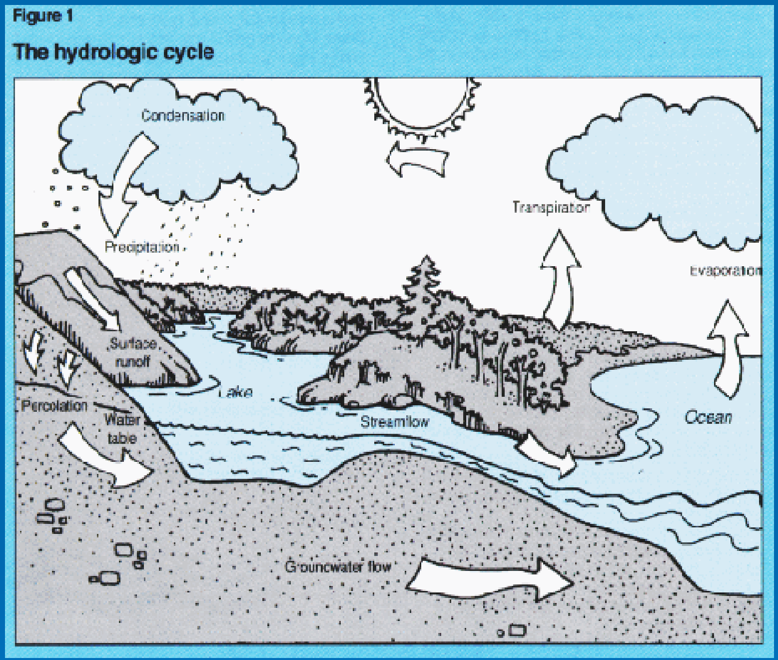
Hydrologic Modeling



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

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

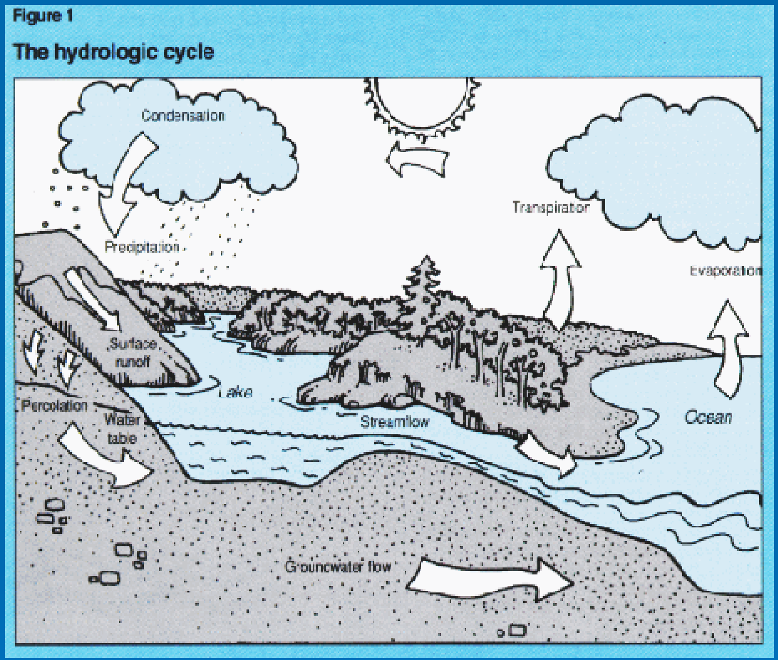
Hydrologic Modeling



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)

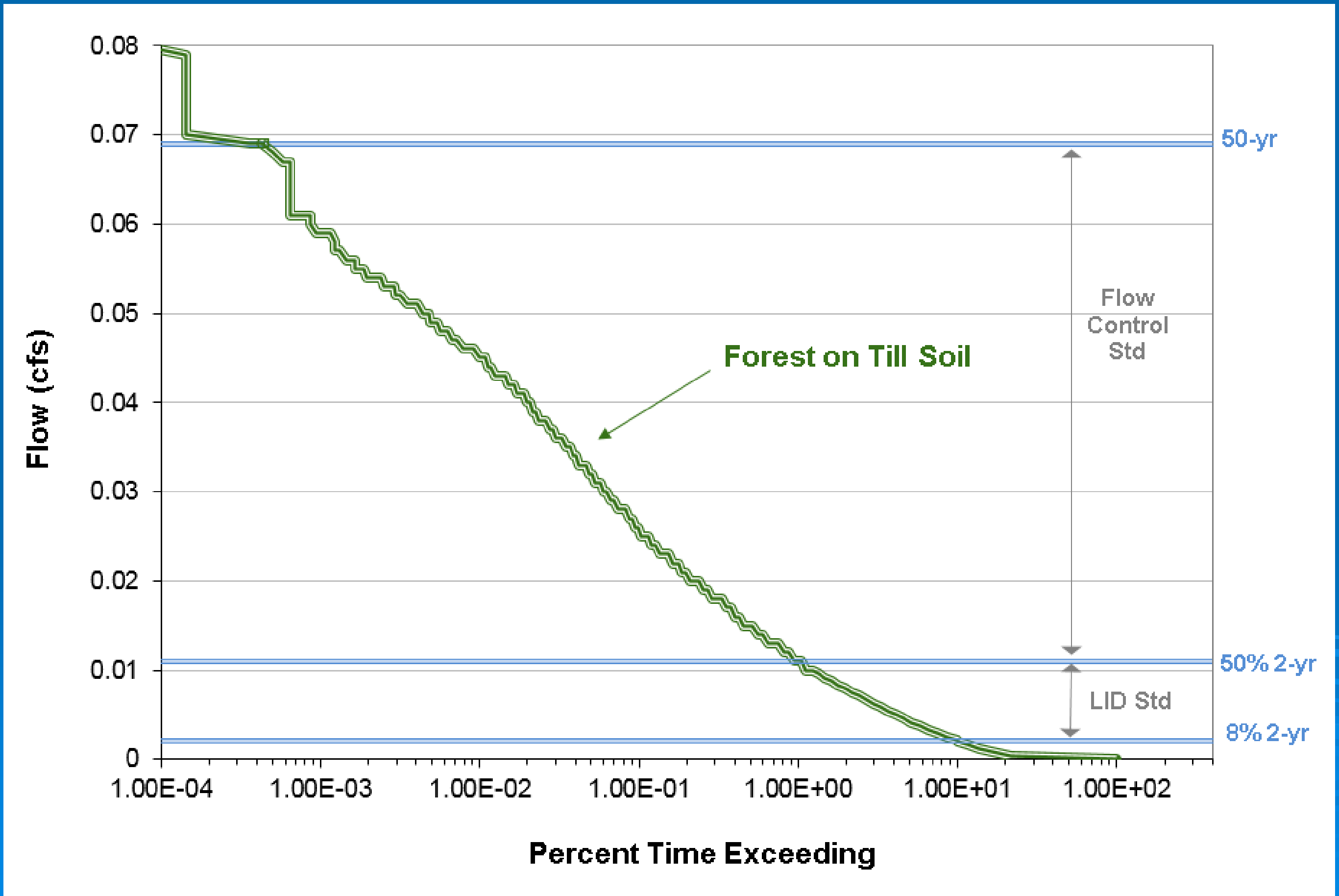
Performance Standards

- On-site Stormwater Management (MR #5) (2013 Permit)
  - Use BMP List

    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)

Flow Duration Standards

- LID Performance Standard (MR #5)
- Flow Control (MR #7)

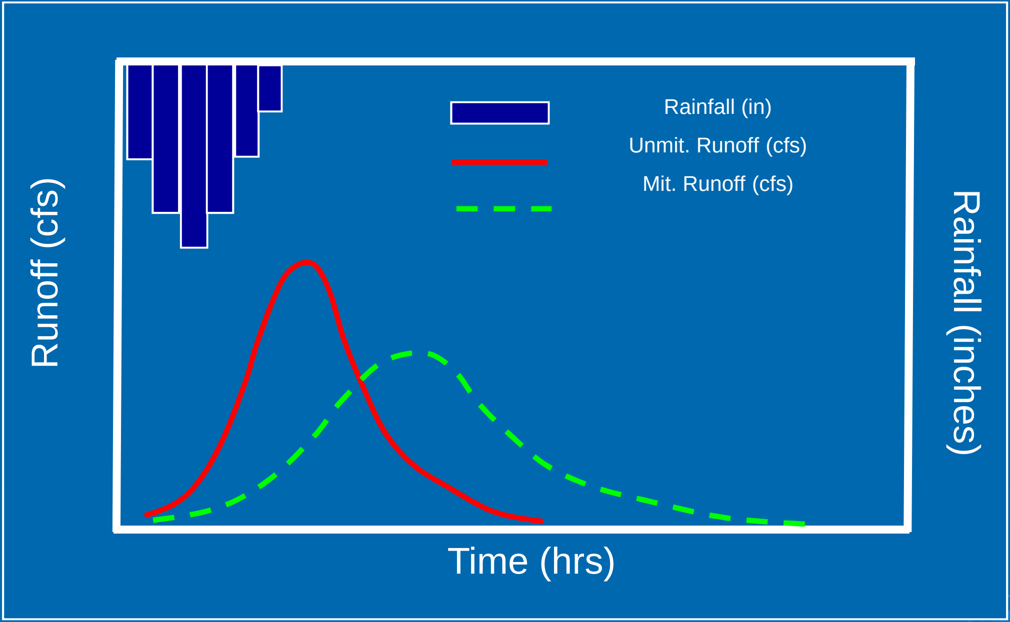


Modeling Methods

- Single-event models
  - May be appropriate for conveyance sizing
- Continuous models
  - Required for sizing facilities to meet the LID performance (MR#5), treatment (MR#6), and flow control (MR#7) standards
- Simplified sizing tools
  - Allow sizing without hydrologic modeling
  - Examples: Flow control credits for green roofs and sizing equations for detention cisterns

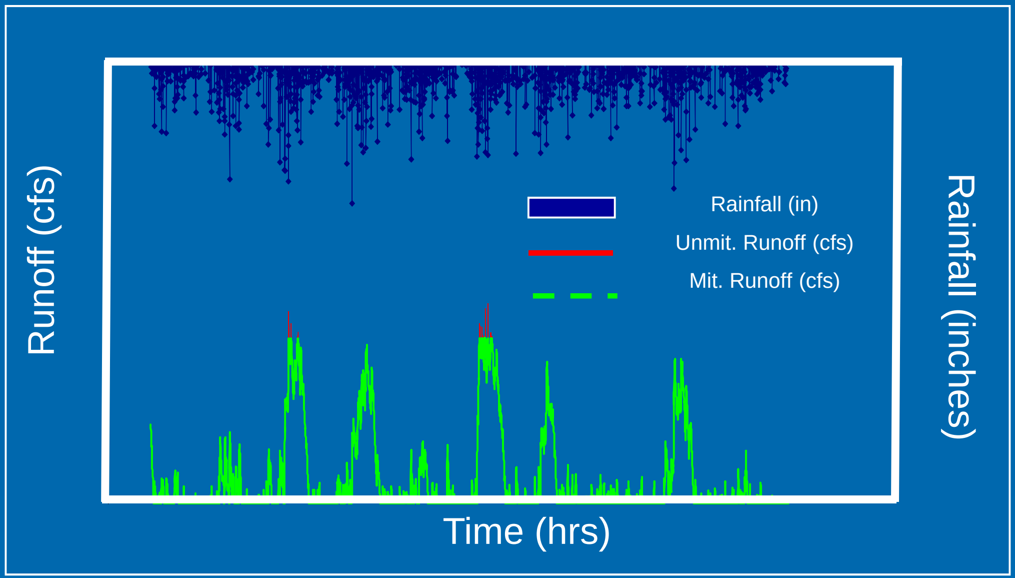
Modeling Methods
Single-Event

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



Modeling Methods
Continuous Simulation

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



Modeling Tools
HSPF Basics – Model Inputs

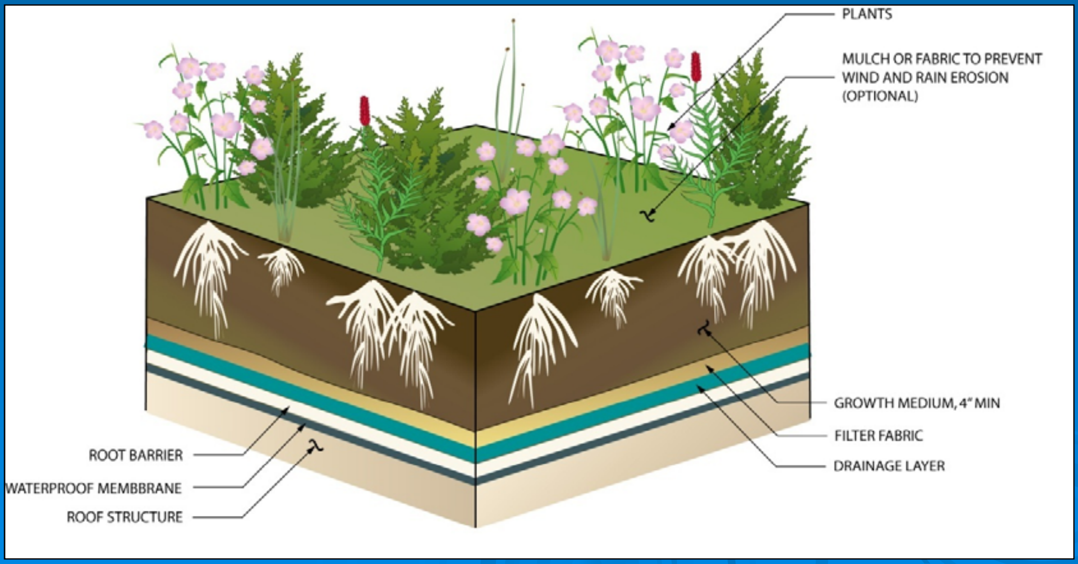
- Meteorological Data
  - Rainfall (5-min, 15-min, hourly)
  - Evaporation (daily)

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

- BMP Configurations

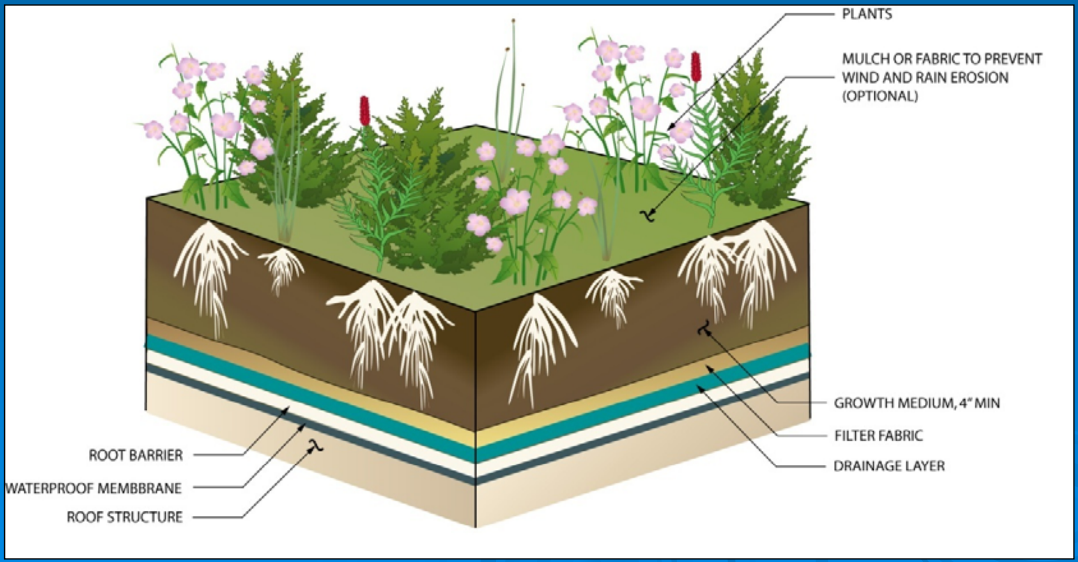
Vegetated Roofs
Current Modeling Guidelines

- Implicit Method
  - 3-8" growing media → model as till lawn
  - >8" growing media → model as till pasture



Vegetated Roofs
2013 Permit Modeling Guidelines

- Implicit Method
  - 3-8” growing media → model as 50% till lawn / 50% impervious area
  - >8” growing media → model as 50% till pasture / 50% impervious area



Vegetated Roofs
Current Modeling Guidelines

- Explicit Methods
  - WWHM2012 and WWHM4
    - Modified PERLND parameters
    - Based on Hamilton Buildings in Portland
    - Considers material depth and vegetated cover
  - MGSFlood4
    - Modified PERLND parameters (similar to WWHM)

Vegetated Roofs

Modified PERLND Parameters

Table 1. Eco-Roof HSPF Parameter Values

HSPF Parameter	Eco-Roof Value	Standard WWHM3 Value*
LZSN	0.75/1.25**	4.50
INFILT	0.05	0.03
LSUR	50	400
SLSUR	0.001	0.050
AGWRC	0.100	0.996
AGWETP	0.80	0.00
UZSN	0.075/0.125**	0.250
NSUR	0.55	0.25
INTFW	1.0	6.0
IRC	0.10	0.50
LZETP	0.80	0.25

* Value for till soil, lawn, flat slope

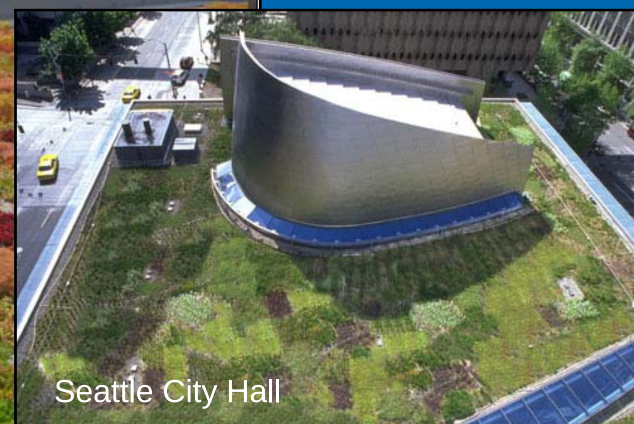
** Values dependent on depth of material (values shown for Portland east and west roofs: 3 inches and 5 inches of material, respectively)

Source: WWHM3 Eco-Roof Documentation, Memorandum prepared by Clear Creek Solutions to Seattle Public Utilities, December 7, 2005.

Vegetated Roof Example
Flow Control (WWHM4)

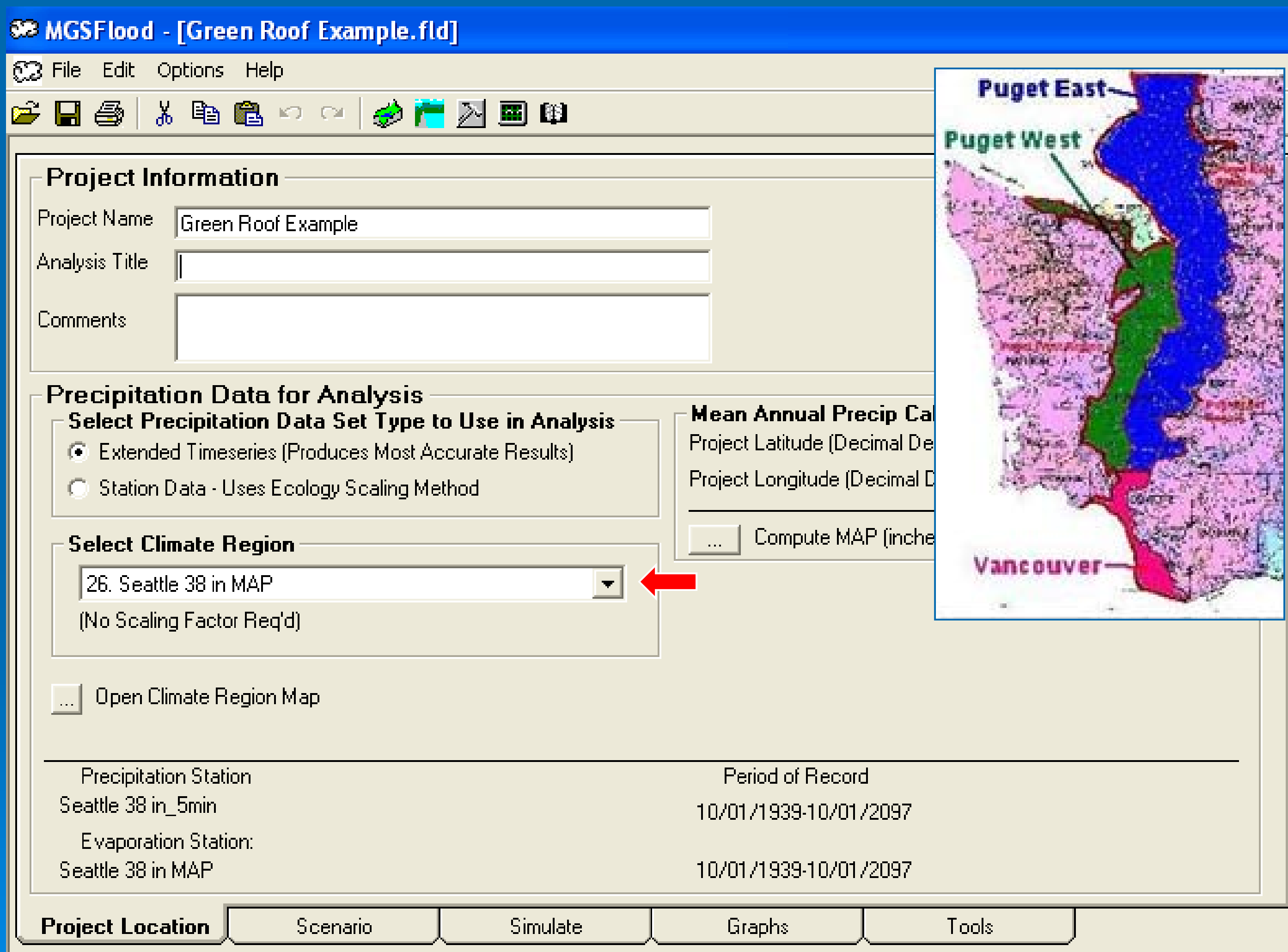
- 1 acre Vegetated Roof
- In Seattle
- Performance relative to Ecology Flow control Standard
- Predeveloped condition is till forest


Park Place


Seattle City Hall

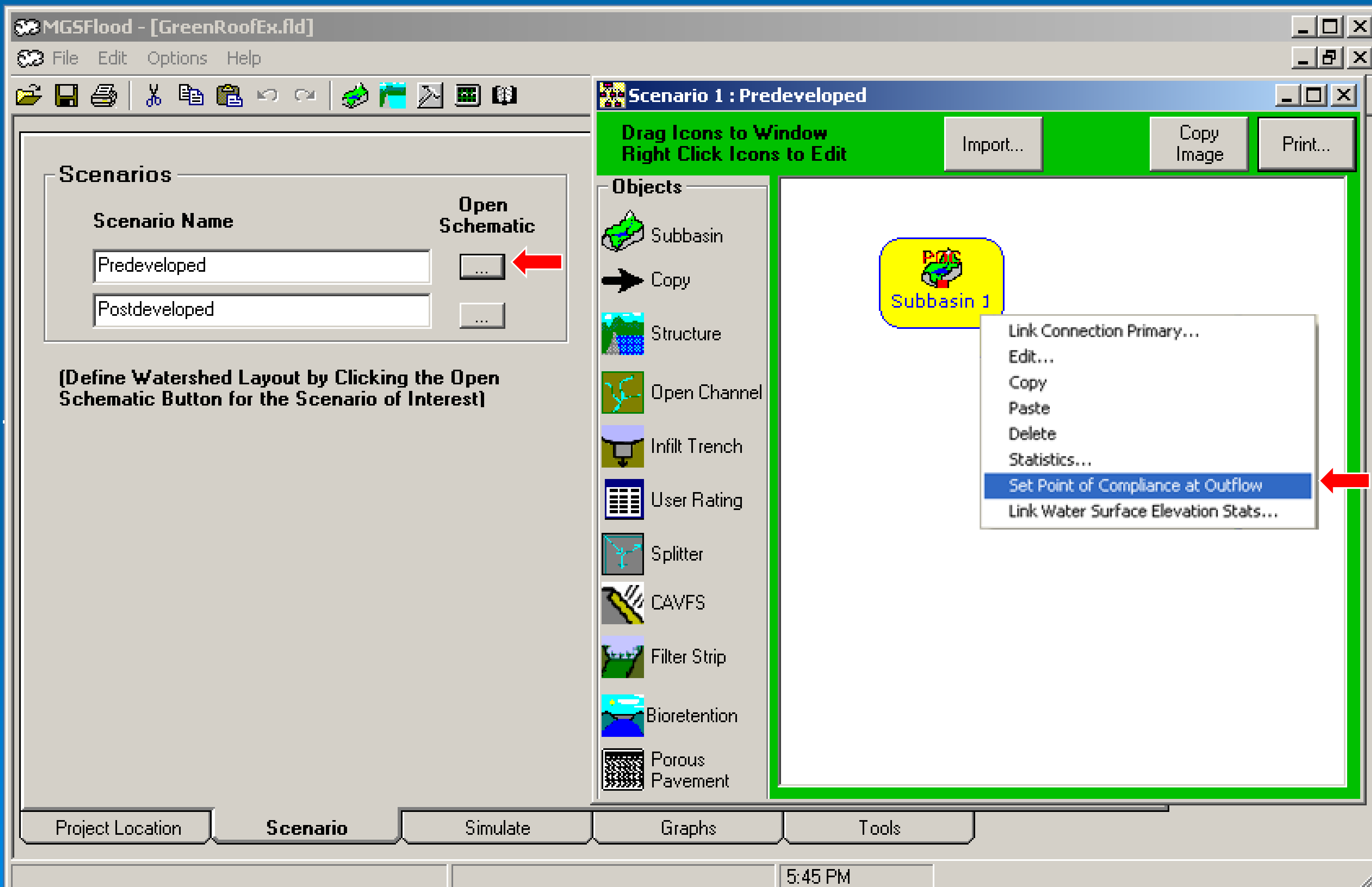
Vegetated Roof Example

Select Precipitation



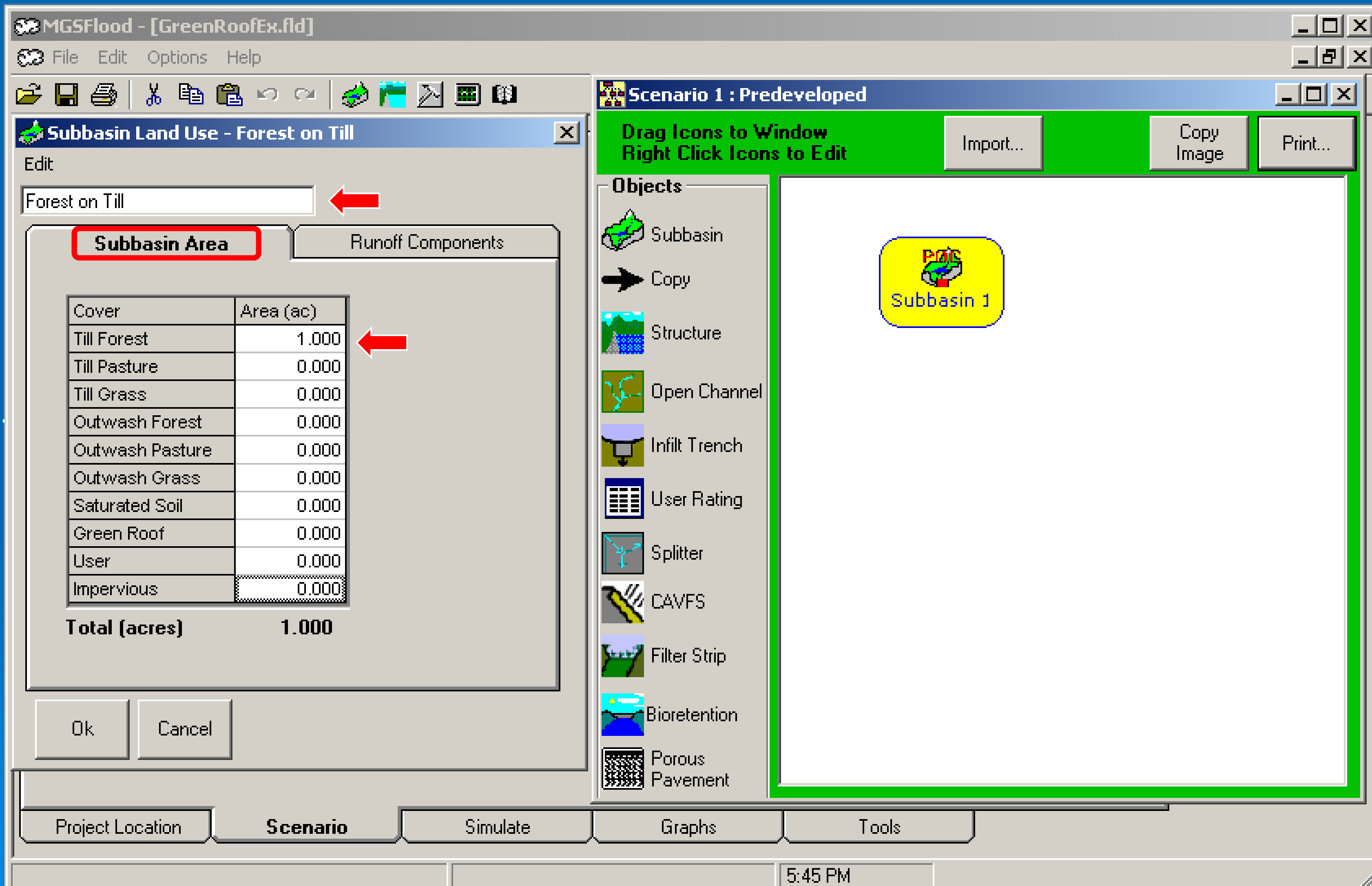
Vegetated Roof Example

Define Predeveloped Condition



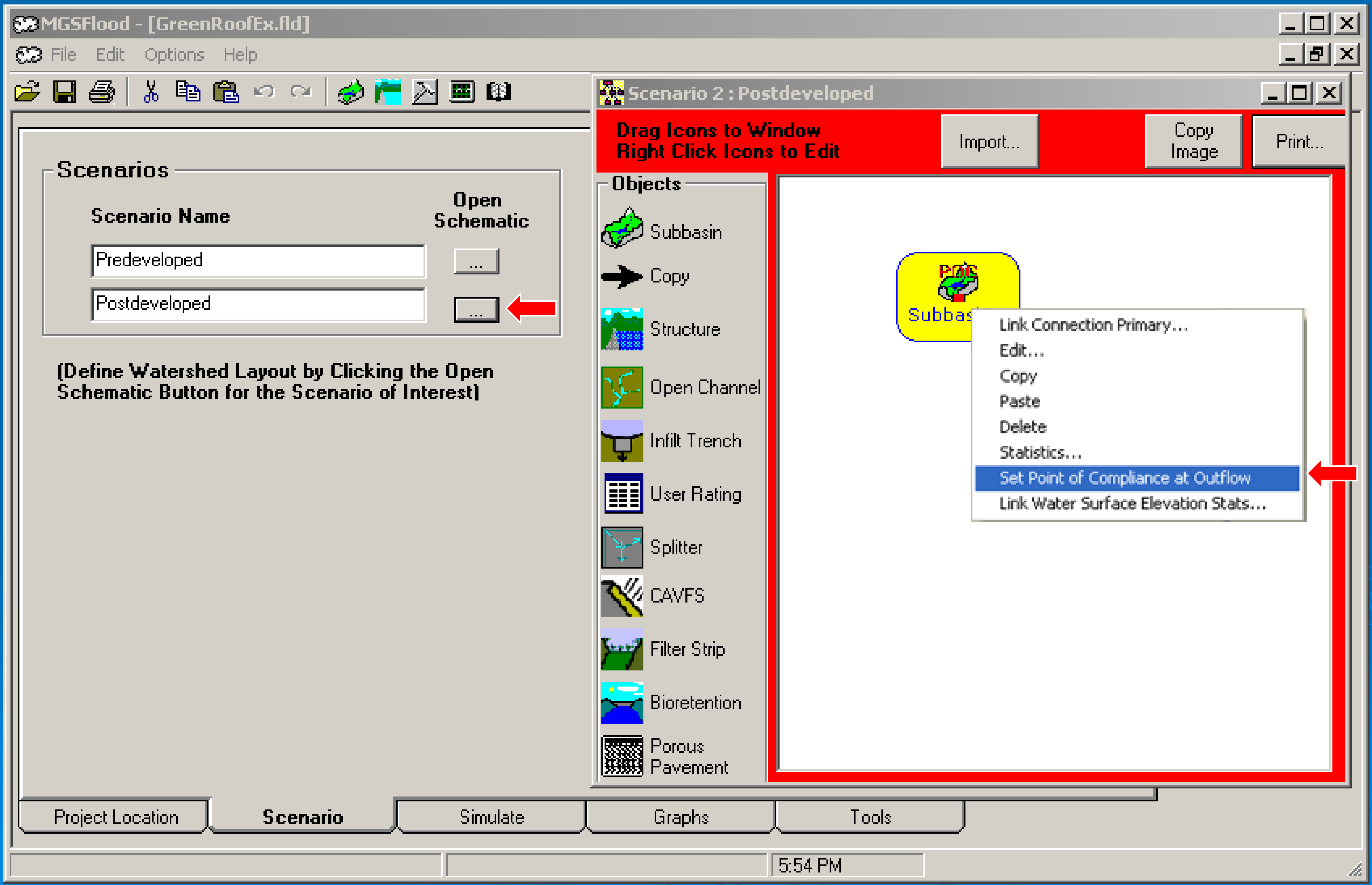
Vegetated Roof Example

Define Predeveloped Condition



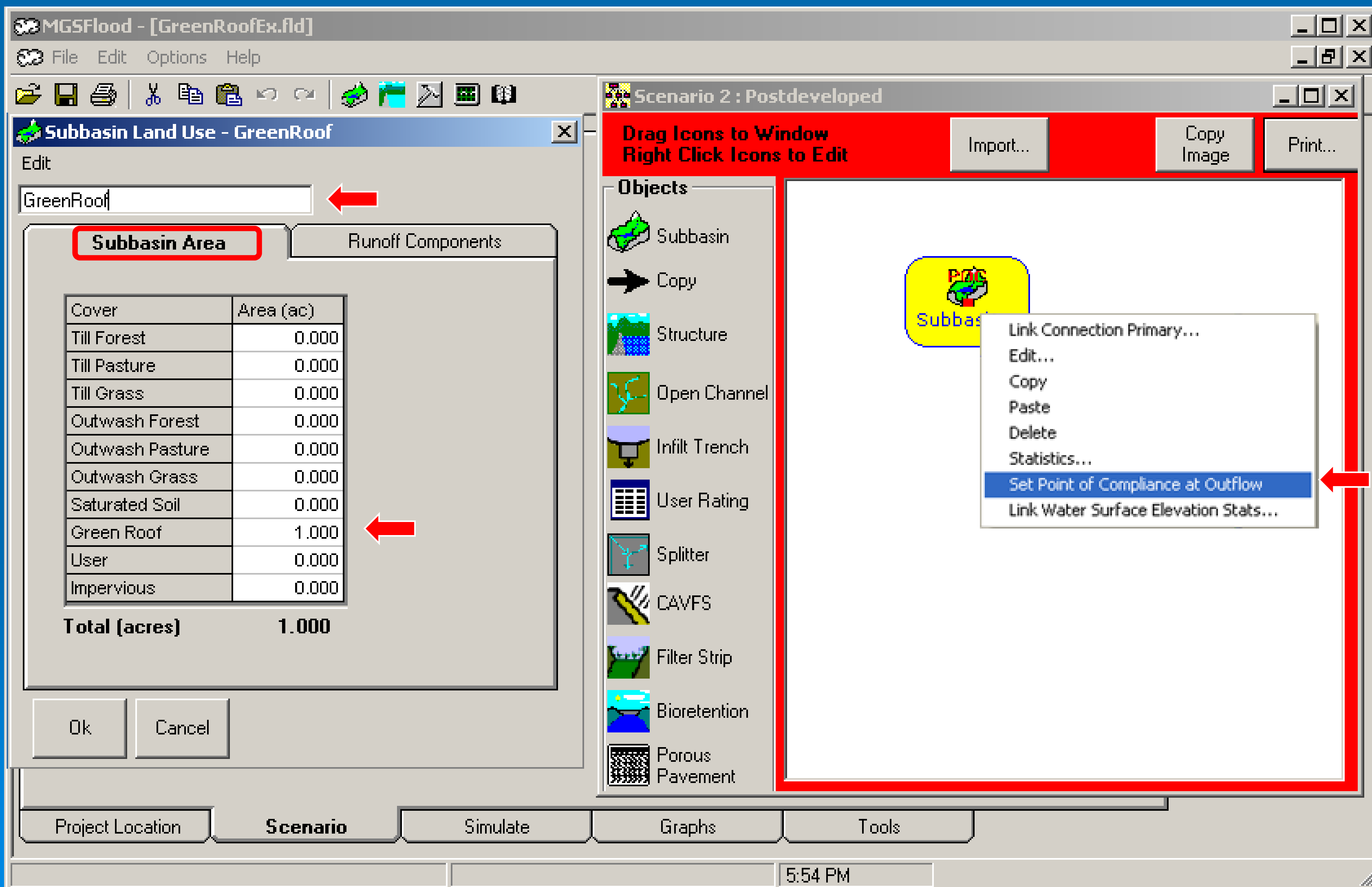
Vegetated Roof Example

Define Developed Mitigated Condition



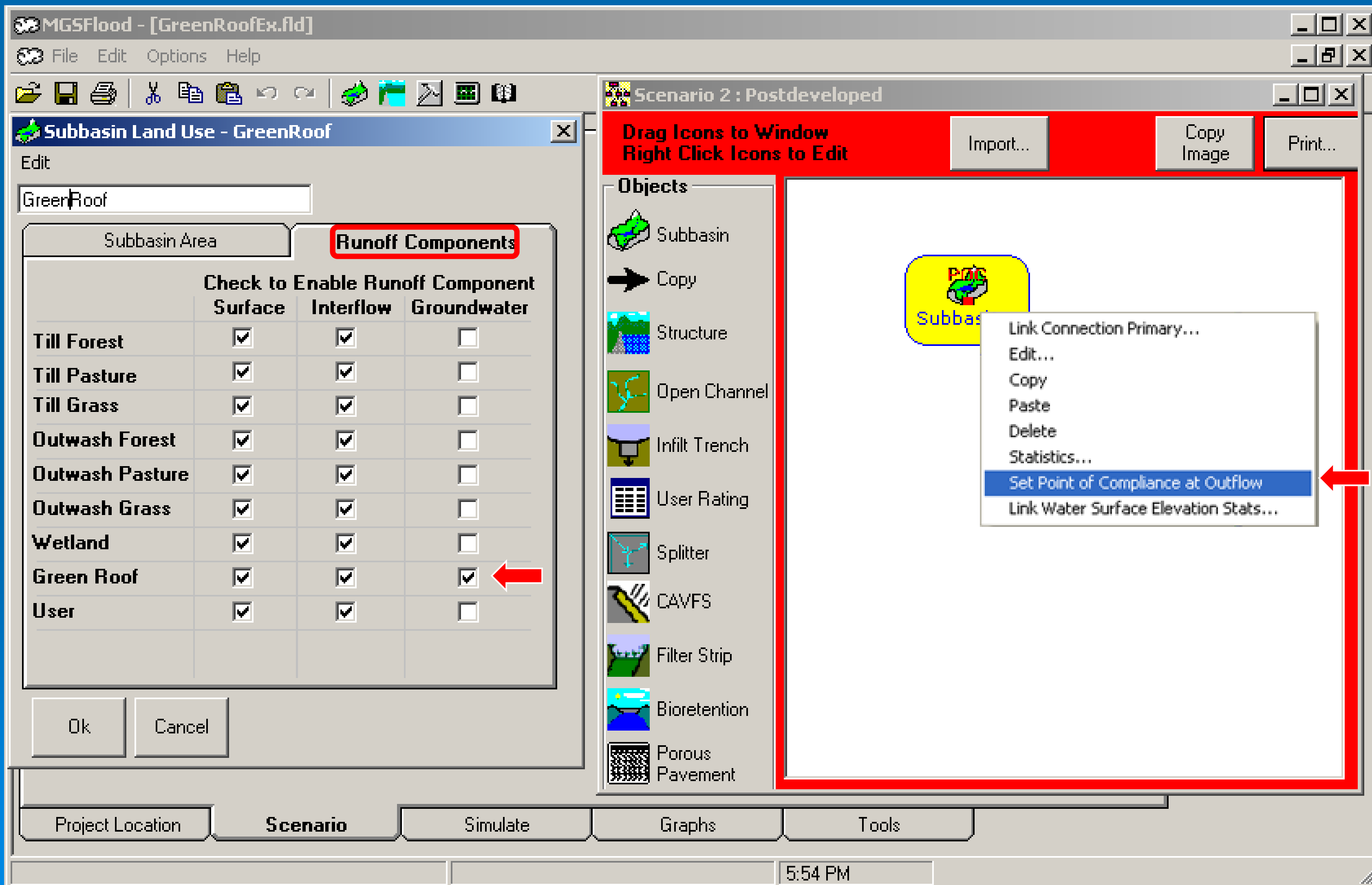
Vegetated Roof Example

Define Developed Mitigated Condition



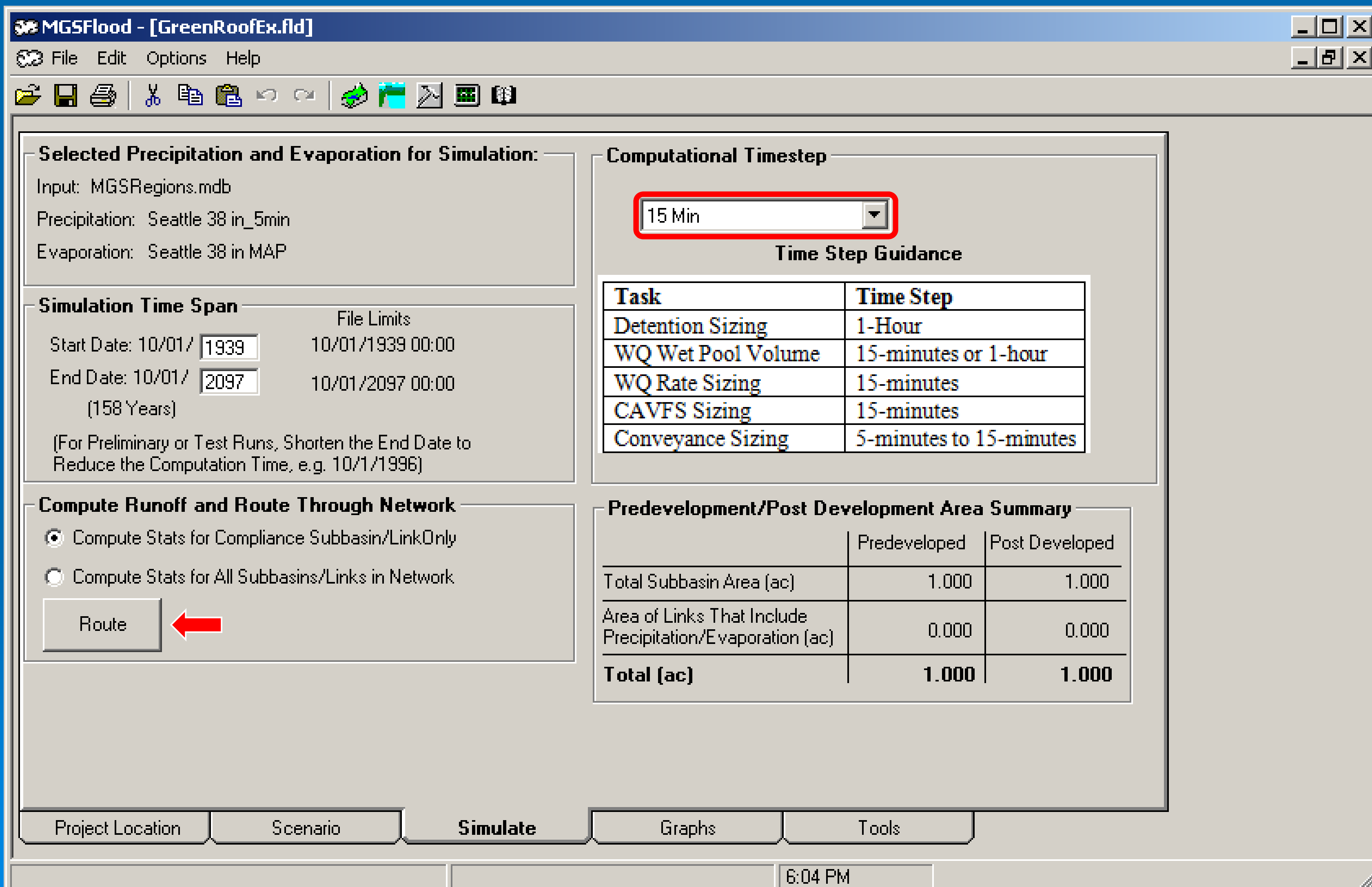
Vegetated Roof Example

Define Developed Mitigated Condition



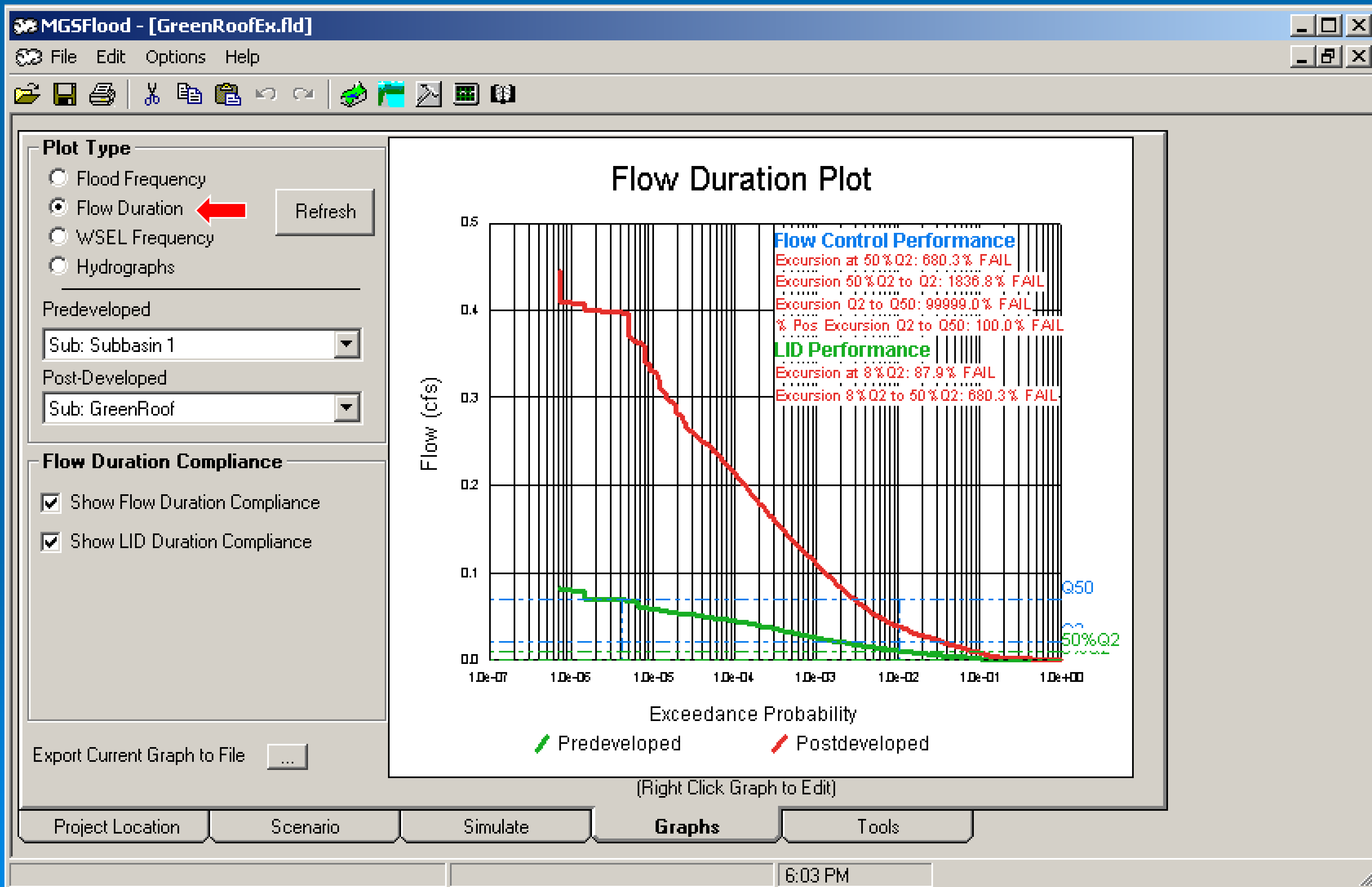
Vegetated Roof Example

Run Model



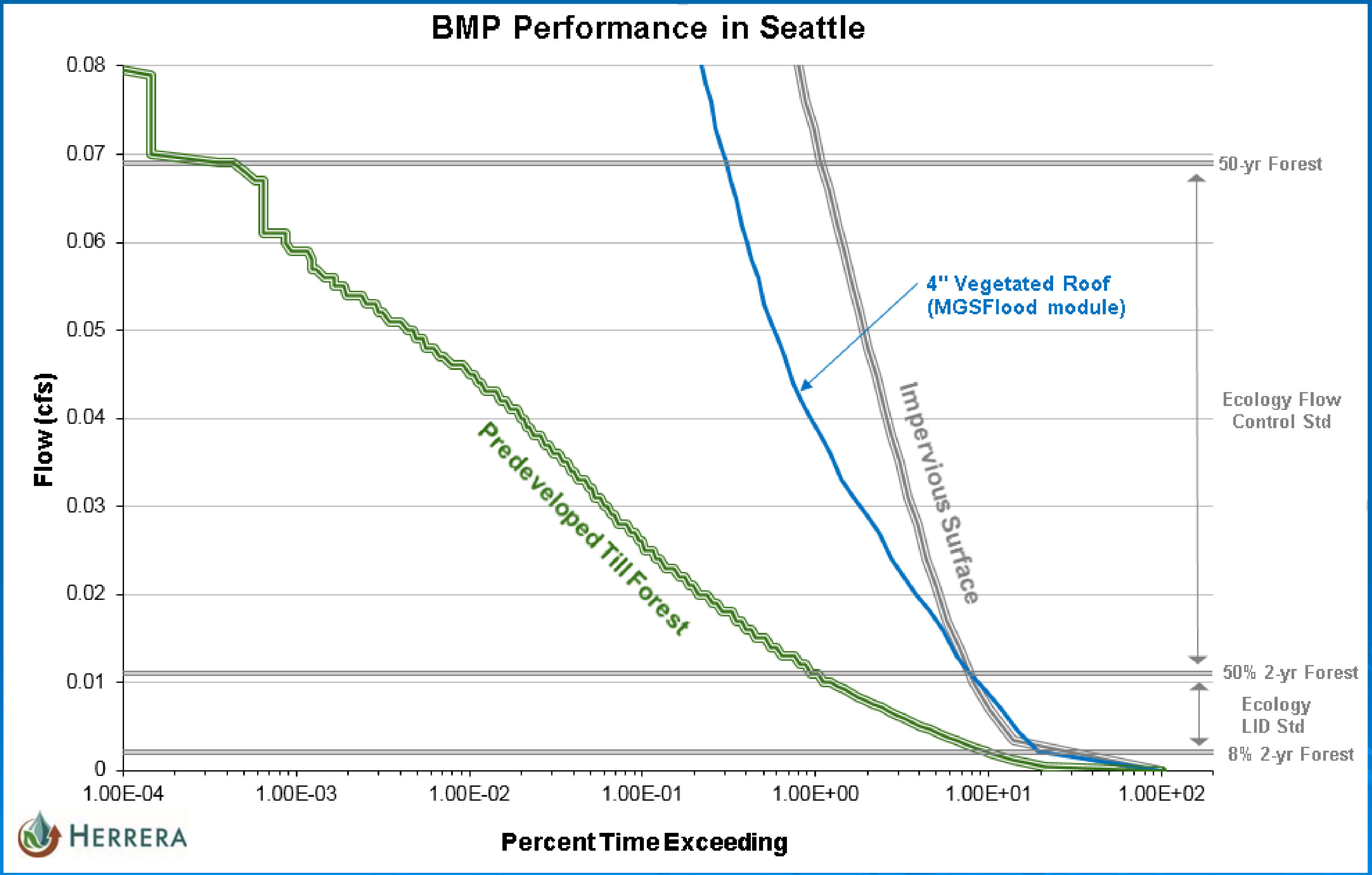
Vegetated Roof Example

Duration Plot



Vegetated Roof Performance

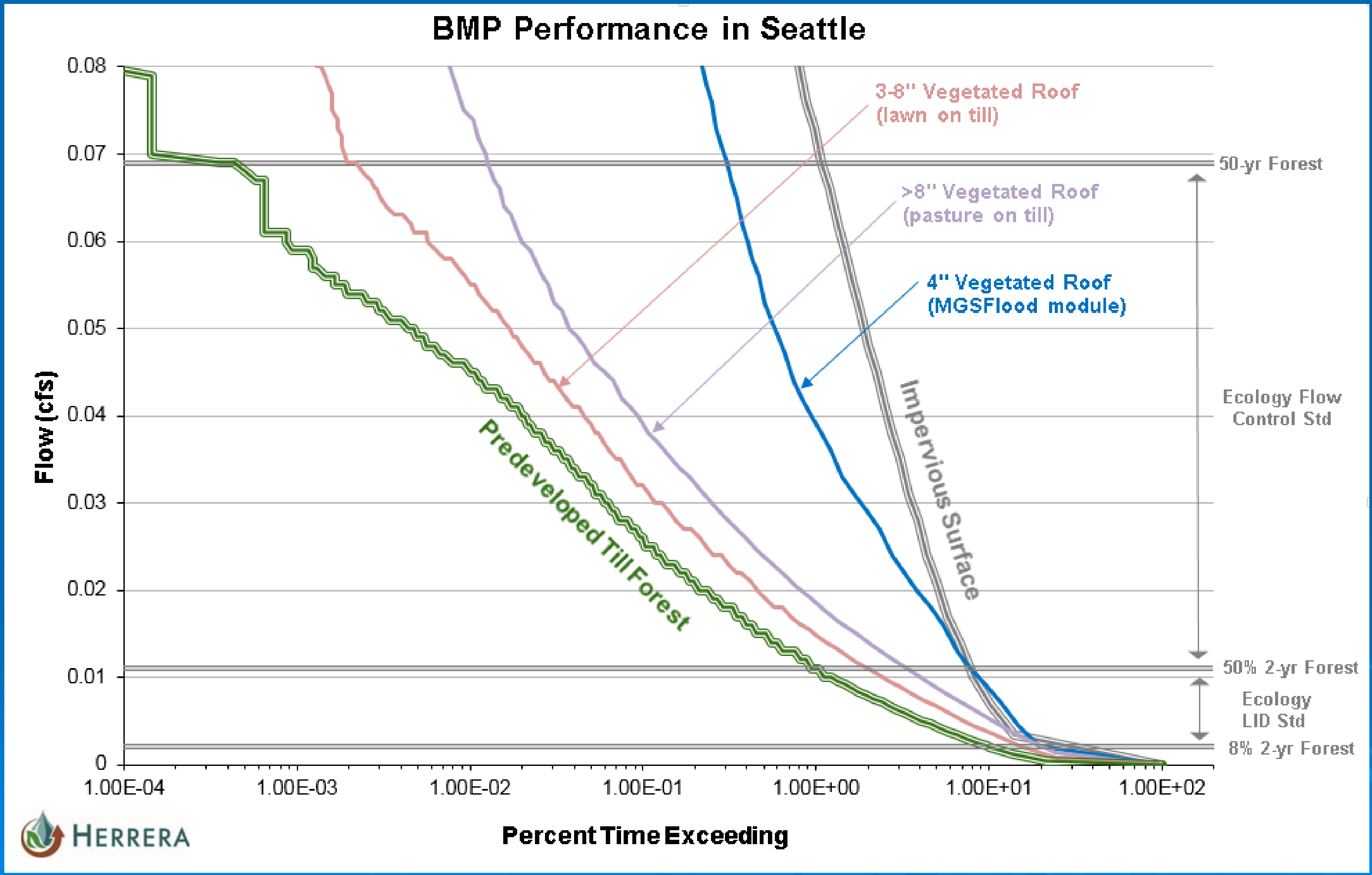
MGSFlood Module



Vegetated roof reduces downstream BMP size

Vegetated Roof Performance

Implicit Methods



Vegetated roof reduces downstream BMP size

Minimal Excavation Foundations
Current* Modeling Guidelines

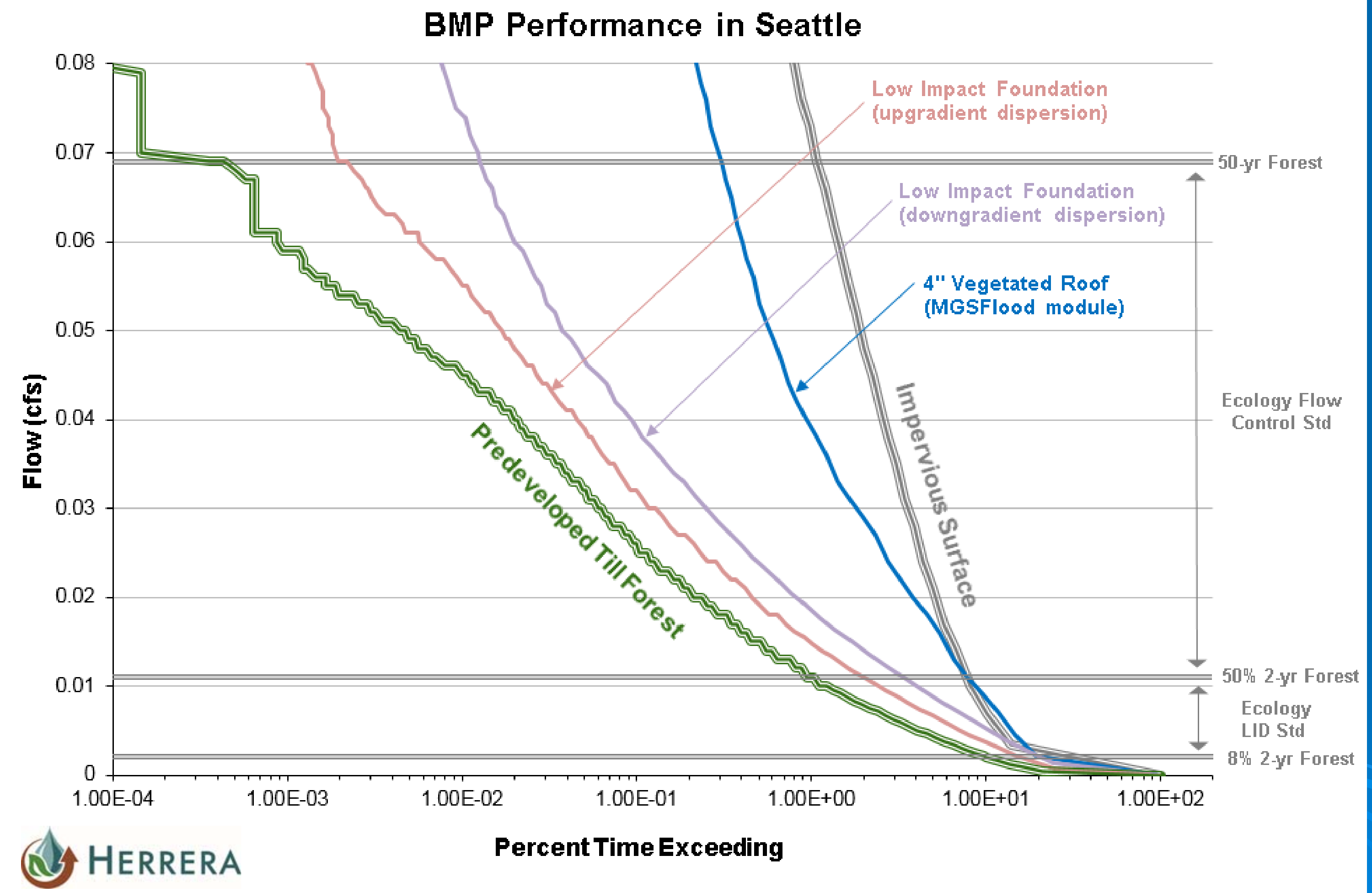
- Roof runoff dispersed on <u>up gradient</u> side of structure
  - Dispersion per BMP T5.10 (downspout dispersion)
  - Model roof as <u>pasture on native soil</u>
  - Highest credit available
  - Note: Area receiving credit reduced when step-forming is used on a slope

- Roof runoff dispersed on <u>down gradient</u> side of structure
  - Dispersion per BMP T5.10 (downspout dispersion) AND at least 50 ft of vegetated flow path that meets BMP T5.13
  - Model roof as <u>lawn/landscape on native soil</u>

* Same as 2013 permit guidelines

LID Foundations Performance

Duration Plot

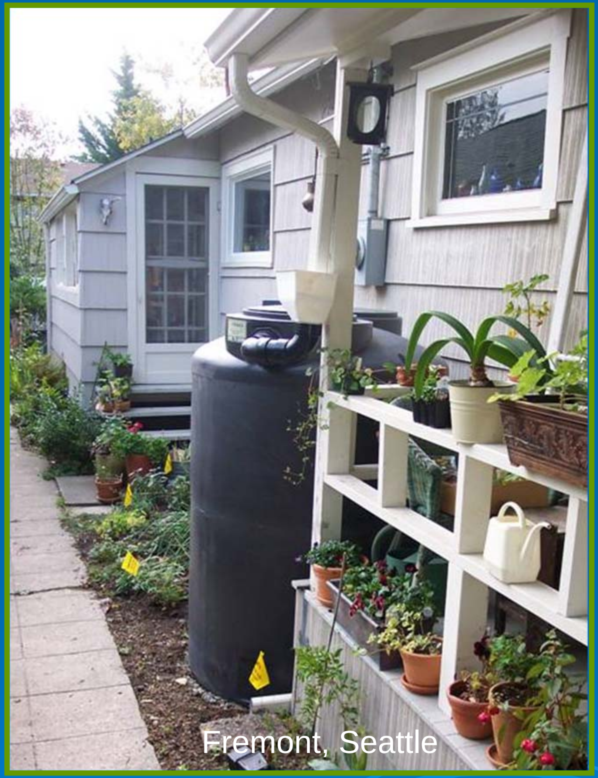


Modeled as lawn on till- same as implicit representation for vegetated roofs (>8")

Modeled as lawn on till- same as implict representation for partial dispersion and vegeated roofs (3-8")

Detention Cisterns
Current Modeling Guidelines

- Explicitly Model
  - Vault/tank with low flow orifice and overflow
- Orifice Limitations
  - Minimum orifice size typically will not achieve creek protection flow duration standards
  - Useful tool for CSO control



Note: No recommendations in 2005 or 2012 LID Manual

Harvesting Cisterns
Current* Modeling Guidelines

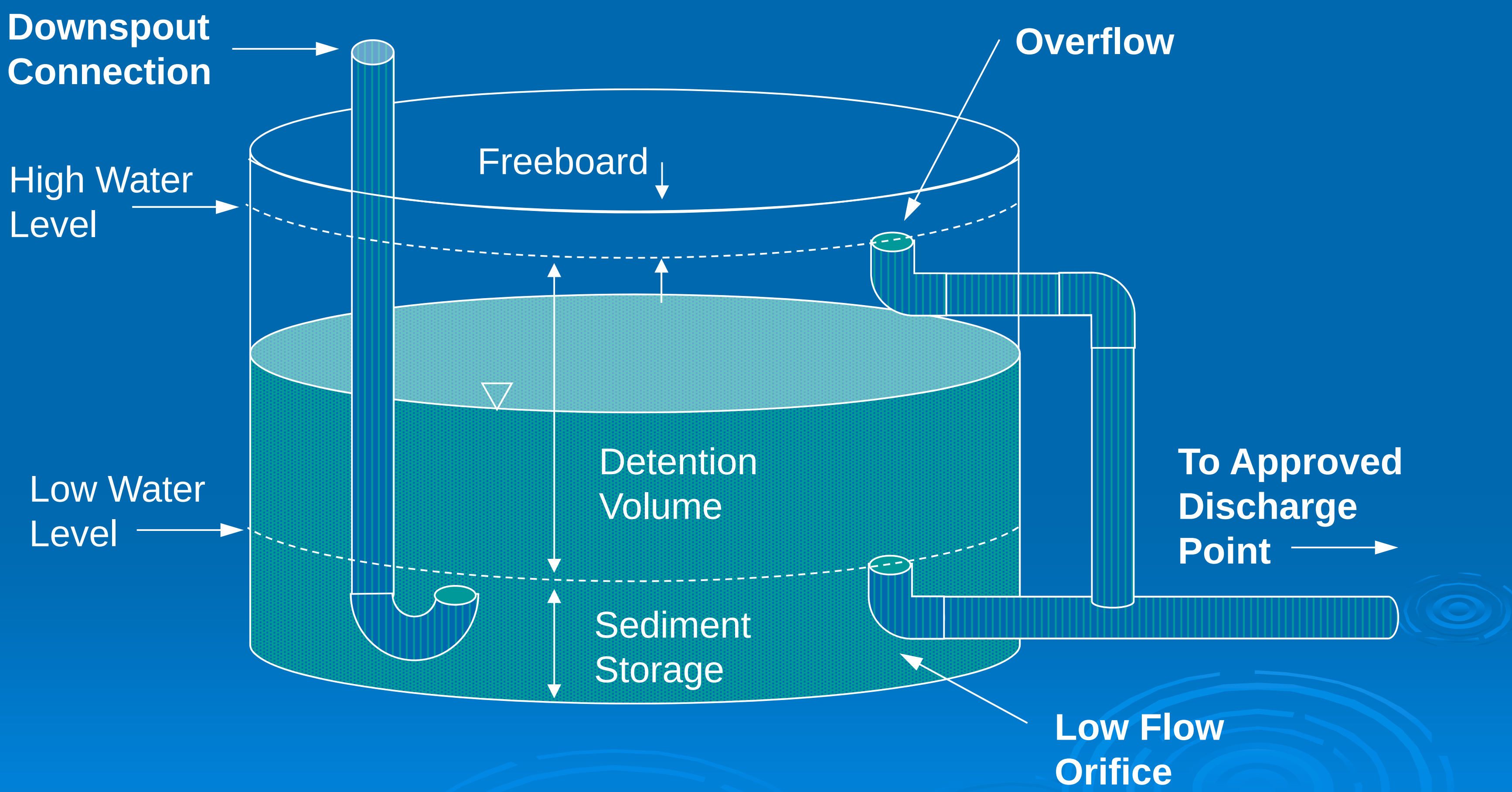
- **Explicitly Model**
  - Estimate average annual runoff volume (V) using continuous model
  - Size cisterns to provide storage, V
  - For interior reuse, perform monthly water balance
  - Subtract roof area from site-wide model if sizing flow control or water quality treatment
- **Recommendation**
  - Perform daily (or sub-daily if rainfall data available) water balance model
  - Factor results into site-wide model for flow control sizing


Chicago Center for Green Technology

* Same as 2013 permit guidelines

Detention Cisterns

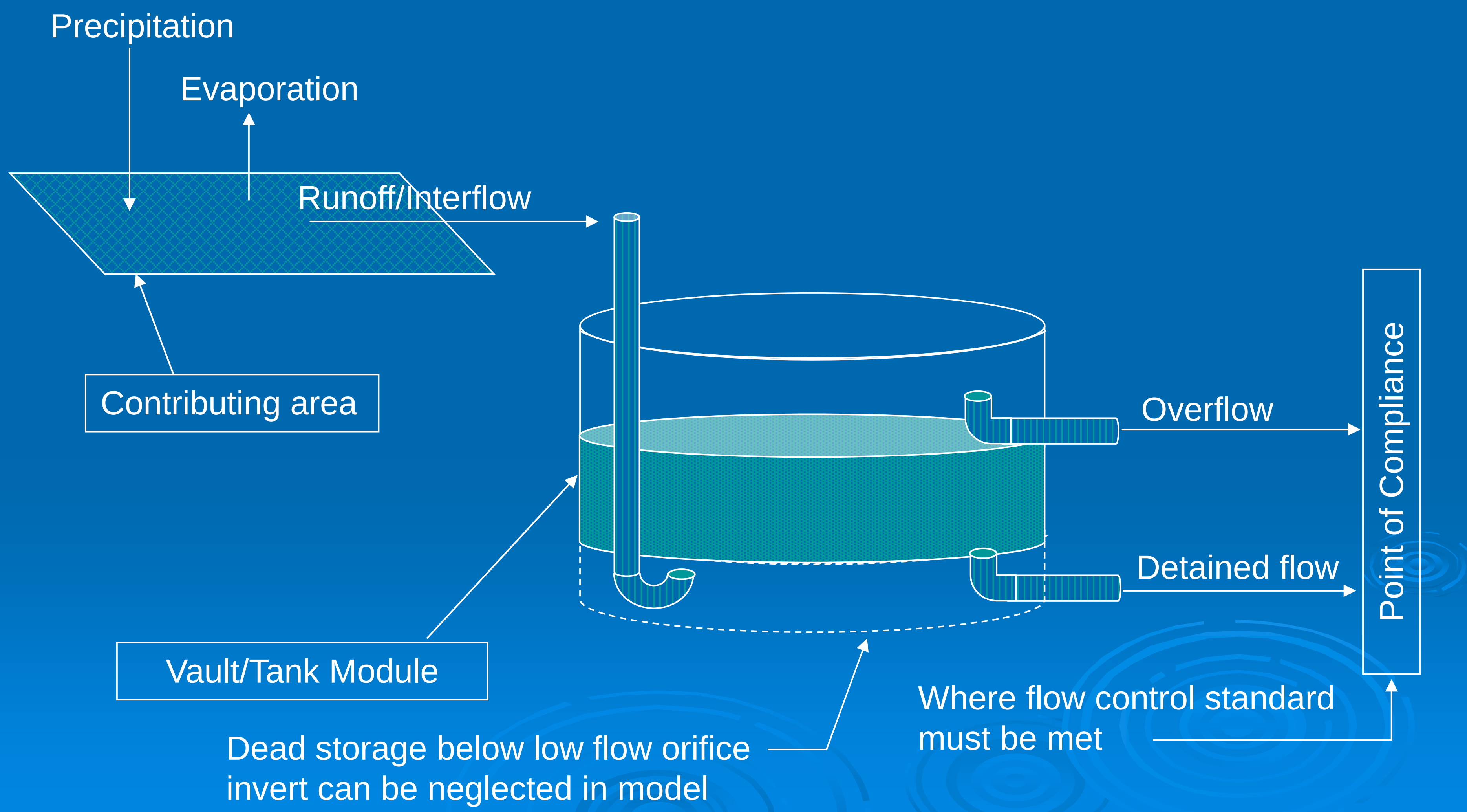
Model Representation



* Can add faucet for rainwater reuse upstream of low flow orifice

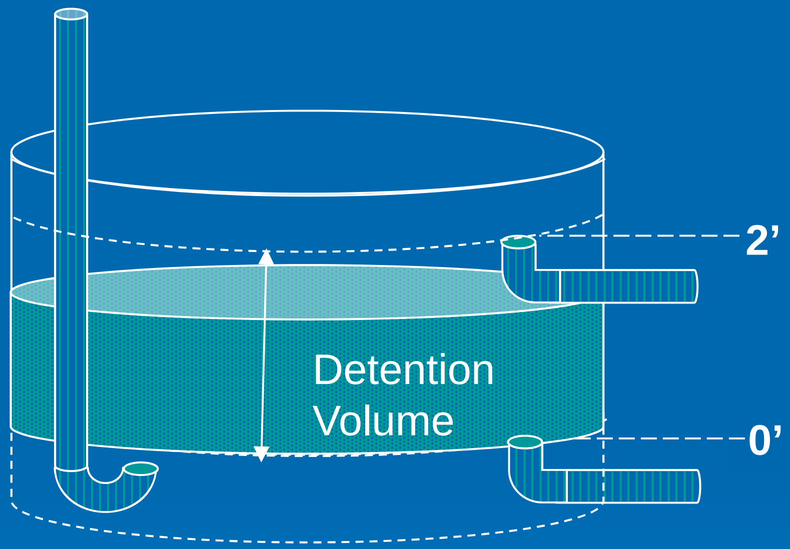
Detention Cisterns

Model Representation



Detention Cisterns

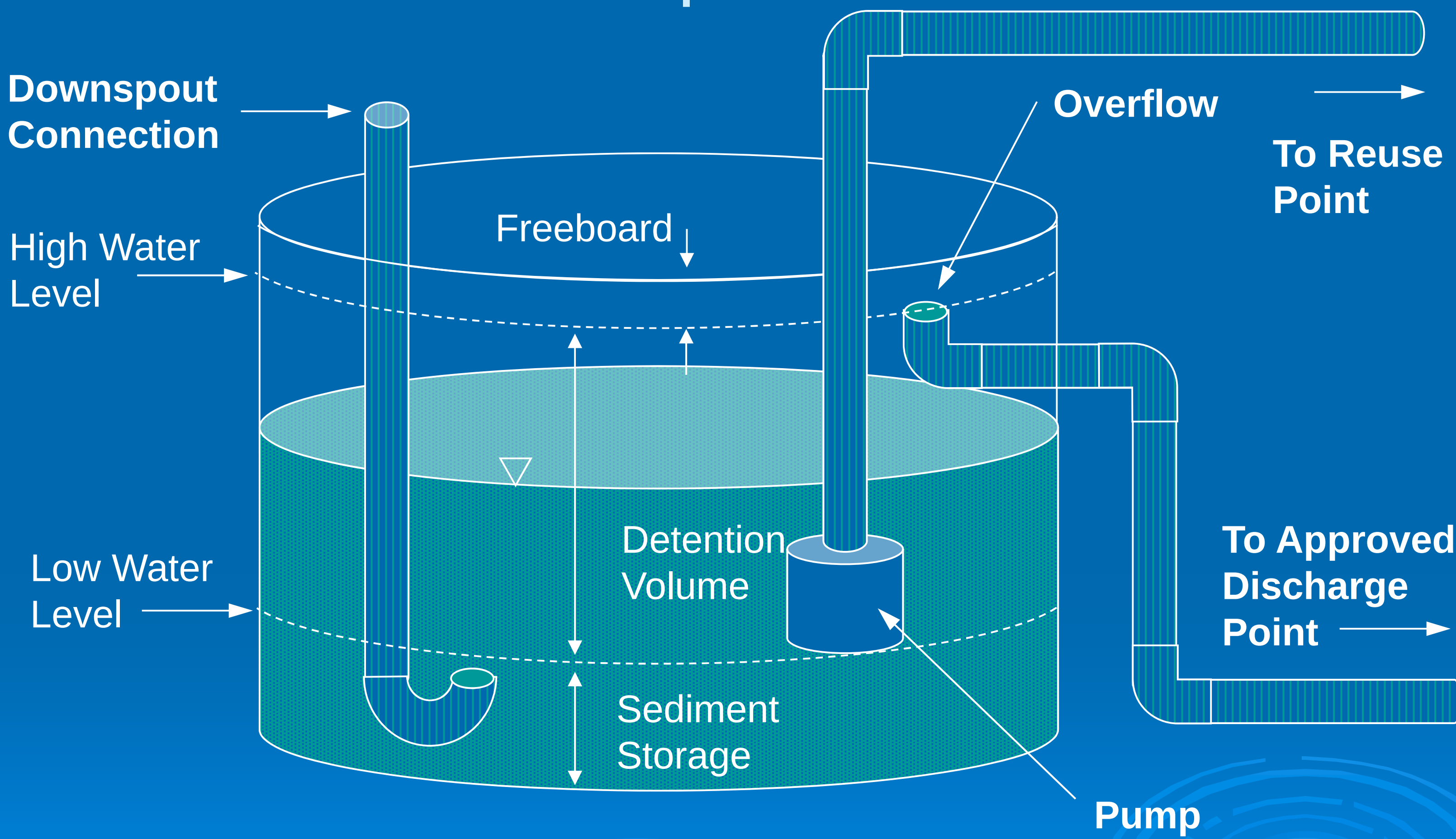
Routing



Stage (ft)	Area (sf)	Storage (cf)	Low Flow (cfs)	Overflow (cfs)
0.00	0	0	0	0
0.25	28	7	0.0008	0
0.50	28	14	0.0012	0
0.75	28	21	0.0014	0
1.00	28	28	0.0016	0
1.25	28	35	0.0018	0
1.50	28	42	0.0020	0
1.75	28	49	0.0022	0
2.00	28	56	0.0024	0
2.25	28	63	0.0026	0.4
2.50	28	70	0.0028	1.15

Harvesting Cisterns

Model Representation



* Can add faucet for rainwater reuse and/or low flow orifice

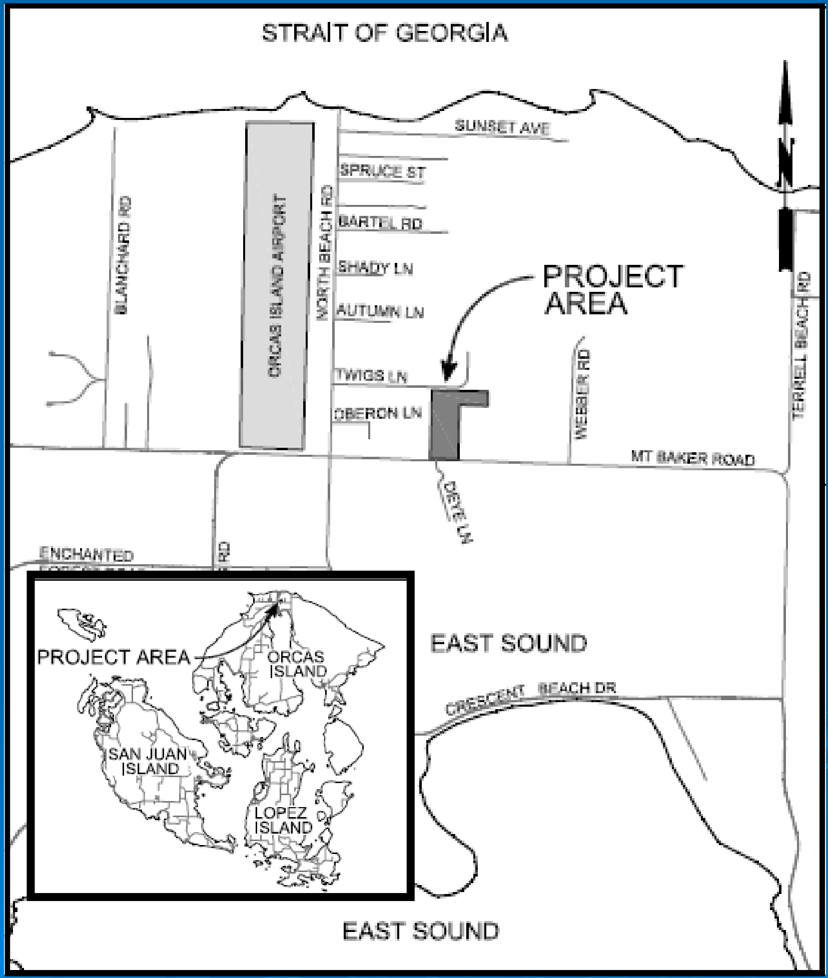
Harvesting Cistern Example
Water Reuse/ Flow Control

OPAL Community Land Trust, Orcas Island

Flow Control

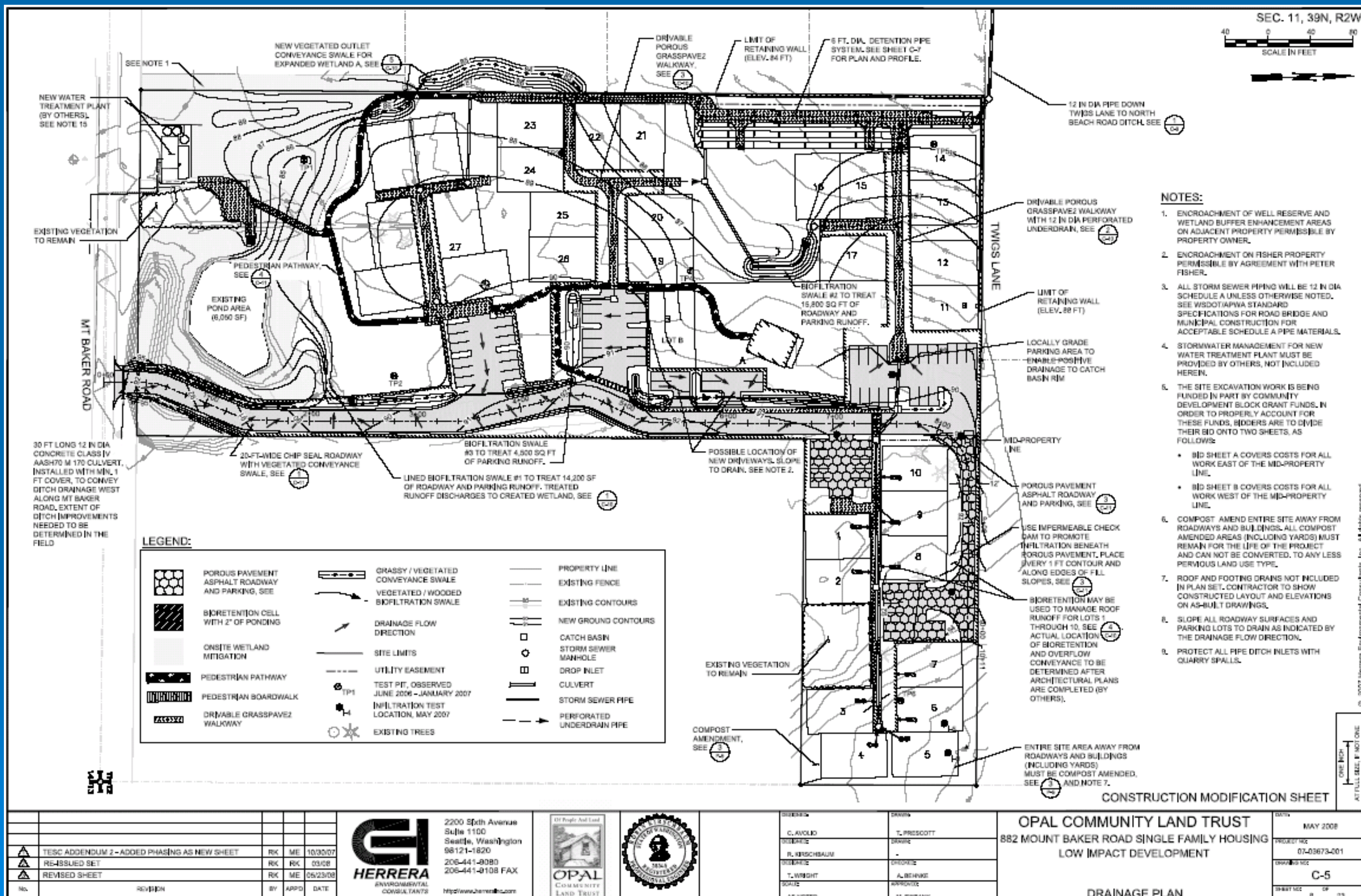
OPAL - Site Location

- Eastsound, WA (Orcas Island)
- 7-acre site, 34 new homes, average roof size = 995 sq. ft.
- 3,000 gallon underground cisterns with indoor reuse
- Daily water balance model in EXCEL
- Size residual detention and WQ for remainder of site (e.g., roadways, driveways, lawns) → 2005 DOE



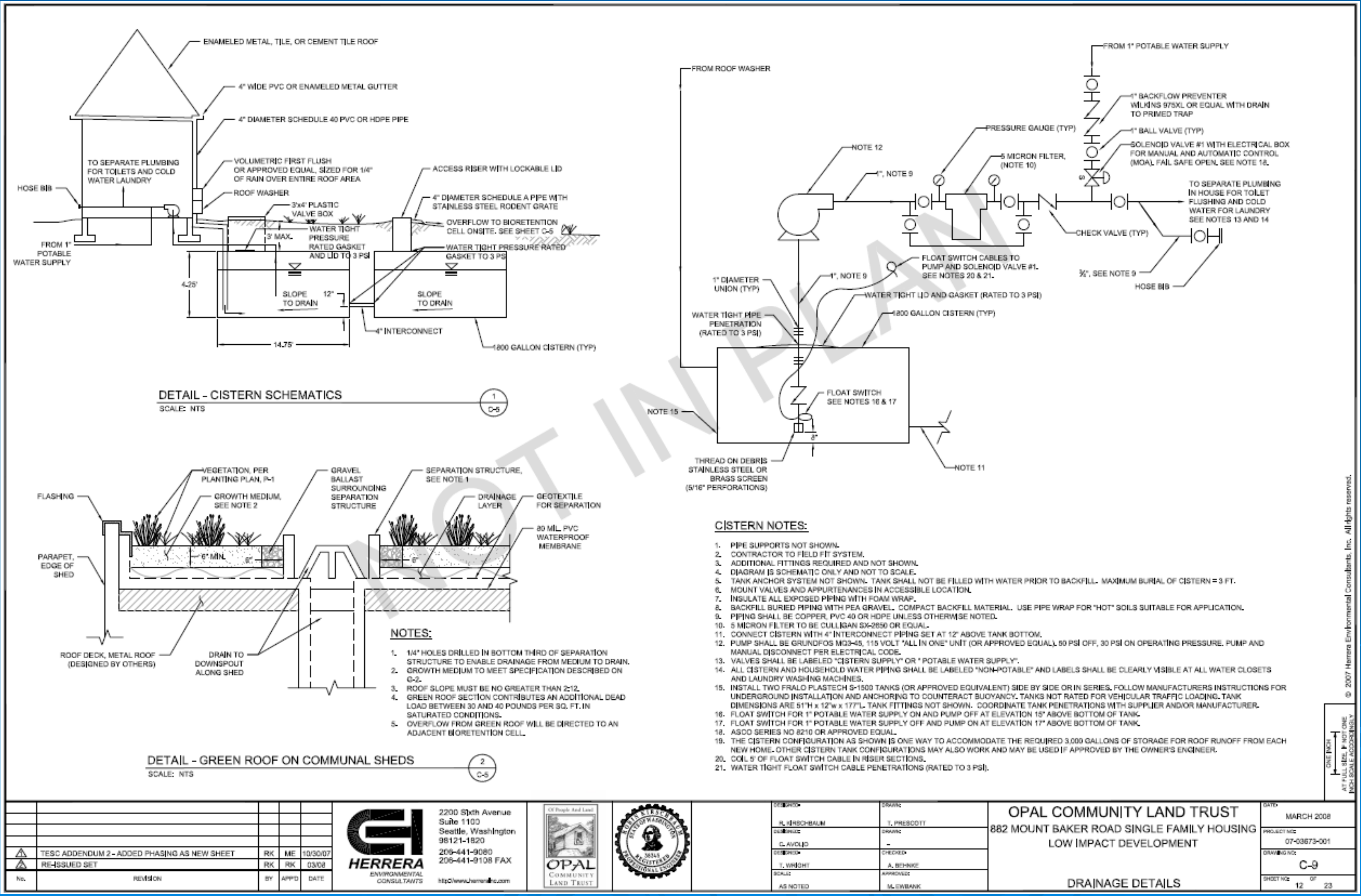
Flow Control

OPAL - Site Plan



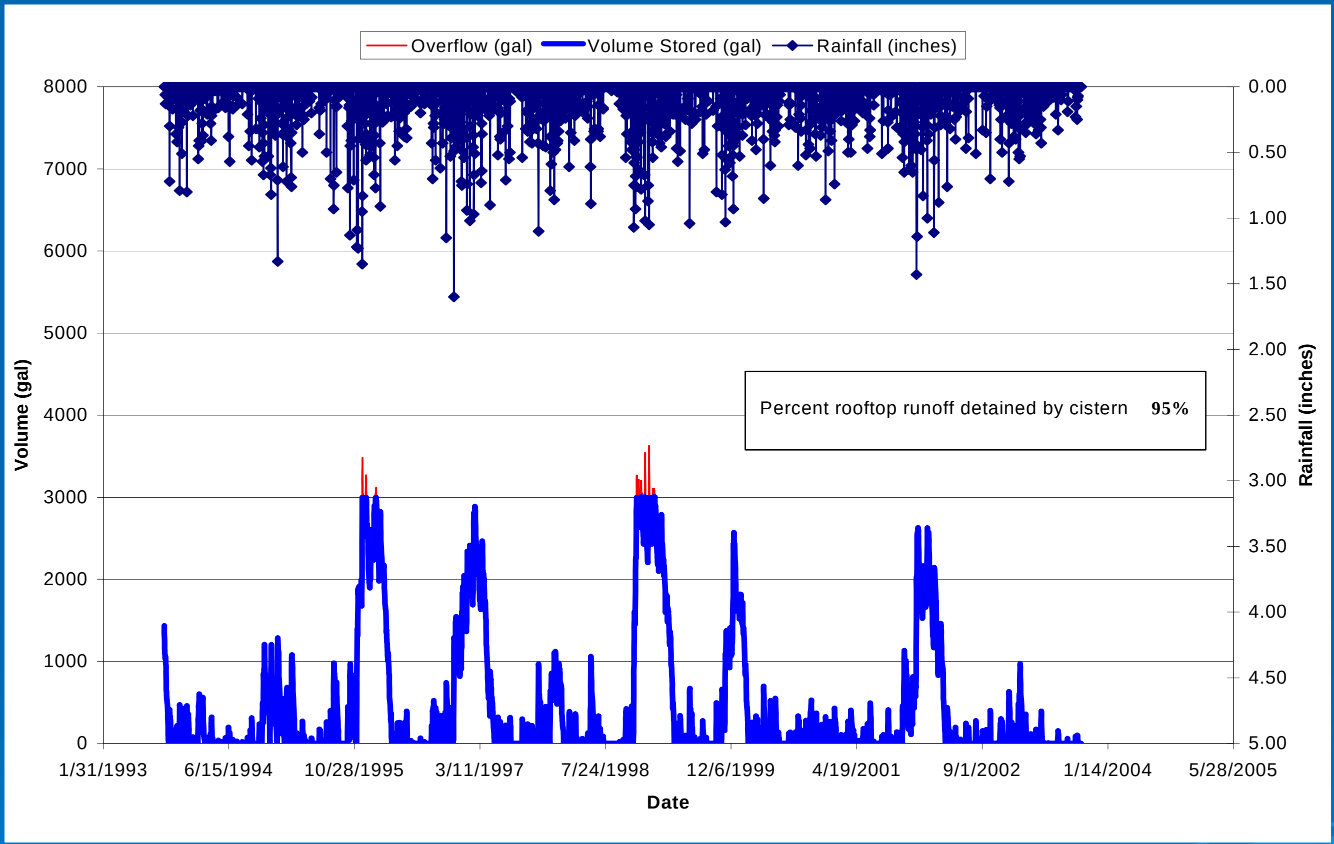
Flow Control

OPAL – Design of Cisterns for Reuse



Flow Control

OPAL – Evaluation of Cisterns for Reuse

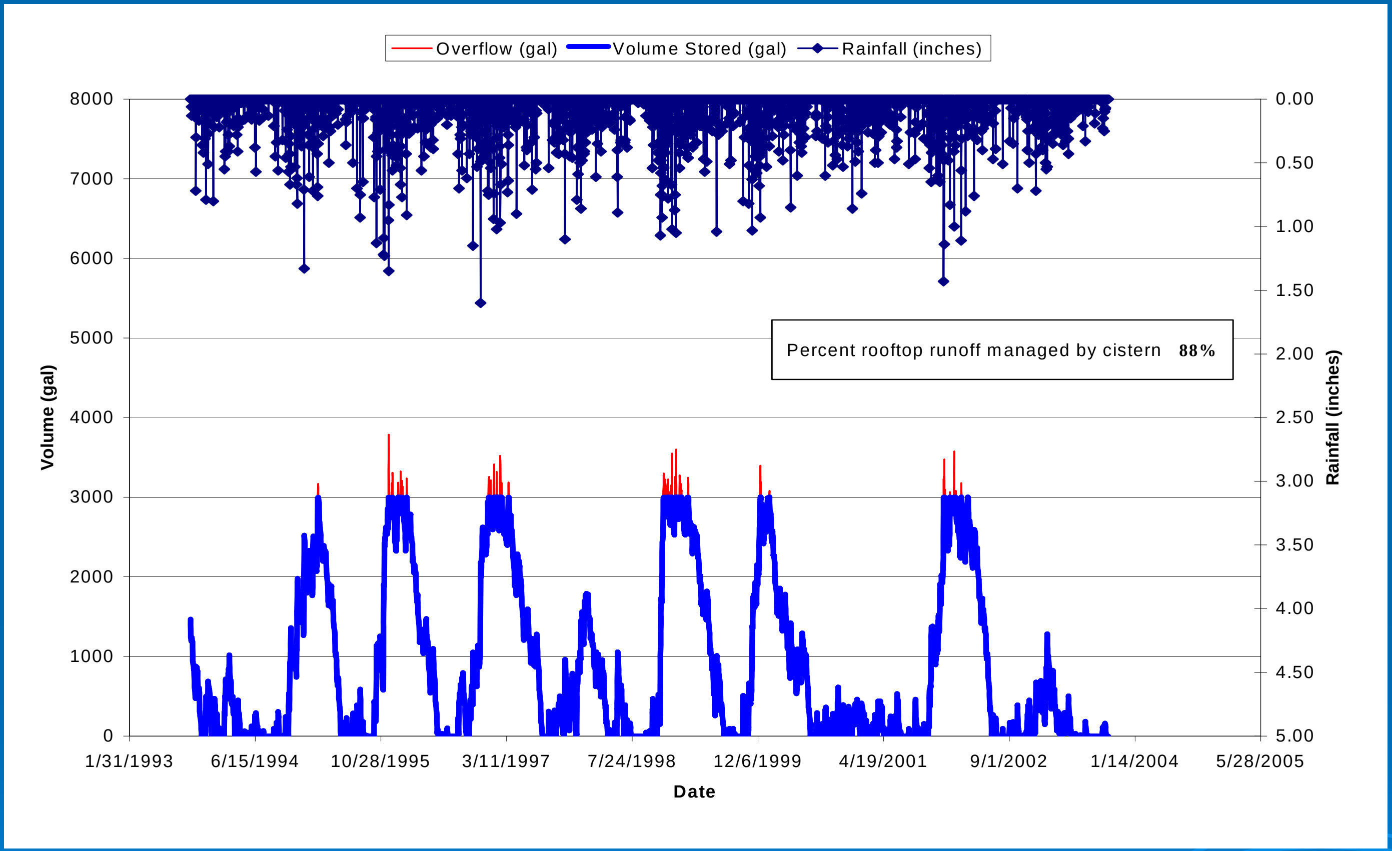


Notes:

1. **Large home (1,050 sq. ft. roof)**
2. **Assume 4 people per house**
3. **Assume (2) 1,500-gal underground cisterns with indoor plumbing for toilet flushing, cold water for laundry, and irrigation**
4. **Total daily water demand for reuse assumed to be 90 gal/day**
5. **Using daily rainfall data from OLGA station (Orcas Island)**

Flow Control

OPAL – Evaluation of Cisterns for Reuse

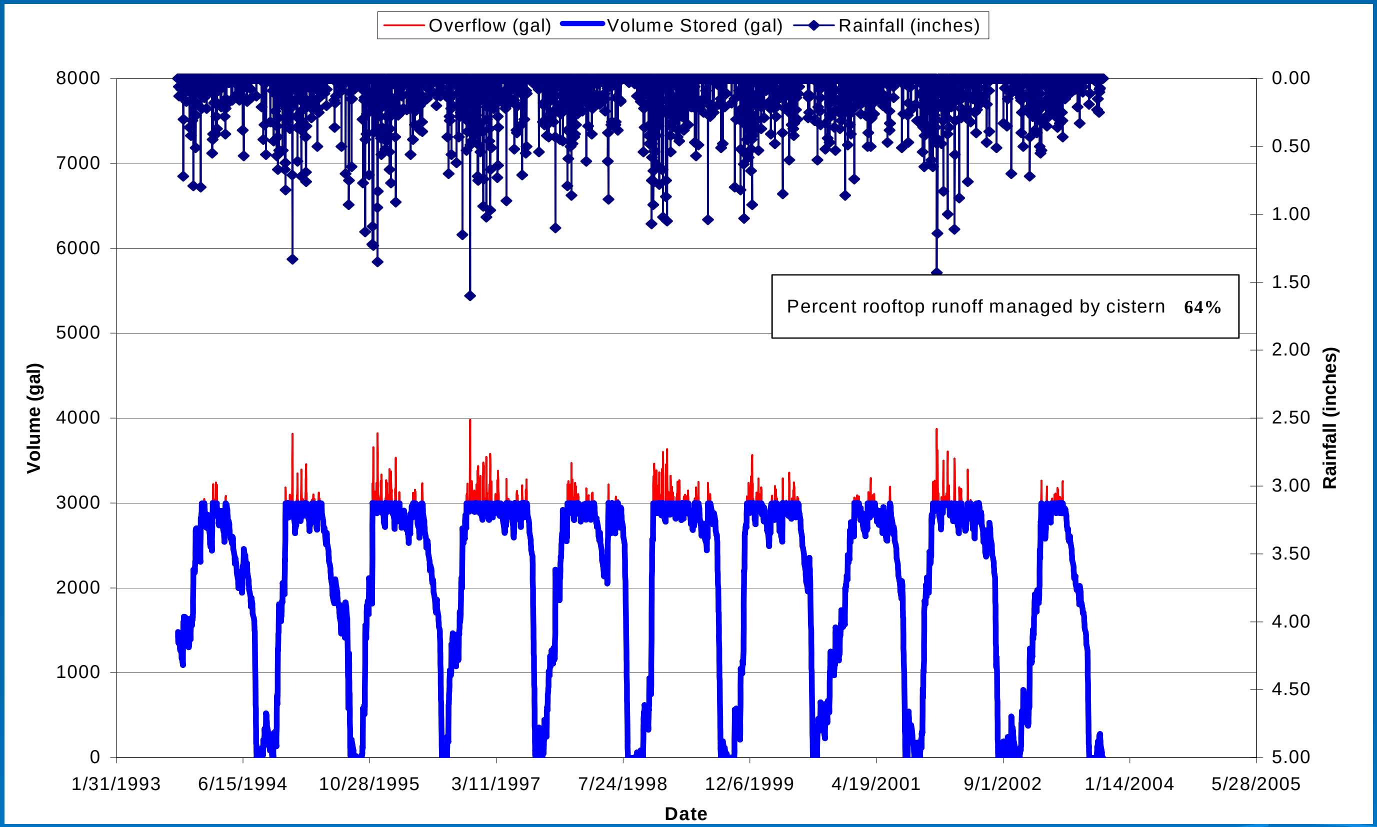


Notes:

1. **Average home size (995 sq. ft. roof)**
2. **Assume 4 people per house**
3. **Assume (2) 1,500-gal underground cisterns with indoor plumbing for toilet flushing, cold water for laundry, and irrigation**
4. **Total daily water demand for reuse assumed to be 58 gal/day**
5. **Using daily rainfall data from OLGA station (Orcas Island)**

Flow Control

OPAL – Evaluation of Cisterns for Reuse

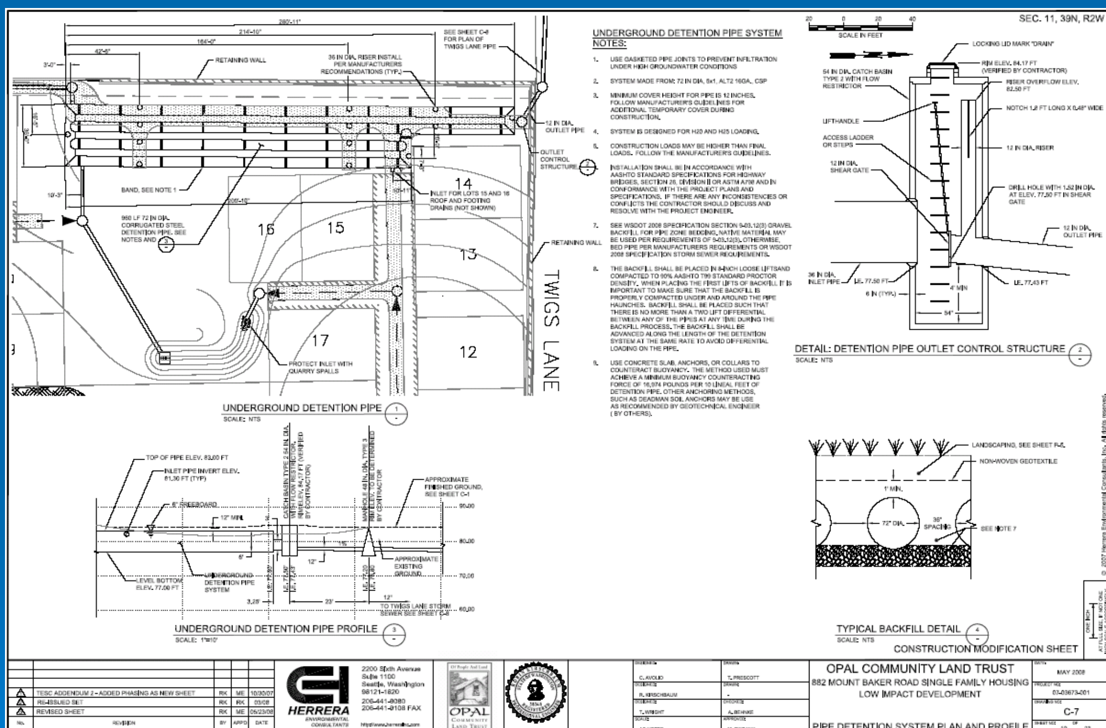


Notes:

1. **Average home size (995 sq. ft. roof)**
2. **Assume 2 people per house**
3. **Assume (2) 1,500-gal underground cisterns with indoor plumbing for toilet flushing, cold water for laundry, and irrigation**
4. **Total daily water demand for reuse assumed to be 29 gal/day**
5. **Using daily rainfall data from OLGA station (Orcas Island)**

Flow Control

OPAL – Residual Flow Control and WQ Treatment



- Modeling Approach
  - Continuous hydrologic model
  - Larger sites → can lump total roof area and route through equivalent lumped cistern
  - Smaller sites → can explicitly model individual cistern performance within site-wide model

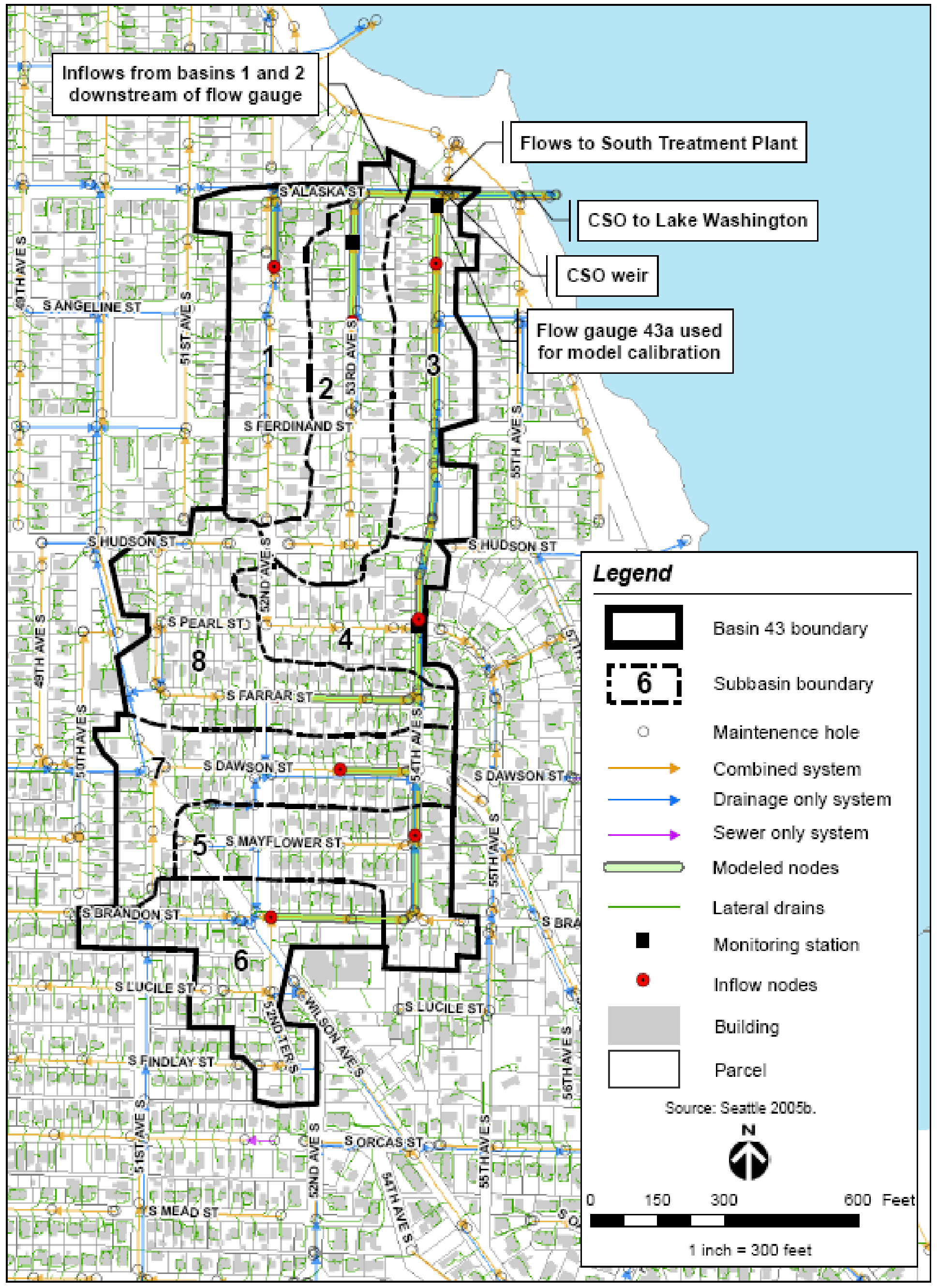
Detention Cistern Example

Peak Reduction/ Flow Control

Lakewood RainCatchers, Seattle

Peak Reduction

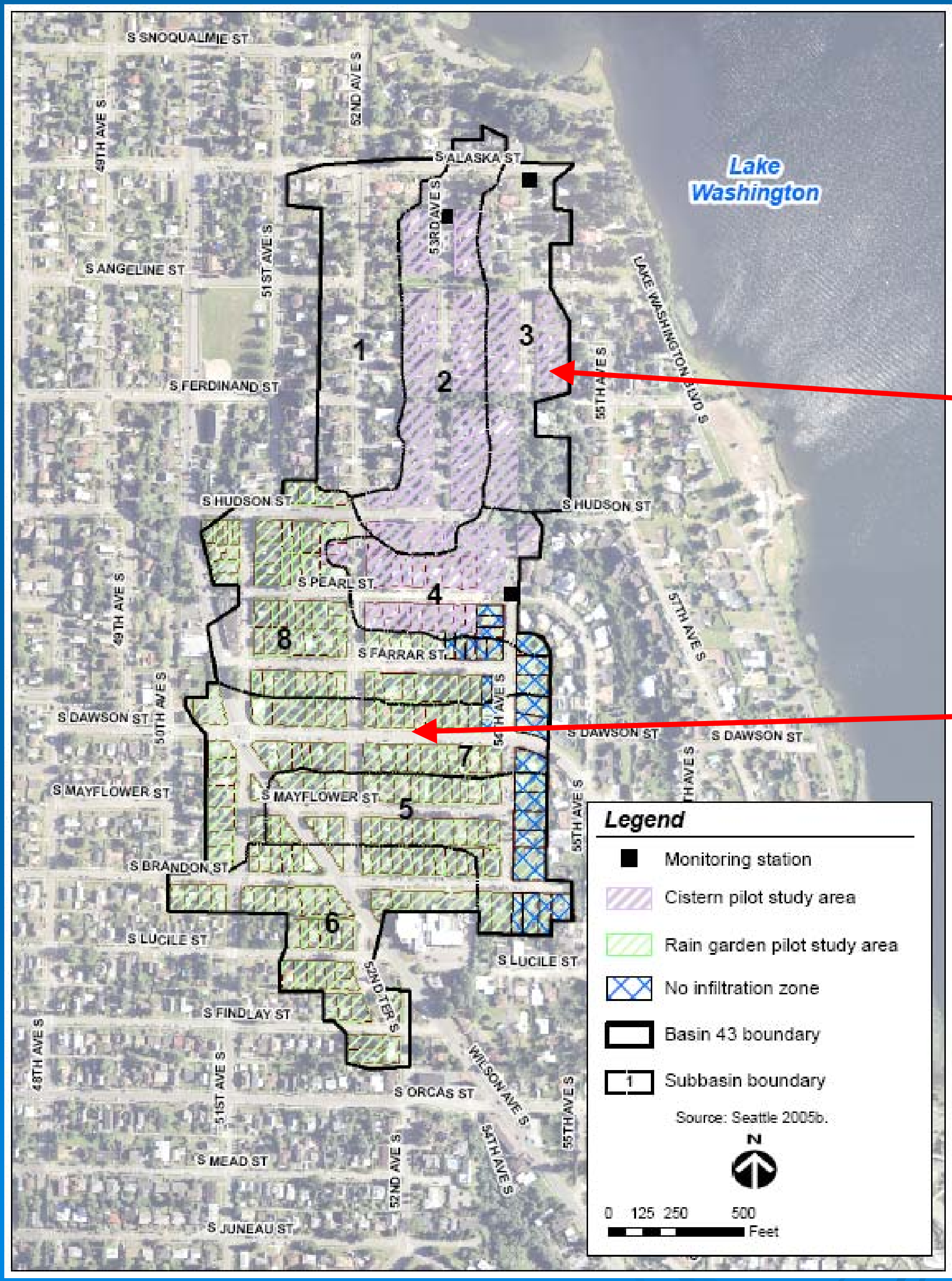
- Lakewood RainCatchers Project
- SPU pilot project to reduce CSOs
- 75-acre residential neighborhood
- 300 homes
- BMPs
  - Cisterns
  - Rain gardens



Peak Reduction

- Partially combined system
  - Roofs to combined
  - Streets to separated
- Combined system modeled in InfoWorks CS

Peak Reduction



Cistern areas

Rain garden areas

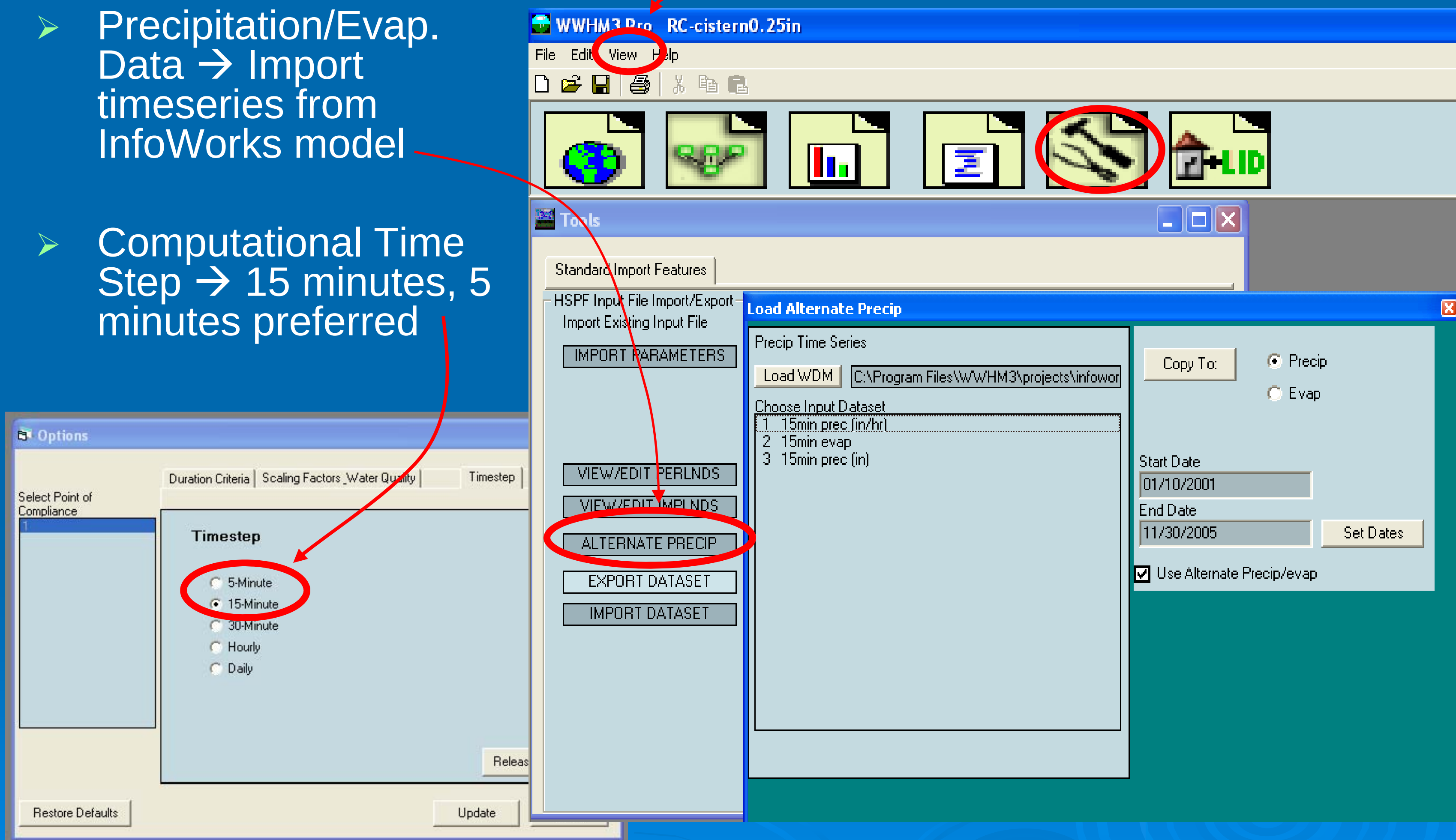
Peak Reduction

- Cistern modeling method
  - Typical rooftop / cistern scenario for individual home modeled in WWHM3
    - Half roof (870 sf) routed to cistern (500 gallon)
  - Detained runoff timeseries exported and multiplied by the number of homes in the basin
  - Imported into InfoWorks CS to evaluate performance

Peak Reduction

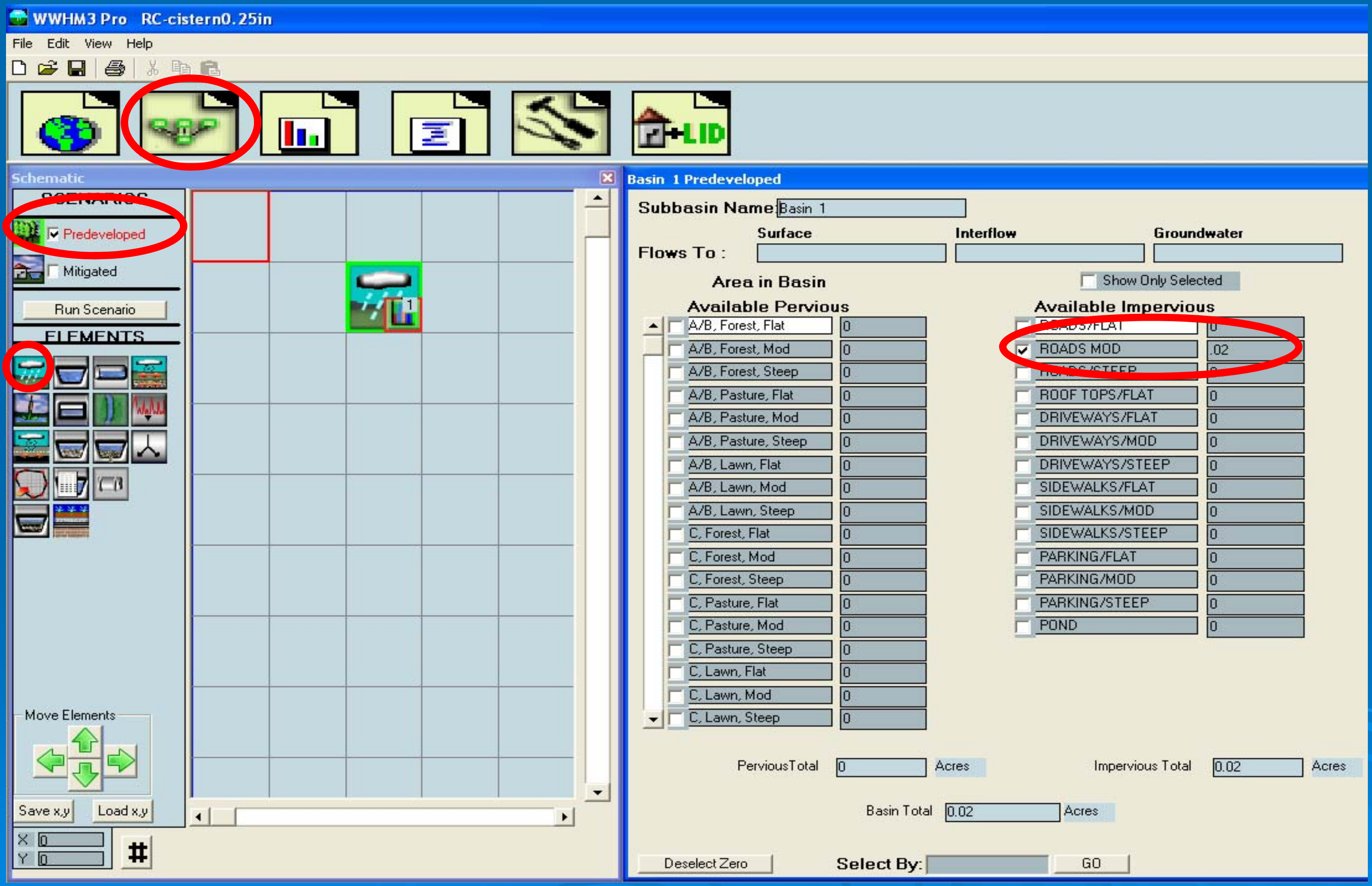
- Precipitation/Evap. Data → Import timeseries from InfoWorks model
- Computational Time Step → 15 minutes, 5 minutes preferred

Option Menu



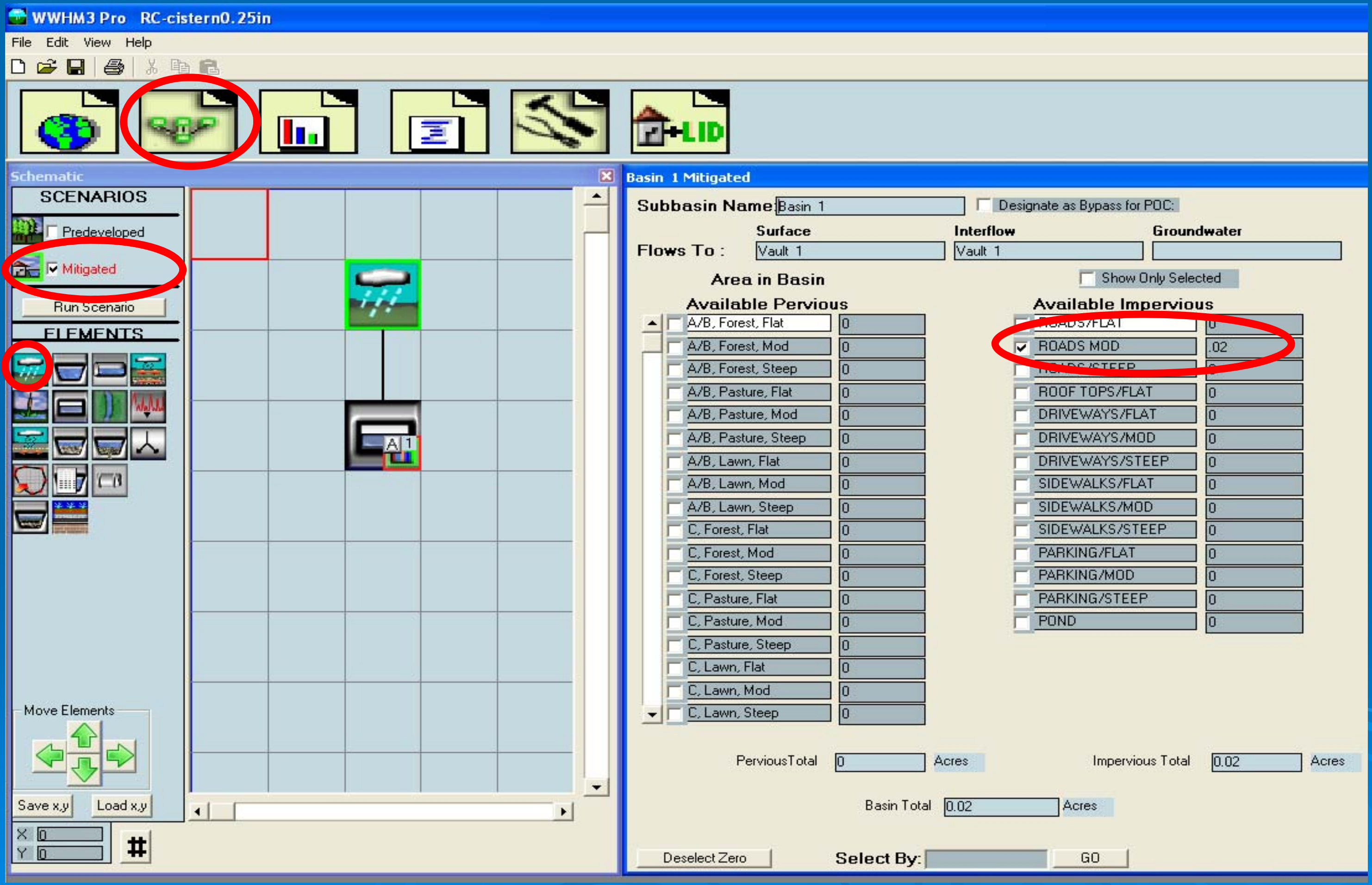
Peak Reduction

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



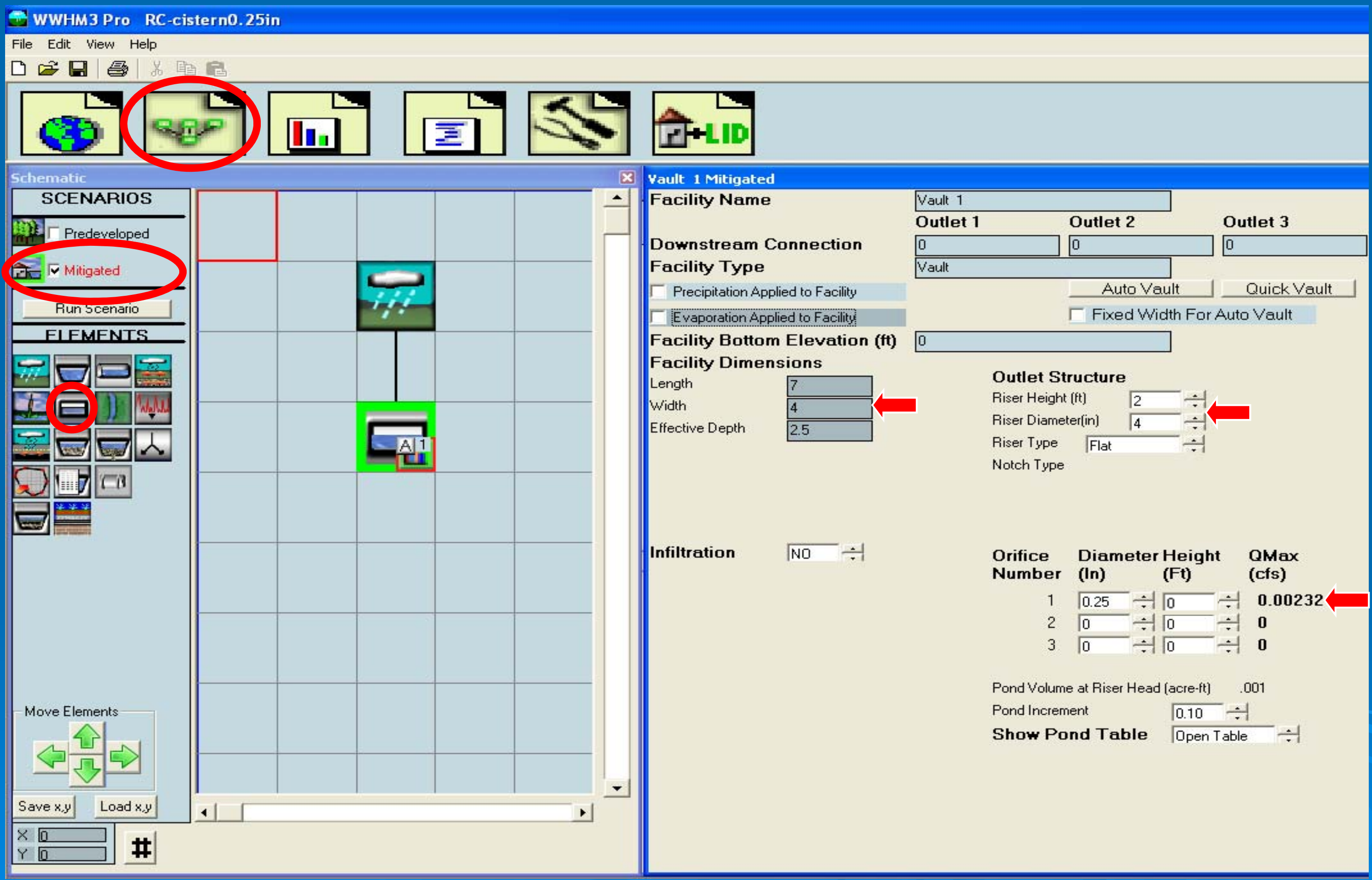
Peak Reduction

Developed Mitigated Basin → Impervious with same area and slope….



Peak Reduction

Developed Mitigated Basin Continued: Route to vault module



Peak Reduction

Stage Storage Discharge Table

Vault 1

Stage (ft)	Area (acres)	Storage (acre-ft)	Dschrge (cfs)
0.000000	0.000643	0.000000	0.000000
0.027778	0.000643	0.000018	0.000000
0.055556	0.000643	0.000036	0.000000
0.083333	0.000643	0.000054	0.000000
0.111111	0.000643	0.000071	0.000000
0.138889	0.000643	0.000089	0.000000
0.166667	0.000643	0.000107	0.000000
0.194444	0.000643	0.000125	0.000000
0.222222	0.000643	0.000143	0.000000
0.250000	0.000643	0.000161	0.000000
0.277778	0.000643	0.000179	0.000000
0.305556	0.000643	0.000196	0.000000
0.333333	0.000643	0.000214	0.000000
0.361111	0.000643	0.000232	0.000000
0.388889	0.000643	0.000250	0.000000
0.416667	0.000643	0.000268	0.000000
0.444444	0.000643	0.000286	0.000000
0.472222	0.000643	0.000304	0.000000
0.500000	0.000643	0.000321	0.000000
0.527778	0.000643	0.000339	0.000274
0.555556	0.000643	0.000357	0.000387
0.583333	0.000643	0.000375	0.000474
0.611111	0.000643	0.000393	0.000547
0.638889	0.000643	0.000411	0.000612
0.666667	0.000643	0.000429	0.000670
0.694444	0.000643	0.000446	0.000724
0.722222	0.000643	0.000464	0.000774
0.750000	0.000643	0.000482	0.000821
0.777778	0.000643	0.000500	0.000865
0.805556	0.000643	0.000518	0.000907
0.833333	0.000643	0.000536	0.000948

Vault 1

Stage (ft)	Area (acres)	Storage (acre-ft)	Dschrge (cfs)
1.694444	0.000643	0.001089	0.001794
1.722222	0.000643	0.001107	0.001815
1.750000	0.000643	0.001125	0.001835
1.777778	0.000643	0.001143	0.001856
1.805556	0.000643	0.001161	0.001876
1.833333	0.000643	0.001178	0.001895
1.861111	0.000643	0.001196	0.001915
1.888889	0.000643	0.001214	0.001935
1.916667	0.000643	0.001232	0.001954
1.944444	0.000643	0.001250	0.001973
1.972222	0.000643	0.001268	0.001992
2.000000	0.000643	0.001286	0.002010
2.027778	0.000643	0.001303	0.017058
2.055556	0.000643	0.001321	0.044557
2.083333	0.000643	0.001339	0.080160
2.111111	0.000643	0.001357	0.122318
2.138889	0.000643	0.001375	0.170134
2.166667	0.000643	0.001393	0.223004
2.194444	0.000643	0.001411	0.280484
2.222222	0.000643	0.001428	0.342229
2.250000	0.000643	0.001446	0.407963
2.277778	0.000643	0.001464	0.477458
2.305556	0.000643	0.001482	0.550518
2.333333	0.000643	0.001500	0.626980
2.361111	0.000643	0.001518	0.706696
2.388889	0.000643	0.001536	0.789540
2.416667	0.000643	0.001553	0.875397
2.444444	0.000643	0.001571	0.964165
2.472222	0.000643	0.001589	1.055752
2.500000	0.000643	0.001607	1.150074

Overflow

Peak Reduction

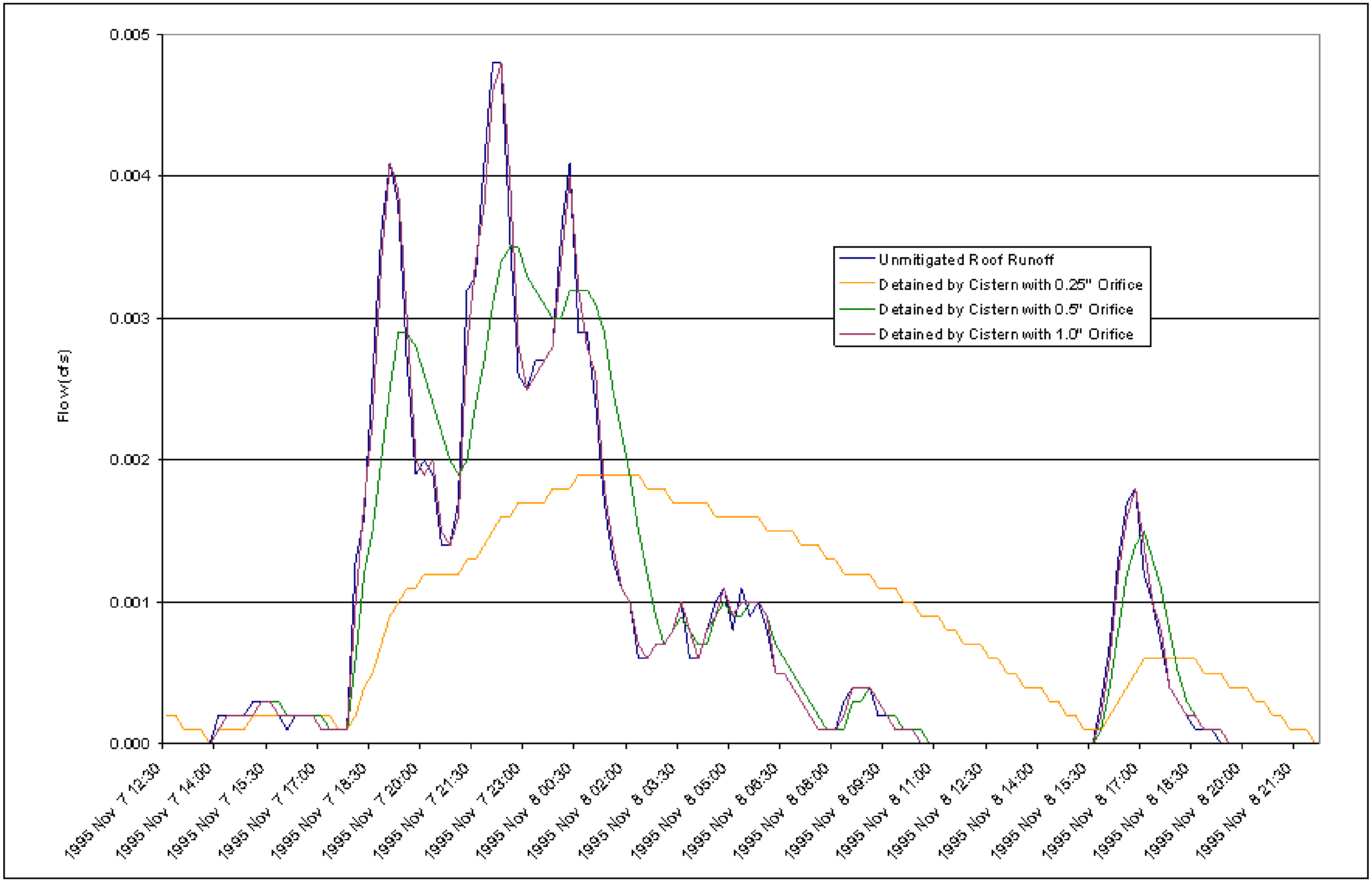
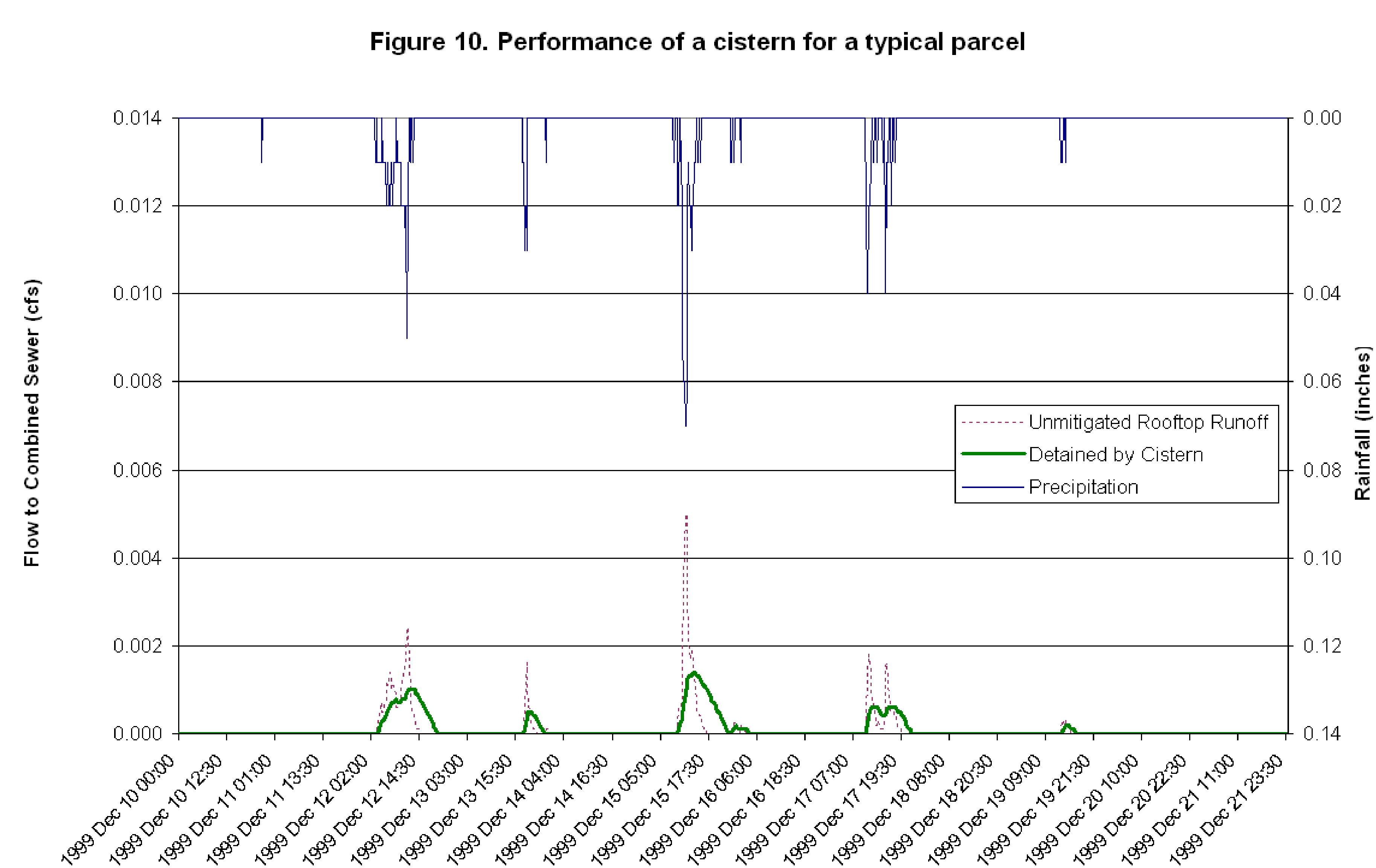


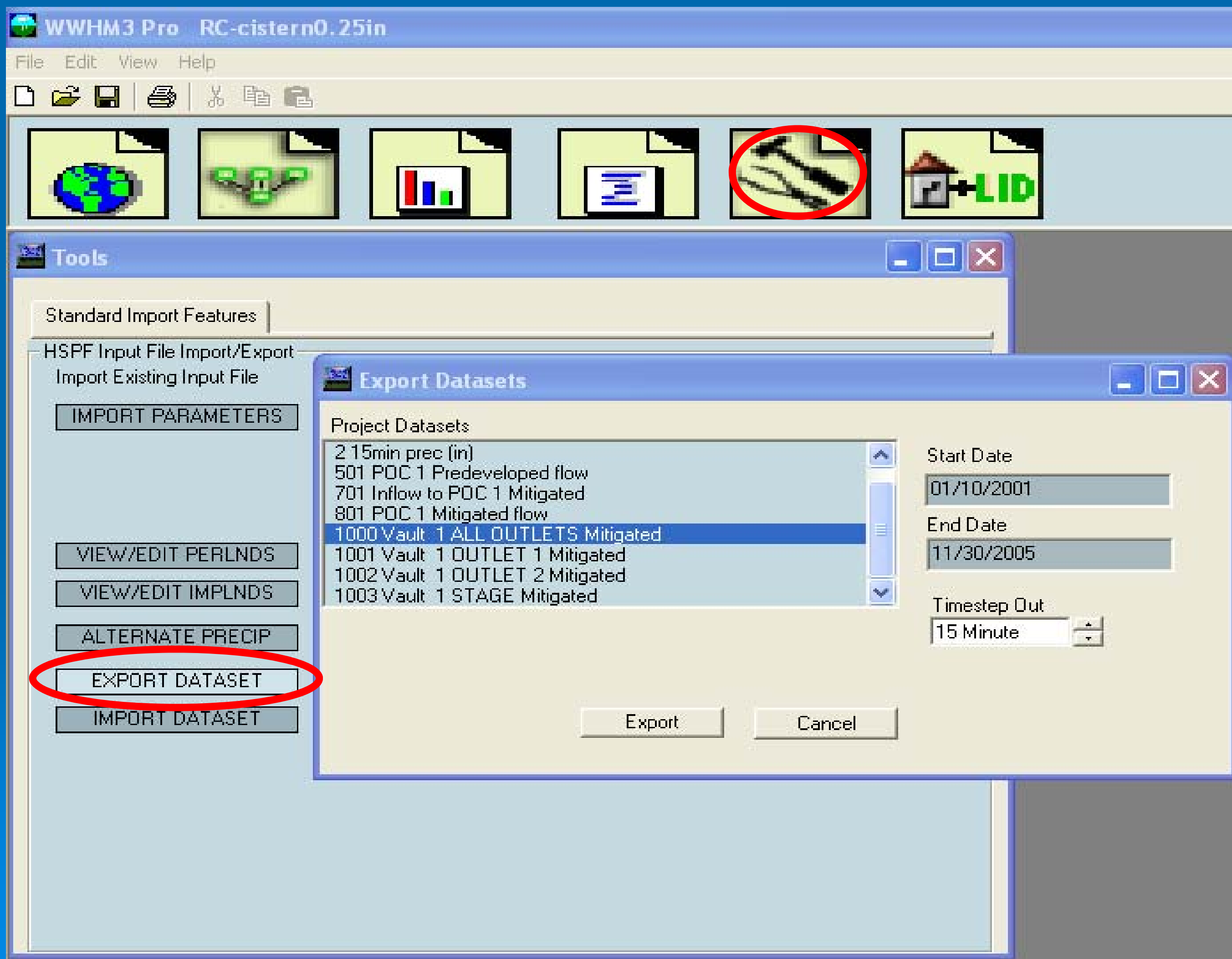
Figure 17. Comparison of roof runoff detention benefits for cisterns with varying orifice sizes.

Peak Reduction



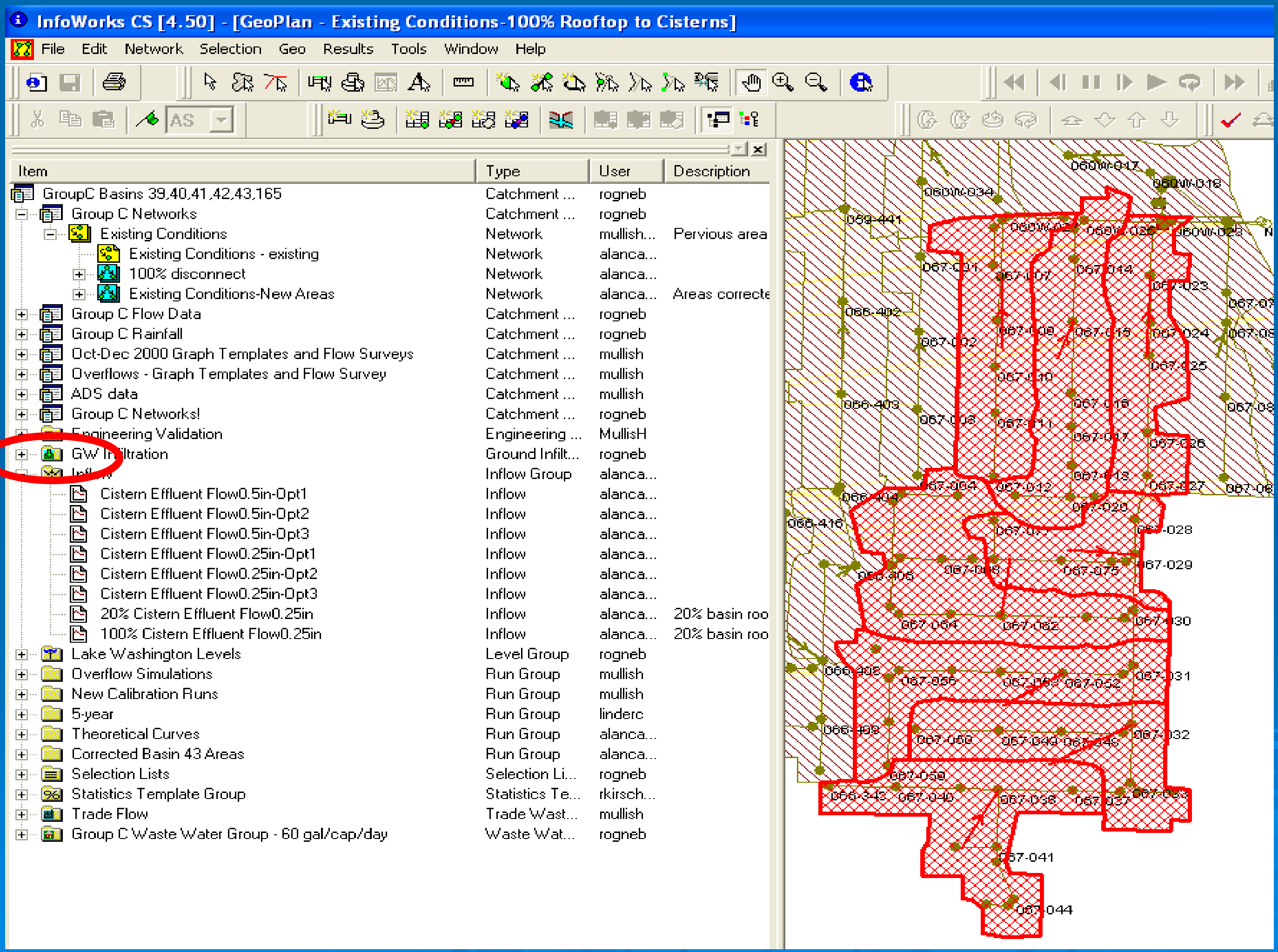
Peak Reduction

Time Series Export



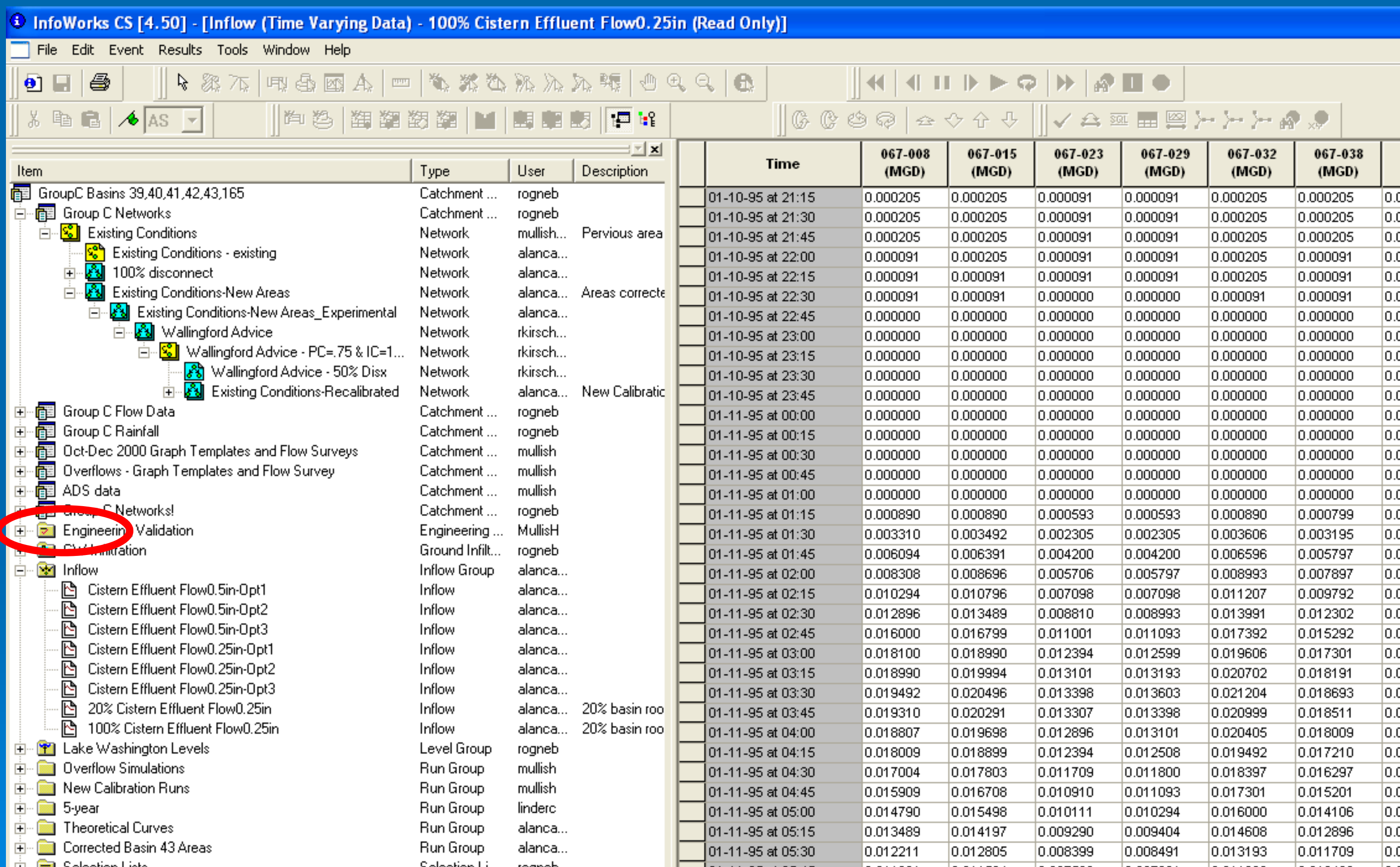
Peak Reduction

Time Series Import to InfoWorks



Peak Reduction

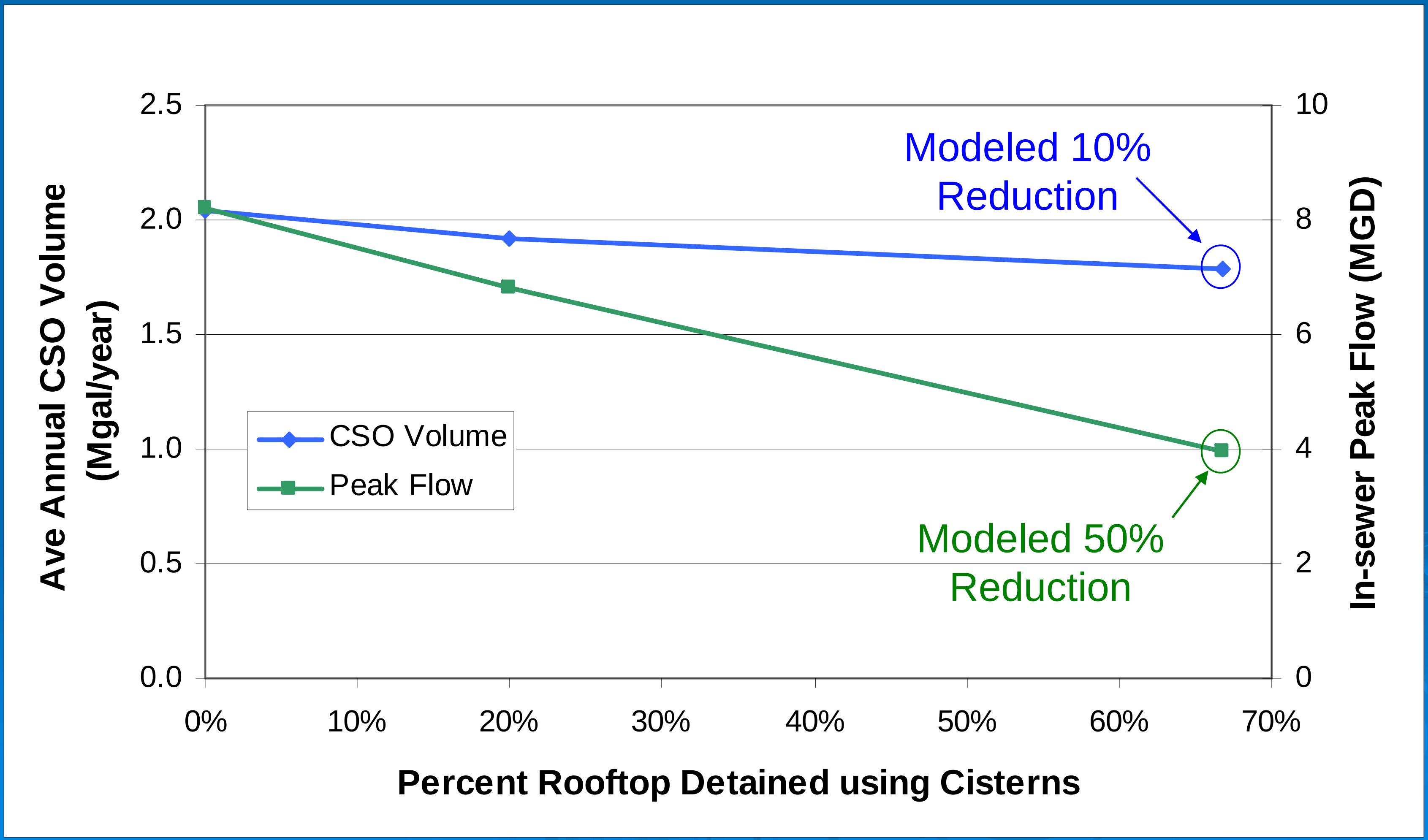
Time Series Import to InfoWorks



Time	067-008 (MGD)	067-015 (MGD)	067-023 (MGD)	067-029 (MGD)	067-032 (MGD)	067-038 (MGD)	0
01-10-95 at 21:15	0.000205	0.000205	0.000091	0.000091	0.000205	0.000205	0.00
01-10-95 at 21:30	0.000205	0.000205	0.000091	0.000091	0.000205	0.000205	0.00
01-10-95 at 21:45	0.000205	0.000205	0.000091	0.000091	0.000205	0.000205	0.00
01-10-95 at 22:00	0.000091	0.000205	0.000091	0.000091	0.000205	0.000091	0.00
01-10-95 at 22:15	0.000091	0.000091	0.000091	0.000091	0.000205	0.000091	0.00
01-10-95 at 22:30	0.000091	0.000091	0.000000	0.000000	0.000091	0.000091	0.00
01-10-95 at 22:45	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-10-95 at 23:00	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-10-95 at 23:15	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-10-95 at 23:30	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-10-95 at 23:45	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 00:00	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 00:15	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 00:30	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 00:45	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 01:00	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00
01-11-95 at 01:15	0.000890	0.000890	0.000593	0.000593	0.000890	0.000799	0.00
01-11-95 at 01:30	0.003310	0.003492	0.002305	0.002305	0.003606	0.003195	0.00
01-11-95 at 01:45	0.006094	0.006391	0.004200	0.004200	0.006596	0.005797	0.00
01-11-95 at 02:00	0.008308	0.008696	0.005706	0.005797	0.008993	0.007897	0.00
01-11-95 at 02:15	0.010294	0.010796	0.007098	0.007098	0.011207	0.009792	0.01
01-11-95 at 02:30	0.012896	0.013489	0.008810	0.008993	0.013991	0.012302	0.01
01-11-95 at 02:45	0.016000	0.016799	0.011001	0.011093	0.017392	0.015292	0.01
01-11-95 at 03:00	0.018100	0.018990	0.012394	0.012599	0.019606	0.017301	0.01
01-11-95 at 03:15	0.018990	0.019994	0.013101	0.013193	0.020702	0.018191	0.02
01-11-95 at 03:30	0.019492	0.020496	0.013398	0.013603	0.021204	0.018693	0.02
01-11-95 at 03:45	0.019310	0.020291	0.013307	0.013398	0.020999	0.018511	0.02
01-11-95 at 04:00	0.018807	0.019698	0.012896	0.013101	0.020405	0.018009	0.02
01-11-95 at 04:15	0.018009	0.018899	0.012394	0.012508	0.019492	0.017210	0.01
01-11-95 at 04:30	0.017004	0.017803	0.011709	0.011800	0.018397	0.016297	0.01
01-11-95 at 04:45	0.015909	0.016708	0.010910	0.011093	0.017301	0.015201	0.01
01-11-95 at 05:00	0.014790	0.015498	0.010111	0.010294	0.016000	0.014106	0.01
01-11-95 at 05:15	0.013489	0.014197	0.009290	0.009404	0.014608	0.012896	0.01
01-11-95 at 05:30	0.012211	0.012805	0.008399	0.008491	0.013193	0.011709	0.01

Peak Reduction

Preliminary Results, Basin-Wide InfoWorks Model



Resources

- LID Technical Guidance Manual
  http://www.pierce.wsu.edu/Water_Quality/LID/LID_manual2005.pdf
  (Draft 2012 Manual does not yet have modeling section developed)

- WWHM
  http://www.clearcreeksolutions.com/

- MGSFlood
  http://www.mgsengr.com/MGSFlood.html

- HSPF
  http://water.usgs.gov/software/HSPF/

- WDMUtils
  http://www.epa.gov/waterscience/basins/b3webdwn.htm

Questions and Answers

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Contact Information

- Alice Lancaster, PE
  alancaster@herrerainc.com

- Robin Kirschbaum, PE, LEED
  robin.kirschbaum@hdrinc.com