SUSTAIN Workshop

SUSTAIN Model Evaluation

A summary of modeling methods, results, lessons learned, and limitations

HERRERA

Mindy Roberts, PE MROB461@ECY.WA.GOV
John Lenth jlenth@herrerainc.com
Alice Lancaster, PE alancaster@herrerainc.com
Meghan Feller mfeller@herrerainc.com
Peter Steinberg

SUSTAIN Model Evaluation

HERRERA

Acknowledgements

- Washington State Department of Ecology
  - Mindy Roberts
  - Ed O'Brien
- US Environmental Protection Agency
  - Dino Marshalonis
- Tetra Tech, Inc.
  - Alvi Khalid
  - Ryan Murphy
  - John Riverson
  - Jenny Zhen
- City of Federal Way
  - William Appleton
  - Fei Tang
- King County
  - Jeff Burkey
  - Curtis DeGasperi

Presentation Outline

- Background
- Modeling Overview
- Existing Conditions
  - SWMM Model Development
  - SUSTAIN Model Development
- Future Conditions
  - Retrofit Scenario Development
  - SUSTAIN Model Optimization
- Results
- Conclusions

Project Background

HERRERA

Project Background

Control of Toxic Chemicals in Puget Sound

- Three phases of research on toxic chemicals in Puget Sound
- Phase 1 and 2 key study findings:

"Surface runoff is the main pathway for the delivery of toxic chemicals to Puget Sound"

Project Background

Control of Toxic Chemicals in Puget Sound

- Phase 3 Study of Toxics in Surface Runoff
  - 16 small (0.3 to 6 mi2) subbasins
  - 8 Snohomish River watershed subbasins
    - 2 x forest, field, other ("forested")
    - 2 x residential
    - 2 x agriculture
    - 2 x commercial/industrial ("commercial")
  - 8 Puyallup River watershed (2 x 4 land covers)
  - 6 storm events, 2 baseflow, continuous flow over 12 months
  - Metals, PCBs, PBDEs, PAHs, herbicides, pesticides, TPH, oil and grease, nutrients, etc.

Project Background

Phase 3 Study of Toxics in Surface Runoff

- Key Study Findings
  - Pollutant levels higher during storms
  - Levels higher from developed lands than from forested lands
  - Commercial lands have highest loading rate
  - Forested lands have highest total load
    - 83% forested watershed

Now What?

- Identify tools to help fix the problem
  - System for Urban Stormwater Treatment and Analysis INtegration Model

What is the cost-effective configuration of BMPs that are needed to reduce pollutant loading and/or runoff?

Project Background

Study Objectives

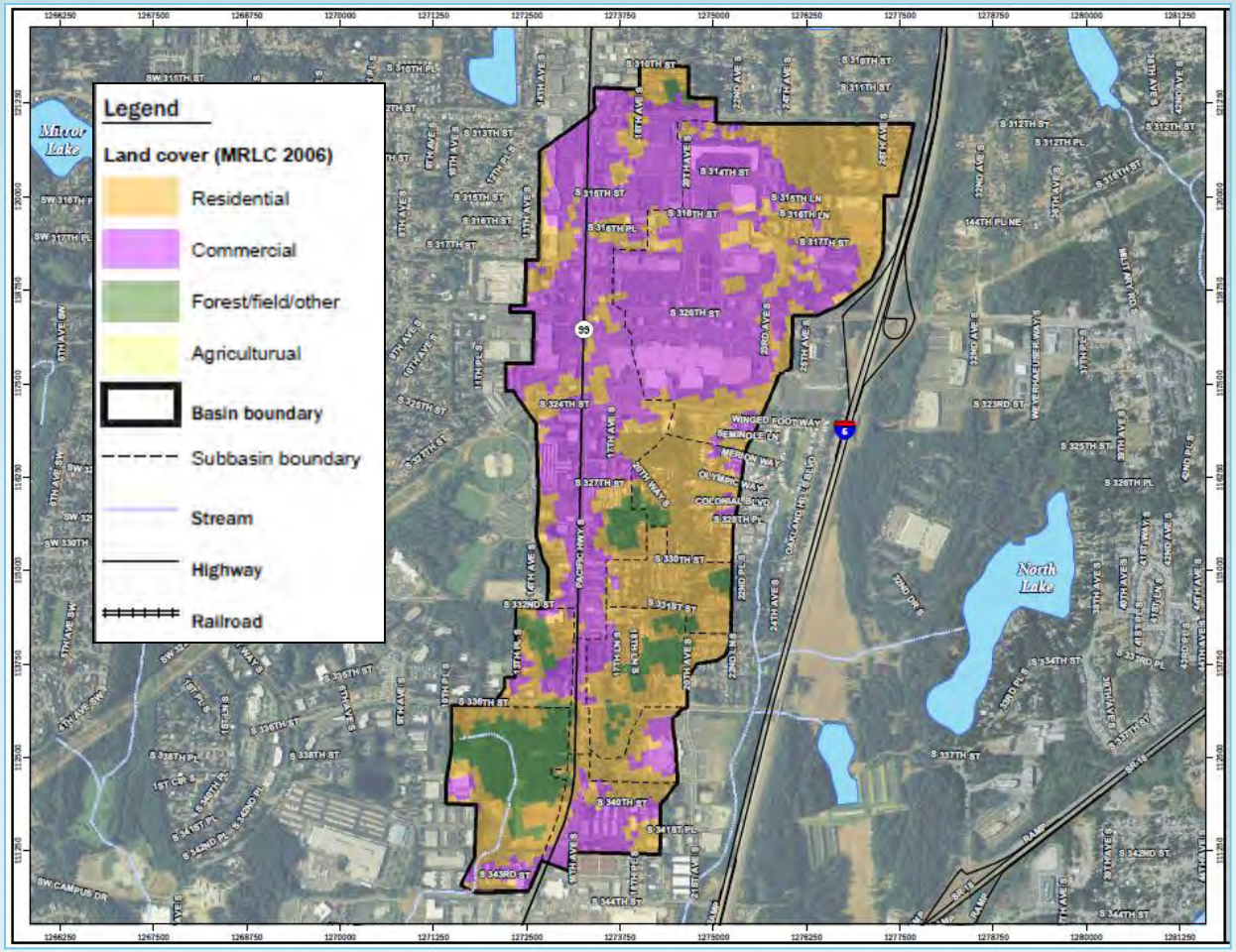
- Develop regional BMP cost database
- Evaluate a real-world SUSTAIN application:
  - Water quality focus
  - Explore capabilities and limitations of model
  - Share “lessons learned”

Modeling Overview

HERRERA

Modeling Overview

Study Basin: CBB from Phase 3 Study



- Highly commercial
- Federal Way
- Puyallup River Watershed
- High quality calibration data

Modeling Overview

Study Water Quality Parameters

- Total suspended solids
- Total and dissolved copper
- Total and dissolved zinc
- Chrysene

Modeling Overview

Study Treatment BMPs

- Two retrofit scenarios
  - Scenario A: publicly-owned ROW +regional facilities
  - Scenario B: publicly-owned ROW +regional facilities + public/private parcels
- Decentralized BMPs
  - Bioretention
  - Permeable Pavement
- Regional / Centralized BMPs
  - Constructed Wetland
  - Wet Pond

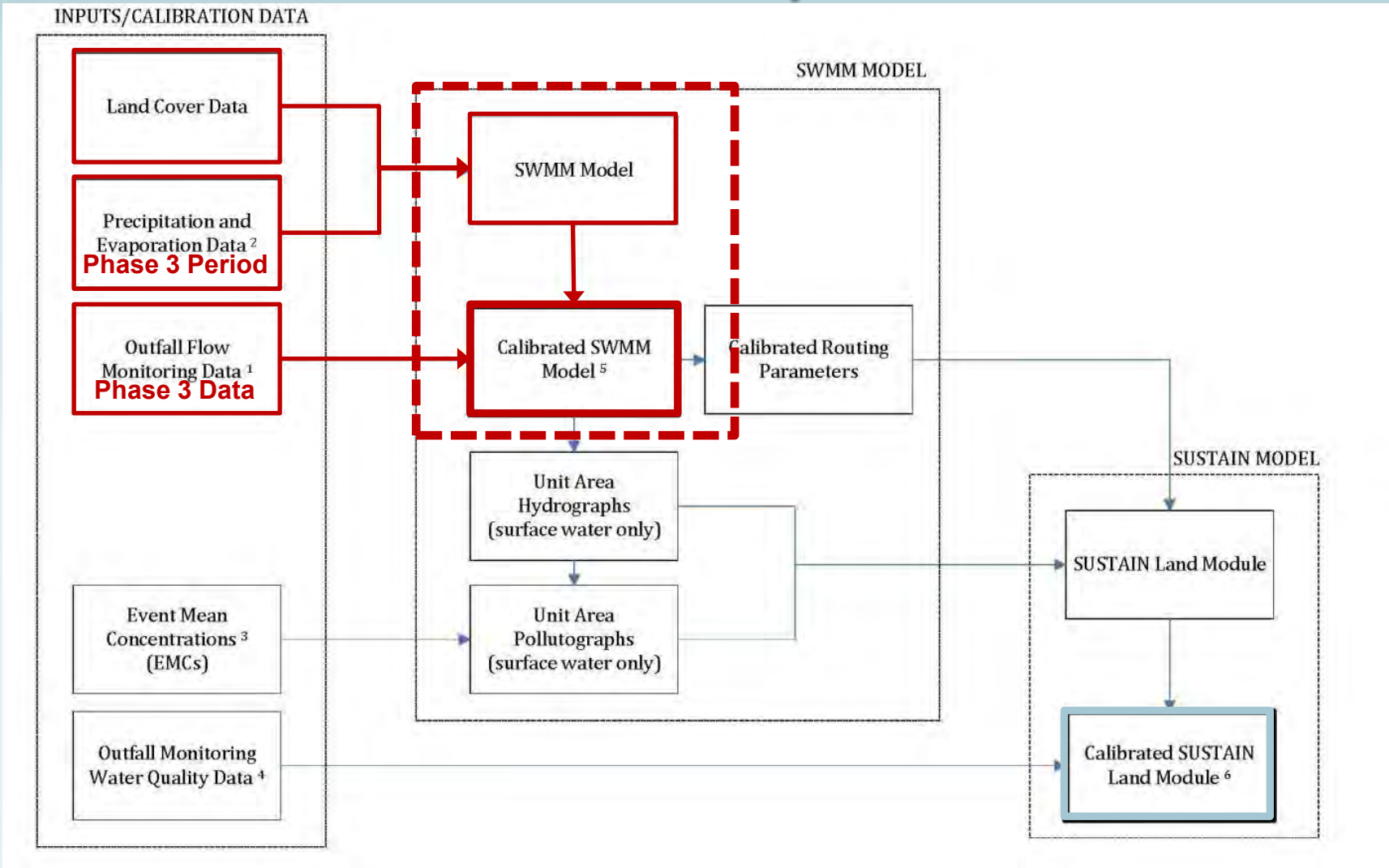
Modeling Overview

Model Approach

- SUSTAIN BMP approach
  - Aggregate for LID: represent multiple BMPs distributed throughout a subcatchment without explicit siting or flow routing
  - Explicit representation for regional BMPs
  - Aggregate requires subcatchment hydrology be simulated externally → SWMM
- General steps
  - Developed/calibrated SWMM model
  - Developed unit area hydrographs and pollutographs using SWMM
  - Imported to SUSTAIN
  - Ran optimization model

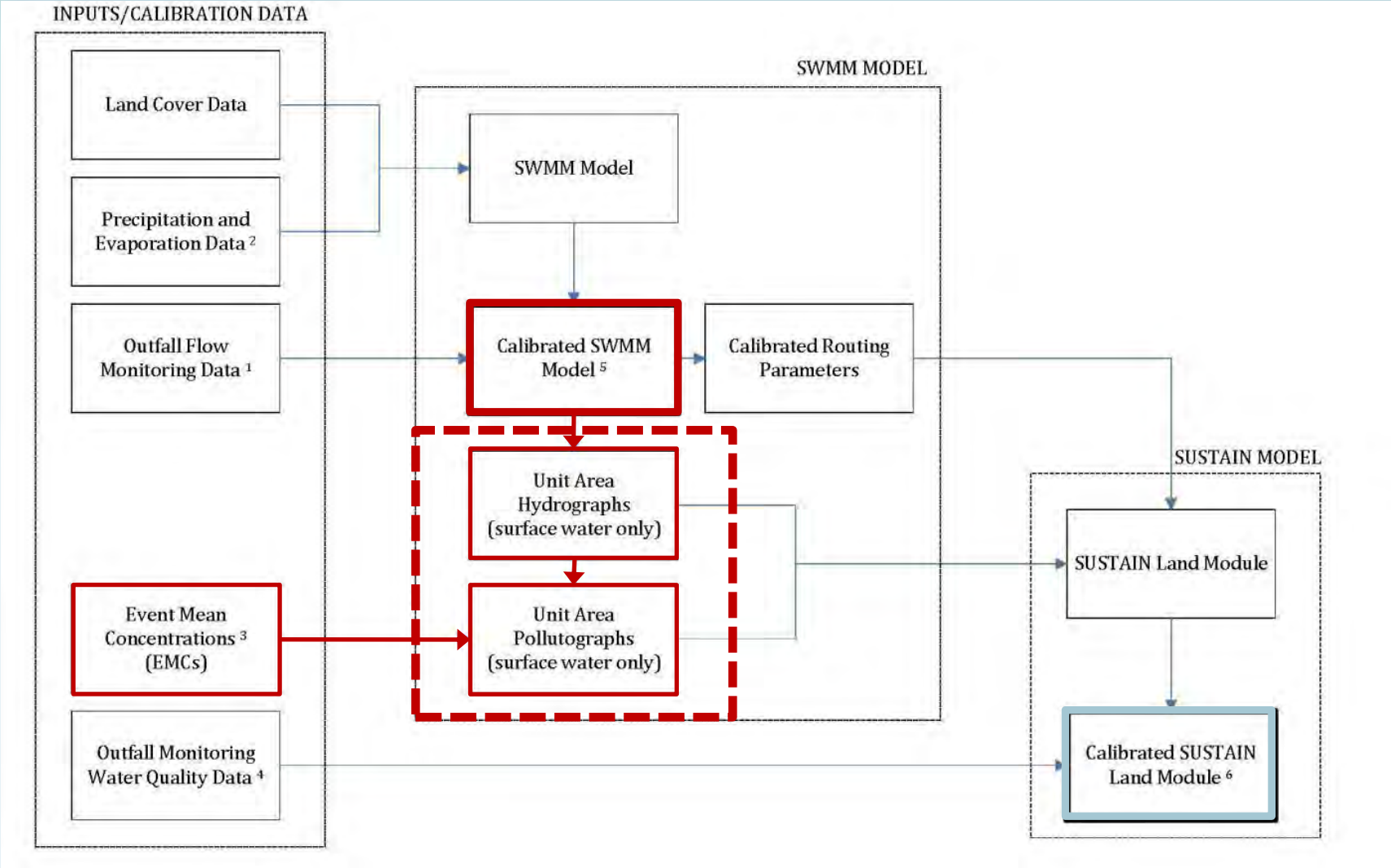
Modeling Overview

SWMM Model Development/Calibration



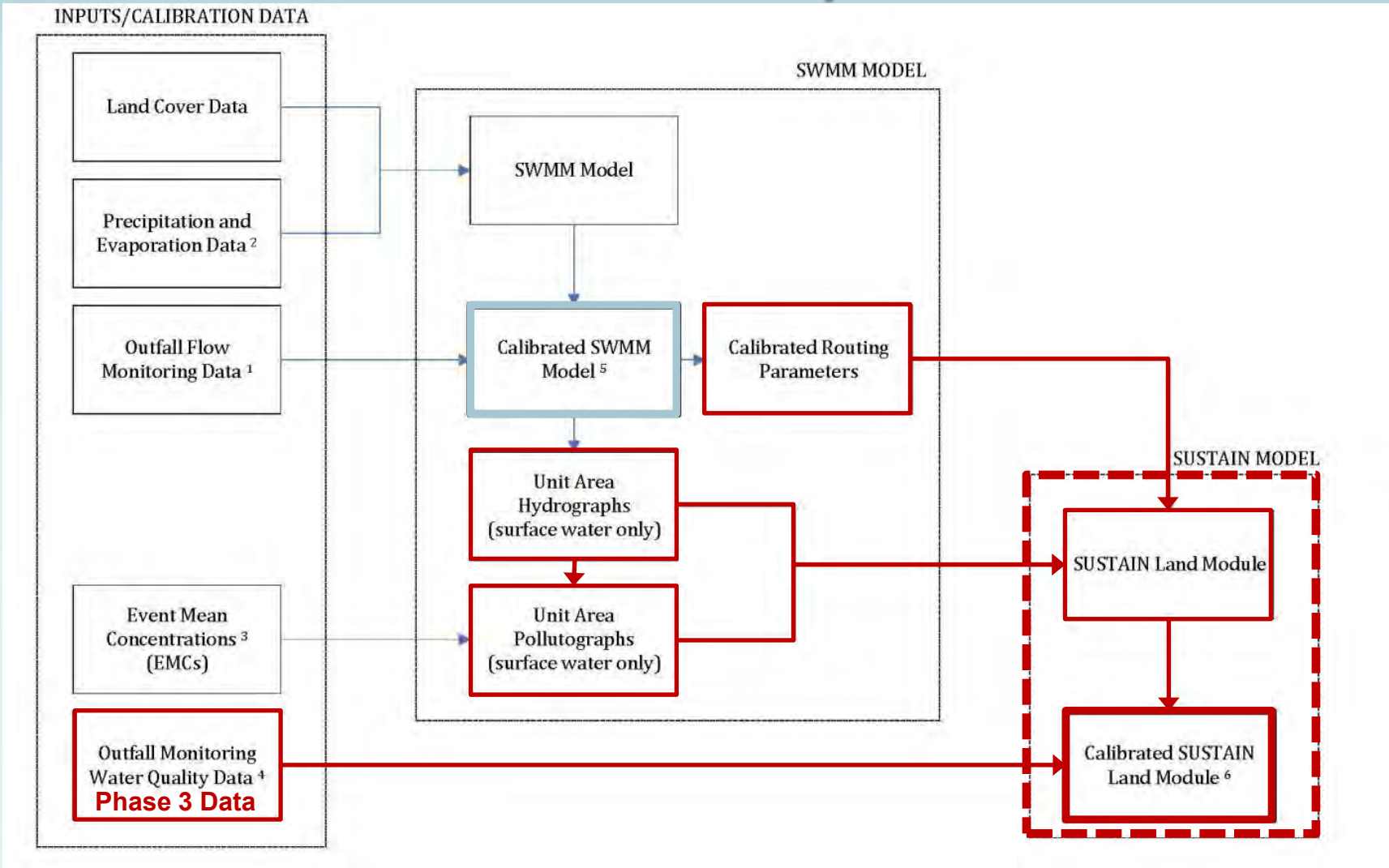
Modeling Overview

Unit Area Hydrographs and Pollutographs



Modeling Overview

SUSTAIN Model Development/Calibration



Existing Conditions

SWMM Model Development

HERRERA

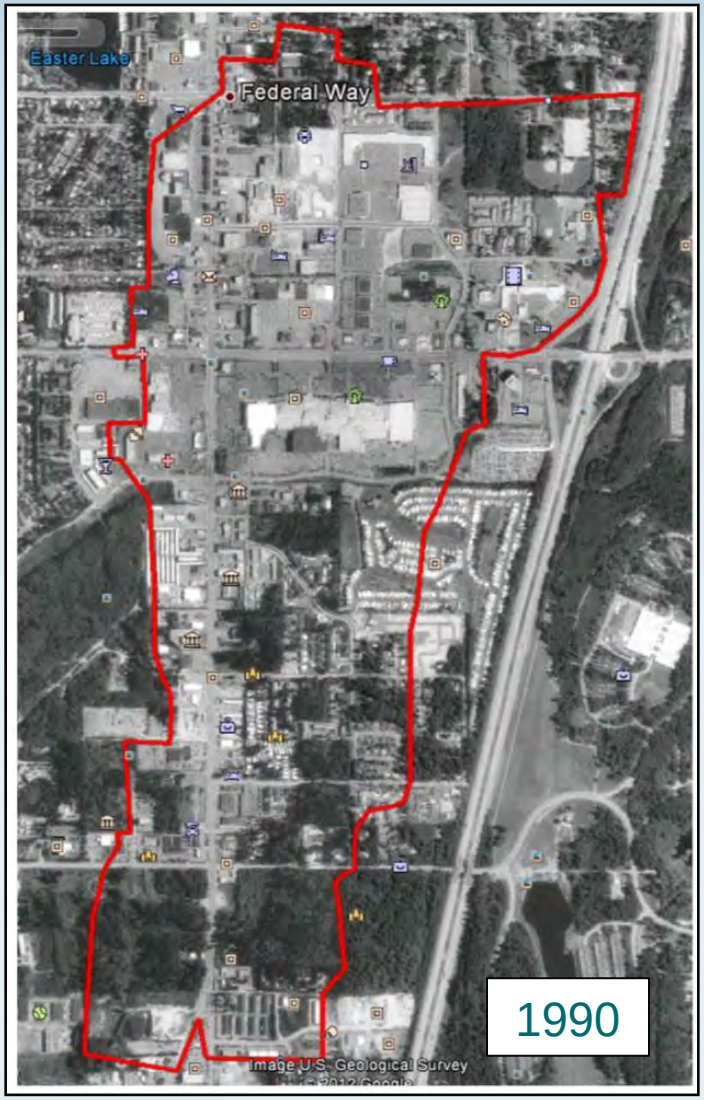
SWMM Model Development

Basis of Analysis

- SWMM Version 5.0.022
- CH2M Hill 1994 SWMM model
- Federal Way GIS Data
- Federal Way record drawings
- SWMM model used to:
  - Develop unit area hydrographs for use in SUSTAINs Land Module
  - Develop pollutographs for each land use and subcatchment
    - Based on unit area hydrographs and Phase 1 EMCs
  - Calibrate existing regional facility hydrology

Basis of Analysis

Land Cover Changes



SWMM Model Development

Input Parameters

- Precipitation and evaporation data
- Drainage areas
- Subcatchment width and slope
- Imperviousness
- Surface roughness
- Soil infiltration parameters
- Routing data
- Depression storage
- Regional facilities

SWMM Model Development

Input Parameters

- Precipitation and evaporation data
- Drainage areas
- Subcatchment width and slope
- Imperviousness
- Surface roughness
- Soil infiltration parameters
- Routing data
- Depression storage
- Regional facilities

Input Parameters

Precipitation and Evaporation Data

- Model calibration
  - Precipitation: King County Lake Doloff Station 41v
  - Evaporation: SeaTac
  - Phase 3 monitoring period
    - August 2009 to July 2010
- BMP performance evaluation
  - Precipitation and evaporation: MGS Engineering extended series
    - Eastern Puget Sound Lowlands
    - Mean annual precipitation = 44 inches
    - 158-year, 5-minute timeseries (truncated to 30-years)

SWMM Model Development

Input Parameters

- Precipitation and evaporation data
- Drainage areas
- Subcatchment width and slope
- Imperviousness
- Surface roughness
- Soil infiltration parameters
- Routing data
- Depression storage
- Regional facilities

1994 SWMM Model Inputs

SWMM Model Development

Input Parameters

- Precipitation and evaporation data
- Drainage areas
- Subcatchment width and slope
- Imperviousness
- Surface roughness
- Soil infiltration parameters
- Routing data
- Depression storage
- Regional facilities

Input Parameters

Routing Data

- Kinematic wave routing

Depression Storage

- Impervious: 0.1 inch
- Pervious: 0.2 inch

SWMM Model Development

Input Parameters

- Precipitation and evaporation data
- Drainage areas
- Subcatchment width and slope
- Imperviousness
- Surface roughness
- Soil infiltration parameters
- Routing data
- Depression storage
- Regional facilities

Input Parameters

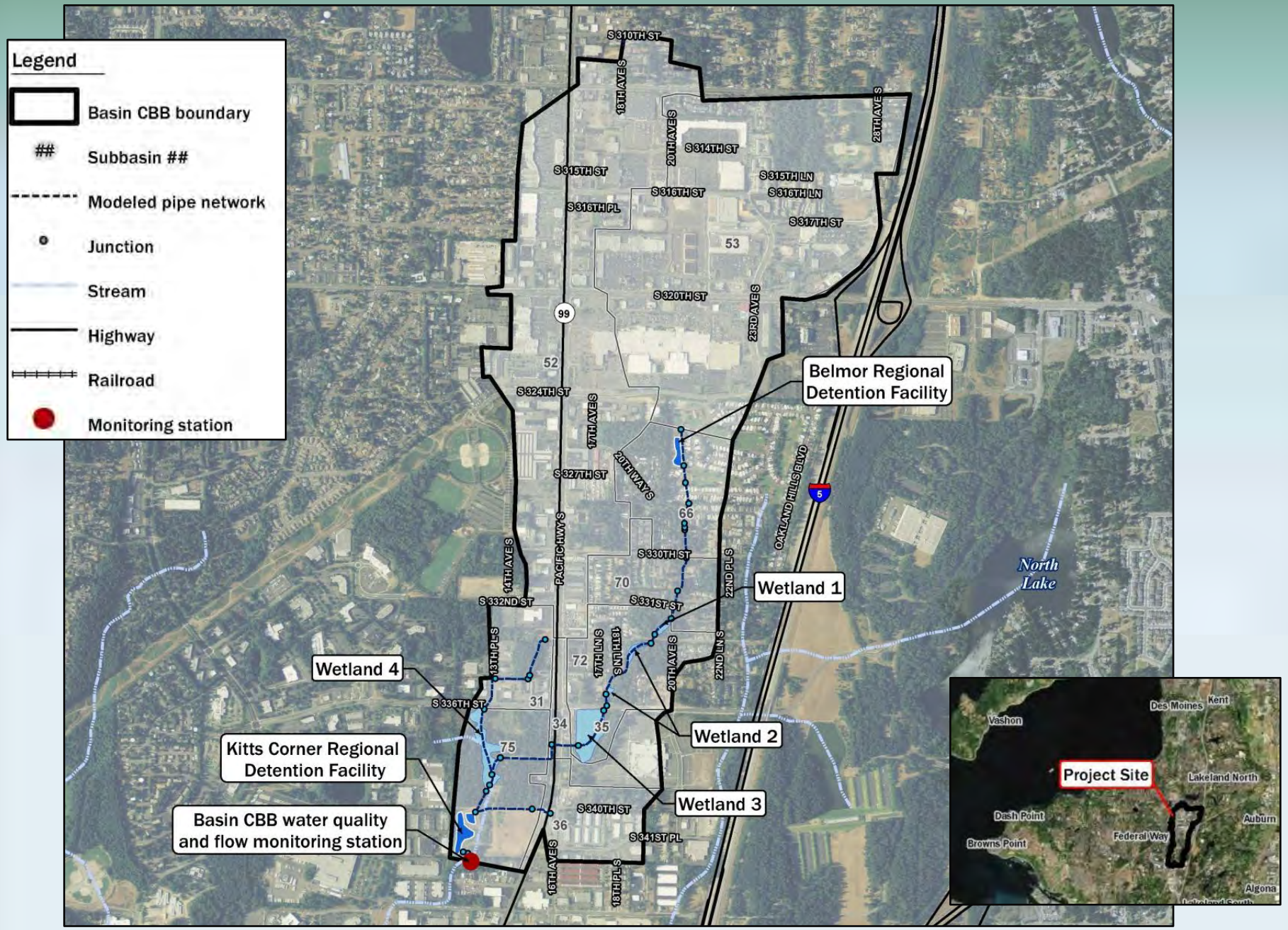
Regional Facilities/Wetlands

- 4 natural wetlands
  - Aerial imagery
  - Footprint: 20,000 sf – 190,000 sf, depth: 6 inches
  - Outlet: existing culvert(s) and emergency “spillway” (roadway)
- 1 aggregate storage vault (subcatchment 53)
  - 1994 SWMM model (5 facilities)
  - Footprint: 55,700 sf
  - Outlet: Five 0.58-foot diameter orifices
- 2 regional detention ponds
  - Federal Way record drawings

Input Parameters

Regional Facilities (cont.)

- Kitts Corner Regional Detention Facility (1997)
  - Footprint: 163,000 sf
  - Volume: stage-storage curve
  - Outlet: v-notch weir, transverse weir, emergency spillway
- Belmor Regional Detention Facility (1998)
  - Footprint: 44,000 sf
  - Volume: stage-storage curve
  - Outlet: 2 rectangular orifices, transverse weir, emergency spillway
  - Seasonal outlet control


Legend
Basin CBB boundary
Subbasin
Modeled pipe network
Junction
Stream
Highway
Railroad
Monitoring station
Belmor Regional Detention Facility
Wetland 1
Wetland 2
Wetland 3
Wetland 4
Kitts Corner Regional Detention Facility
Basin CBB water quality and flow monitoring station
North Lake
S 310TH ST
S 314TH ST
S 315TH ST
S 315TH LN
S 316TH ST
S 316TH LN
S 316TH PL
S 317TH ST
S 320TH ST
S 324TH ST
S 327TH ST
S 330TH ST
S 331ST ST
S 332ND ST
S 336TH ST
S 340TH ST
S 341ST PL
18TH AVE S
20TH AVE S
28TH AVE S
23RD AVE S
17TH AVE S
20TH WAY S
PACIFIC HWY S
14TH AVE S
13TH PL S
17TH LN S
18TH LN S
22ND PL S
22ND LN S
16TH AVE S
18TH PL S
OAKLAND HILLS BLVD
53
52
66
70
72
31
34
35
75
36
99
5
Vashon
Des Moines
Kent
Project Site
Lakeland North
Dash Point
Auburn
Browns Point
Federal Way
Algona

SWMM Model Development

Model Calibration

- Precipitation/Evaporation
  - Lake Doloff Station
- Field-Observed Streamflow Data
  - Phase 3 study of toxics in surface runoff
- Calibrated to match flows at basin outlet (monitoring location)
  - Match timing, magnitude, and total volume

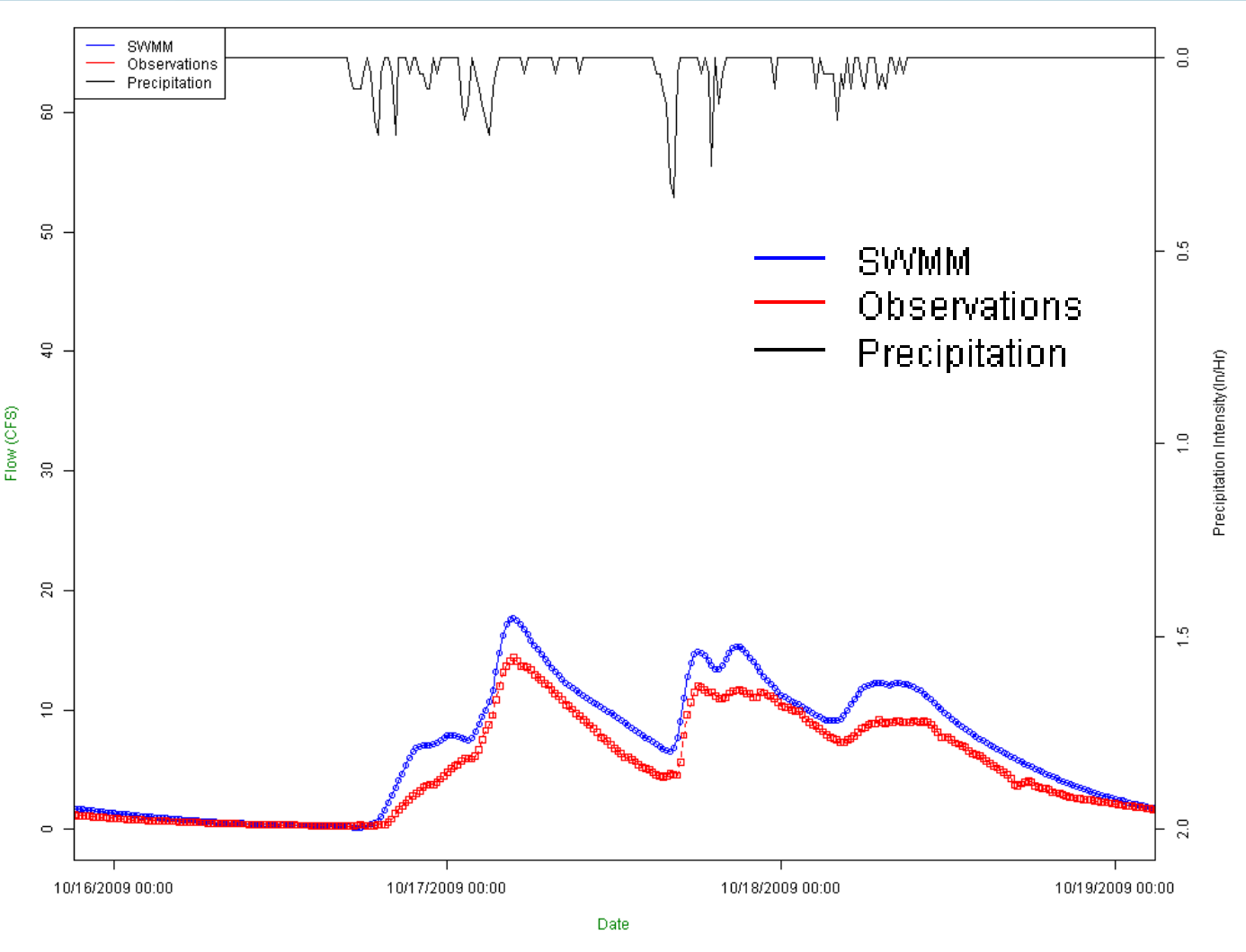
SWMM Model Development

Model Calibration (cont.)

- First calibration effort
  - No wetlands
    - Bias: -0.3 cubic feet per second
      - Model overpredicting runoff by 0.3 cfs
    - Linear correlation (modeled to observed): 0.92
- Final calibration effort
  - Wetlands with minimal infiltration (0.07 in/hr)
    - Bias: 0.009 cubic feet per second
    - Linear correlation (modeled to observed): 0.93

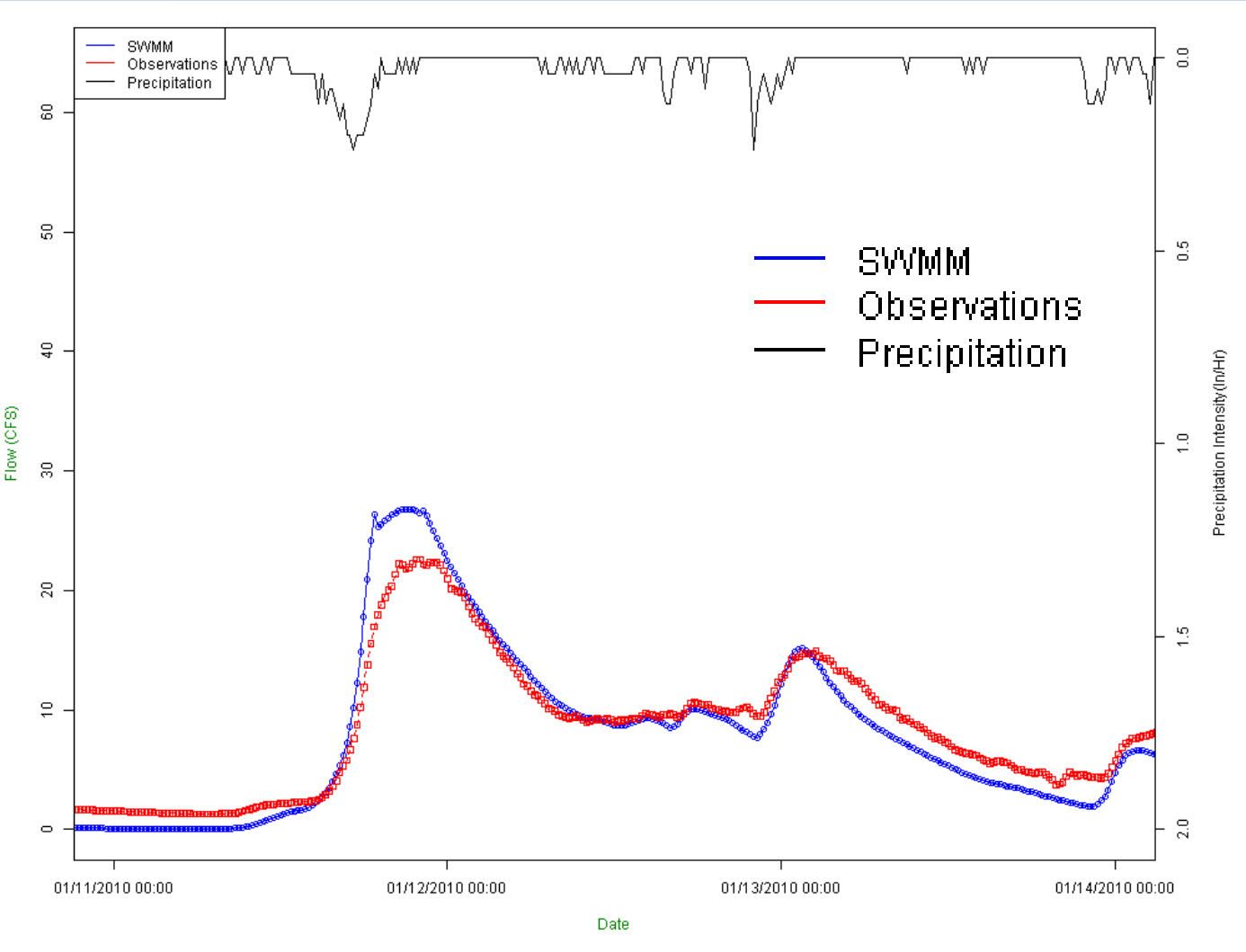
Model Calibration

October 16 – 19, 2009



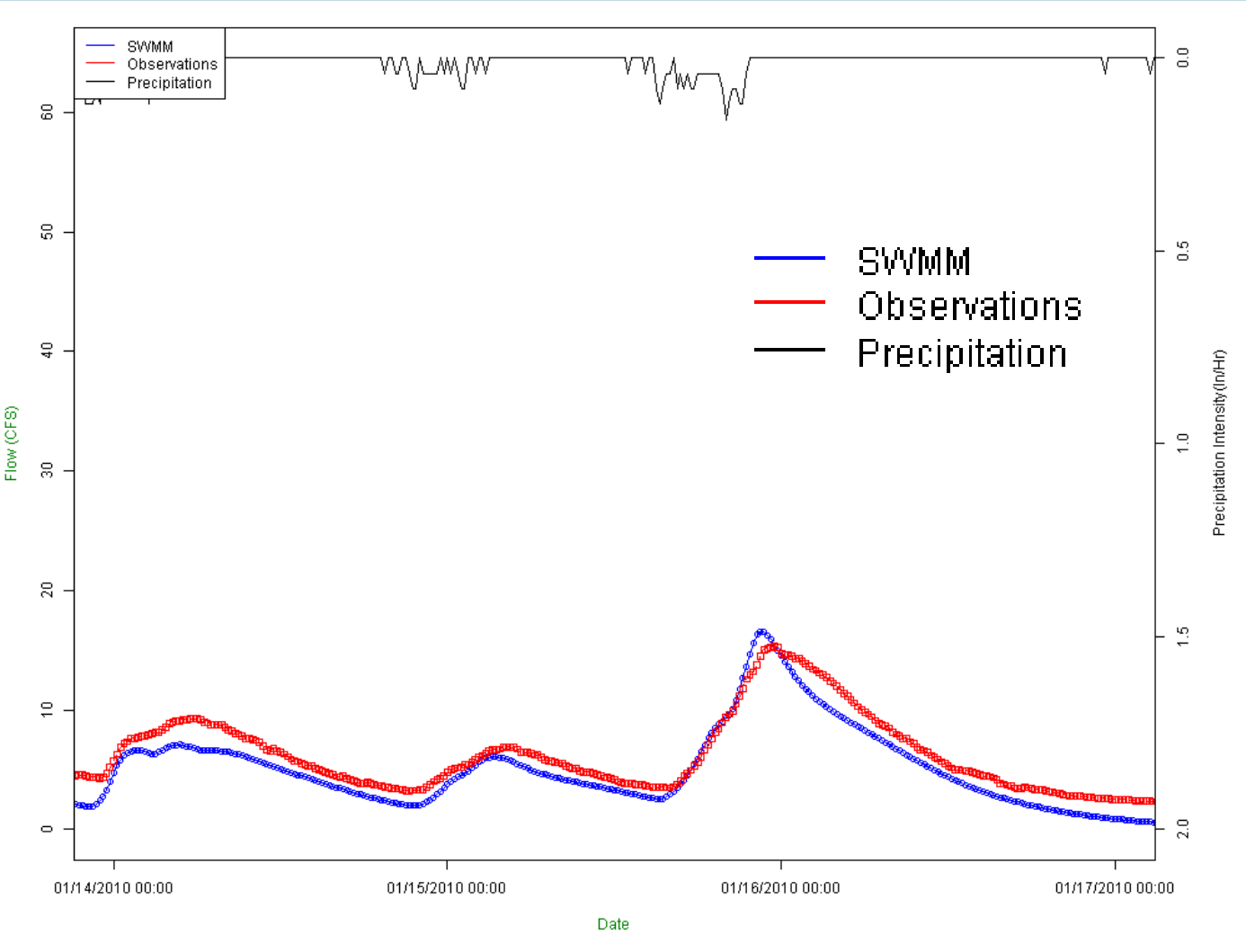
Model Calibration

JANUARY 11 – 14, 2010



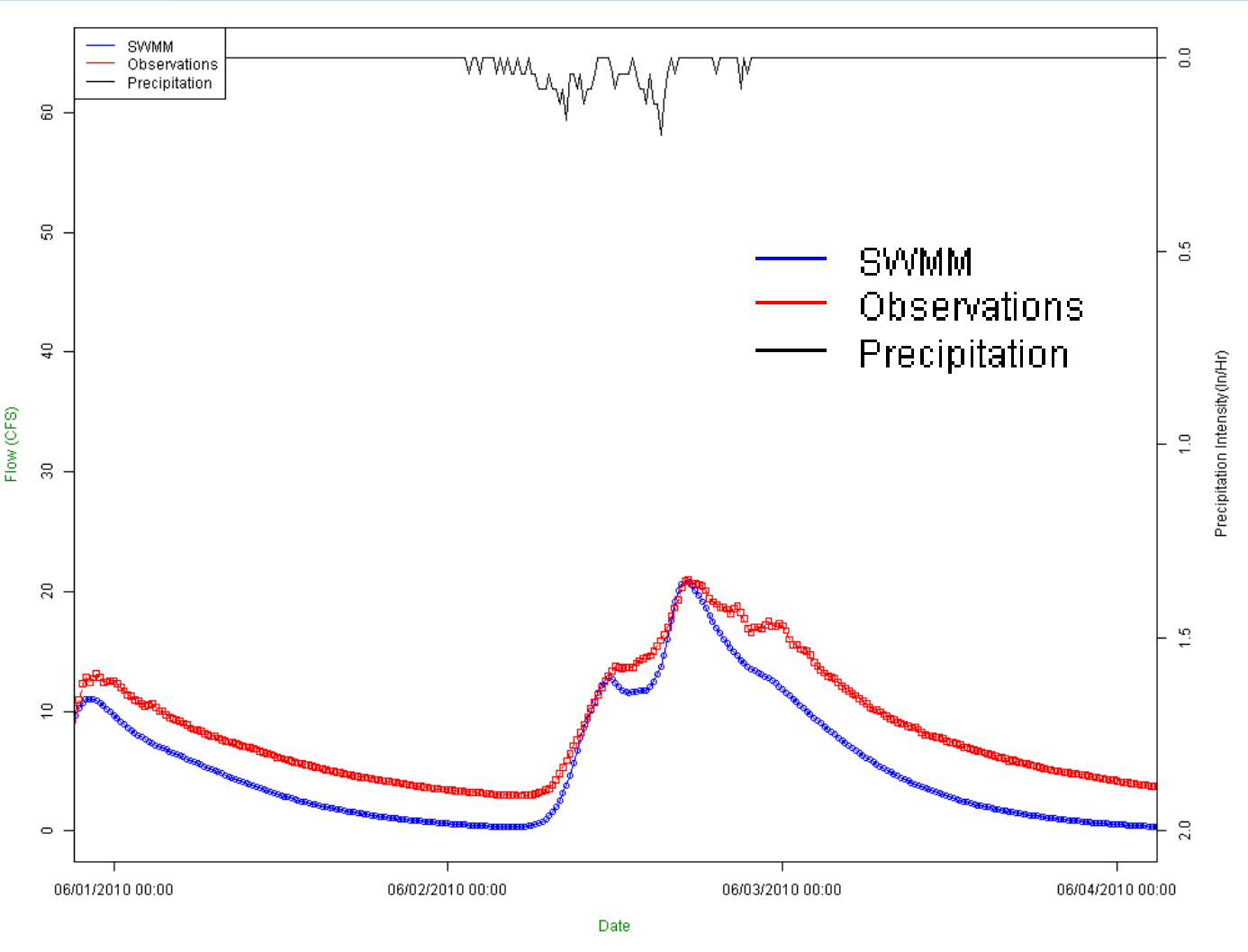
Model Calibration

JANUARY 14 – 17, 2010



Model Calibration

June 1 – 4, 2010



Hydrograph Development

- Six unit area hydrographs developed for each subcatchment
  - Commercial, Residential, Forest/Field/Other
  - Two hypothetical basin conditions
    - 100% impervious
    - 100% pervious
  - Runoff divided by subcatchment area ➔ unit area hydrographs ➔ SUSTAIN land module

Pollutograph Development

- Unit area hydrographs multiplied by EMCs for 6 pollutants of interest:
  - Total Suspended Solids
  - Total Copper
  - Dissolved Copper
  - Total Zinc
  - Dissolved Zinc
  - Chrysene
- EMCs from Phase 1 jurisdiction monitoring
  - Commercial ➔ Commercial Hydrograph
  - High-Density Residential ➔ Residential Hydrograph
  - Low-Density Residential ➔ Forest/Field/Other Hydrograph

Existing Conditions

SUSTAIN Model Development

HERRERA

SUSTAIN Model Development

Basis of Analysis

- SUSTAIN Version 1.2 (June 2012)
- Existing conditions SUSTAIN model includes:
  - Land Module
    - Externally developed hydrographs and pollutographs
  - Conveyance Module
    - 1994 calibrated routing parameters
  - BMP Module
    - Existing regional facilities and Herrera calibrated wetlands
- Model used to:
  - Calibrate existing pollutant removal
    - Regional facility (wetland and regional detention pond) decay rates

SUSTAIN Model Development

BMP Module

- Further simplified representation of BMPs in SUSTAIN
  - Limited inlet configurations
    - Not capable of modeling high- or low-flow bypass or flow splitters in conveyance network
  - Limited outlet configurations
    - Allowed just one orifice and one weir
    - Used the “pump” function in SUSTAIN to represent outlet control via stage-discharge curve
  - No modulated controls
    - Belmor seasonal outlet control (adjustable sluice gate) neglected

Decay Rates for Existing Pollutant Removal

1. Run model with no pollutant decay for existing BMPs
2. Compare concentrations from Step 1 to measured flow weighted averages
3. Compute target reductions for each pollutant
4. Perform repeated SUSTAIN model runs to develop relationships between decay rates and pollutant reductions given different CSTRs
5. Identify appropriate decay rates for each pollutant based on targets in Step 3.

Decay Rate Calibration

Flow Weighted Average Concentrations and Corresponding Facility Decay Rates

Pollutant	Flow Weighted Concentrations		Target Pollutant Reduction (%)	Decay Rate (1/hour)	
	SUSTAIN (mg/L)	Sampling (mg/L)		Detention Ponds	Wetlands
TSS	64.3	9.96	85	0.2090	0.2151
Total Copper	0.0211	0.0036	83	0.1943	0.1973
Dissolved Copper	0.0083	0.0023	73	0.1188	0.1237
Total Zinc	0.0985	0.0334	66	0.0877	0.0902
Dissolved Zinc	0.0469	0.0280	40	0.0289	0.0305
Chrysene	0.000094	0.000034	64	0.0815	0.0842

mg/L: milligrams per liter

Future Conditions

Retrofit Scenario Development

HERRERA

Retrofit Scenario Development

Overview

- BMP Selection
- BMP Design and Sizing
- BMP Retrofit Scenarios
- BMP Feasibility
- BMP Cost
- BMP Performance

BMP Summary

BMP Type	BMP	General Application within Basin
LID BMP	Bioretention with Underdrain	• Distributed in each subcatchment. • Applied to right-of-way and public /private parcels.
	Porous Asphalt	• Distributed in each subcatchment. • Applied to public /private parcel (parking lots only).
Regional BMP	Wet Pond	• Located at bottom of basin treating runoff from all subcatchments. • City may consider expansion of the existing Kitts Corner facility.
	Wetland	• Located at bottom of basin treating runoff from all subcatchments. • City may consider installing pre-treatment upstream of the Kitts Corner wet pond such as a constructed wetland.

Bioretention Design

- Underdrain (infiltration negligible)
- Surface ponding= 6 inches
- Bioretention soil
  - Depth= 1.5 feet
  - Porosity= 0.4
  - Infiltration rate= 3 in/hr

Bioretention Sizing

- Sizing method:
  - Sized in SUSTAIN to infiltrate 91 percent of the runoff file
- Size of single cell:
  - 4.1 x 4.1 feet for 1,000 sf drainage area
- Representation in SUSTAIN:
  - Explicitly modeled as unit area BMP

Permeable Pavement Design

- Self-mitigating (no run-on)
- Porous asphalt
- Section:
  - Porous asphalt: 4 inches*
  - Choker course: 1.5 inches*
  - Aggregate storage layer: 9 inches*
  - Sand treatment layer: 4 inches* (for outwash soil only)
- Infiltration rates:
  - Till = 0.15 in/hr
  - Outwash = 1.5 in/hr
  - Pavement layers= unlimiting

* (porosity= 0.3)

Permeable Pavement Sizing

- Sizing method/results:
  - Minimum aggregate layer of 9 inches required for structural loading
  - 9 inch section infiltrates >91 percent of the runoff file when modeled in SUSTAIN
- Size of single pavement BMP:
  - 1,000 sf pavement area (with no run-on)
- Representation in SUSTAIN:
  - 9-inch aggregate layer explicitly modeled as unit area BMP
  - Storage in wearing course, choker course and treatment layer neglected

Treatment Wetland Design & Sizing

- Sizing method/results:
  - Water quality treatment volume = 4,810 cubic feet (MGSFlood)
  - Presettling and wetland cell areas and dimensions calculated per Ecology
- Size of single wetland BMP:
  - Drainage area= 1 acre
  - Presettling cell: area= 720 sf, depth= 6 feet, side slopes= 2:1
  - Wetland cell: area= 1315 sf, depth= 1.5 feet, side slopes= 2:1
- Representation in SUSTAIN:
  - Simple representative storage reservoir (several CSTRs)
  - Area= 45 feet x 45 feet
  - Average depth= 1.6 feet
  - Overflow set at average ponding depth (sized so unrestrictive)

Basic Wet Pond Design & Sizing

- Sizing method/results:
  - Water quality treatment volume = 4,810 cubic feet (MGSFlood)
  - Presettling and wetland cell areas and dimensions calculated per Ecology
- Size of single wetland BMP:
  - Drainage area= 1 acre
  - First cell: area= 720 sf, depth= 6 feet, side slopes= 2:1
  - Second cell: area= 1315 sf, depth= 6 feet, side slopes= 2:1
- Representation in SUSTAIN:
  - Simple representative storage reservoir (several CSTRs)
  - Area= 45 feet x 45 feet
  - Average depth= 2.4 feet
  - Overflow set at average ponding depth (sized so unrestrictive)

Scenario Summary

	Bioretention	Permeable Pavement	Constructed Wetland	Wet Pond
Retrofit Scenario A				
Right-of-Way	Applied in all right-of-way subcatchment areas deemed feasible for retrofit	Not applied	Applied as a regional facility	Applied as a regional facility
Public Parcels	Not applied			
Private Parcels				
Retrofit Scenario B				
Right-of-Way	Applied in all right-of-way subcatchment areas deemed feasible for retrofit	Not applied	Applied as a regional facility	Applied as a regional facility
Public Parcels	Applied in 50% parcel subcatchment areas deemed feasible for retrofit *	Applied in 50% parcel subcatchment areas deemed feasible for retrofit (assumed parking lots only) *		
Private Parcels				

*Note: only one aggregate BMP type can be applied to each unit area in a subcatchment

Maximum Area Treated By BMP

- Area of each subcatchment for which LID BMPs are feasible was estimated based on:
- Technical feasibility (engineering constraints)
  - Infiltration restrictions (e.g., high GW, steep slopes)
  - Existing infrastructure
  - Available space
  - Positive drainage to discharge point
- Anticipated participation in /public acceptance of retrofit programs

Technical and Participation Factors

- "Technical Factor": percent of subcatchment area likely technically feasible for LID retrofit
- "Participation Factor": percent of subcatchment area likely socially feasible for LID retrofit

Property Type	Bioretention with Underdrains		Porous Asphalt	
	Technical Factor (%)	Participation Factor (%)	Technical Factor (%)	Participation Factor (%)
Private	50	20	50	20
Public	50	80	50	80
Right-of-Way	50	100	NA	NA

"Maximum Area Treated" by bioretention on private parcels = Private parcel area x 50% x 20% = Private parcel area x 10%

BMP Cost Components

- Property Acquisition
  - Regional facilities only
- Construction
  - Native soil considerations (permeable pavement)
  - Retrofit costs (e.g., utility conflicts)
- Design
  - Percent of construction
- Operation and Maintenance (O&M)
  - 30-year lifecycle costs
  - Present value

BMP Cost By Component

BMP Type	Units	Property Cost	Construction Cost	Design Cost		O&M Cost			TOTAL Cost
				A	B	C	D	E	
Rain Garden with Underdrain	SF	--	$35	25%	$8.75	--	--	$40.04	$206.42
Early (year 2 and 3)	--	--	--	--	--	$1.40	Annual	--	--
Mature (year 4 through 30)	--	--	--	--	--	$0.70	Annual	--	--
Porous Asphalt on Till	SF	--	$20	20%	$4.00	$0.05	Annual	$2.75	$26.75
Porous Asphalt on Outwash	SF	--	$19	20%	$3.80	$0.05	Annual	$2.75	$25.55
Constructed Wetland	SF	$4	$15	15%	$2.25	--	--	$16.57	$37.82
Sediment Removal	--	--	--	--	--	$0.64	5-year	--	--
Vegetation Management	--	--	--	--	--	$0.16	1-year	--	--
Wetpond	SF	$4	$10	10%	$1.00	$0.35	15-year	$9.70	$24.70

A – Percent Construction
B – Design Cost
C – $/year
D – Schedule
E – PV 30-year Lifecycle

BMP Total Cost (by Area)

BMP Type	Units	Property Cost	Construction Cost	Design Cost		O&M Cost			TOTAL Cost
				A	B	C	D	E	
Rain Garden with Underdrain	SF	--	$35	25%	$8.75	--	--	$40.04	$206.42
Early (year 2 and 3)	--	--	--	--	--	$1.40	Annual	--	--
Mature (year 4 through 30)	--	--	--	--	--	$0.70	Annual	--	--
Porous Asphalt on Till	SF	--	$20	20%	$4.00	$0.05	Annual	$2.75	$26.75
Porous Asphalt on Outwash	SF	--	$19	20%	$3.80	$0.05	Annual	$2.75	$25.55
Constructed Wetland	SF	$4	$15	15%	$2.25	--	--	$16.57	$37.82
Sediment Removal	--	--	--	--	--	$0.64	5-year	--	--
Vegetation Management	--	--	--	--	--	$0.16	1-year	--	--
Wetpond	SF	$4	$10	10%	$1.00	$0.35	15-year	$9.70	$24.70

- Total cost applied to per square foot facility

Remember: SUSTAIN represents facilities as unit area BMPs

BMP Costs (Unit Area Implications)

Permeable Pavement

- Unit area approach fits ➔ No cost implications

Wetlands and Wet Ponds

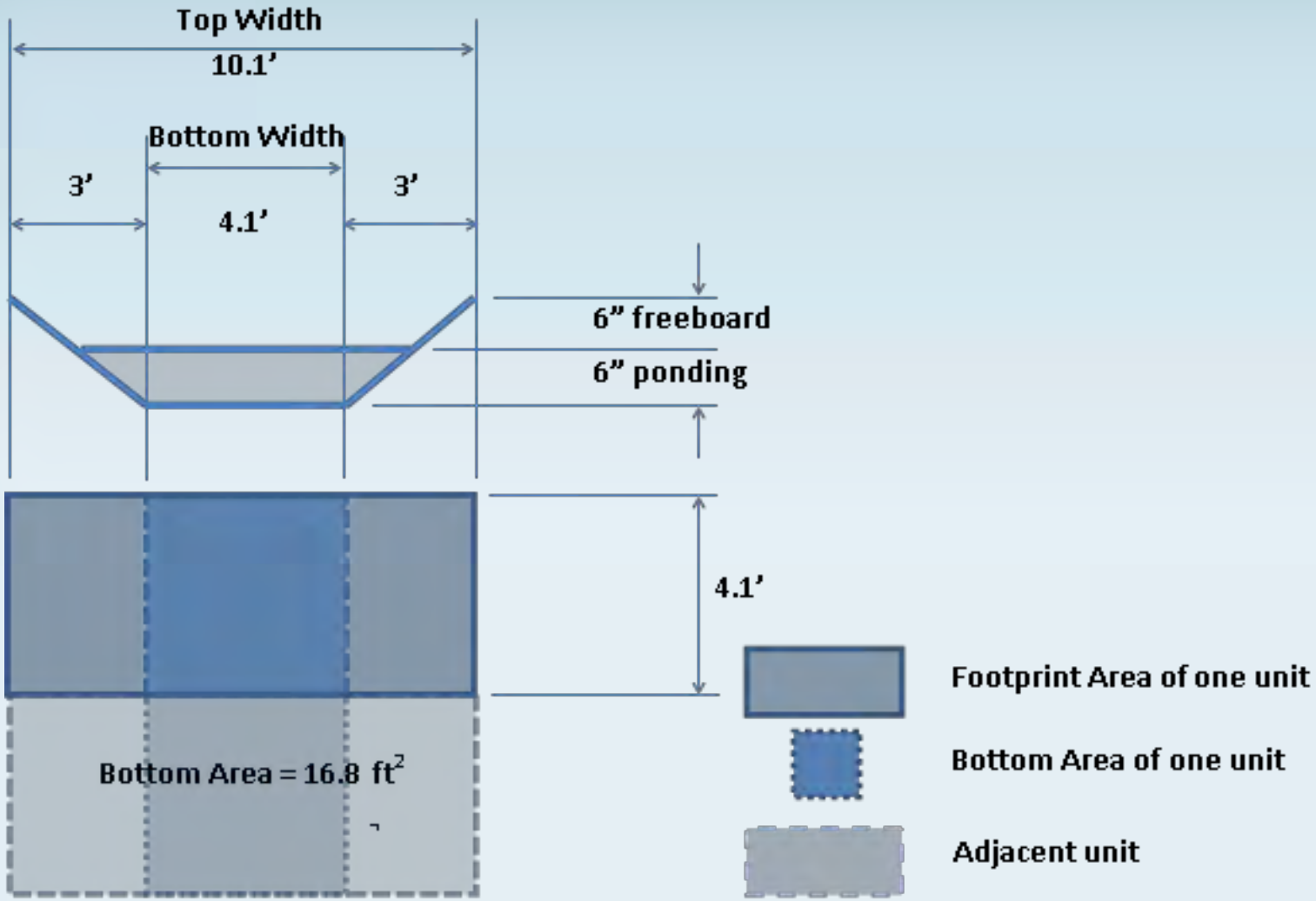
- Represented as footprint area
  - Average depth uniformly applied across facility

Bioretention

- Unit area approach neglects sideslopes
- Scaling factor applied to unit area cost
  - Based on facility geometry
    - Ratio of bottom area to facility footprint

BMP Costs (Unit Area Implications)

Bioretention Cost Scaling



BMP Costs (Unit Area Implications)

BMP Cost Data

BMP Type	Units	Property Cost	Construction Cost	Design Cost		O&M Cost			TOTAL Cost
				A	B	C	D	E	
Rain Garden with Underdrain	SF	--	$35	25%	$8.75	--	--	$40.04	$206.42
Early (year 2 and 3)	--	--	--	--	--	$1.40	Annual	--	--
Mature (year 4 through 30)	--	--	--	--	--	$0.70	Annual	--	--
Porous Asphalt on Till	SF	--	$20	20%	$4.00	$0.05	Annual	$2.75	$26.75
Porous Asphalt on Outwash	SF	--	$19	20%	$3.80	$0.05	Annual	$2.75	$25.55
Constructed Wetland	SF	$4	$15	15%	$2.25	--	--	$16.57	$37.82
Sediment Removal	--	--	--	--	--	$0.64	5-year	--	--
Vegetation Management	--	--	--	--	--	$0.16	1-year	--	--
Wet Pond	SF	$4	$10	10%	$1.00	$0.35	15-year	$9.70	$24.70

- Scaling factor of 2.5 applied to bioretention per square foot cost to account for facility sideslopes

BMP Treatment Performance

Target Pollutant Removals for BMPs in SUSTAIN

	TSS (%)	Total Copper (%)	Dissolved Copper (%)	Total Zinc (%)	Dissolved Zinc (%)	Chrysene (%)
Bioretention	70.0	56.5	40.0	70.0	70.0	34.0
Wet Pond	70.0	46.6	18.0	60.3	50.0	18.0
Permeable Pavement [a]	0.0	0.0	0.0	0.0	0.0	0.0
Wetland	70.0	46.6	18.0	60.3	50.0	18.0

[a] Percent removal for treated effluent from permeable pavement was assumed to be 0% when routed to surface water and 100% where it infiltrates to the ground.

BMP Treatment Performance

Treatment Representation for BMPs in Future Condition Scenarios

- Bioretention facility underdrains – percent removal
- Permeable pavement - no removal to surface water; 100% removal that infiltrates
- Wet ponds and wetlands - first order decay rates derived from percent removal

Decay Rate Calibration for Wet Ponds and Wetlands in Future Condition Scenarios

1. Develop series of SUSTAIN models with appropriately sized wet ponds and wetlands
2. Perform repeated SUSTAIN model runs to develop relationships between decay rates and pollutant reductions given different CSTRs
3. Identify appropriate decay rates for each pollutant based on percent removal targets

Decay Rates for Wet Ponds and Wetlands

Pollutant	Decay Rate for Wetponds [a] (1/hour)	Decay Rate for Wetlands [b] (1/hour)
TSS	0.0175	0.0275
Total Copper	0.0116	0.0139
Dissolved Copper	0.0045	0.0045
Total Zinc	0.0151	0.0180
Dissolved Zinc	0.0125	0.0149
Chrysene	0.0045	0.0045

[a] Decay rates reflect pollutant removal with 3 CSTRs

[b] Decay rates reflect pollutant removal with 5 CSTRs

Future Conditions

SUSTAIN Model Optimization

HERRERA

SUSTAIN Model Optimization

Management Targets

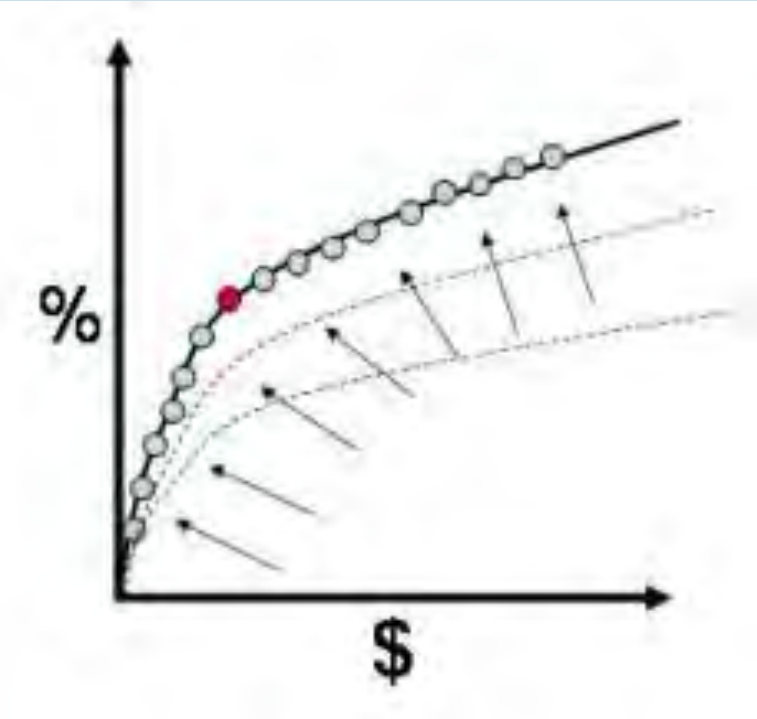
- Dissolved Copper, Dissolved Zinc, Chrysene
  - Scatter search algorithm used to identify optimum BMP configuration for meeting acute and chronic water quality standards
  - Chrysene concentrations for optimum BMP configuration evaluated to determine if national recommended standards were met
- Total Suspended Solids, Total Copper, and Total Zinc
  - NSGA-II algorithm used to build cost effectiveness curves for each parameter

Decision Variables

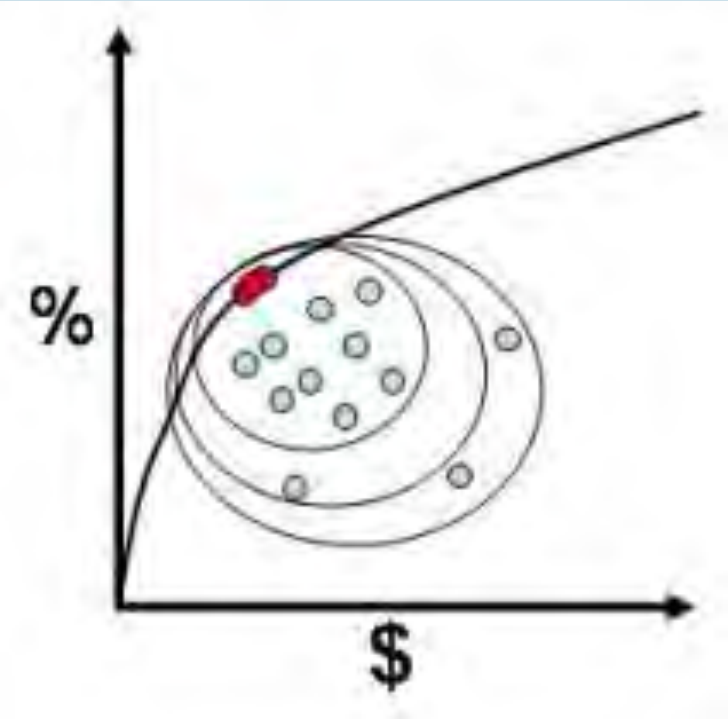
- Maximum number of facilities for both the distributed and regional BMPs
- Bin increments for facility number optimization

SUSTAIN Model Optimization

Optimization Routine



NSGA-II



Scatter Search

SUSTAIN Model Results

HERRERA

SUSTAIN Model Results

Runtime Considerations

- Runtime a function of:
  - Length of simulation period
  - Simulation timestep
  - Number of decision variable combinations

SUSTAIN Model Results

Runtime Considerations

- Runtime a function of:
  - Length of simulation period
  - Simulation timestep
  - Number of decision variable combinations

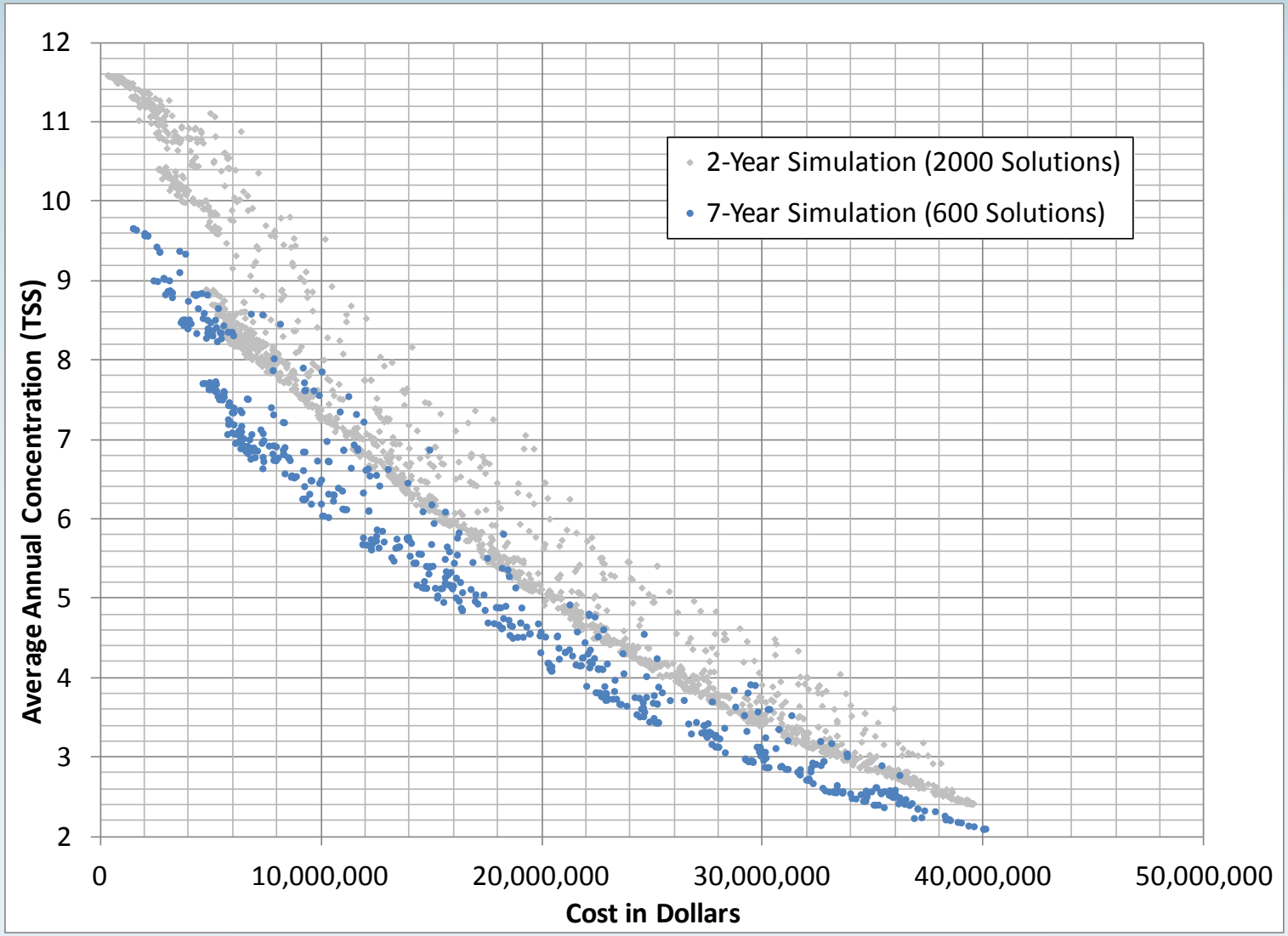
Runtime Considerations

Length of Simulation Period

- 158-year simulation → unstable model
- 7-year simulation → long runtimes (>>24 hours)
  - Deemed infeasible
- Shortened to 2-years to allow for near convergence within 24 hours

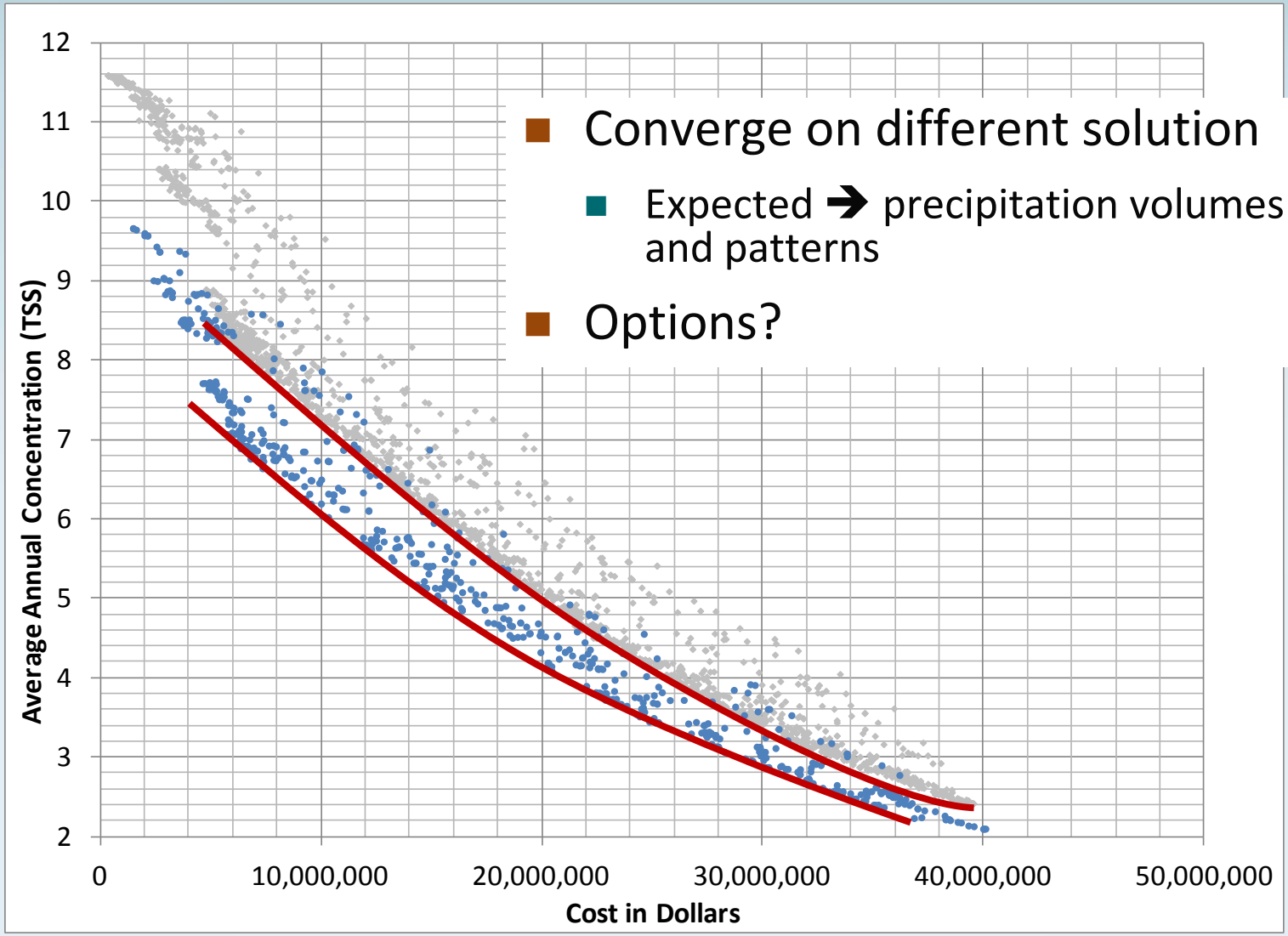
Runtime Considerations

Length of Simulation Period



Runtime Considerations

Length of Simulation Period



- Converge on different solution
  - Expected ➔ precipitation volumes and patterns
- Options?

SUSTAIN Model Results

Runtime Considerations

- Runtime a function of:
  - Length of simulation period
  - Simulation timestep
  - Number of decision variable combinations
    - 15 minutes (maximum timestep)
    - SUSTAIN does not allow for timestep greater than externally developed hydrograph and pollutograph timestep

SUSTAIN Model Results

Runtime Considerations

- Runtime a function of:
  - Length of simulation period
  - Simulation timestep
  - Number of decision variable combinations
    - Maximum number of BMPs
    - BMP bin increment

Runtime Considerations

Number of Decision Variable Combinations

Bin Increment:

Wetlands and wet ponds → 2

Bioretention and permeable pavement → 10

- Scenario A
  - No permeable pavement
  - 9.5E+11 possible combinations
    - Near convergence in 5 to 8 hours
- Scenario B
  - Additional facility combinations
  - 4.4E+21 possible combinations
    - Infeasibly long runtimes (>>24 hours)

Runtime Considerations

Number of Decision Variable Combinations

Bin Increment:

Wetlands and wet ponds → 2

Bioretention and permeable pavement → 10

- Scenario A
  - No permeable pavement
  - 9.5E+11 possible combinations
    - Near convergence in 5 to 8 hours
- Scenario B
  - Additional facility combinations
  - 4.4E+21 possible combinations
    - Infeasibly long runtimes (>>24 hours)

4.6 billion times more combinations!

Runtime Considerations

Number of Decision Variable Combinations

- Scenario B
  - Adjust bin increment:
    - Wetlands and wet ponds ➔ 10 percent of max. number of BMPs
    - Bioretention and permeable pavement ➔ 20 percent max. number of BMPs (or a fixed increment of 10, if larger)
  - 1.3E+14 possible combinations
  - Still 33.8 million times more combinations
    - But…near convergence in approximately 14 hours

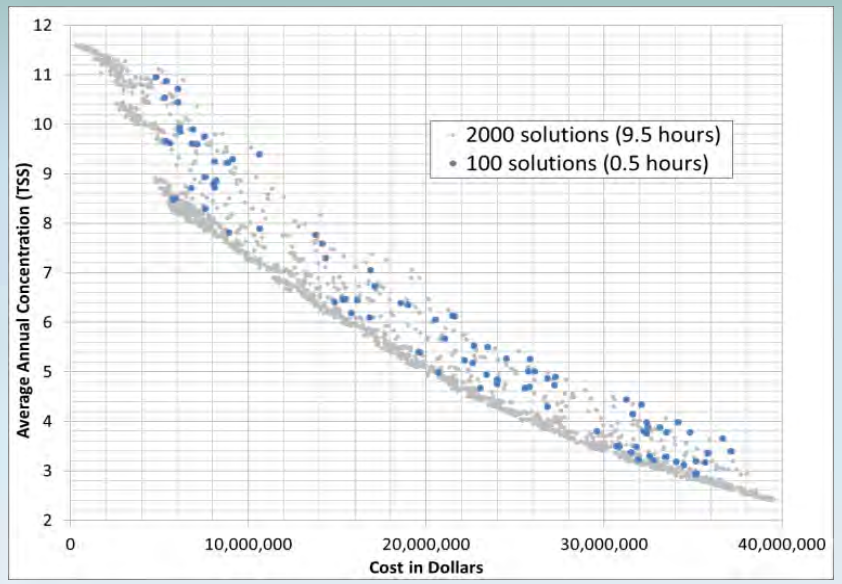
SUSTAIN Model Results

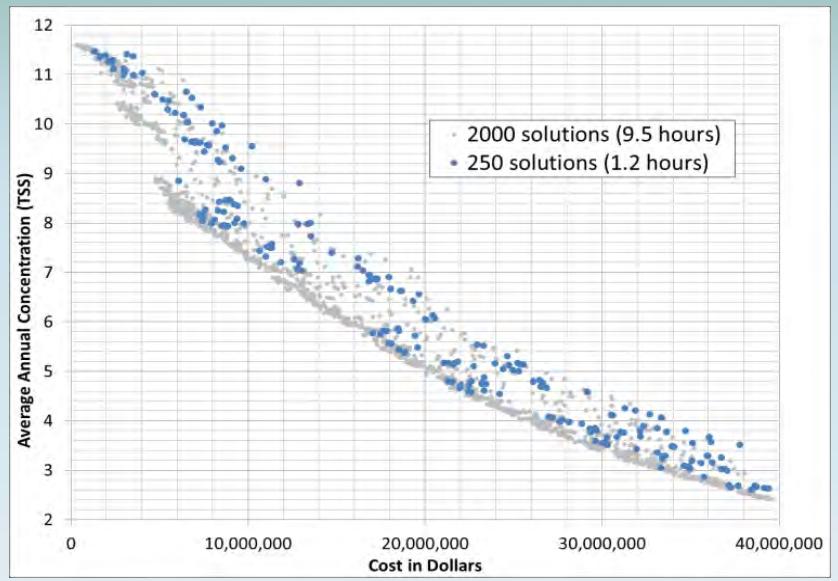
Solution Convergence

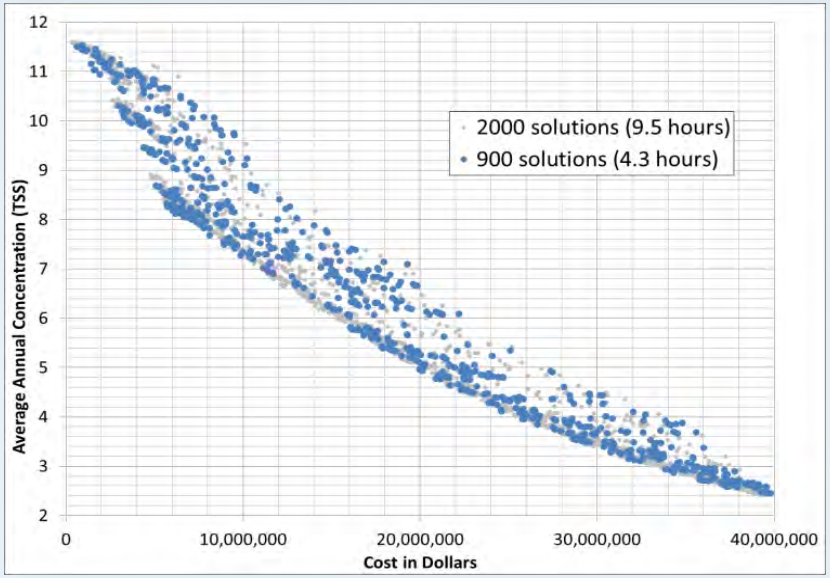
- NSGA-II
  - User must select number of iterated solutions for evaluation
  - Number of solutions must be sufficiently large to allow for convergence
    - Occurs when more solutions do not advance cost-effectiveness curve
      - i.e., do not result in more cost-effective solutions

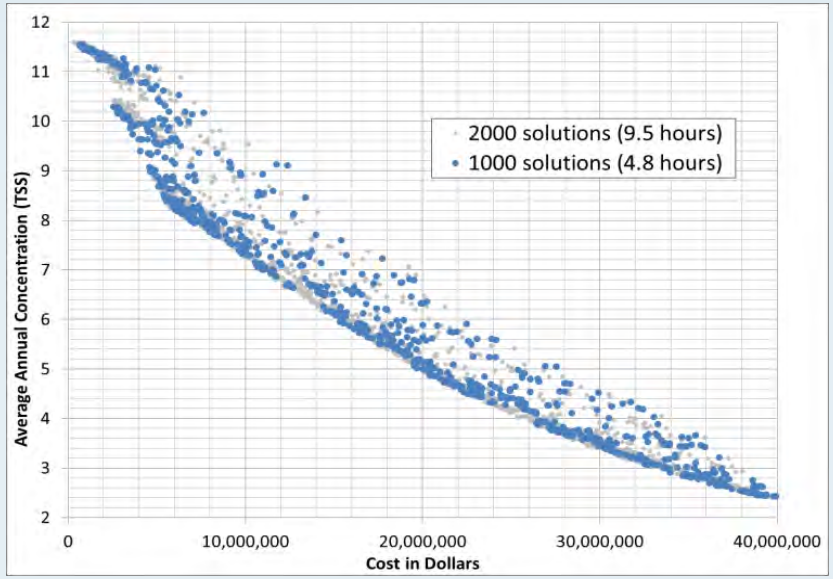
Evaluate to determine number of solutions for each scenario

Scenario A Convergence

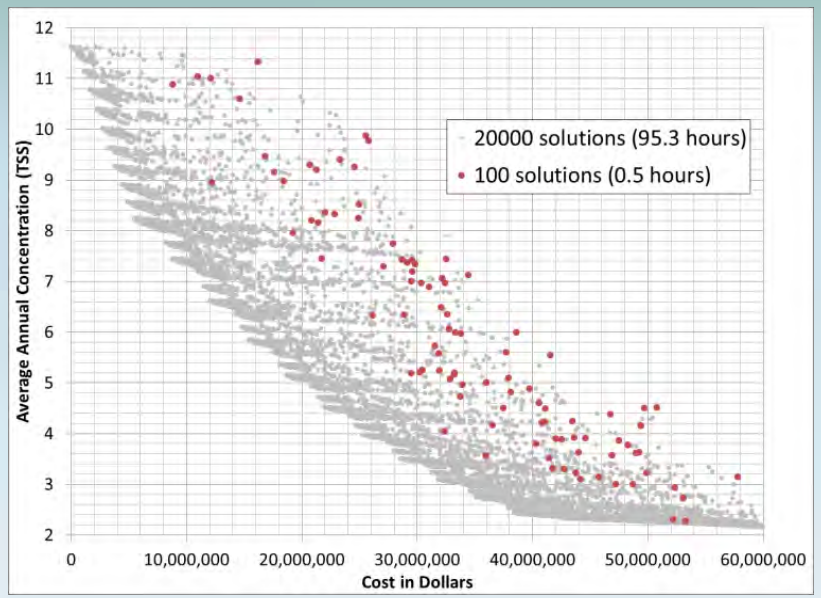


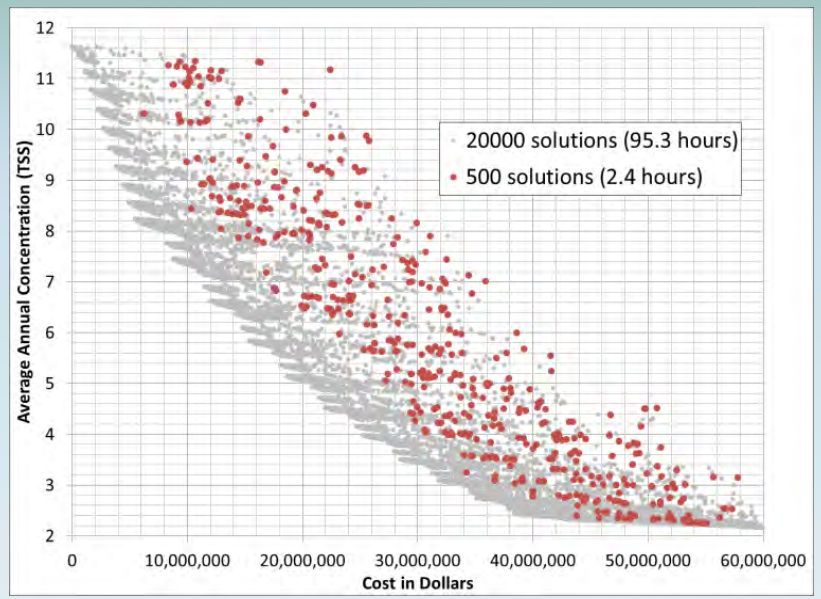


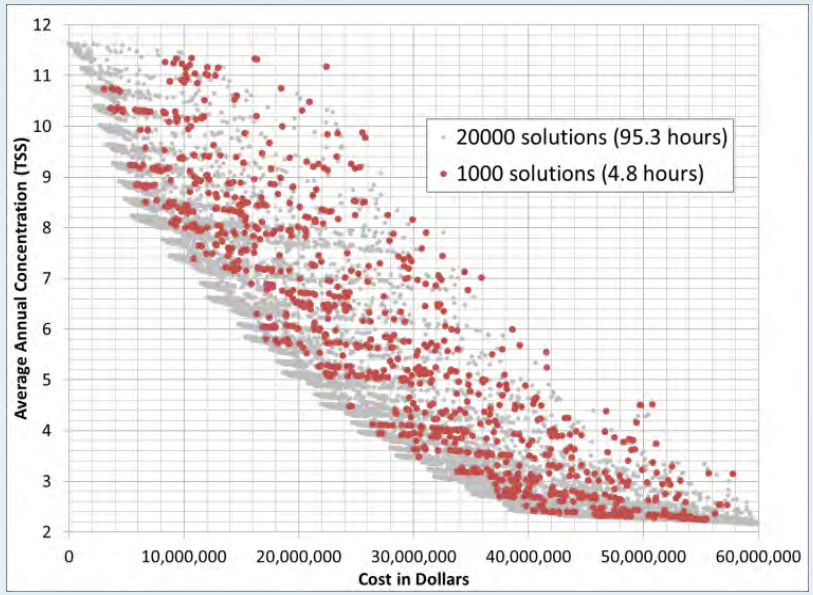


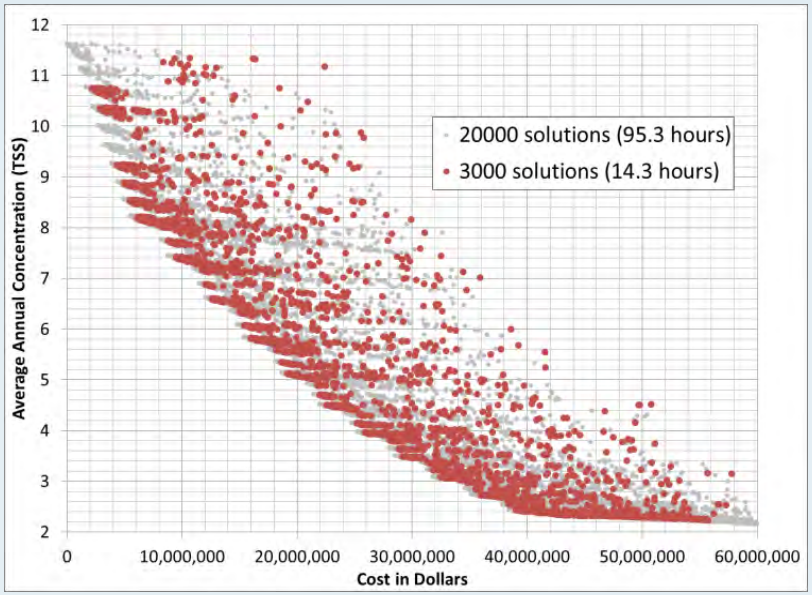


Scenario B Convergence









SUSTAIN Model Results

NSGA-II

- Cost-effectiveness curves
  - TSS
  - Total copper
  - Total zinc
- Relates removal efficiency to various BMP configurations/costs

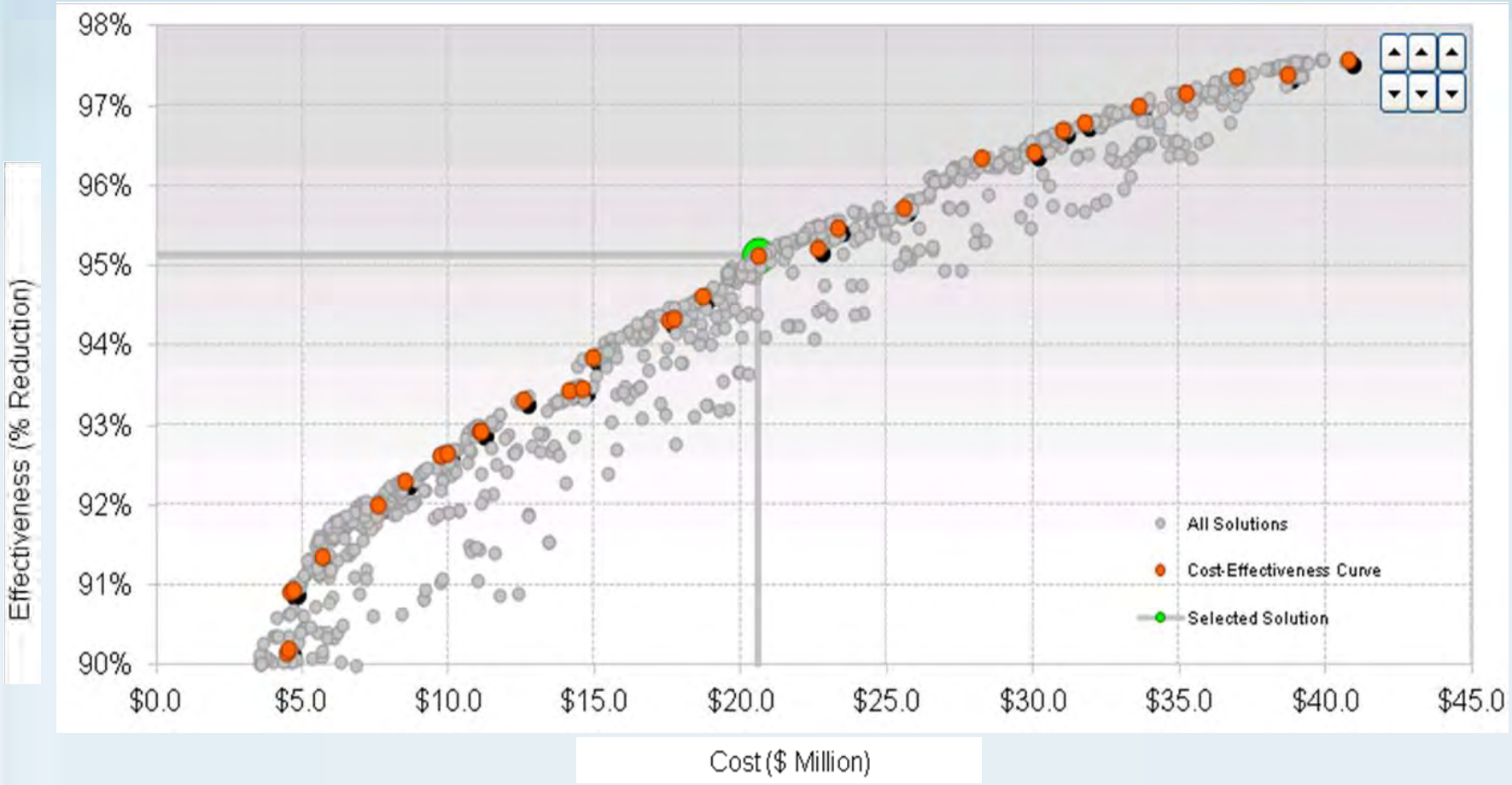
Scenario A

- Distributed bioretention → treatment of right-of-way runoff
- Regional treatment (wetland and wet pond) → treatment at bottom of basin

NSGA-II: Scenario A

Total Suspended Solids Optimization

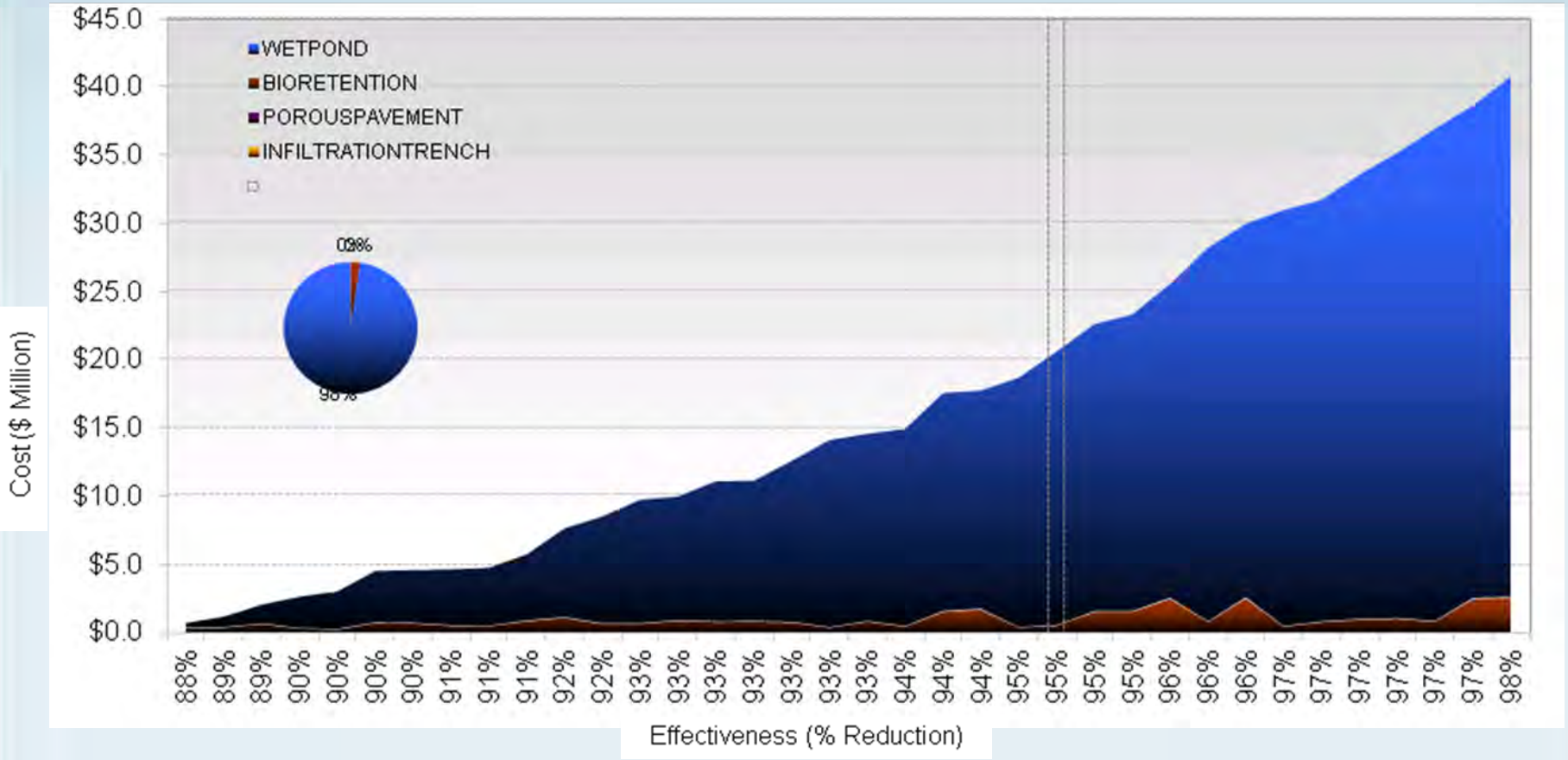
- Cost-effectiveness curve



NSGA-II: Scenario A

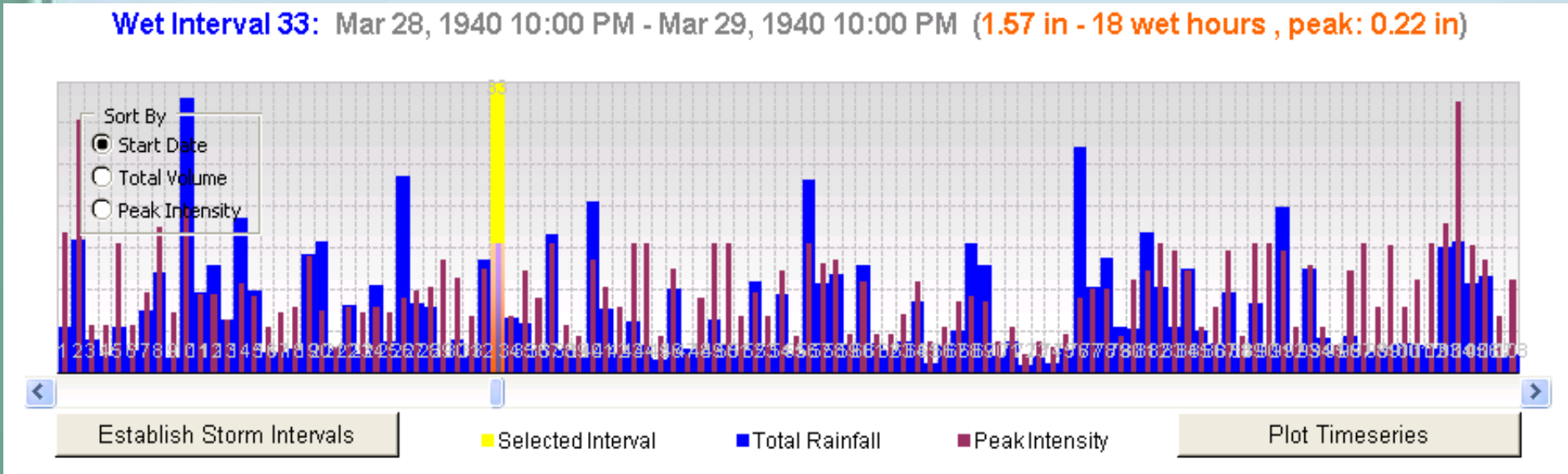
Total Suspended Solids Optimization

- Cost distribution by BMP



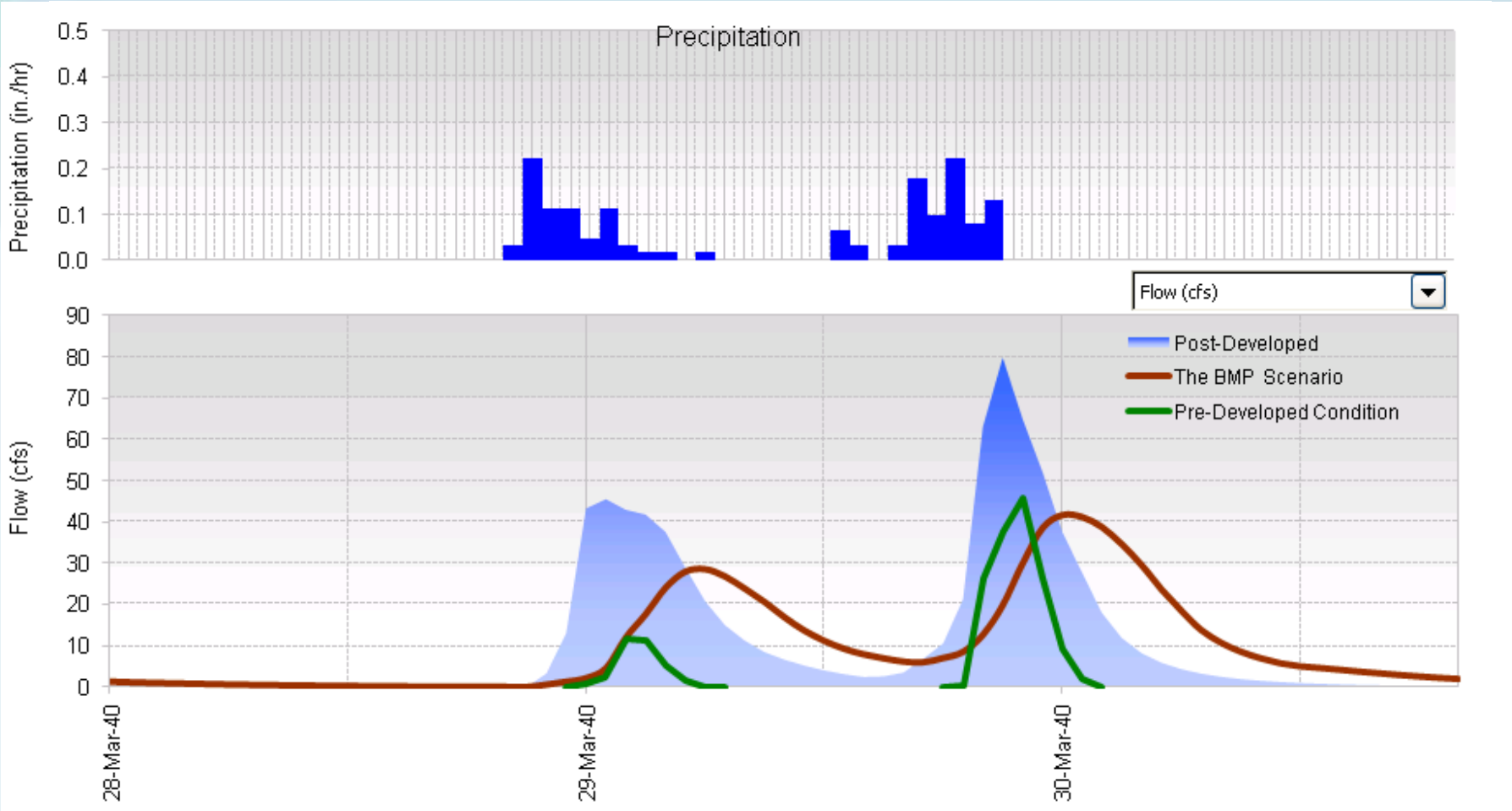
Total Suspended Solids Optimization

- Rainfall and runoff response



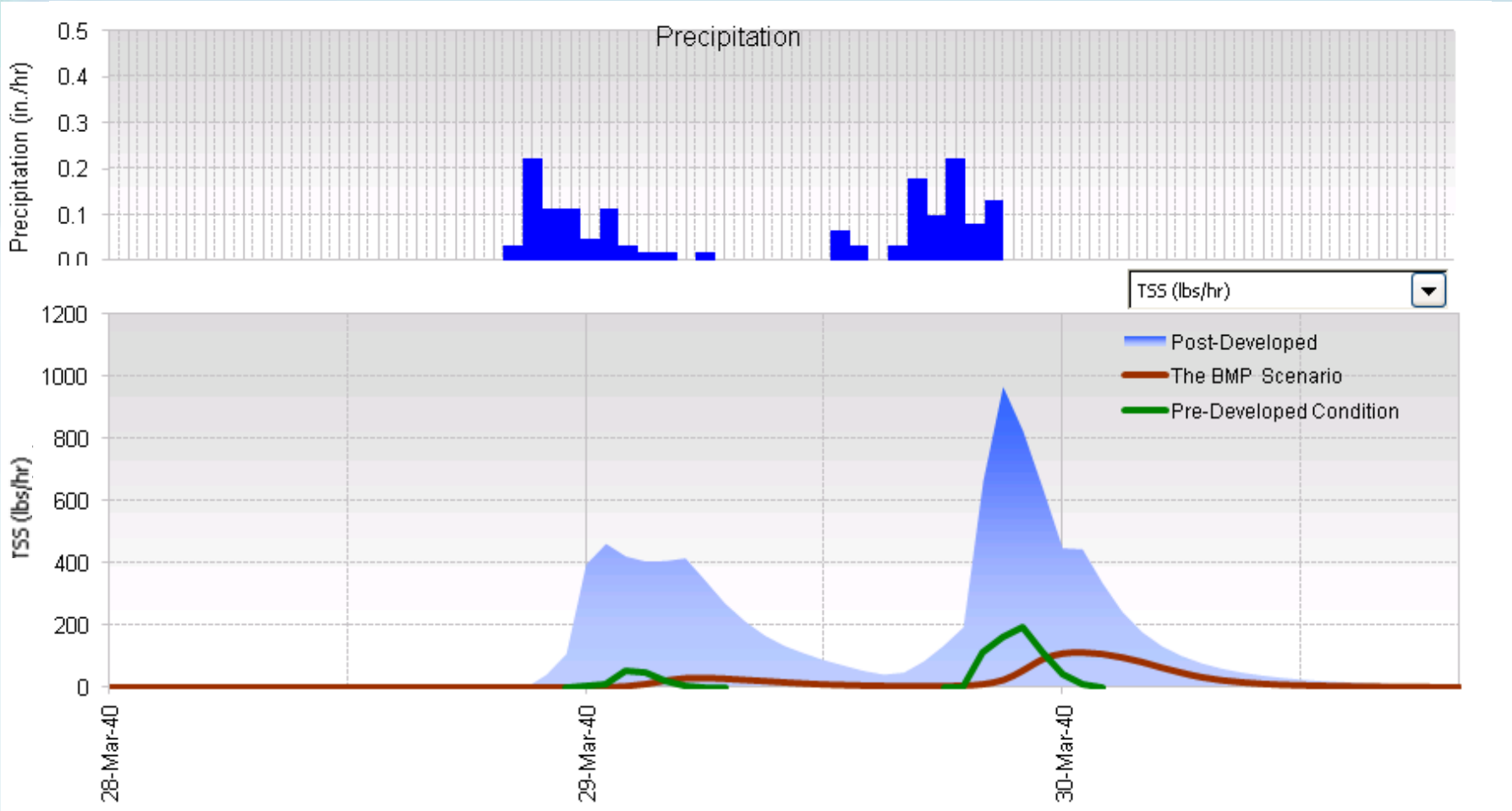
Total Suspended Solids Optimization

- Rainfall and runoff response – select solution



Total Suspended Solids Optimization

- Rainfall and runoff response – select solution



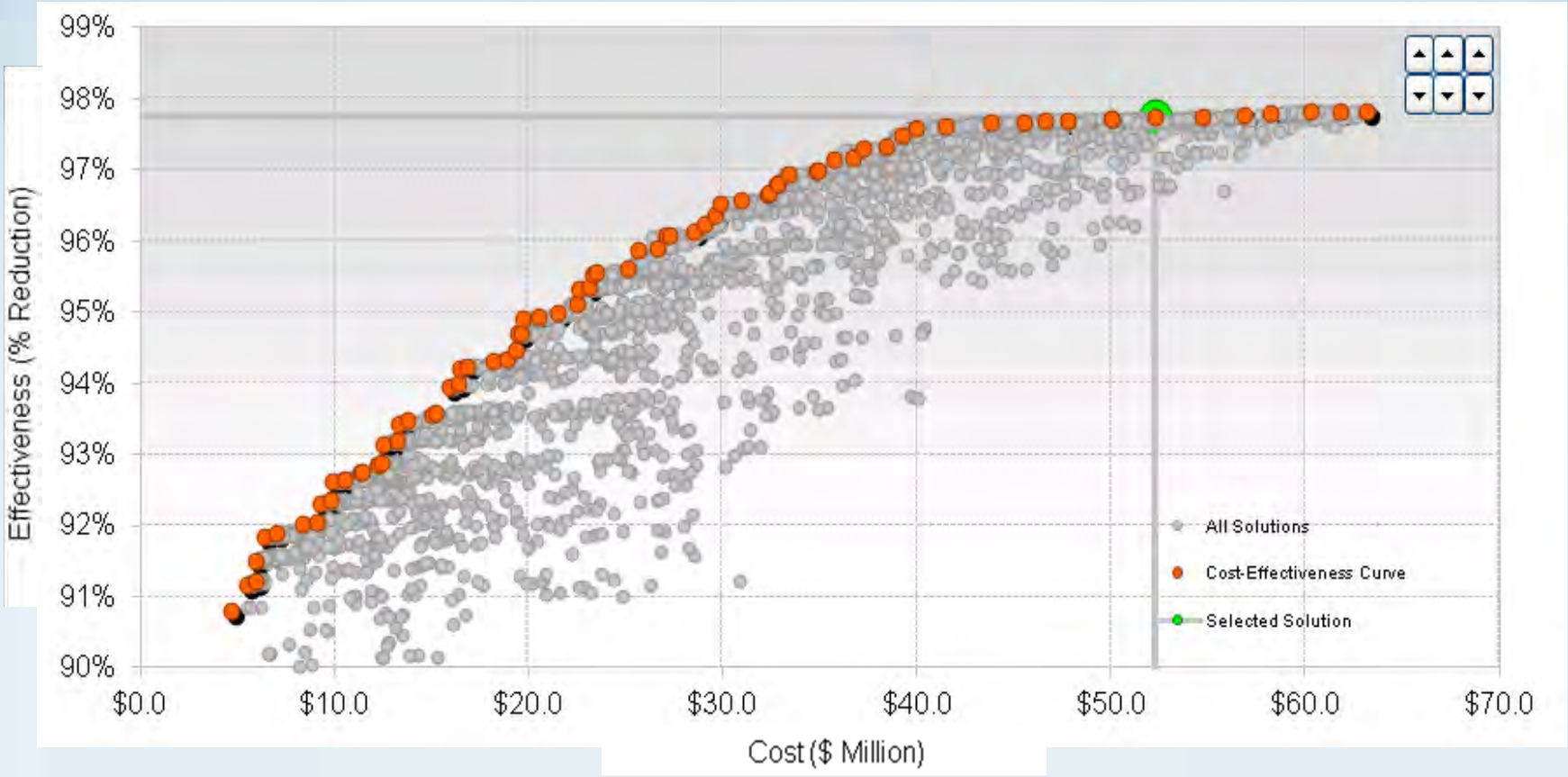
Scenario B

- Distributed bioretention ➔ treatment of right-of-way and parcel runoff
- Distributed permeable pavement ➔ treatment of parcel runoff (parking lots)
- Regional treatment (wetland and wet pond) ➔ treatment at bottom of basin

NSGA-II: Scenario B

Total Suspended Solids Optimization

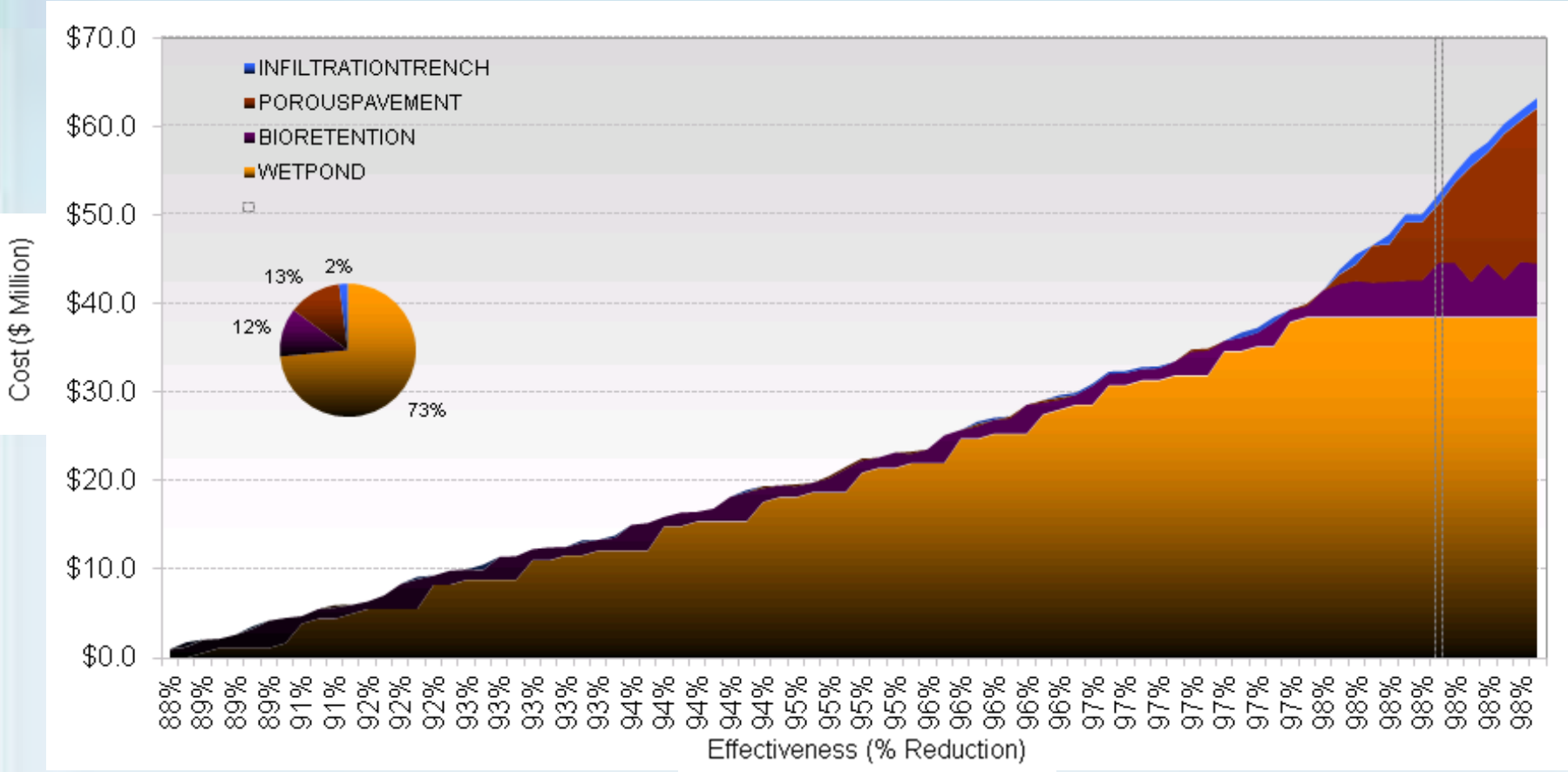
- Cost-effectiveness curve



NSGA-II: Scenario B

Total Suspended Solids Optimization

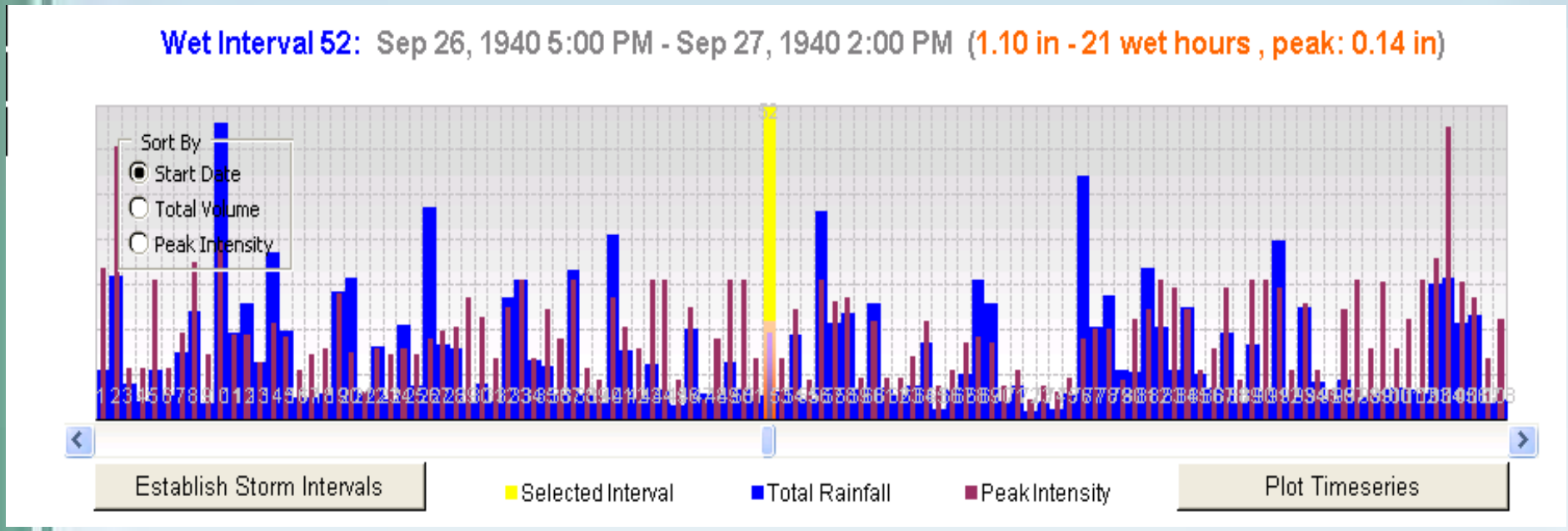
- Cost distribution by BMP



NSGA-II: Scenario B

Total Suspended Solids Optimization

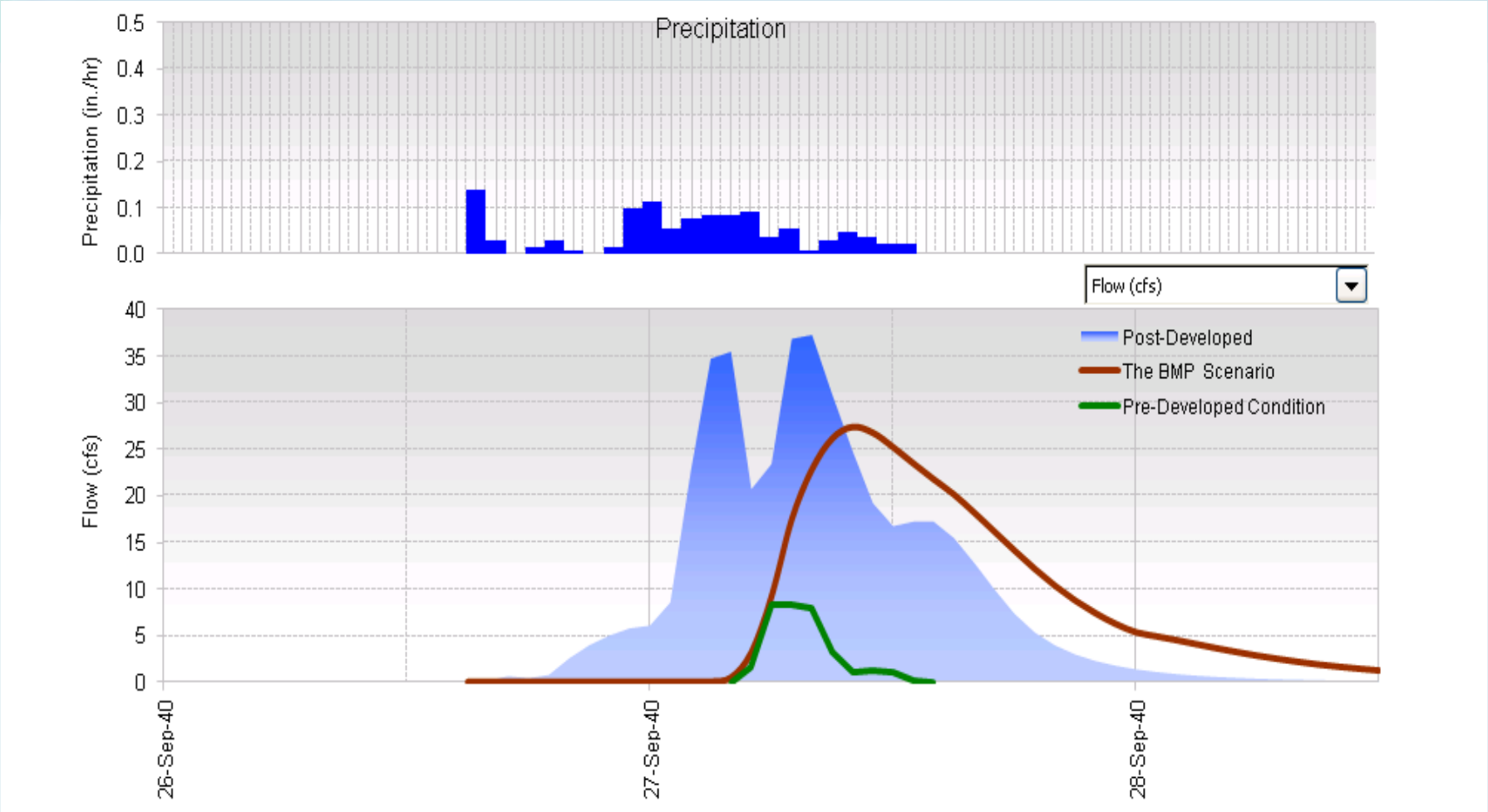
- Rainfall and runoff response



NSGA-II: Scenario B

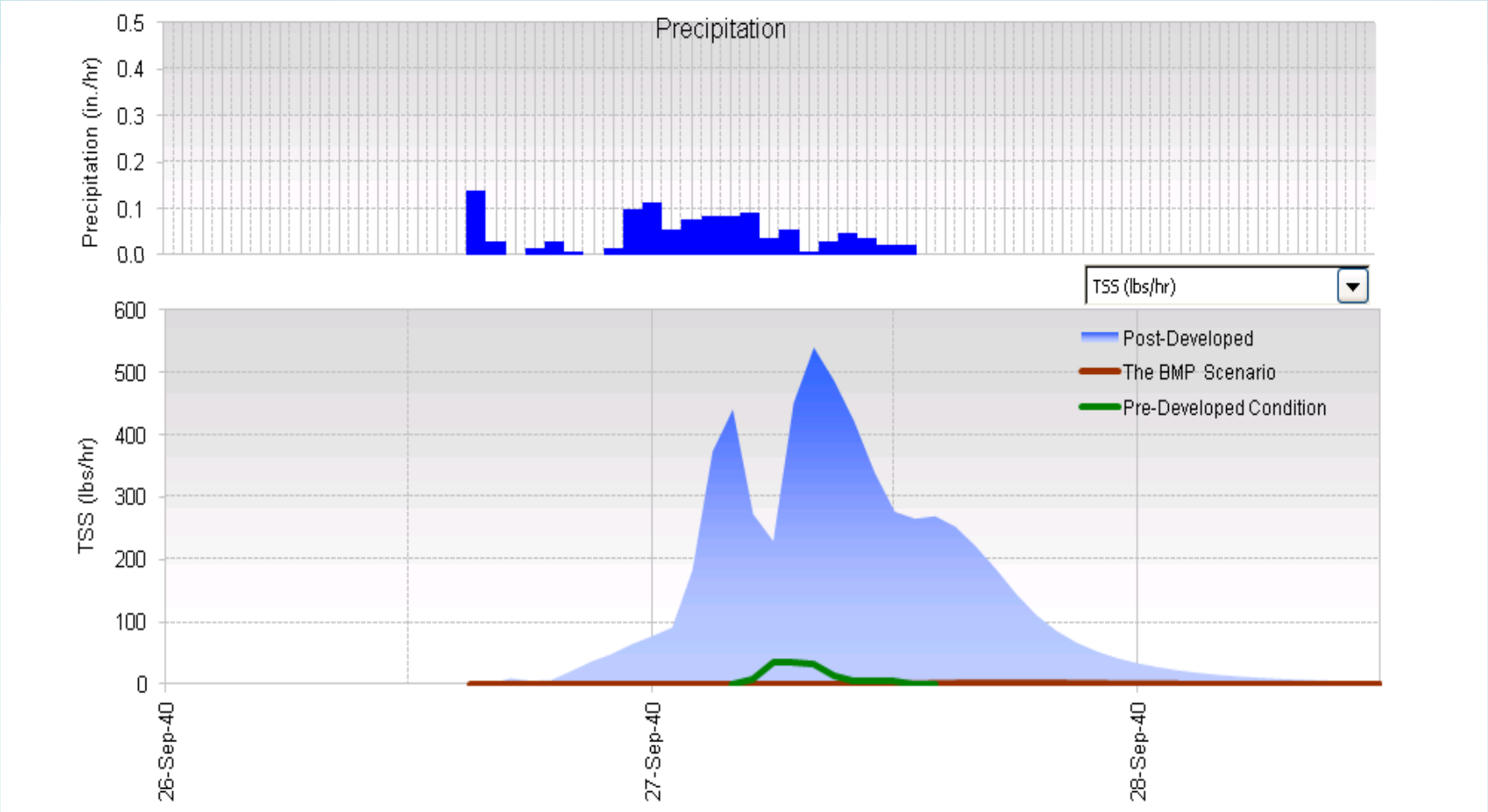
Total Suspended Solids Optimization

- Rainfall and runoff response – select solution



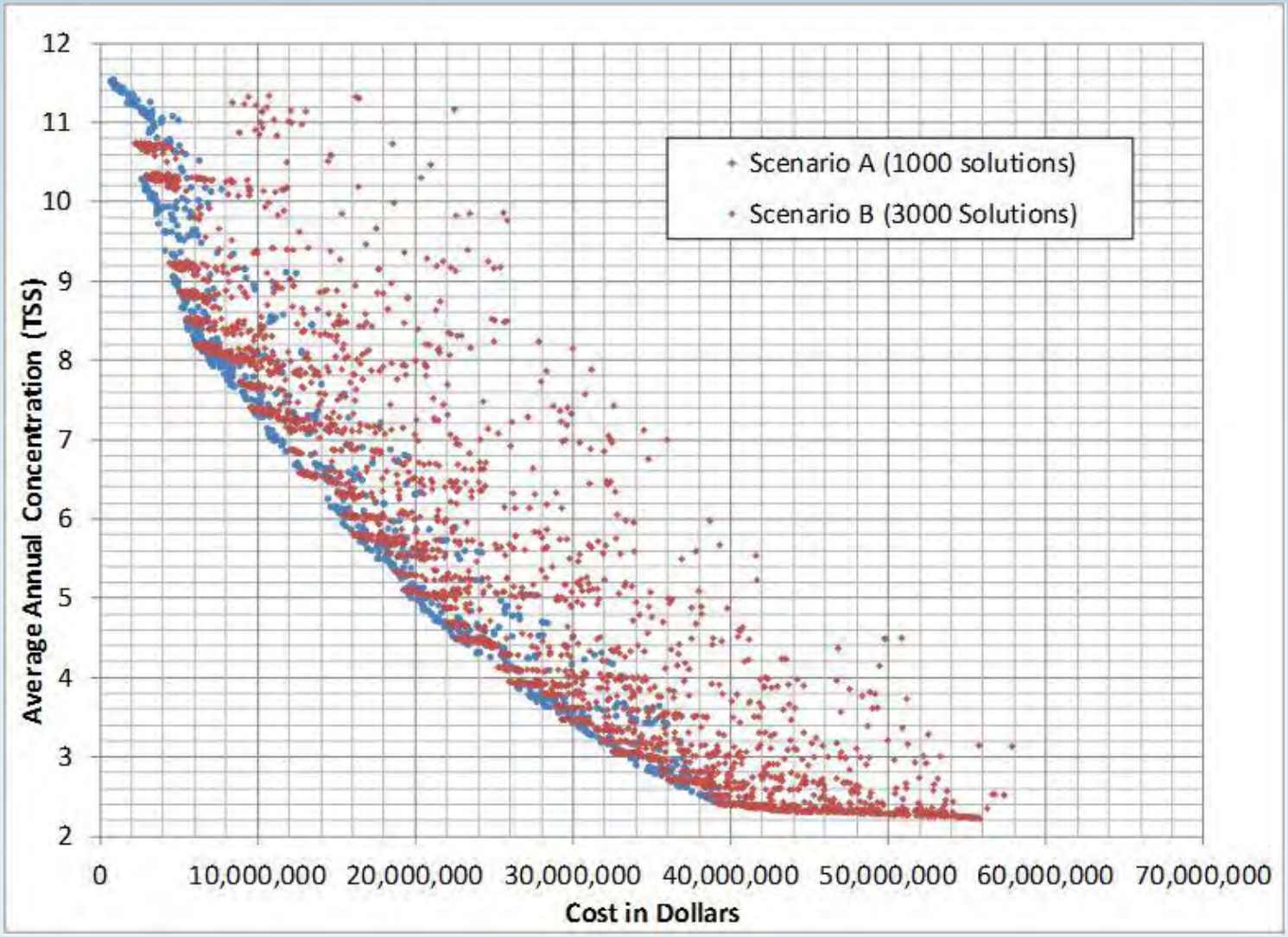
Total Suspended Solids Optimization

- Rainfall and runoff response – select solution



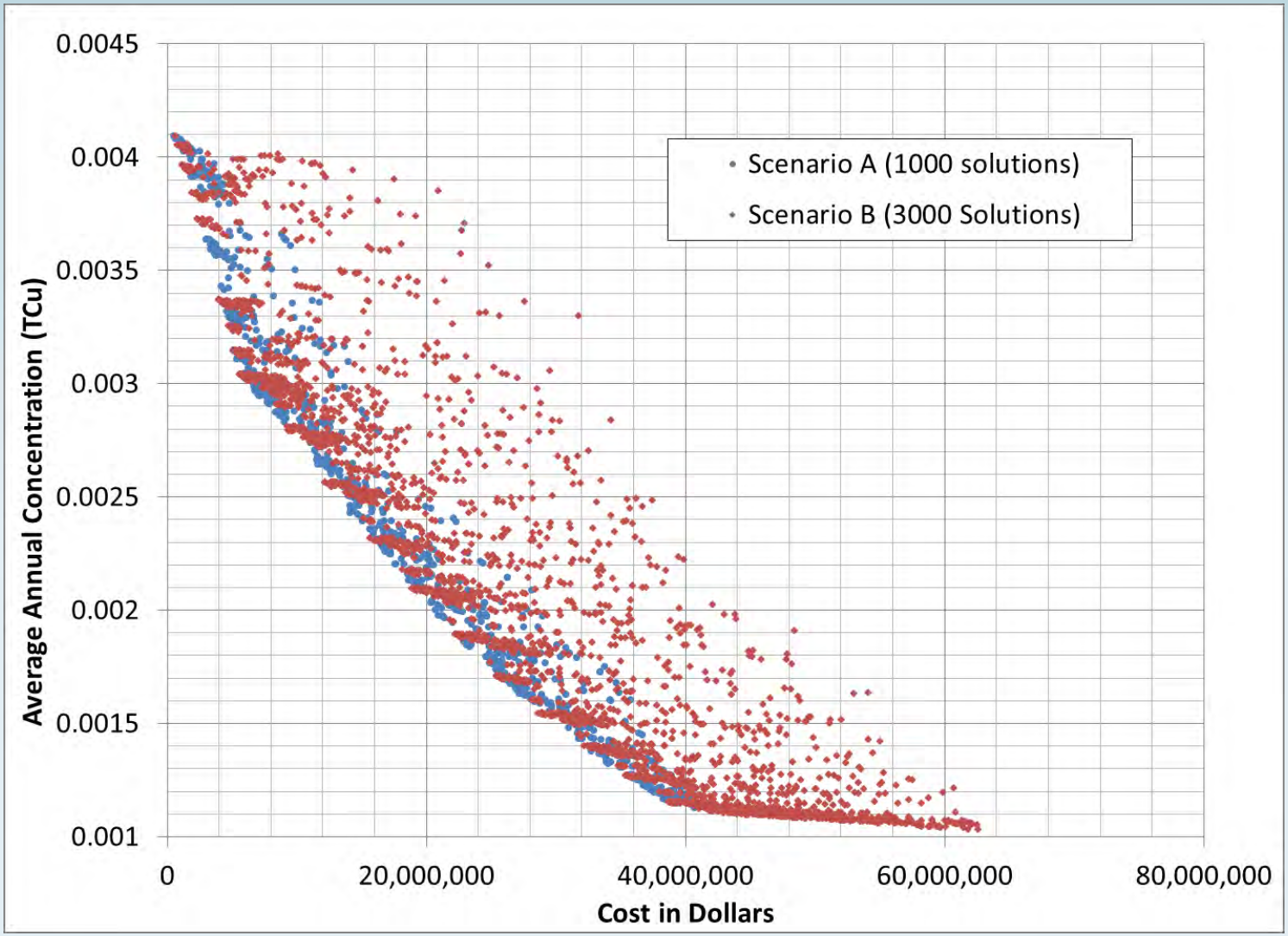
NSGA-II: Scenario A & B

Total Suspended Solids Optimization



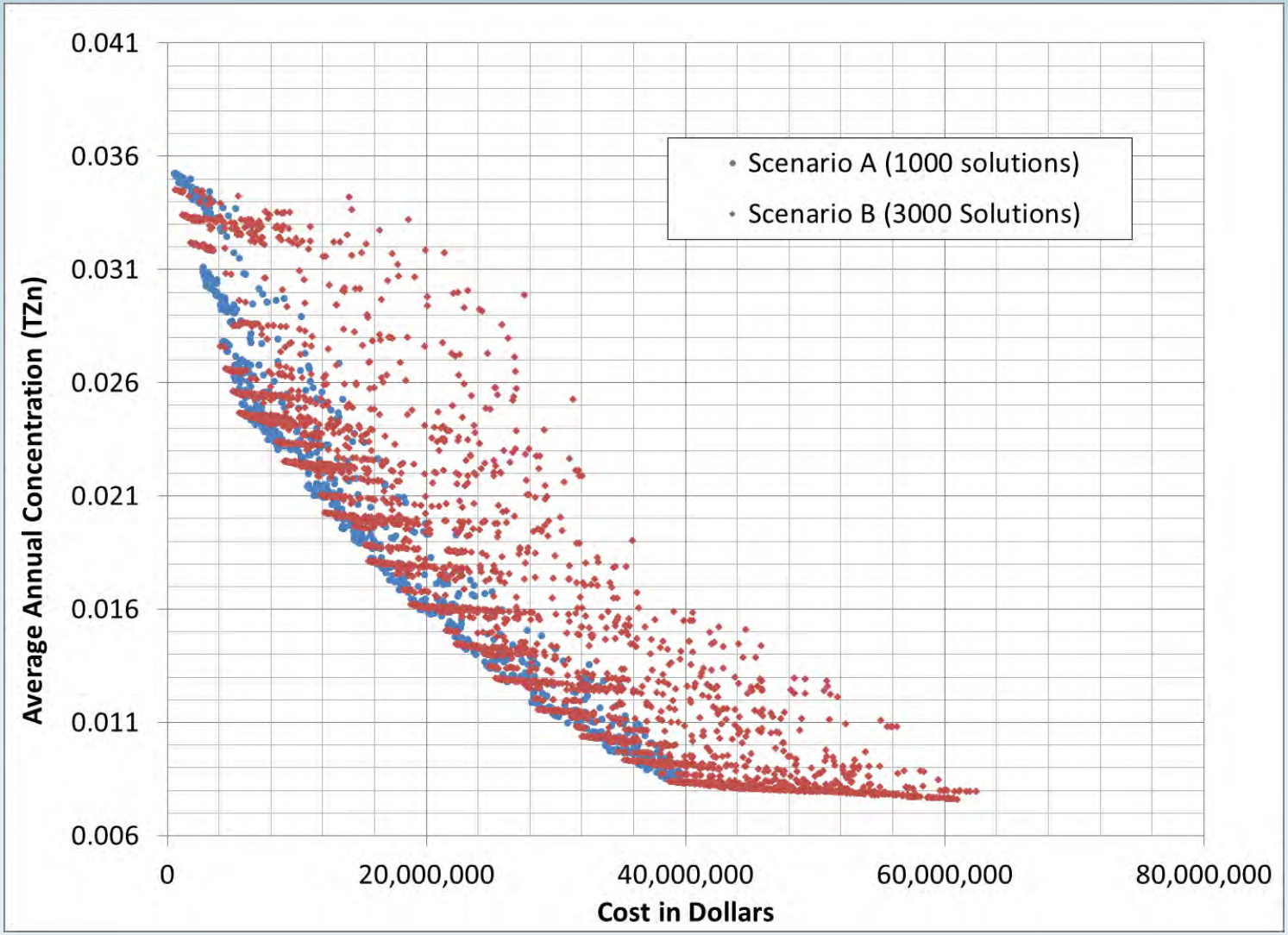
NSGA-II: Scenario A & B

Total Copper Optimization



NSGA-II: Scenario A & B

Total Zinc Optimization



SUSTAIN Model Results

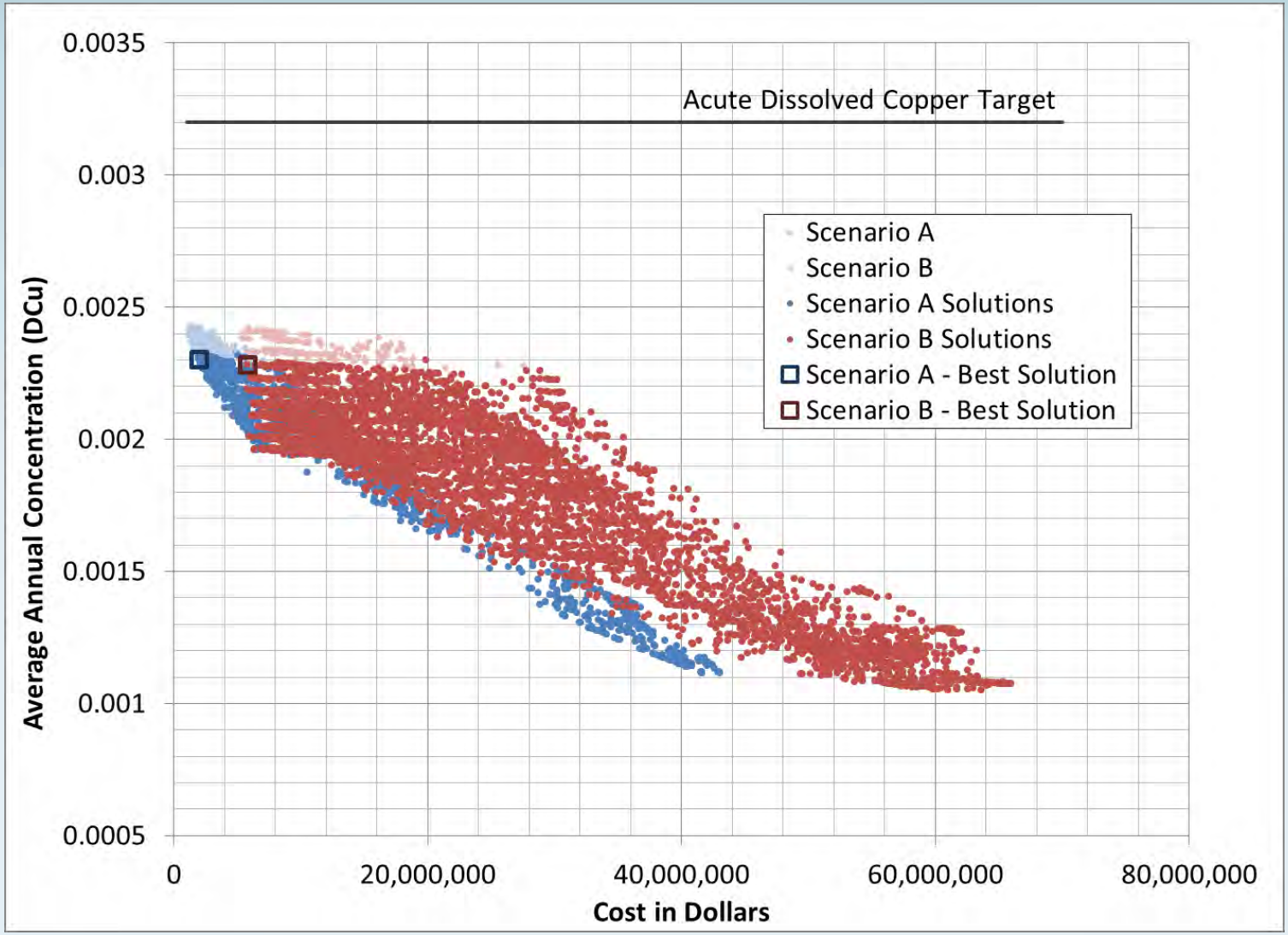
Scatter Search

- Determine most cost-effective solution for meeting multiple targets
  - Dissolved copper and zinc
    - Acute and chronic exposure
  - Chrysene evaluated for each optimization against nation recommended standard

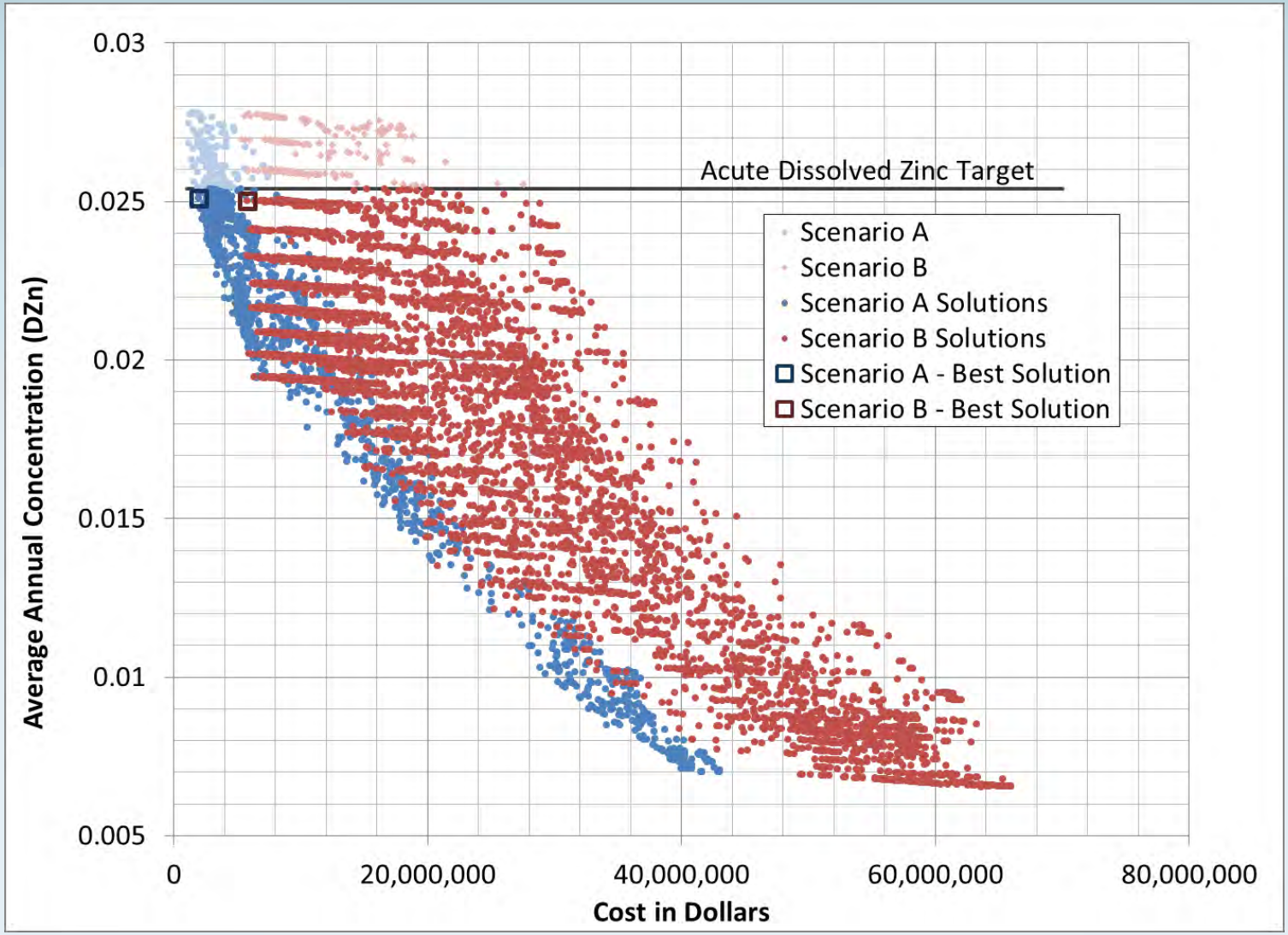
Acute Water Quality Standards

- Dissolved Copper → 3.2 µg/L
- Dissolved Zinc → 25.4 µg/L

Acute Water Quality Standards - Copper



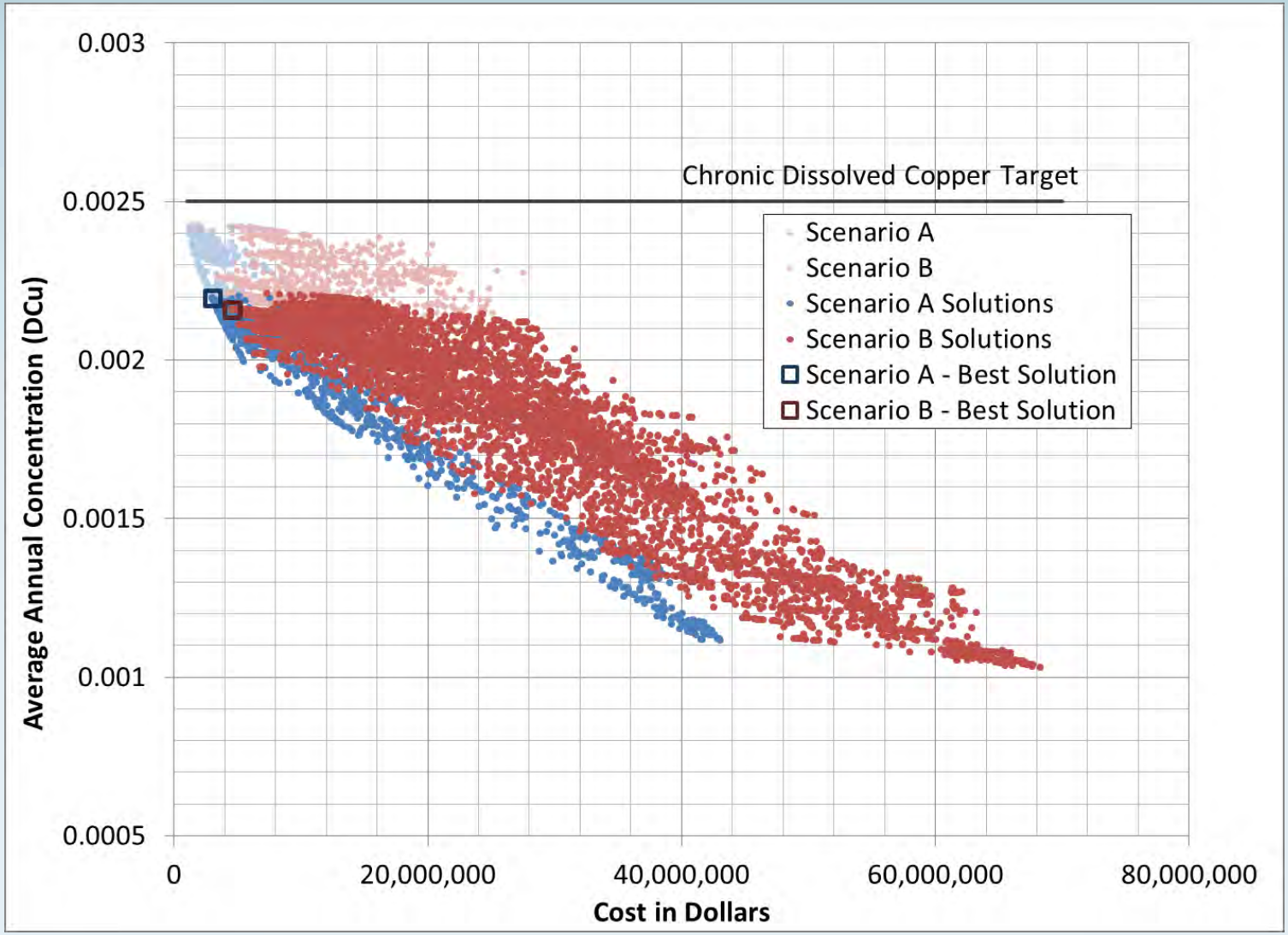
Acute Water Quality Standards - Zinc



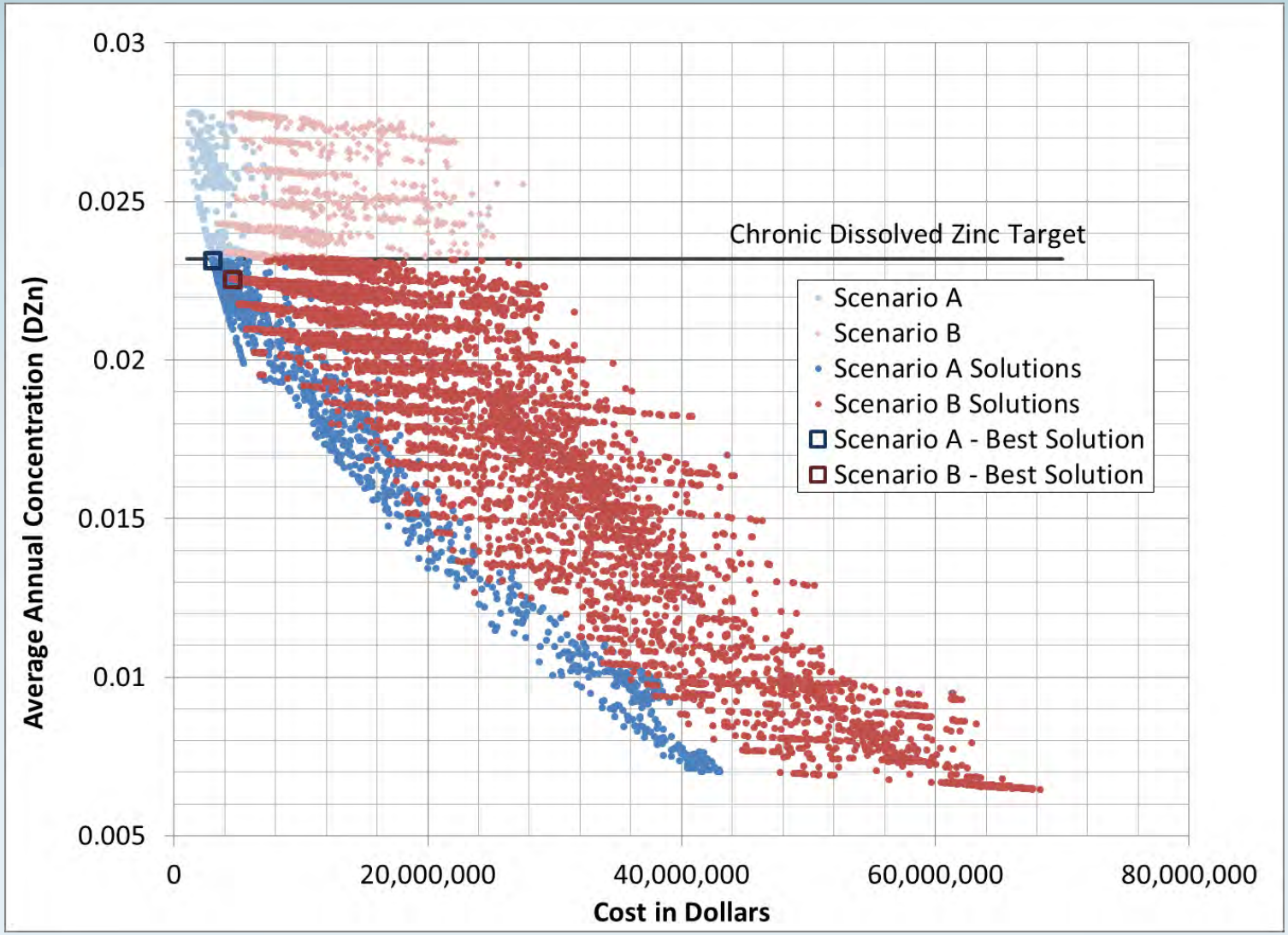
Chronic Water Quality Standards

- Dissolved Copper ➔ 2.5 µg/L
- Dissolved Zinc ➔ 23.2 µg/L

Chronic Water Quality Standards - Copper



Acute Water Quality Standards - Zinc



SUSTAIN Model Results

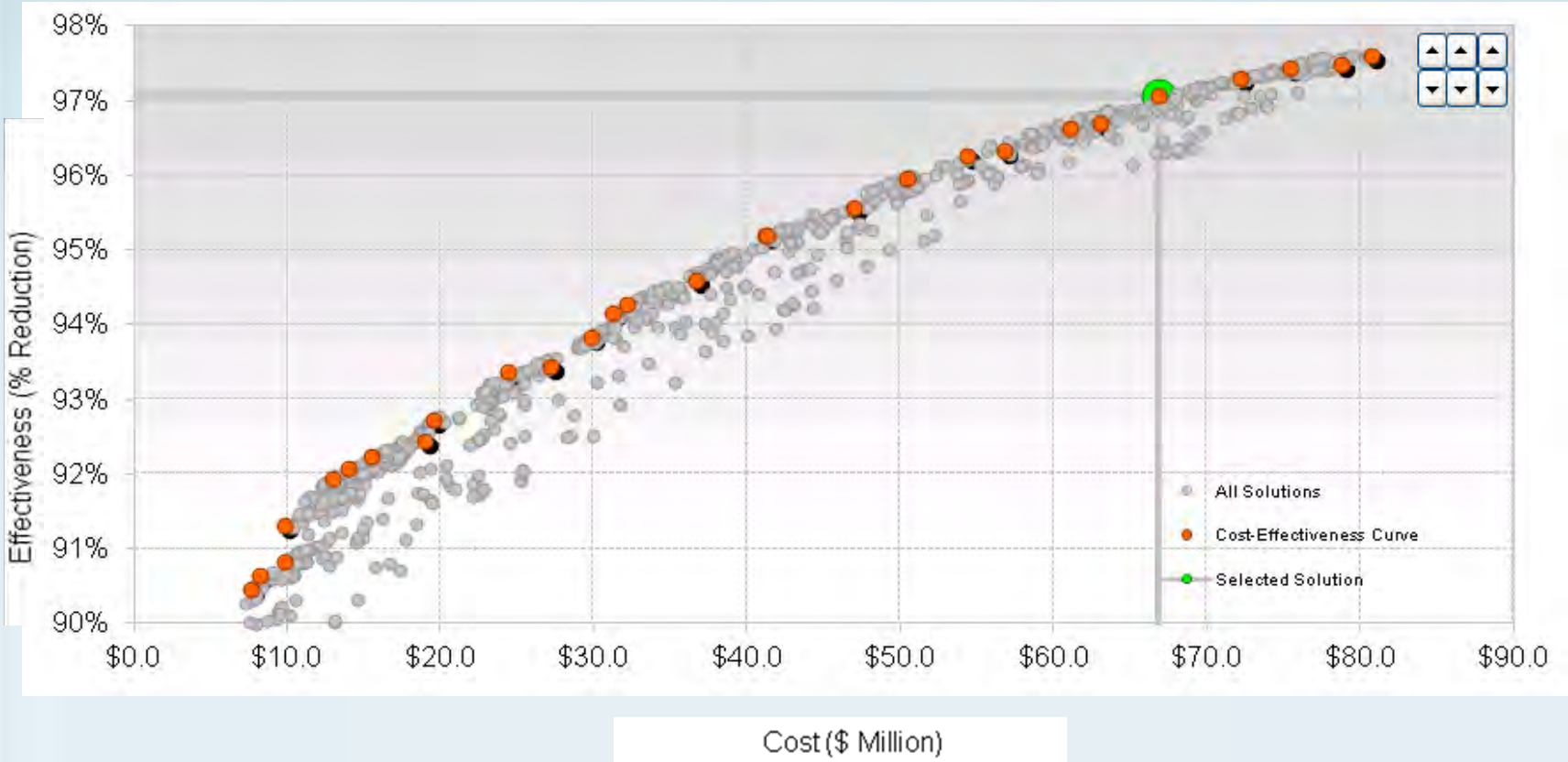
Sensitivity Analysis

- Test sensitivity of BMP costs on SUSTAIN BMP selection
  - Scenario A
  - Regional facilities → most cost effective
  - Increase regional facility cost (wetland and wet pond) by 100%
  - Results:
    - Total cost of solutions increase
    - Model still prioritizes wetlands and wet ponds over bioretention and permeable pavement

SUSTAIN Model Results

Sensitivity Analysis

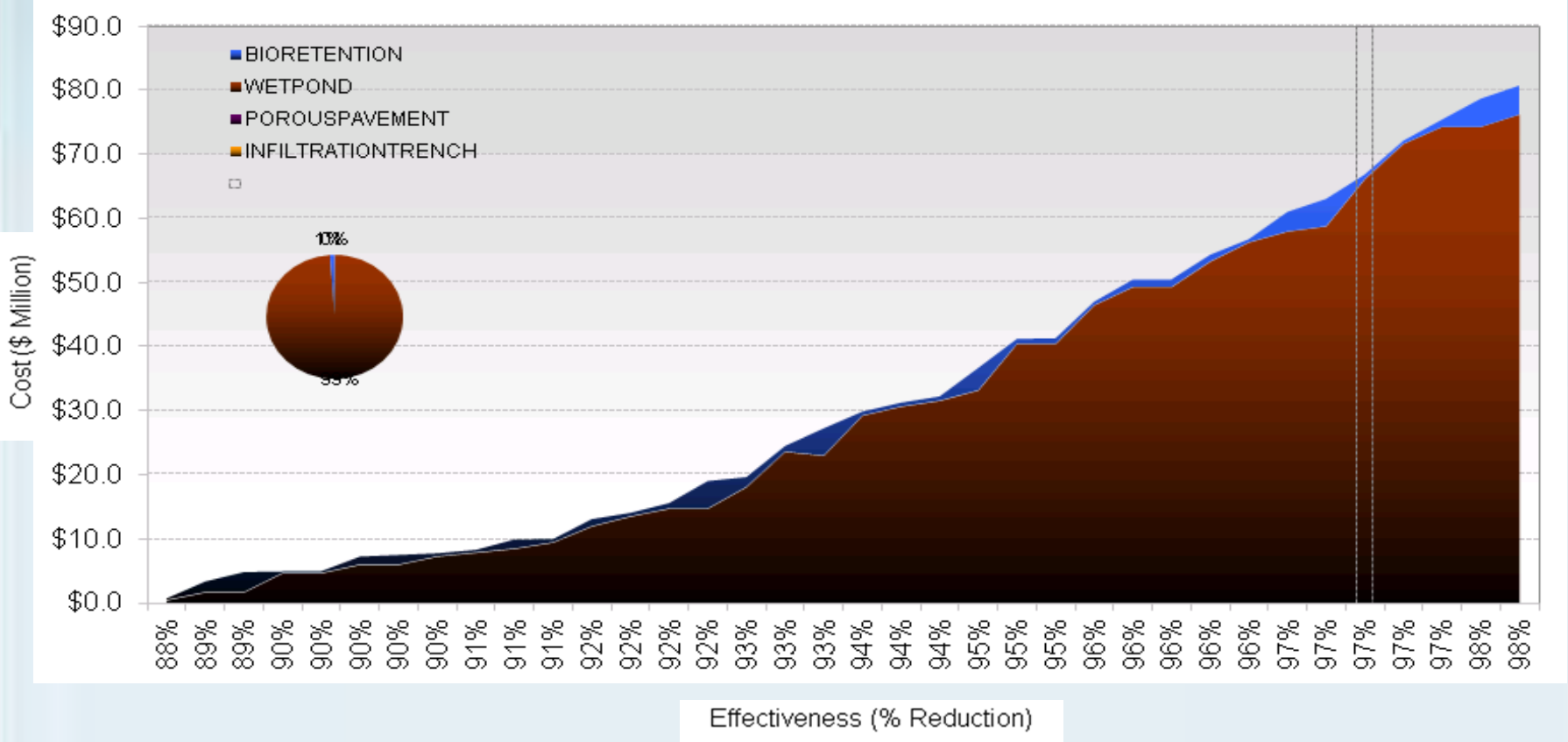
- Cost-effectiveness curve: 100% increase in regional facility costs



SUSTAIN Model Results

Sensitivity Analysis

- Cost distribution by BMP: 100% increase in regional facility costs



SUSTAIN Model Results

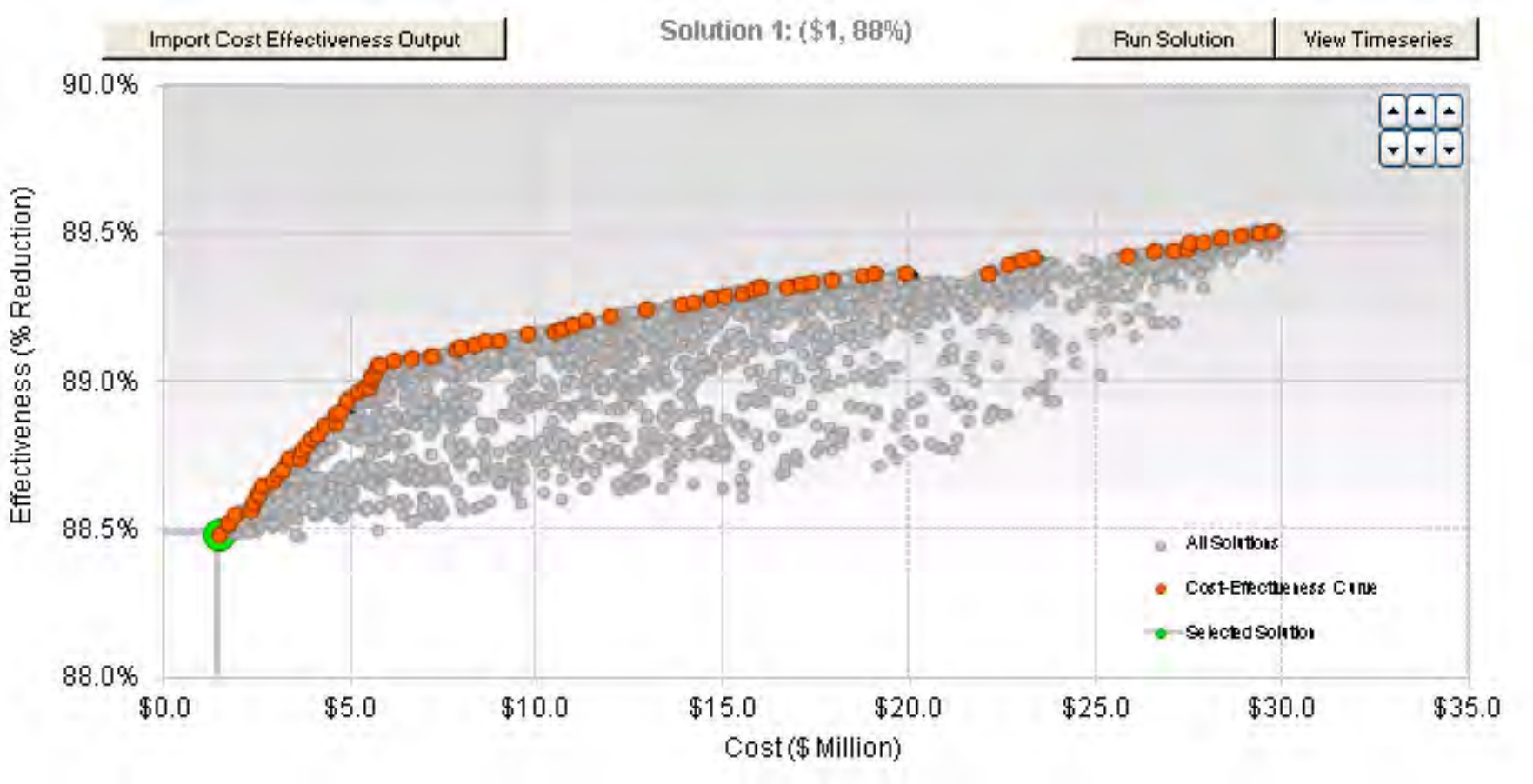
Sensitivity Analysis

- Test significance of BMP selection options on SUSTAIN BMP selection and costs
  - Scenario B
  - Remove regional facilities from simulation
  - Results:
    - Model selects bioretention (most cost-effective)
    - Similar results at lower % removal

SUSTAIN Model Results

Sensitivity Analysis

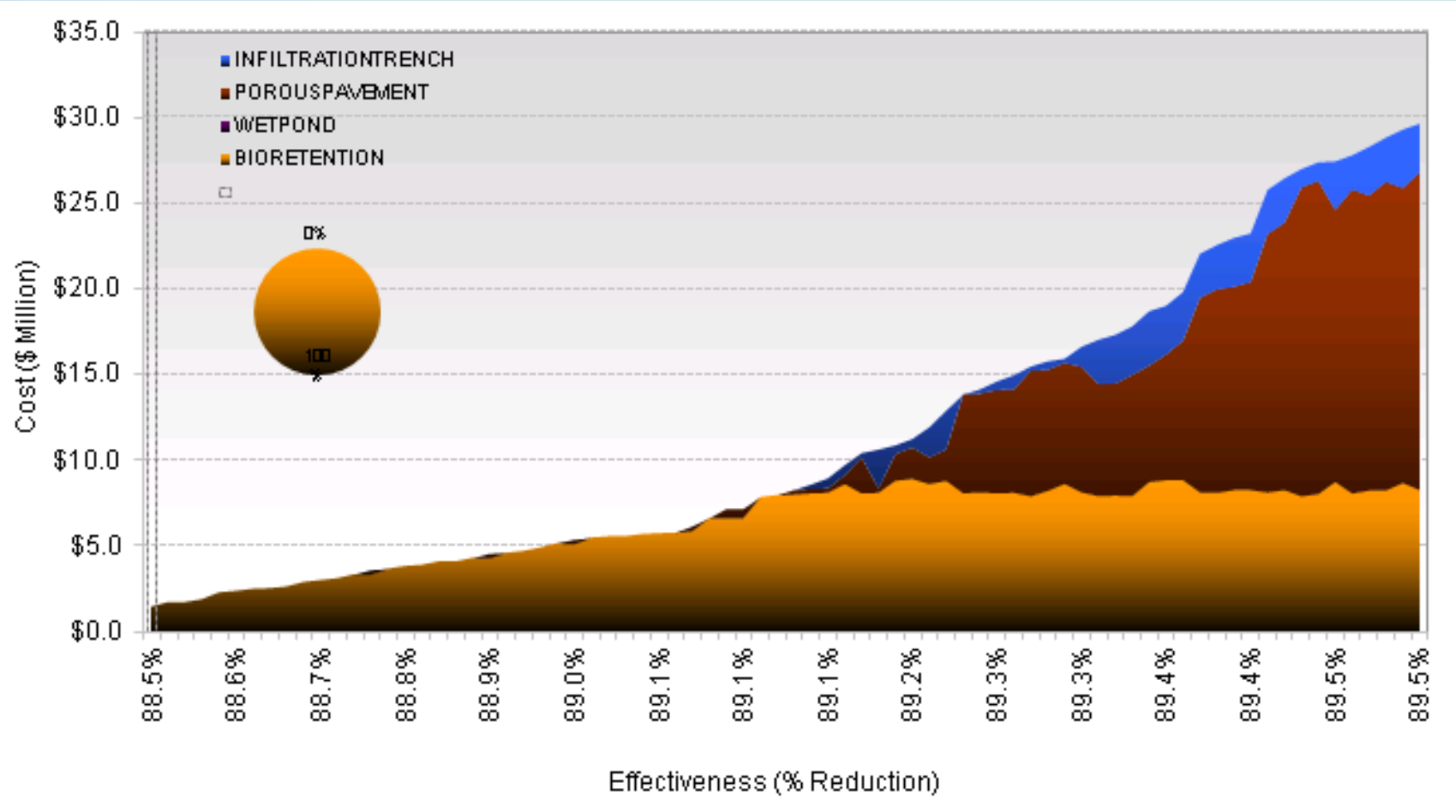
- Cost-effectiveness curve: no regional facilities



SUSTAIN Model Results

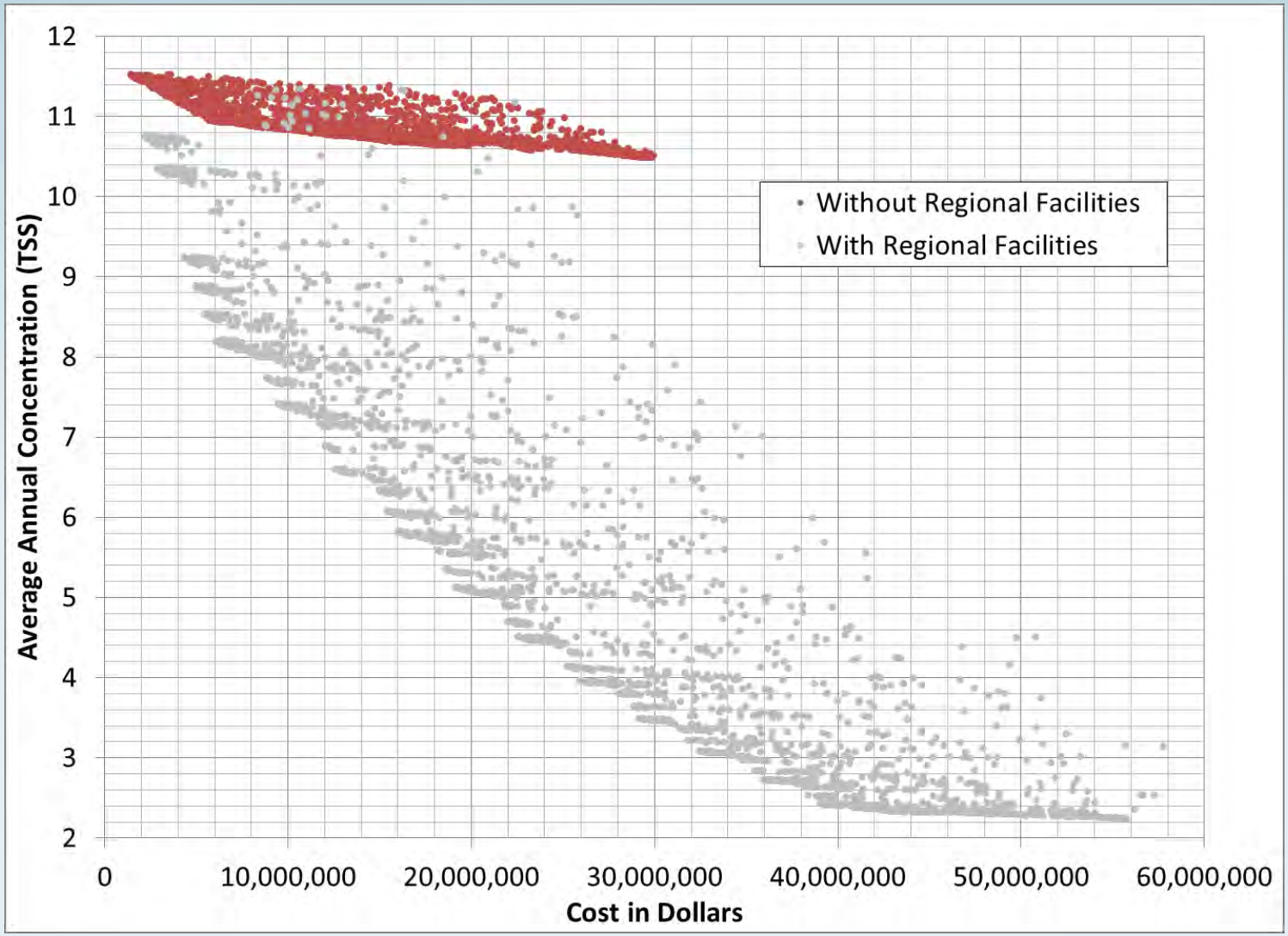
Sensitivity Analysis

- Cost distribution by BMP: no regional facilities



SUSTAIN Model Results

Sensitivity Analysis



Ancillary Flow Control Benefits

- Initial approach:
  - compare recurrence interval statistics for 2-, 10-, 25-, and 50-year flows for existing conditions and retrofit scenarios
  - long term precipitation series (i.e., the 158-year extended series)
- *SUSTAIN* model not stable for this long-term simulation period, so:
  - simulation period was shortened to 7-yrs for existing conditions runs
  - further shortened to 2-yrs for optimization scenarios due to run time limitations
  - flow statistics (e.g., recurrence interval flows) could not be evaluated
- Final approach:
  - Compare total runoff volume and maximum peak flow value for the 2-year time series

SUSTAIN Model Results

Ancillary Flow Control Benefits

- Scatter search ➔ single, optimized solution
- Scenario A ➔ full convergence

Scenario	Optimization	Volume (cf)	Volume Reduction (%)	Maximum Peak Flow (cfs)	Maximum Peak Flow Reduction (%)
Existing Conditions	NA	126,343,000	--	137.9	--
A	Acute	99,922,000	21%	64.0	54%
A	Chronic	99,663,000	21%	64.0	54%

Conclusions

HERRERA

Federal Way SUSTAIN Model

- Regional versus distributed BMPs??
  - Externally generated time series for hydrographs and pollutographs
  - Explicit and aggregate representation of BMPs
  - BMP pollutant routing with CSTRs in series and removal with first order decay rates
  - Optimizing using both the NSGA-II and Scatter search algorithms

HERRERA

User Experience

- Optimization module
- Post Processor
- Preconfigured suite of BMPs
- Flexibility for defining land surfaces, routing, and BMP configurations
- Editable input files provide open platform for model modifications
- Flexibility for incorporating external time series

HERRERA

User Experience

- Error catching and bugs
- Model documentation
- Complex model directory structure
- User interface design
- No post processor for reviewing model quality
- Software compatibility

HERRERA

Limitations

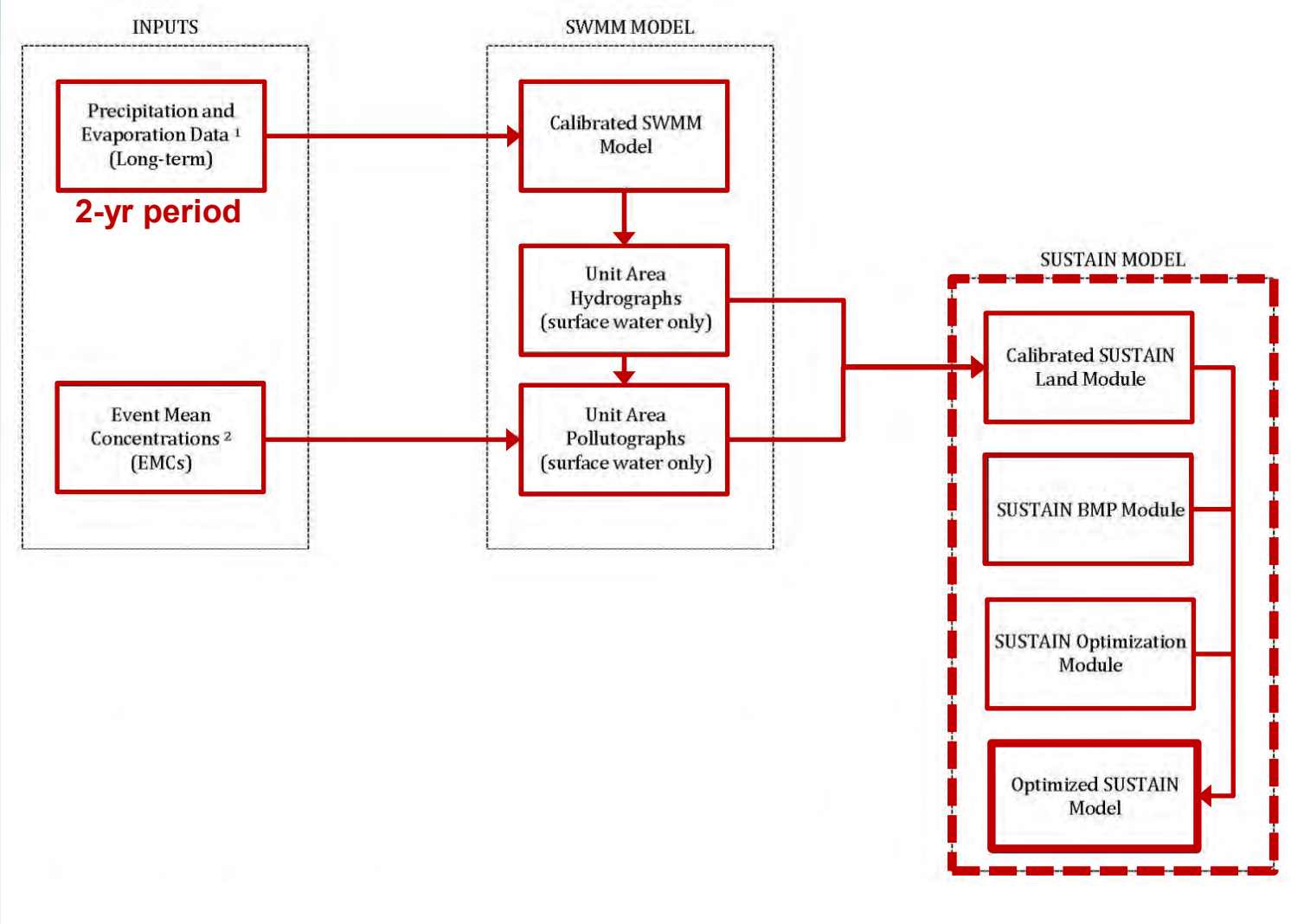
- Routing network
- Runtime considerations
- BMP representation
- BMP selection
- BMP differentiation
- First order decay rates

HERRERA

Extra Slides

HERRERA

SUSTAIN Model Optimization



Pollutograph Development

EMCs by Land Use

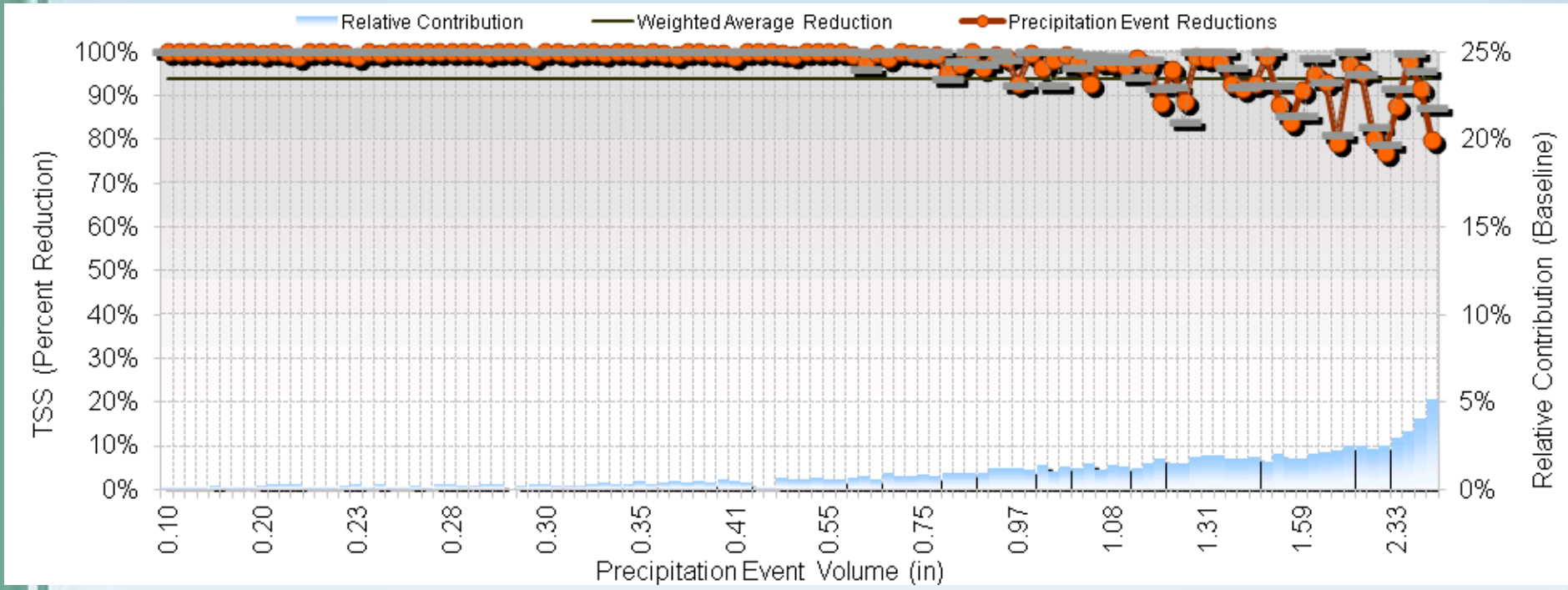
Parameter	Units	Commercial	High-density Residential	Low-density Residential
TSS	mg/L	75.4	50.99	18.98
Total Copper	ug/L	28.42	10.06	3.08
Dissolved Copper	ug/L	11.06	4.1	2.26
Total Zinc	ug/L	124.45	61.49	23.1
Dissolved Zinc	ug/L	57.04	32.21	18.83
Chrysene	ug/L	0.12	0.04	0.12

µg/L: micrograms per liter; mg/L: milligrams per liter

Source: Roberts 2011 personal communication.

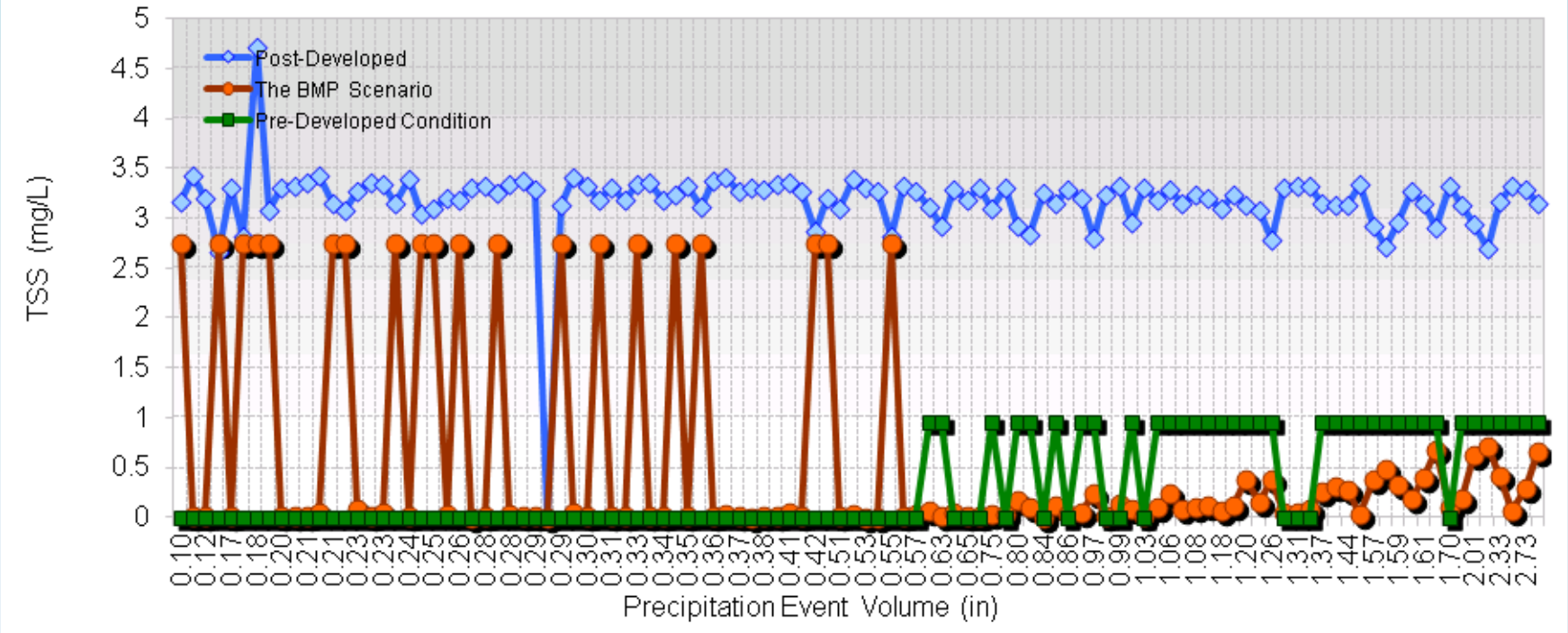
Total Suspended Solids Optimization

- Pollutant Performance Summary



Total Suspended Solids Optimization

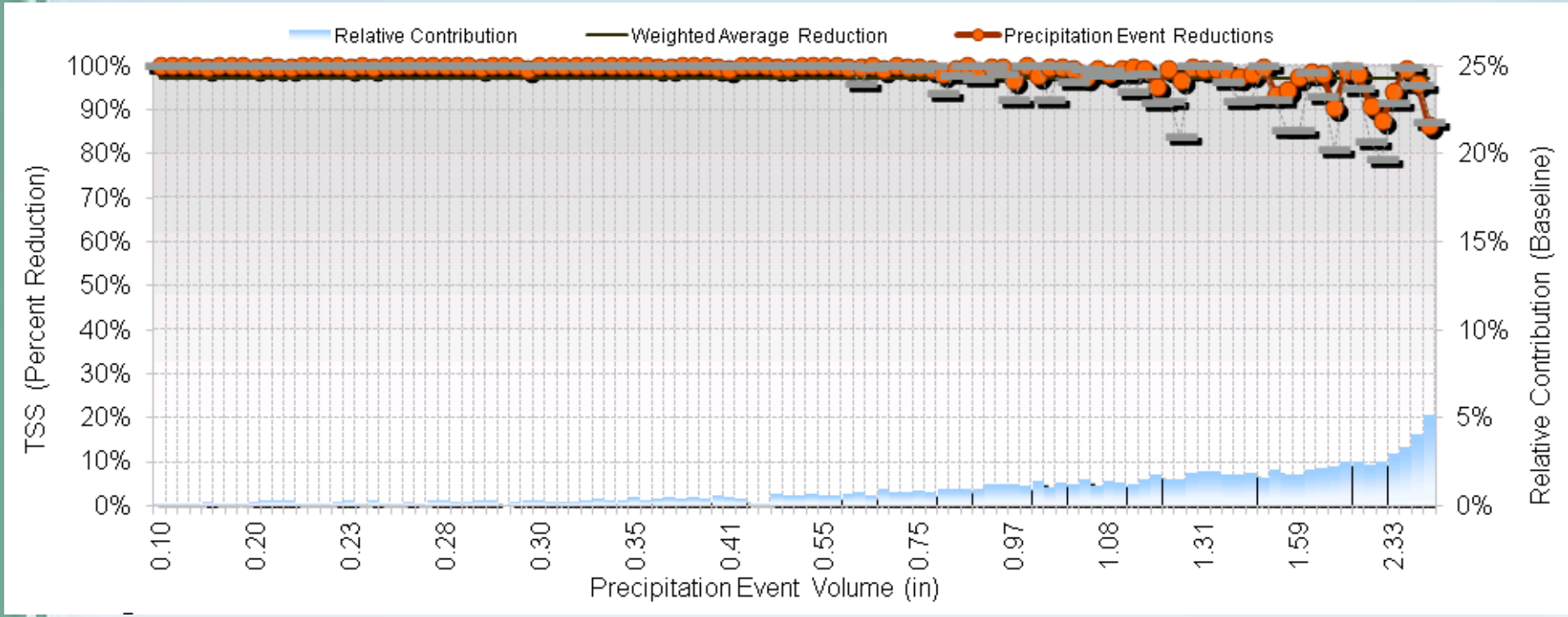
- Pollutant Performance Summary

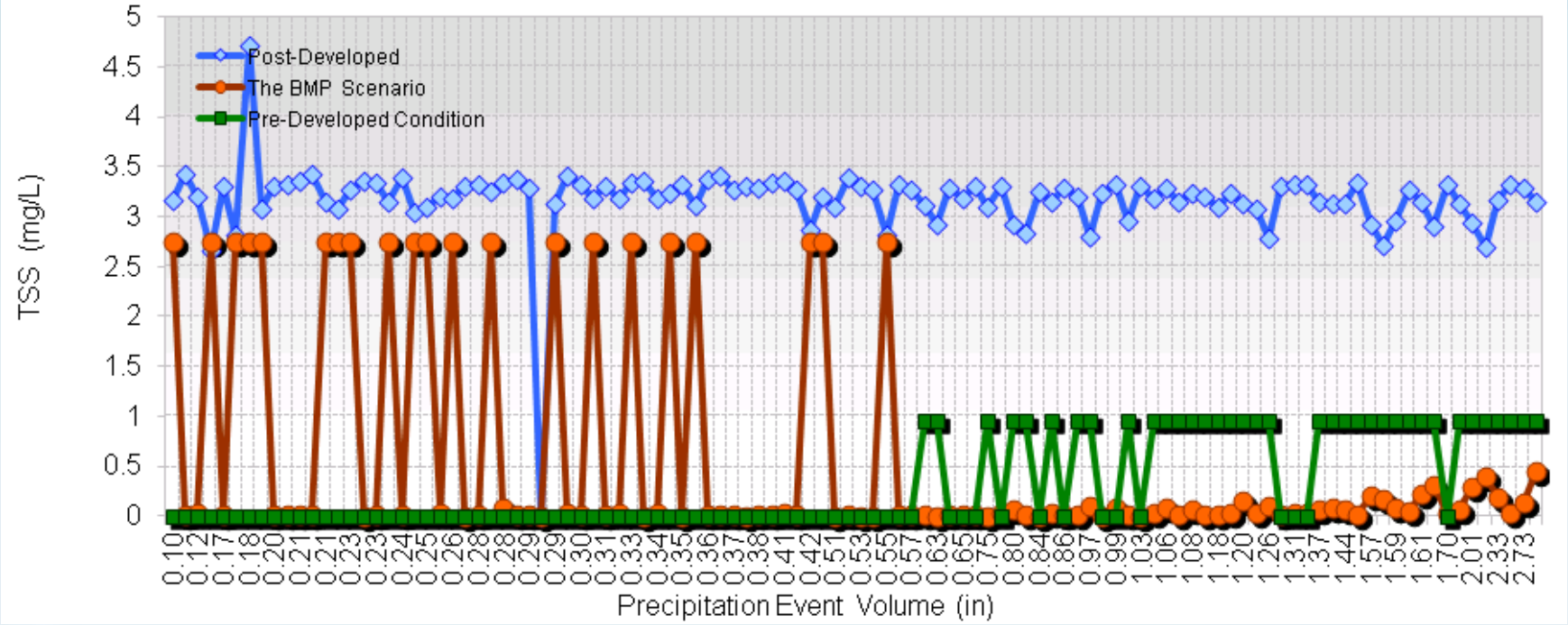


NSGA-II: Scenario B

Total Suspended Solids Optimization

- Pollutant Performance Summary



Total Suspended Solids Optimization

- Pollutant Performance Summary