E. Coli TMDLs in Colorado: Finding Solutions

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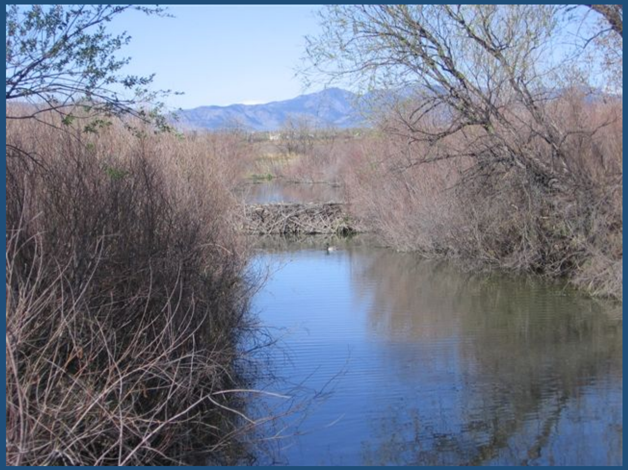
2019 CASFM Crested Butte, CO

WRIGHT WATER ENGINEERS, INC. | City of Fort Collins | BIG DRY CREEK | City of Boulder | MILE HIGH FLOOD DISTRICT | Geosyntec consultants

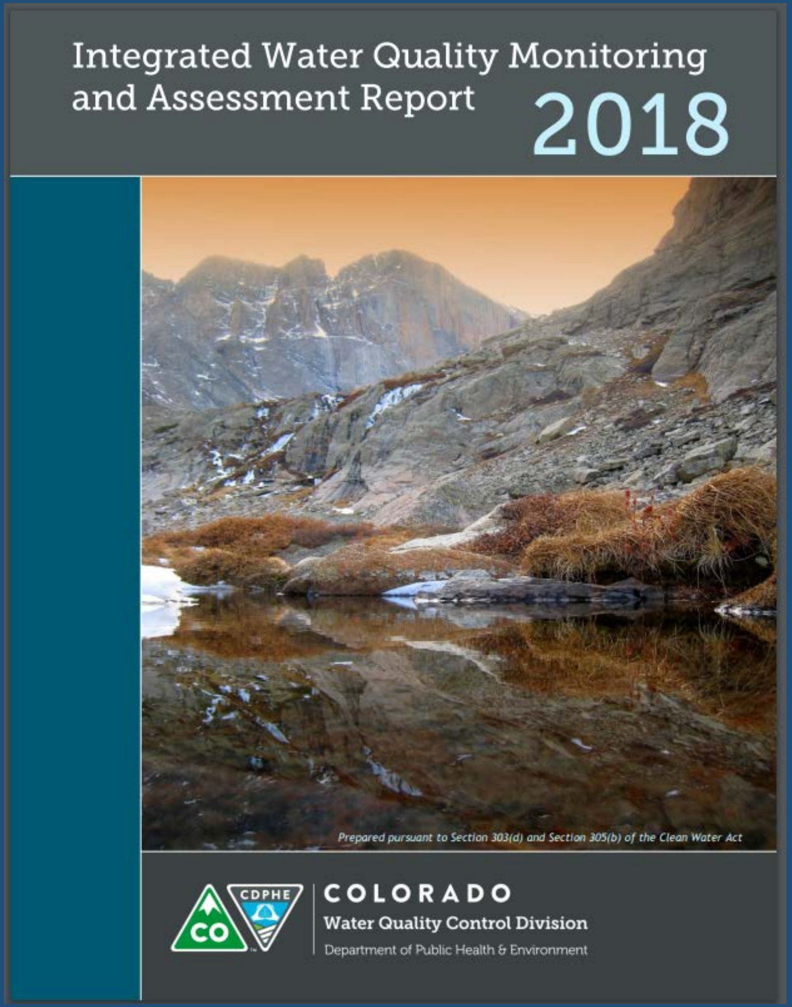
Overview

- What's the problem with E. coli?
- Regulatory Basics
- Resources for MS4s
- Case Studies:
  - Fort Collins
  - Boulder



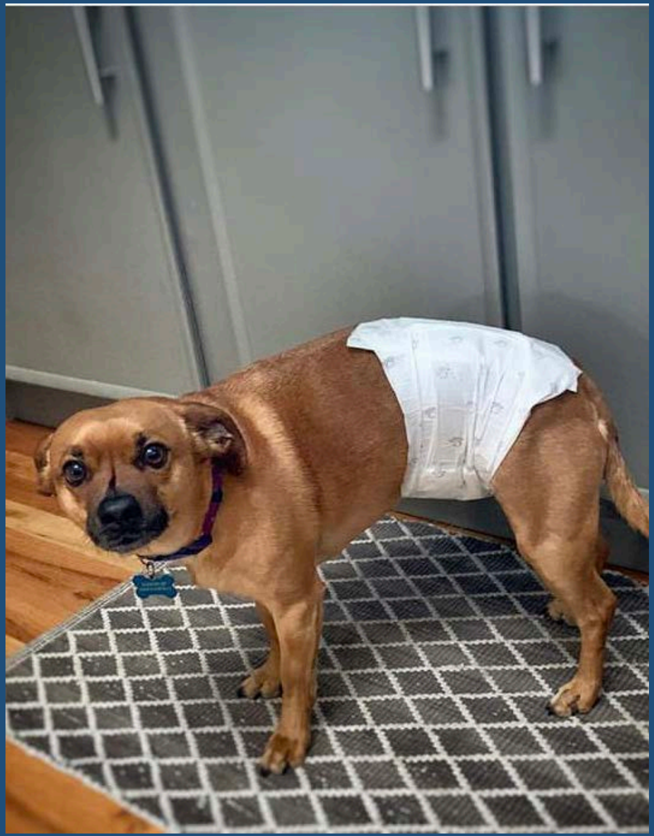

What's the problem with E. coli: 10 Issues

1. Recreating in waters with fecal contamination can make you sick.
2. Over 90 stream segments in Colorado are listed as impaired or on M&E for E. coli.
3. It's easy to exceed the E. coli stream standard, particularly in the summer.
4. Interpretation of monitoring data can be difficult or inconclusive.
5. We don't live in a sterile environment—E. coli can originate from both natural and human-related sources. Health risk from sources may vary.

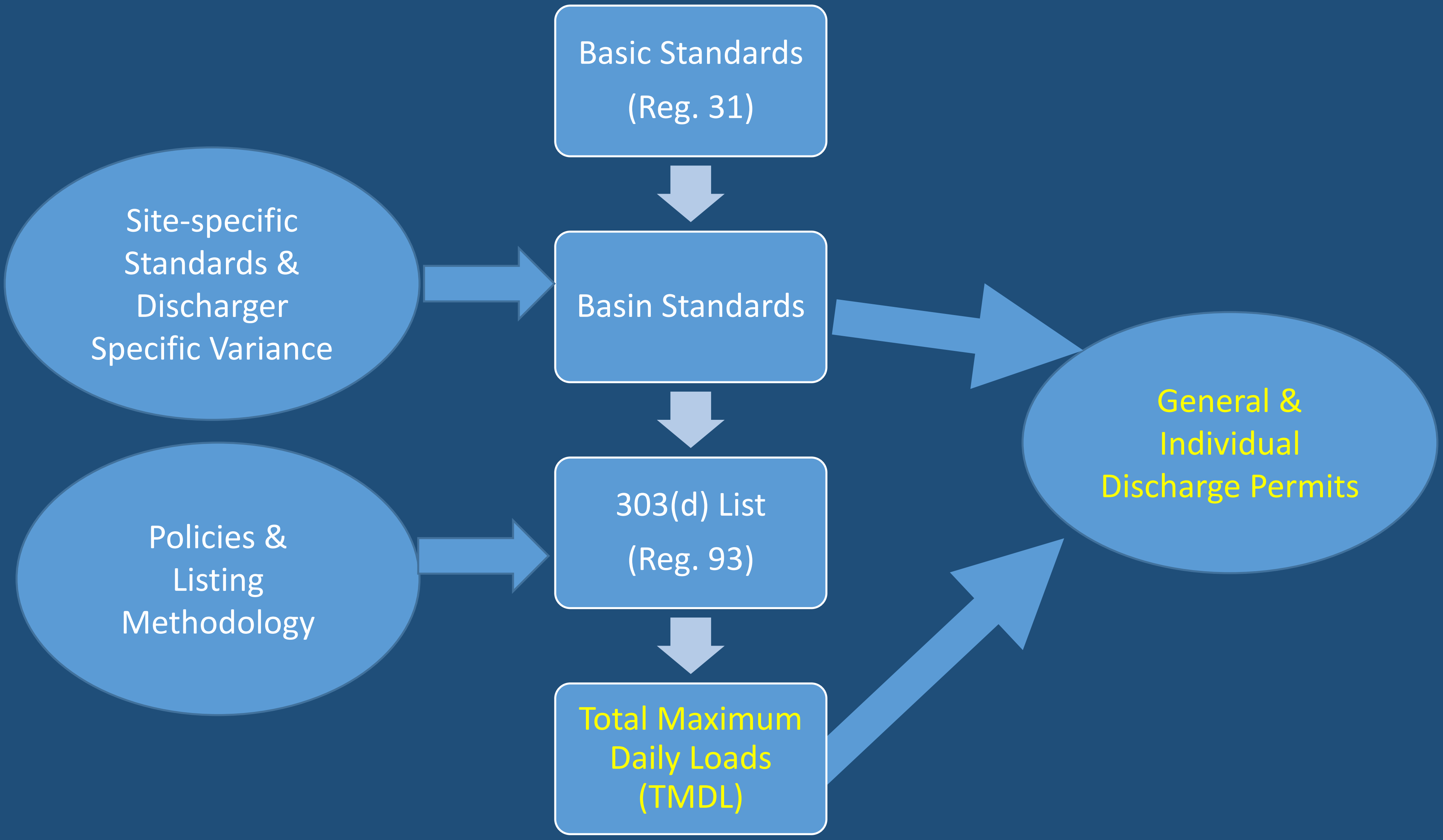


What's the problem with E. coli: 10 Issues

6. Solutions cross multiple disciplines and local government departments.
7. Finding the source(s) can be challenging and expensive.
8. Treating dry and wet weather runoff can be challenging and expensive.
9. In urban areas, there may not be a "silver bullet" that solves the problem.
10. Can the stream standard be consistently attained? If so, how? What are the MS4 permit implications if it's not?



Regulatory Relationships in Colorado: Standards-TMDLs-Permits



Colorado Stream Standards

- Fecal indicator bacteria vs. pathogens (e.g., *E. coli* O157:H7)
- EPA 2012 Recreational Water Quality Criteria
- Colorado stream standards
  - Magnitude: 126 cfu/100 mL (primary contact)
  - Duration: 61-day rolling geometric mean
  - Frequency: Geometric mean not allowed to exceed standard
- 303(d) List updated biennially: over 90 segments in Colorado impaired or on M&E list for *E. coli*

Colorado Use Classification	*E. coli* (cfu/100 mL)
Class E - Existing Primary Contact	126
Class P - Potential Primary Contact	205
Class N - Not Primary Contact	630
Class U - Undetermined	126

Total Maximum Daily Loads (TMDLs) & Implications for MS4s

TMDL = ΣWLA + ΣLA + MOS

Where:

- WLA =the sum of wasteload allocations (point sources such as permitted wastewater and stormwater discharges)
- LA= the sum of load allocations (nonpoint sources and background)
- MOS=the margin of safety

- WWTPs typically not the source in Colorado
- MS4s likely to have requirements in CDPS permits due to TMDLs
- Nonpoint sources often significant

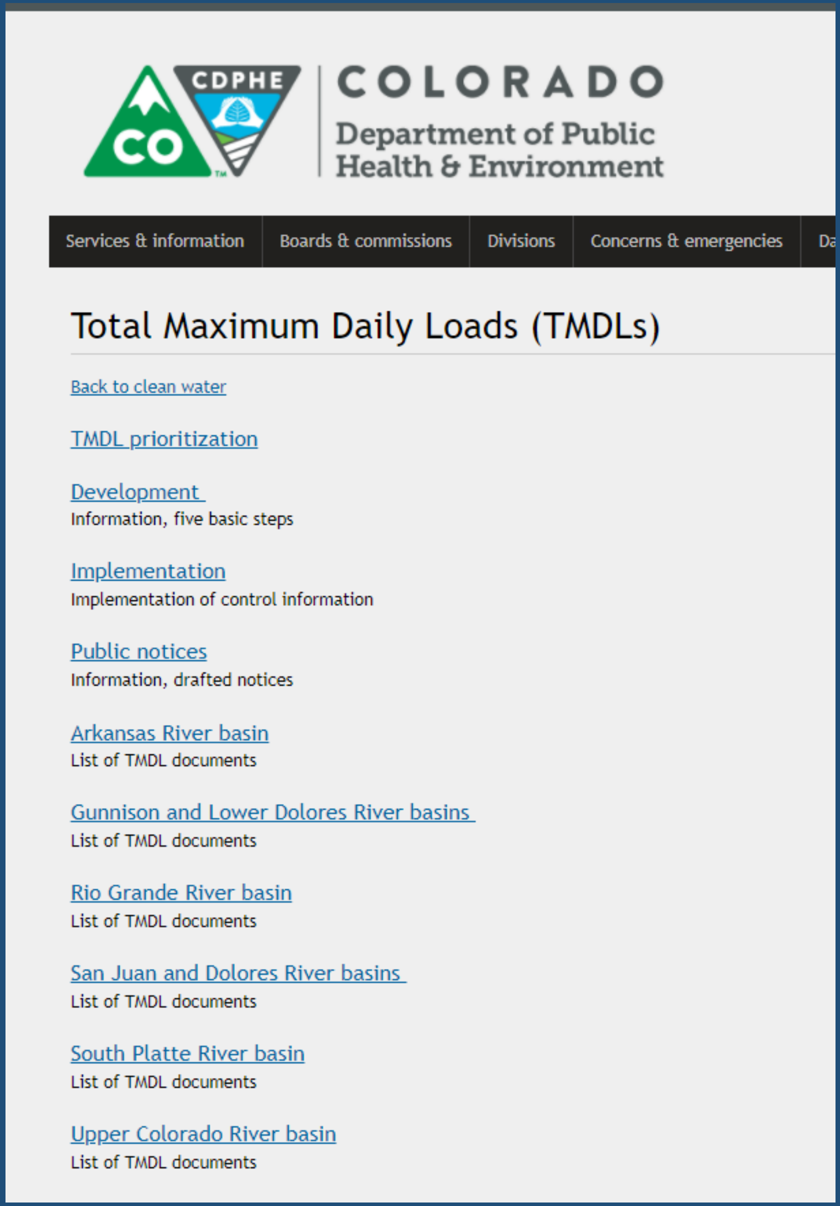
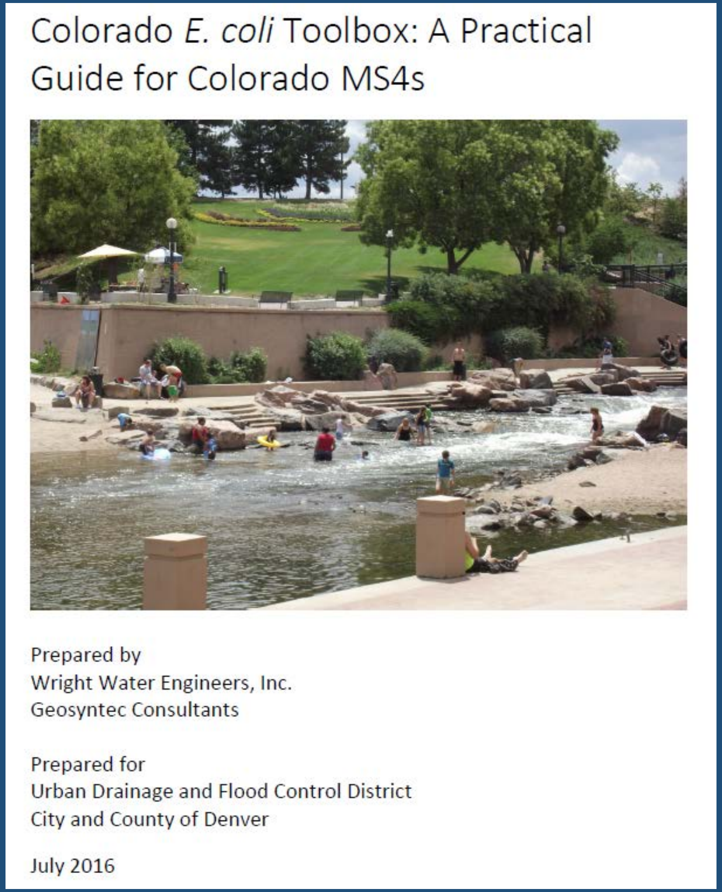


Table 3. Middle Reach *E. coli* TMDL: allowable loading and pollutant reductions necessary to meet the recreation based *E. coli* standard in Big Dry Creek.

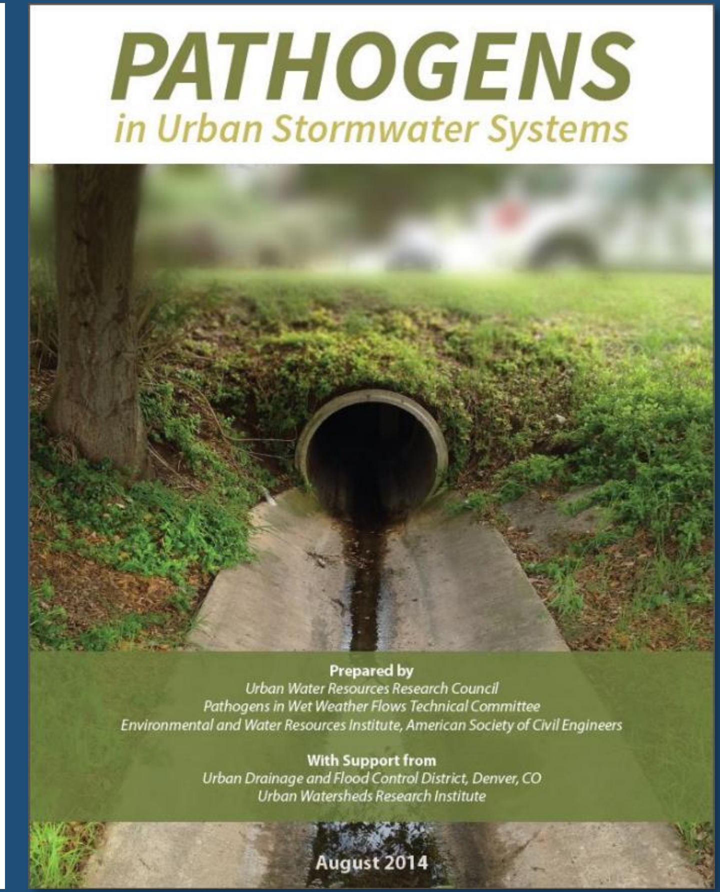
Loading Calculations (Giga-cfu/day)	High Flow	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flow
TMDL	423.34	198.56	129.18	73.58	27.94
MOS (10%)	42.33	19.86	12.92	7.36	2.79
Allowable Load	381.01	178.71	116.26	66.22	25.14
Exisiting Load	1119.13	425.48	244.05	114.49	94.98
Required Reductions	66%	58%	52%	42%	74%
WLA					
Westminster WWTF	58.24	54.32	51.49	31.97	16.99
Broomfield WWTF	74.20	64.00	57.63	31.58	4.92
MS4s	149.14	36.23	4.29	1.60	1.94
Reserve Capacity	7.46	1.81	0.21	0.08	0.10
LA					
Non-point Source	91.97	22.34	2.64	0.99	1.19

Colorado E. coli Toolbox:
A Practical Guide for Colorado MS4s

- Introduction
  - Colorado regulations
  - Extent of problem
  - TMDLs
- Finding the sources
- Developing a control strategy
  - Progression of controls
  - Modeling
- Source controls
- Structural BMPs
- Regulatory considerations/site-specific standards



www.udfcd.org



collaborate.ewrinstitute.org

E. coli Fact Sheets on UDFCD.org

- Regulatory Basics
- Microbial Source Tracking
- Stormwater BMP Performance
- Using GIS in Source Investigations

TOOLS FOR MS4s: MICROBIAL SOURCE TRACKING

WHY DOES THE SOURCE OF *E. COLI* MATTER?

Elevated levels of fecal indicator bacteria (FIB), including *E. coli*, are one of the most common causes of water quality impairment in surface waters across the United States. While some sources of FIB can be identified through a sanitary survey, sources of FIB in many watersheds remain unknown and thus cannot be effectively controlled through targeted management actions. FIB results alone give no indication of the fecal source (human vs non- human). In addition, the health risk associated with exposure to water containing human waste is much greater than that of most non-human sources. Therefore, identifying the source(s) of fecal contamination in waters with chronically high FIB levels is of critical importance to meet recreational water quality criteria and reduce human health risk.

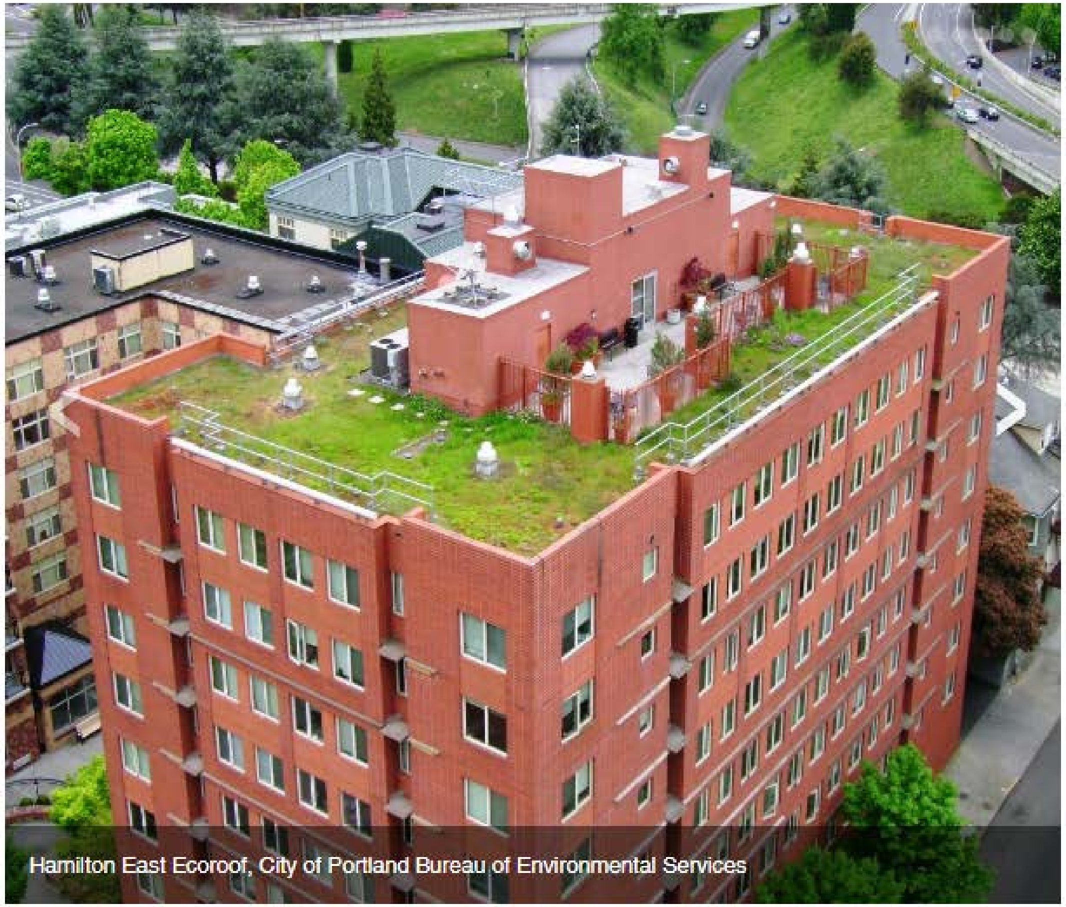
WHAT IS MICROBIAL SOURCE TRACKING?

Microbial source tracking (MST) uses a set of tools that allow for sources of fecal waste to be distinguished. These tools include conventional methods (e.g., ammonia, CCTV, dye testing) that have been used to identify illicit discharges for the past 20+ years, as well as more recently developed advanced laboratory methods that measure DNA specific to humans and other animals known as "markers" to identify sources. However, MST is more than just a set of tools or methods. MST is a process by which potential waste sources are systematically tested and investigated to identify and locate the origin of fecal bacteria in a contaminated water.

International Stormwater BMP Database

Home | Get Data | Submit Data | Documents | Guidance | About

www.bmpdatabase.org



Hamilton East Ecoroof, City of Portland Bureau of Environmental Services

Welcome! The International Stormwater Best Management Practices (BMP) Database project website features a database of over 530 BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications. **New to the site? Start Here**

News

- Coming Soon: Stream Restoration Database
- Agricultural BMP Database Initial Summary Report
- 2014 BMP Database Release
- 2014 BMP Performance Summaries
- 2013 Advanced Analysis
- National Stormwater Quality Database Has A New Home

Related Databases & Research

- Stream Restoration Database
- National Stormwater Quality Database
- Agricultural BMP Database
- Chesapeake Bay Research Portal

Urban Stormwater Research Reports

- 2014 BMP Performance Summaries
- 2014 Statistical Appendices
- 2012 Manufactured Device Performance Analysis Summary
- 2012 Volume Reduction in Bioretention
- 2012 Database Overview
- 2012 Chesapeake Bay BMP Performance Summary

Retrieve Urban Stormwater BMP Performance

- BMP Study Retrieval Tool
- BMP Map Tool
- BMP Category Reports
- Online Statistical Analysis Tool
- Download Access Database

THE Water Research FOUNDATION
www.waterrf.org

U.S. Department of Transportation
Federal Highway Administration

EWRI ASCE
ENVIRONMENTAL & WATER RESOURCES INSTITUTE

EPA

APWA

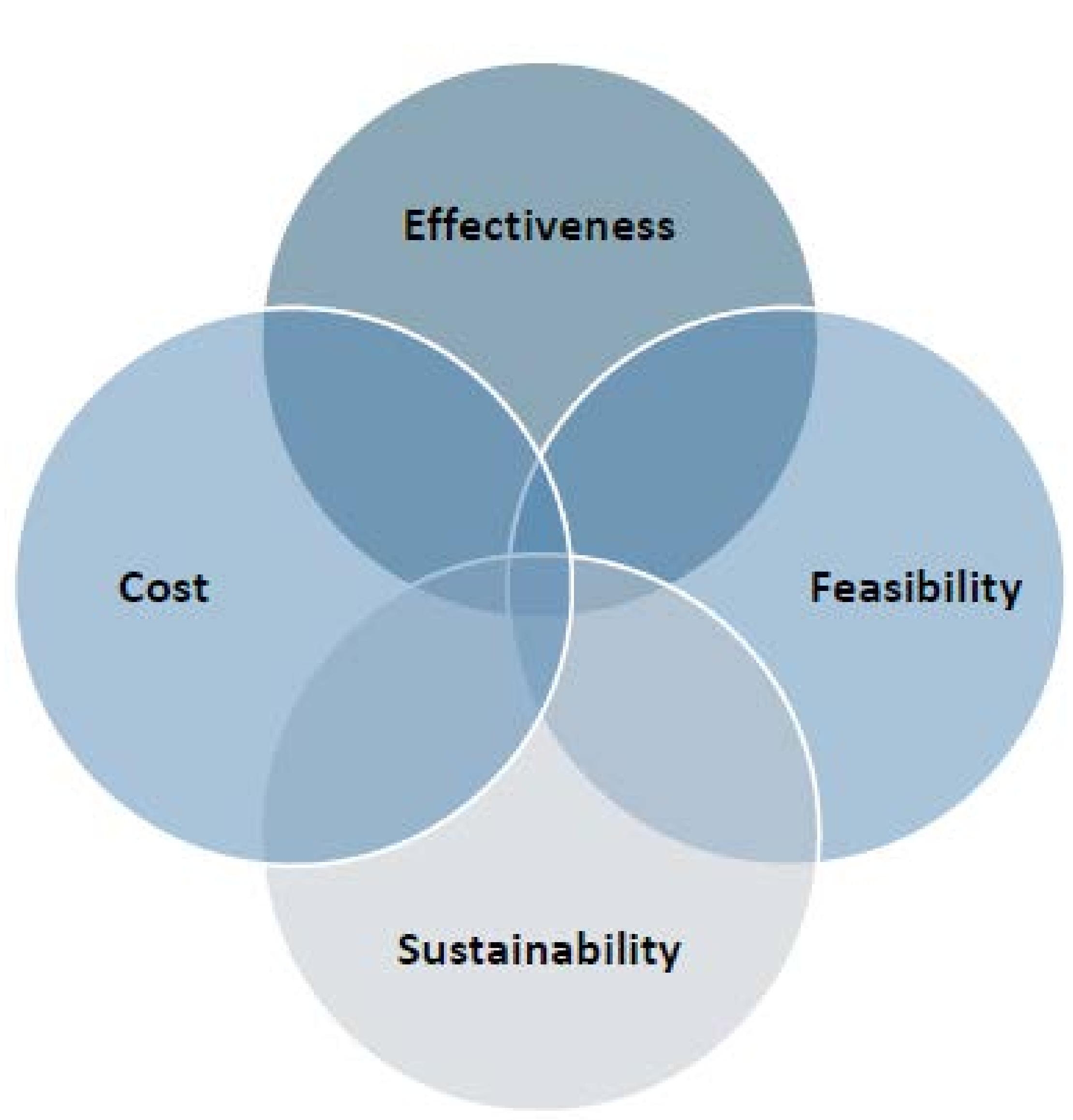
NATIONAL CORN GROWERS ASSOCIATION

USB UNITED SOYBEAN BOARD

Developing an E. coli Control Strategy

General Themes:

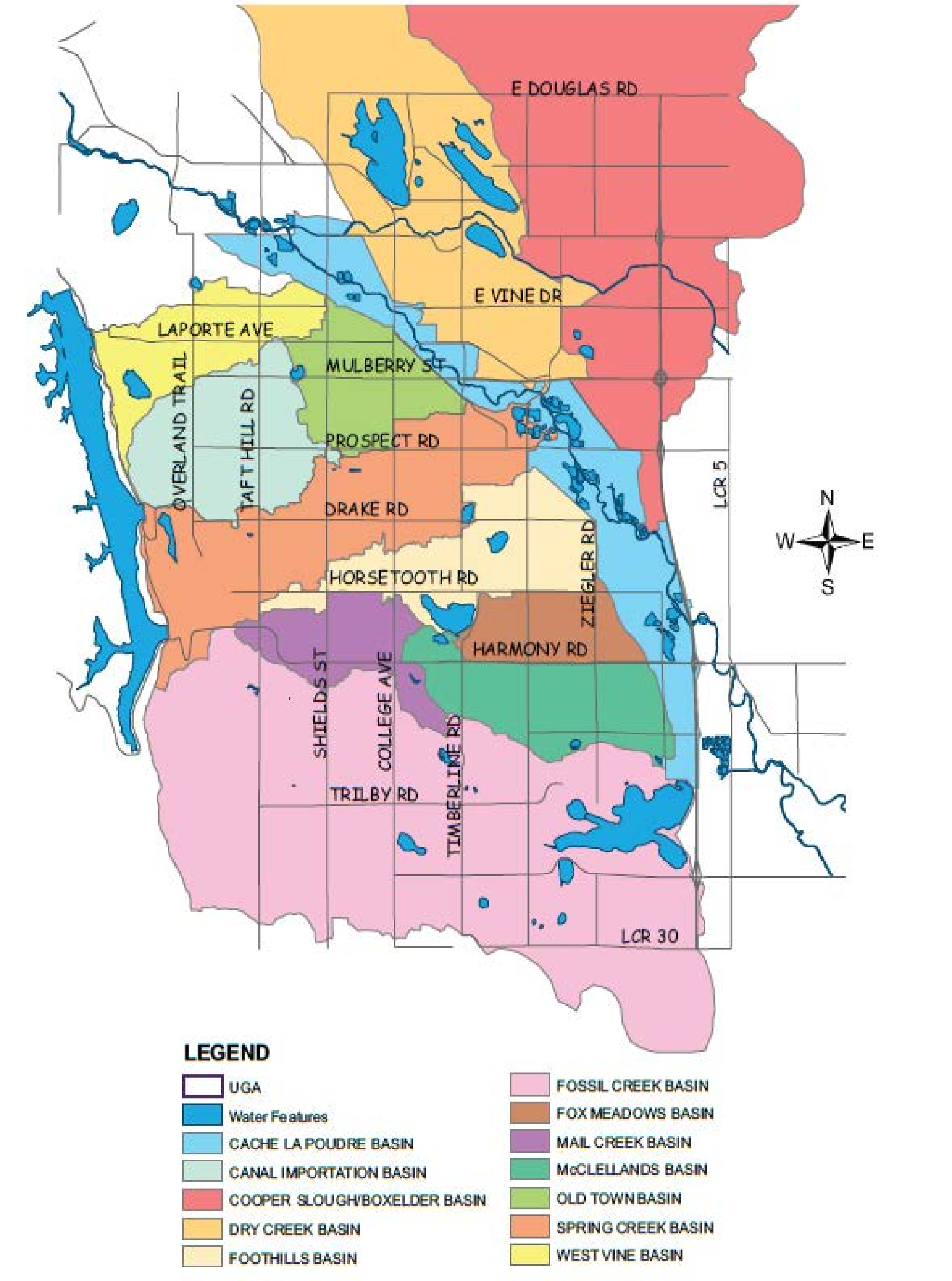
- Find the source(s)
- Address human source first, then other sources
- Address dry weather first, then wet weather
- Implement nonstructural/ source controls, then structural



City of Fort Collins Case Study

Fort Collins E. coli Impairments

Segment ID	Stream Segment Description	Season of Impairment
COSPCP11	Cache La Poudre from Shields St. to above Boxelder Creek	Not specified
COSPCP12	Cache La Poudre from above Boxelder Creek to South Platte River	May-October
COSPCP13a	Spring Creek and Fossil Creek (May-October)	May-October
COSPCP13b	Boxelder Creek from source to confluence with Cache La Poudre	Not specified



Starting Point

- Who is collecting data in your stream?
- Seasonal trends: Winter tends to attain standard; summer tends to exceed.
- Data availability: 5 samples over 61 days often not available
- Any major hot spots?

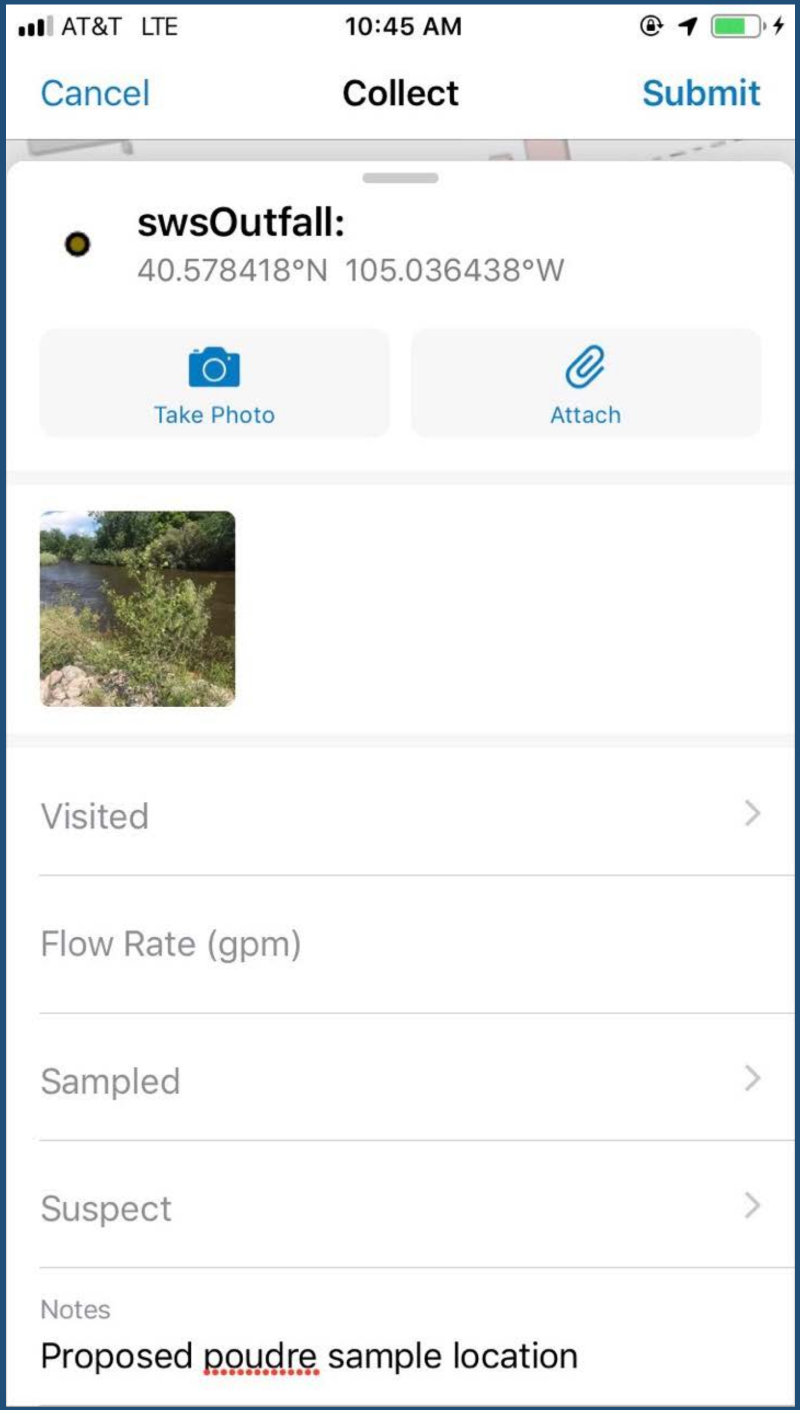
Table 7. All Sites Recreation Season (2014-2018)

2014-2018 Recreational Season Geometric Mean E. coli (MPN/100 mL)

Stream	Source	Site	Nbr.	Min	Max	Geomean
Boxelder Creek	CITYFTCO	BXC54	3	62	345	155
Boxelder Creek	CDPHE	BC-04	15	560	18000	2834
Boxelder Creek	CDPHE	BC-03	15	40	680	140
Boxelder Creek	CDPHE	BC01	3	249	870	455
Boxelder Creek	CDPHE	BC-02	15	20	697	126
Boxelder Creek	CITYFTCO	BXCSG	3	47	250	126
Boxelder Creek	CDPHE	BC-01	14	1	8800	116
Boxelder Creek	CDPHE	BC02	3	214	2420	506
Cache La Poudre	CITYFTCO	CLP287	27	10	9804	41
Cache La Poudre	CITYFTCO	432PLNC	39	13	1733	57
Cache La Poudre	CITYFTCO	390PPROS	39	26	3130	95
Cache La Poudre	CITYFTCO	380PNAT	39	28	2187	130
Cache La Poudre	CITYFTCO	370PBOX	39	25	3654	127
Cache La Poudre	CDPHE	CP03	3	88	206	127
Cache La Poudre	CDPHE	CP04	3	93	548	265
Cache La Poudre	CITYFTCO	325PFOS	39	16	1223	83
Fossil Creek	CITYFTCO	FOSC287	3	48	1553	307
Fossil Creek	CDPHE	FC-05	15	20	1520	184
Fossil Creek	CDPHE	FC-04	15	1	3460	189
Fossil Creek	CDPHE	FC-03	15	1	1040	210
Fossil Creek	CDPHE	FC-02	15	60	11100	516
Fossil Creek	CITYFTCO	FOSC34	3	276	1300	498
Fossil Creek	CDPHE	FC-00	15	1	190	13
Fossil Creek	CDPHE	FC-01	15	1	200	33
Spring Creek	CDPHE	SC-07	15	20	2580	153
Spring Creek	CDPHE	SC-06	15	40	640	140
Spring Creek	CDPHE	SC-05	15	40	800	120
Spring Creek	CDPHE	SC-04	15	40	780	142
Spring Creek	CITYFTCO	SPRC287	3	365	1120	631
Spring Creek	CDPHE	SC-03	15	1	1140	176
Spring Creek	CDPHE	SC-02	15	20	1060	145
Spring Creek	CITYFTCO	SPRCEP	3	34	1986	214
Spring Creek	CDPHE	SC-01	15	1	700	133

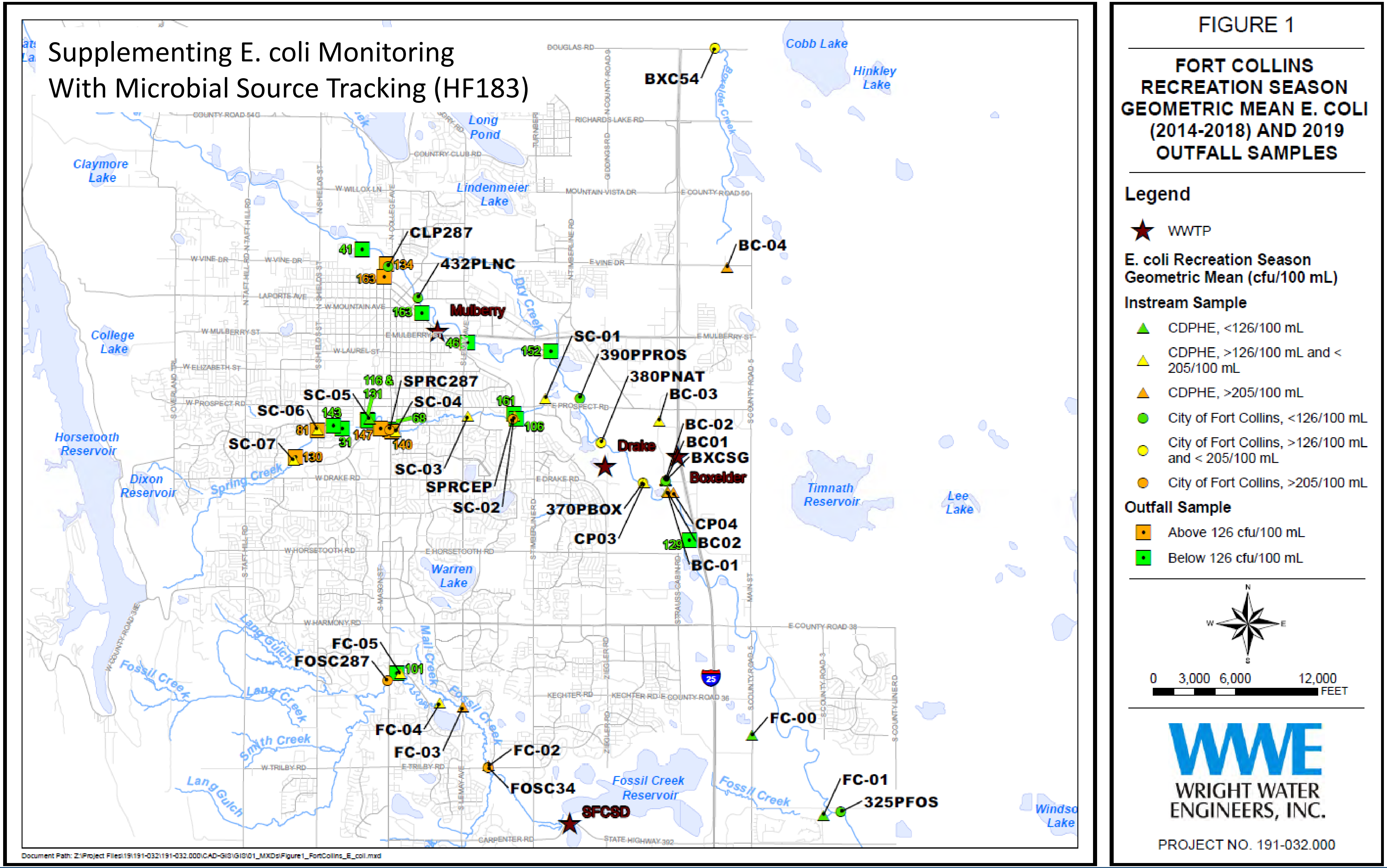
Dry Weather Investigation

- Upload mapped outfalls into Collector App
- How many days to find 150 outfalls?
- Estimating flow rate
- Uploading photos
- Identifying suspect outfalls
- Getting samples to lab on time
- Car or bike or both



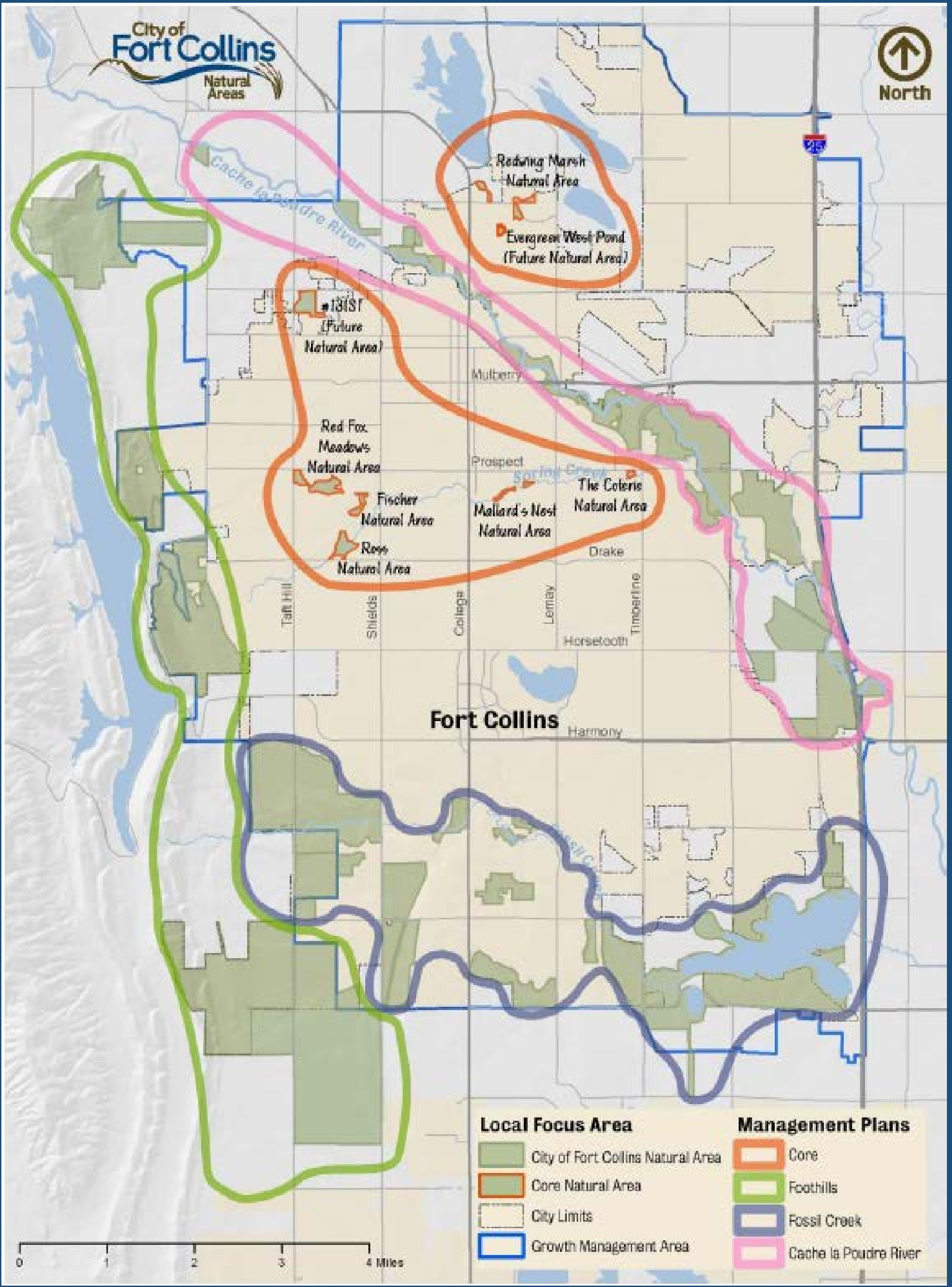
Field Challenges

Supplementing E. coli Monitoring With Microbial Source Tracking (HF183)

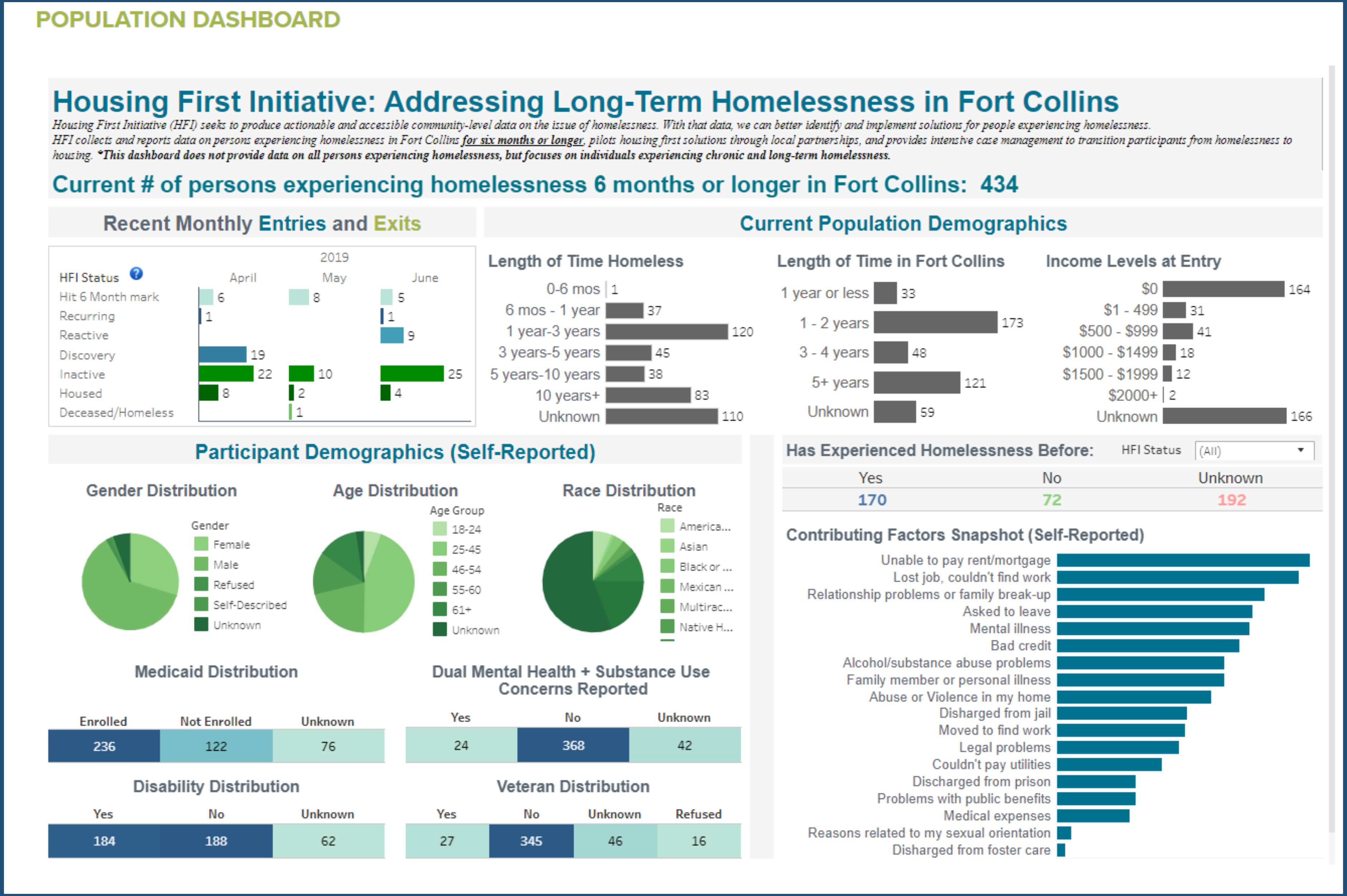


Collecting GIS Data

- Infrastructure age and maintenance history
- BMP locations
- Ditches
- Septic systems
- Hobby farms, large animal facilities/properties
- Natural areas
- Homeless/transient densities



http://www.homeward2020.org



City of Boulder Case Study

STORMWATER PROGRAM TIMELINE

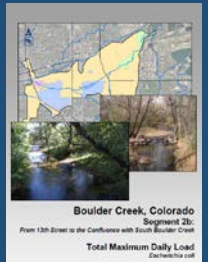
1993
COB Stormwater Program

2003
MS4 Permitting Phase II (COB)

2004
Boulder Creek is placed on the Impaired Waters (303(d)) List for *E.coli*

2008
MS4 Permit Update

2011
E.coli TMDL & Implementation Plan for Boulder Creek



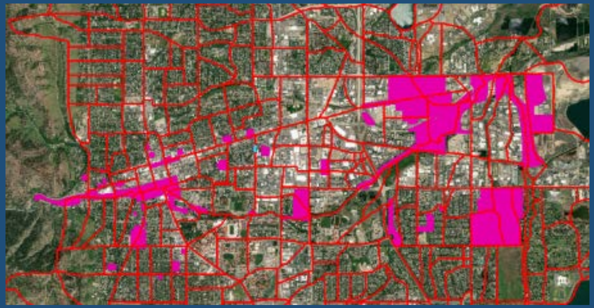
2013
Raccoon Study

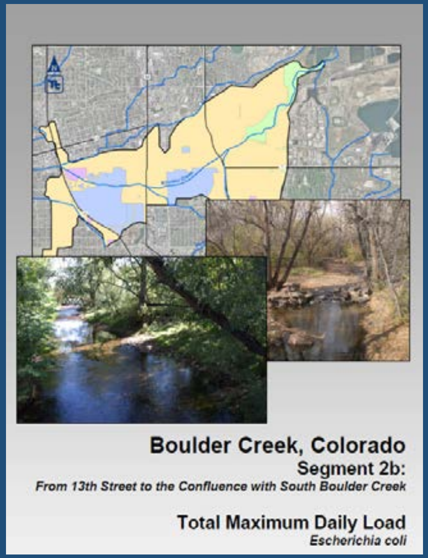
2016
MS4 Permit Update

2019
City *E.coli* TMDL Implementation Plan Update

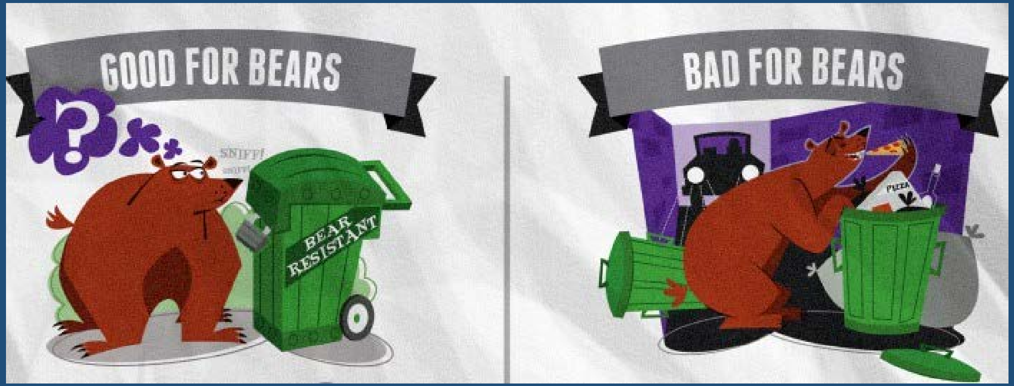
Current Stormwater Quality Program

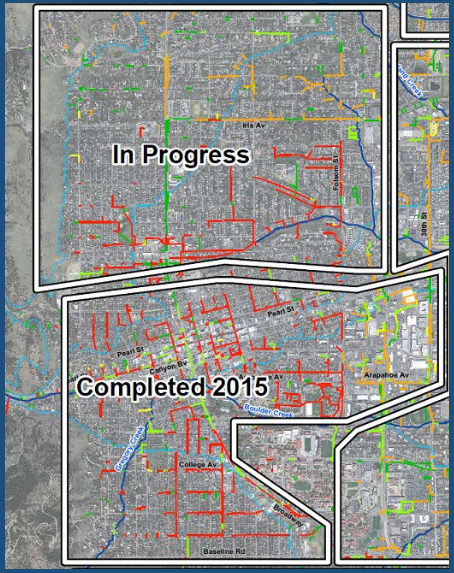
Illicit Discharge Program	Monitoring	TMDL Development	TMDL Implementation Plan Development	TMDL Implementation Plan Update
Slow the Flow Efforts	“Doo Good” Outreach	Pet Waste Stations	Boulder Creek Outfall Surveys	Storm & Sanitary Efforts
Stormwater Master Plan Update	Investigation of Sanitary Mains Under the Creek	Memo: Raccoons in storm drains	Raccoon-proofing Pilot	GI Strategic Plan
Special Monitoring Studies	Neonic Sampling	Macroinvert. Monitoring	Instream Flow Program	Bear-proof Trash Enclosure




Boulder Creek, Colorado
Segment 2b:
From 13th Street to the Confluence with South Boulder Creek
Total Maximum Daily Load
Escherichia coli


Doo Good
Pick up dog doo. Protect streams.
Dog doo is more than a nuisance!
IT SPREADS DISEASE
Dog waste carries parasites and bacteria, like Giardia and E. coli, which account for up to 20% of the pollution in public waterways.
IT HURTS FISH
When they wash into streams, nutrients in dog waste act like a fertilizer, growing algae and reducing oxygen levels.
IT ADDS UP!
Locally, there are 90,000 dogs that make 11,700 tons of waste a year.
www.KeepItCleanPartnership.org


GOOD FOR BEARS
SNIFF!
BEAR RESISTANT
BAD FOR BEARS


In Progress
Completed 2015

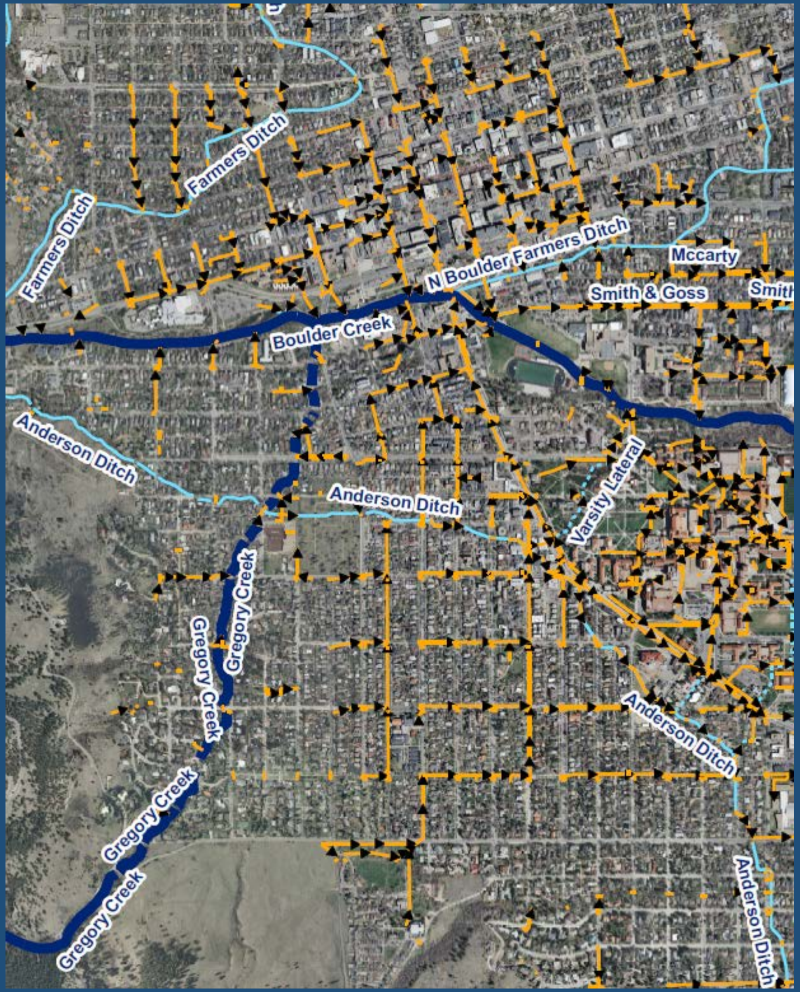
Infrastructure Investments

1.3 Million Dollars to inspect, clean and line the storm sewer system

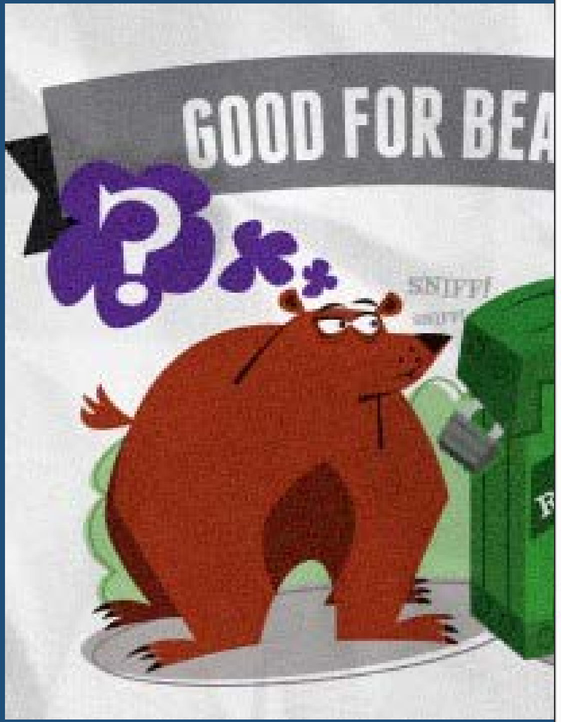
2 Million Dollars to line the sanitary system in the University Hill and Downtown areas

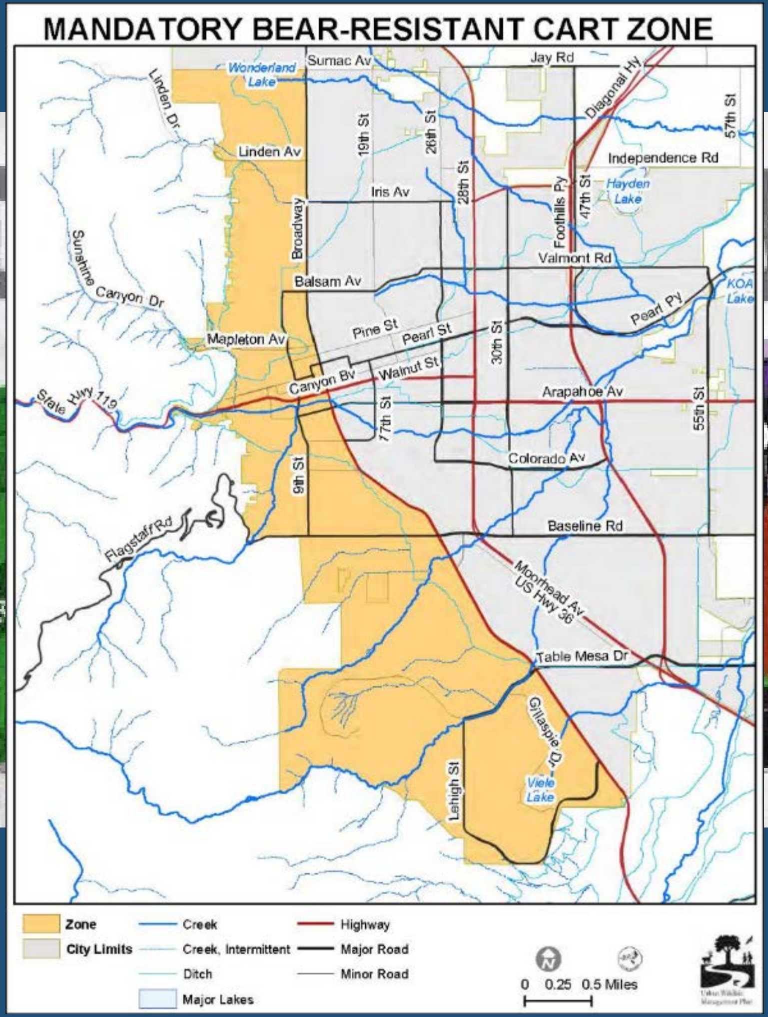
3 Sewer Mains TVed under Boulder Creek

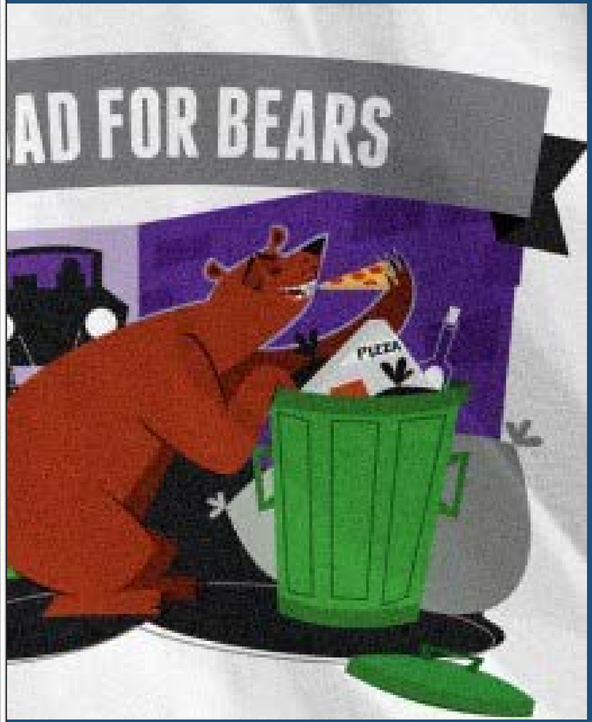
0 Cross-Connections Identified to Date



Bear Trash Enclosure Program







What Can You Do?

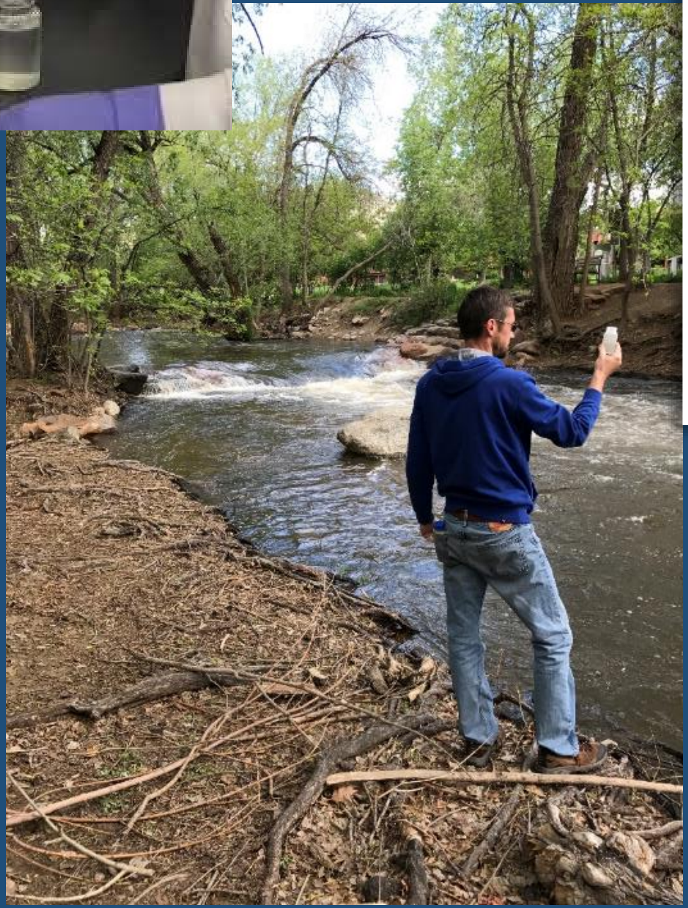
Pick up Pet Waste

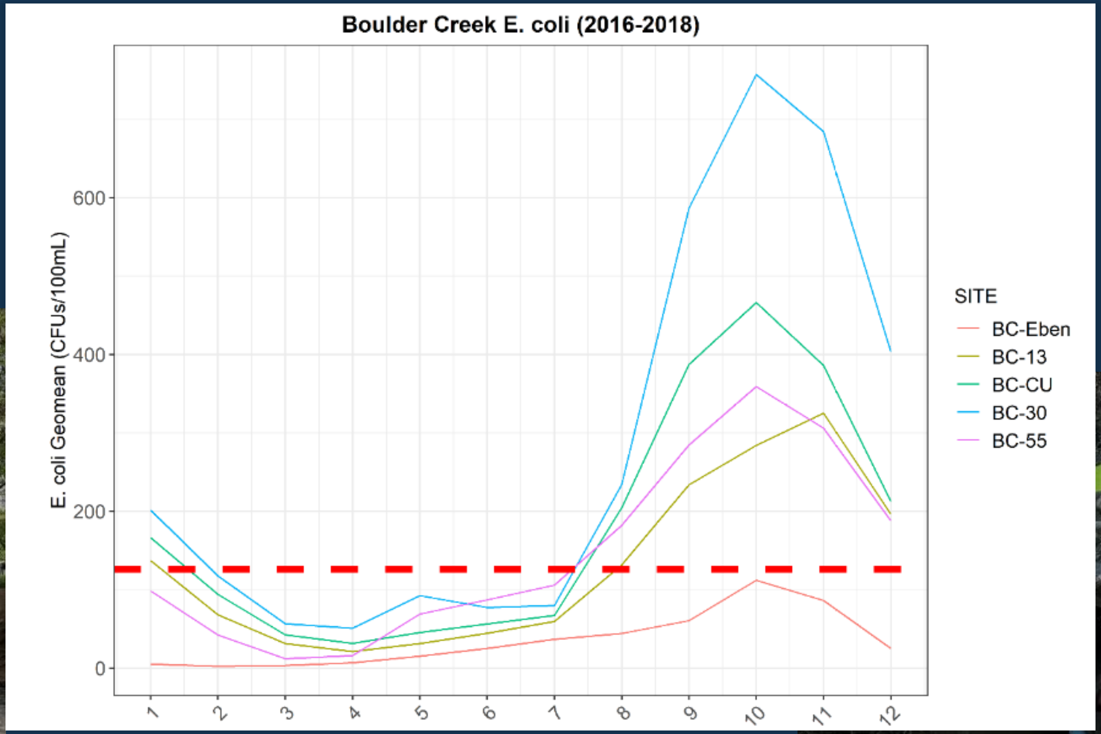
Reduce Irrigation Overspray

Keep Trash from Wildlife

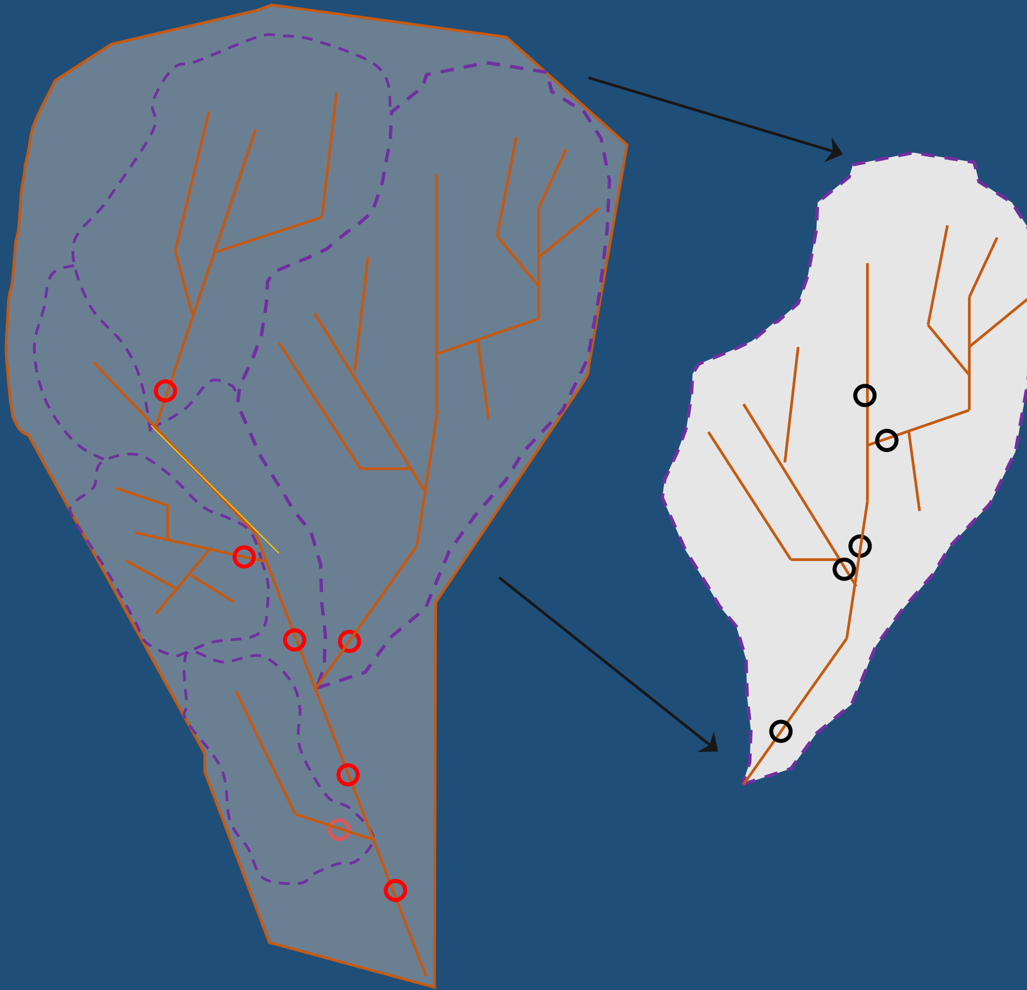
Report Spills

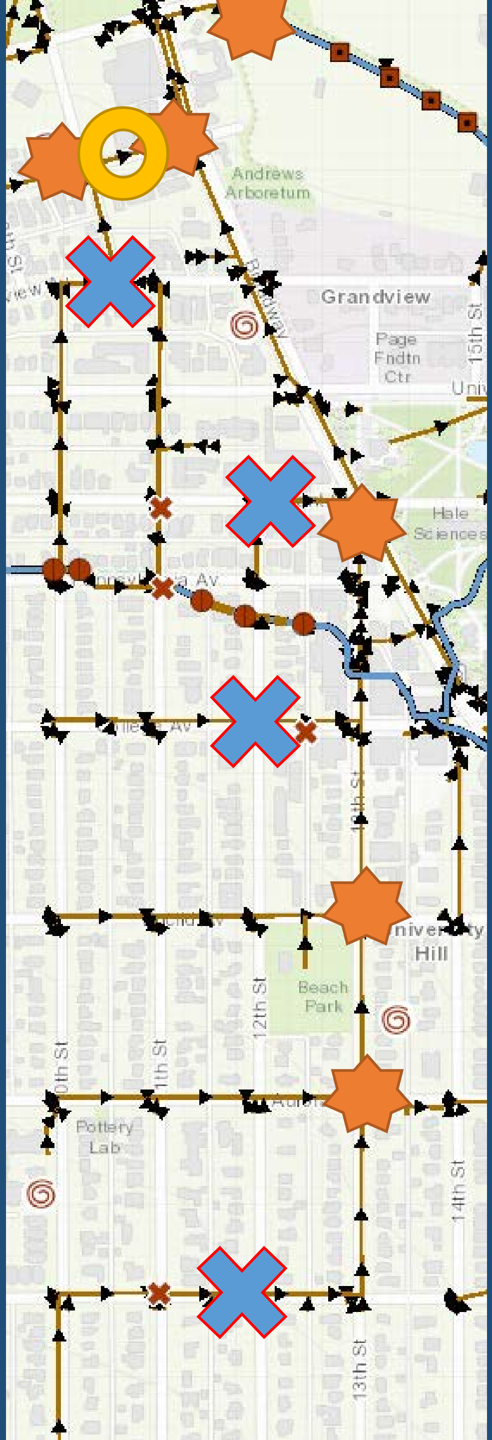
Monitoring

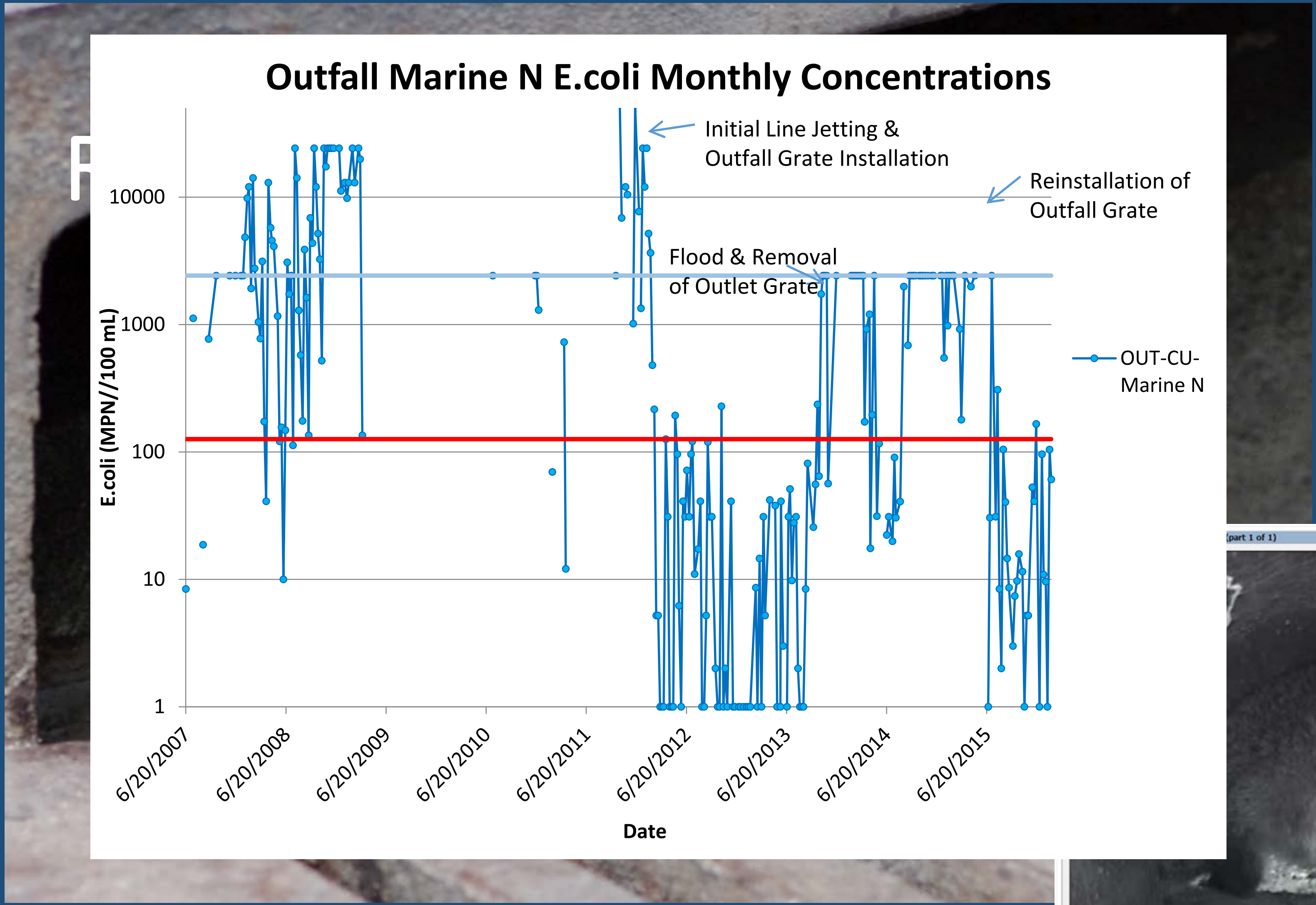



Boulder Creek E. coli (2016-2018)
E. coli Geomean (CFUs/100mL)
0
200
400
600
1
2
3
4
5
6
7
8
9
10
11
12
SITE
BC-Eben
BC-13
BC-CU
BC-30
BC-55

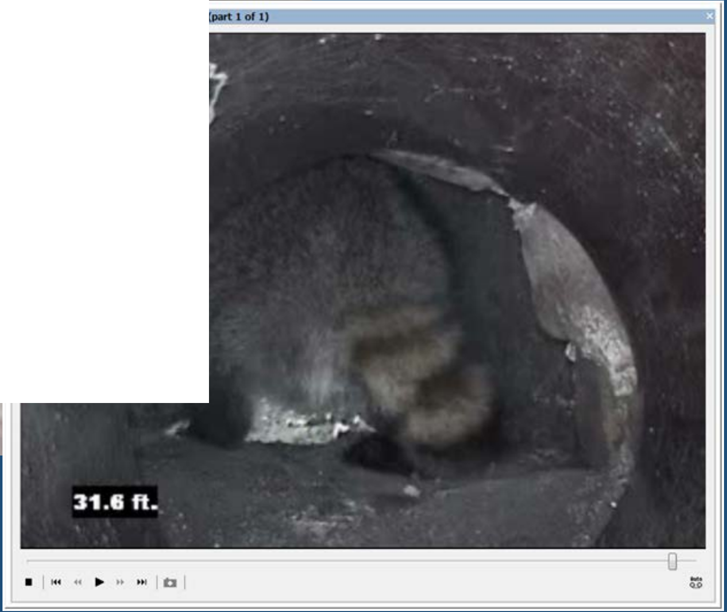
TMDL Implementation Plan




Andrews Arboretum
Grandview
Page Fndtn Ctr
15th St
Hill
Beach Park
12th St
Pottery Lab
14th St
13th St



Outfall Marine N E.coli Monthly Concentrations
Initial Line Jetting &
Outfall Grate Installation
Reinstallation of
Outfall Grate
Flood & Removal
of Outlet Grate
OUT-CU-
Marine N
E.coli (MPN/100 mL)
10000
1000
100
10
1
6/20/2007
6/20/2008
6/20/2009
6/20/2010
6/20/2011
6/20/2012
6/20/2013
6/20/2014
6/20/2015
Date



31.6 ft.

Conclusions

- E. coli: coming soon to an MS4 permit near you!
- Where to start: Better understand the source(s) during dry weather.
- Expect messy data.
- BMPs can help reduce bacteria—this does not always mean attainment of instream standards at end of pipe though.
- Colorado-based resources are available to develop a better understanding of various aspects of bacteria issues.
- Partners are important—solutions likely extend beyond public works departments.

Questions?

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Development of a New Integrated Decision Support Tool (i-DST)

ELIZABETH GALLO

US-EPA NATIONAL PRIORITIES

https://idst.mines.edu/

Outline

- General Background
- i-DST Background
- Watershed Scale Module
- Front-end Graphical User Interface (GUI)
- Stormwater Control Measure (SCM) and Optimization Simulator
- Test Site: Berkeley Neighborhood Watershed

About me

- 3rd year PhD Candidate at Colorado School of Mines
- Completed my masters in 2017
- Hydrologic Science and Engineering Program
- Civil and Environmental Engineering Department
- Advisor: Terri S. Hogue

Motivation

- Urbanization stresses drainage networks and aquatic ecosystems

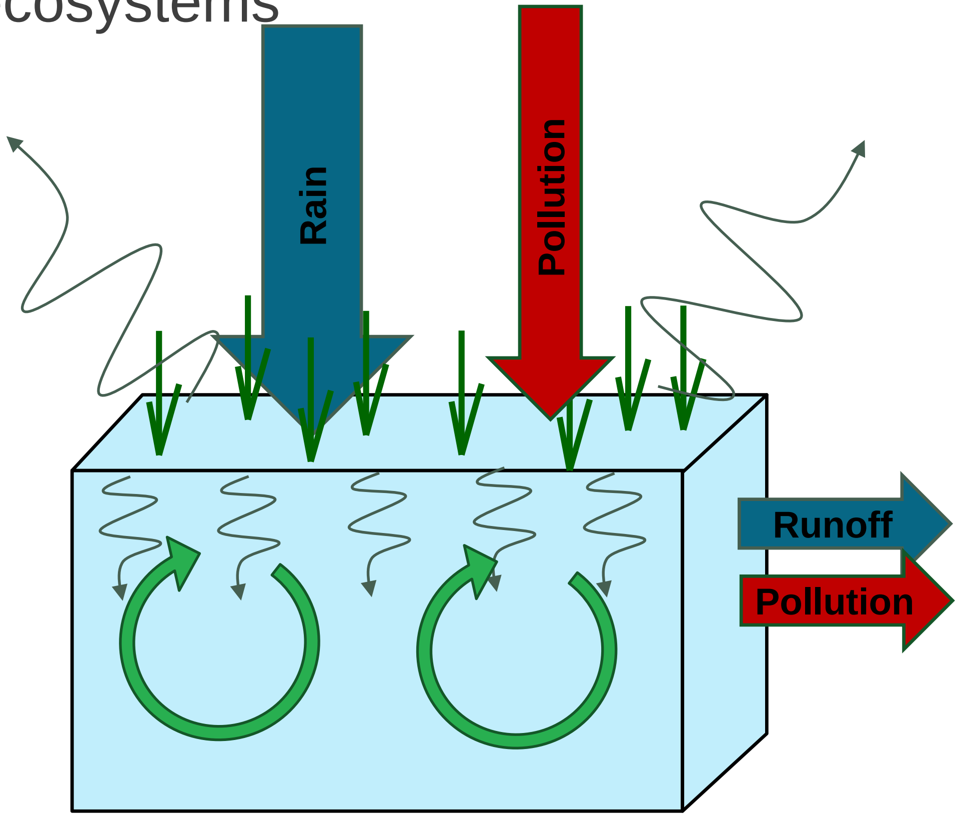

Image from Piotr Redlinski for The New York Times

Motivation

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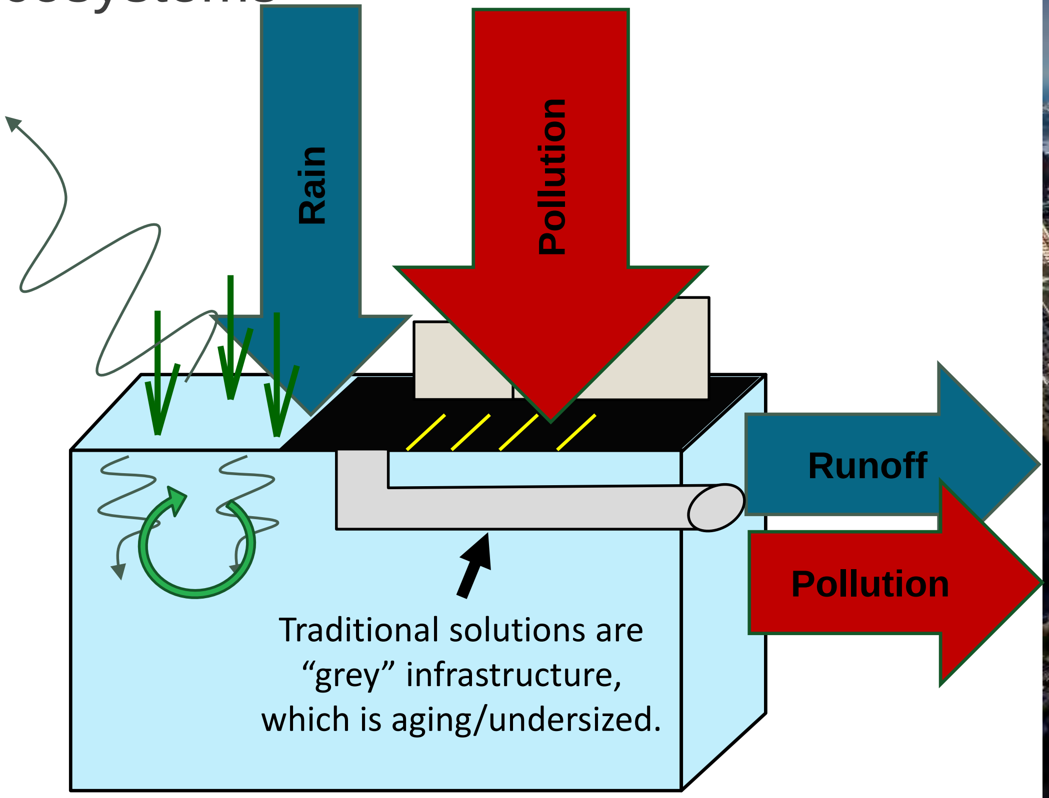


Image from Piotr Redlinski for The New York Times

Solution

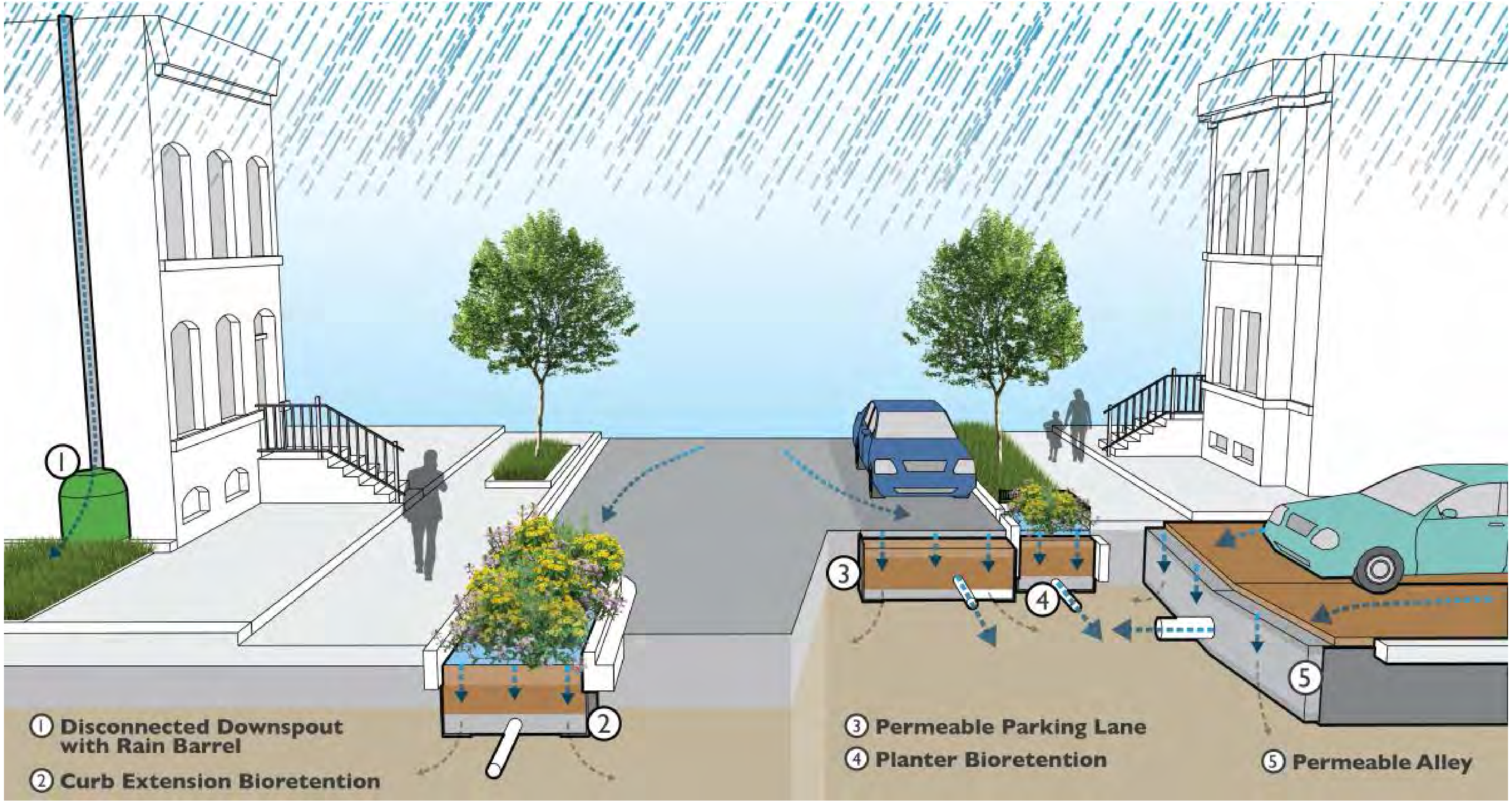
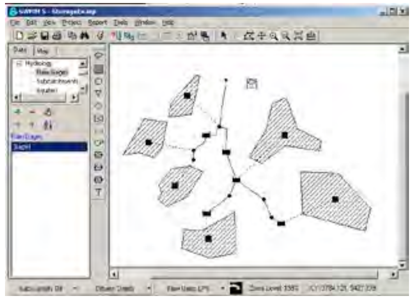


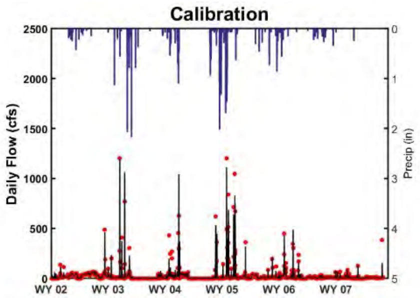
Figure: DC Water (https://www.dcwater.com/green-infrastructure)

Research Focus

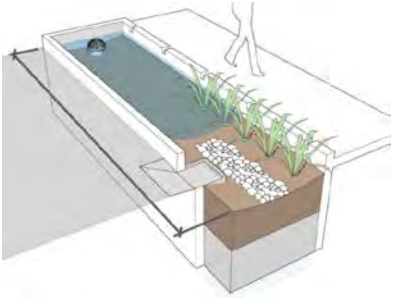
Stormwater Models



Urban Water Quantity and Quality



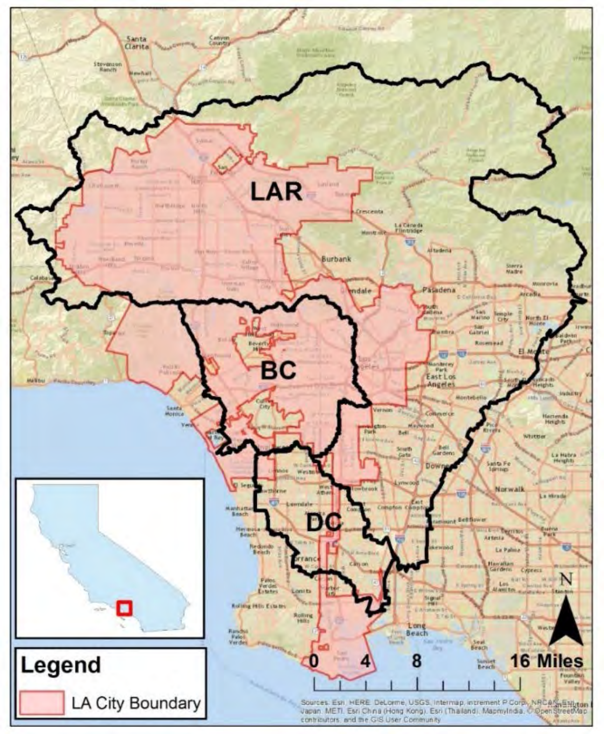
Stormwater Infrastructure



Optimal Watershed Scale Plan

Previous work:

Variability in achieving water quality compliance with SCMs impacts the decision making process when optimizing for a watershed.



	Scenario (BMPs)		Volume Capture (m^3)	BMP Area (km^2)	Peak Flow Reduction	Cost (Billions)	DW Days/yr **	Load Based Exceedances/yr (TMDL Compliance [%])***			WW Days/yr **	Load Based Exceedances/yr (TMDL Compliance [%])***		
								Cu DW	Pb DW	Zn DW		Cu WW	Pb WW	Zn WW
BC	Baseline*	No New	0	-	-	-	259	86 (66.8)	0 (100.0)	0 (100.0)	106	105 (0.9)	0 (100.0)	19 (82.1)
	1	All	1,358,766	3.52	43.0%	0.55	336	0 (100.0)	0 (100.0)	0 (100.0)	29	10 (65.5)	0 (100.0)	1 (96.6)
	2	IT	3,094,830	2.02	95.0%	0.70	354	0 (100.0)	0 (100.0)	0 (100.0)	11	10 (9.1)	0 (100.0)	8 (27.3)
	3	DP	3,094,830	2.02	10.0%	0.69	339	0 (100.0)	0 (100.0)	0 (100.0)	26	6 (76.9)	0 (100.0)	0 (100.0)
	4	VS+BR+PP	2,798,910	11.18	65.0%	1.40	340	0 (100.0)	0 (100.0)	0 (100.0)	25	11 (56.0)	0 (100.0)	2 (92.0)
	5	VS+BR+PP	314,415	1.24	11.0%	0.20	278	73 (73.7)	0 (100.0)	0 (100.0)	87	84 3.4	0 (100.0)	18 (79.3)
DC	Baseline*	No New	0	-	-	-	333	- -	- -	- -	32	18 (43.8)	0 (100.0)	17 (46.9)
	1	BR	2,901,249	6.42	69.6%	1.51	357	- -	- -	- -	8	7 (12.5)	0 (100.0)	6 (25.0)
	1b	BR+PP	2,901,249	6.68	55.7%	1.51	359	- -	- -	- -	6	5 (16.7)	0 (100.0)	5 (16.7)
	2	VS+DP	2,901,249	5.54	4.4%	0.71	354	- -	- -	- -	11	11 (0.0)	0 (100.0)	5 (54.5)
	2b	VS+DP+PP	2,901,249	7.04	34.0%	0.89	356	- -	- -	- -	9	9 (0.0)	0 (100.0)	7 (22.2)
	3	VS+IT	2,901,249	5.41	45.4%	0.70	357	- -	- -	- -	8	8 (0.0)	0 (100.0)	7 (12.5)
	3b	VS+IT+PP	2,901,249	6.92	55.3%	0.90	358	- -	- -	- -	7	7 (0.0)	0 (100.0)	6 (14.3)
LAR	Baseline*	No New	0	-	-	-	333	307 (89.8)	127 (95.8)	214 (35.7)	32	6 (81.3)	2 (93.8)	14 (56.3)
	1	BR	12,818,268	27.97	47.0%	6.60	358	68 (97.9)	51 (98.4)	18 (95.0)	7	1 (85.7)	0 (100.0)	6 (14.3)
	1b	BR+PP	12,818,268	15.02	53.0%	6.80	360	71 (97.8)	53 (98.4)	18 (95.0)	5	2 (60.0)	0 (100.0)	5 (0.0)
	2	VS+DP	12,818,268	37.30	29.0%	3.80	350	62 (98.0)	47 (98.5)	15 (95.7)	15	0 (100.0)	0 (100.0)	3 (80.0)
	2b	VS+DP+PP	12,818,268	24.86	46.0%	5.20	358	69 (97.9)	52 (98.4)	18 (95.0)	7	1 (85.7)	0 (100.0)	6 (14.3)
	3	VS+IT	12,818,268	37.30	55.0%	3.80	361	75 (97.7)	57 (98.2)	19 (94.7)	4	0 (100.0)	0 (100.0)	2 (50.0)
	3b	VS+IT+PP	12,818,268	24.86	57.0%	5.20	361	75 (97.7)	57 (98.2)	19 (94.7)	4	2 (50.0)	0 (100.0)	4 (0.0)

* Baseline Scenario is not included in the developed color scale which highlights the performance of BMP scenarios from best to worst for each criteria.

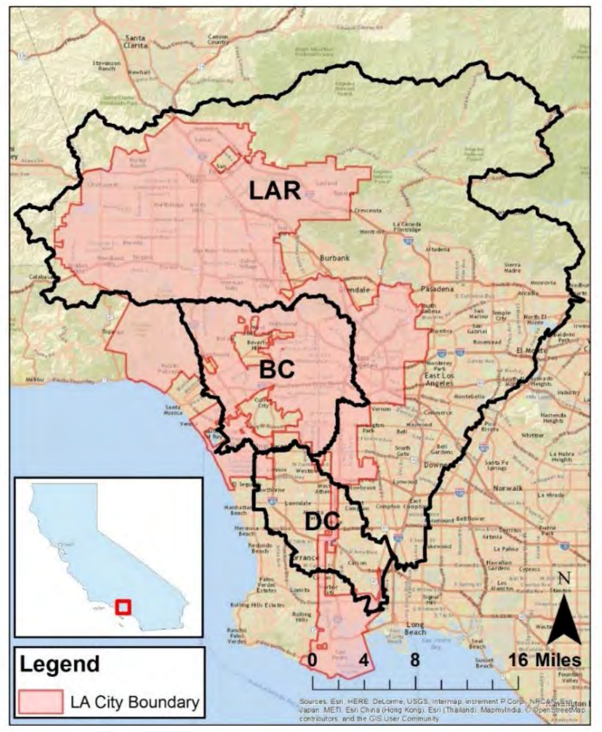
** DW and WW Days/year equals the total possible dry and wet weather exceedances with an exception to LAR Dry weather Cu and Pb. Multiply the DW Days/yr by 9 (TMDL locations) to get the total possible exceedances for LAR Cu and Pb.

*** TMDL Compliance represents the percentage of days that which the TMDL will be met
e.g. WW TMDL Compliance = (WW Days/yr - Exceedances/yr) ÷ WW Days/yr * 100

Stormwater management options and decision-making in the urbanized watersheds of Los Angeles, CA. *Journal of Sustainable Water in the Built Environment.* Gallo et al. In Press.

Previous work:

Variability in achieving water quality compliance with SCMs impacts the decision making process when optimizing for a watershed.



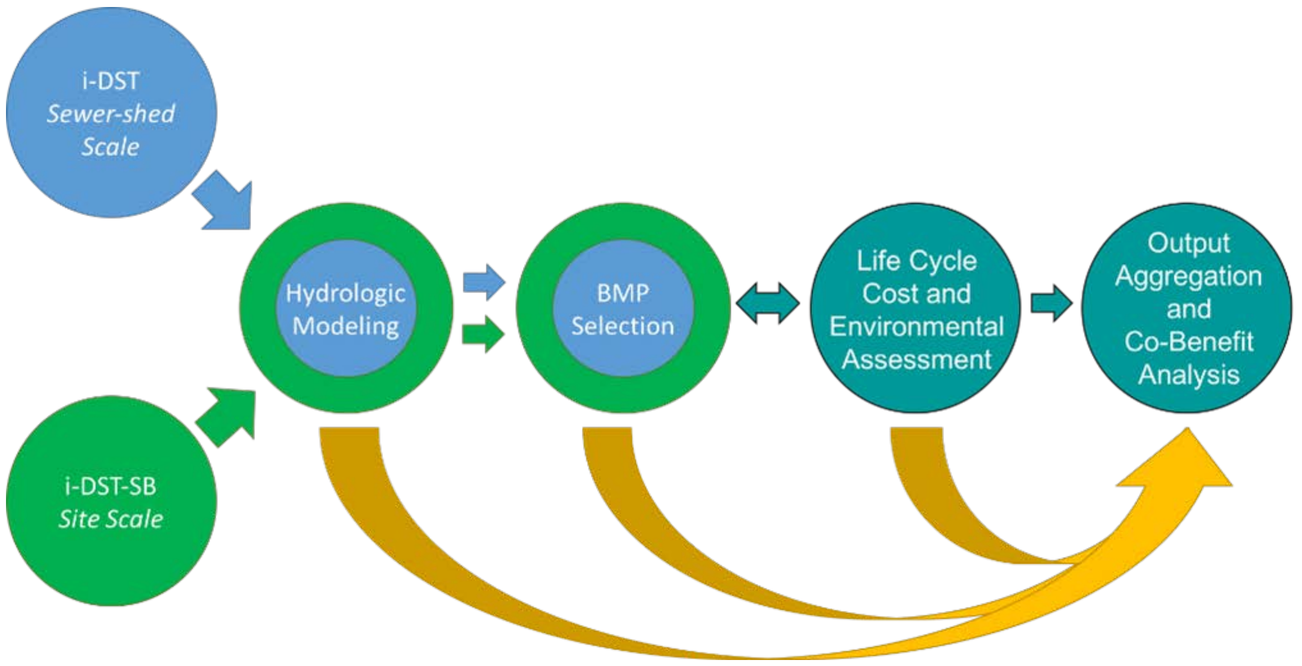
	BC	DC	LAR
Water Quality	Least Degraded	Most Degraded	Variable
Eliminate TMDLs with SCMs?	Yes	No	Variable
Available SCM Options	Any	Treat and Release Only	Treat and release in more urbanized areas
Available Ancillary Benefits to Consider	All	Restricted to above options	Restricted in urban areas

Stormwater management options and decision-making in the urbanized watersheds of Los Angeles, CA. *Journal of Sustainable Water in the Built Environment.* Gallo et al. In Press.

Current work:

Stormwater practitioners lack a comprehensive decision support tool that incorporates both green and grey infrastructure, life cycle costs and environmental assessment, and co-benefits

Integrated Decision Support Tool (i-DST)



Conceptual model of tool components and the flow of information between them

i-DST Tool Background

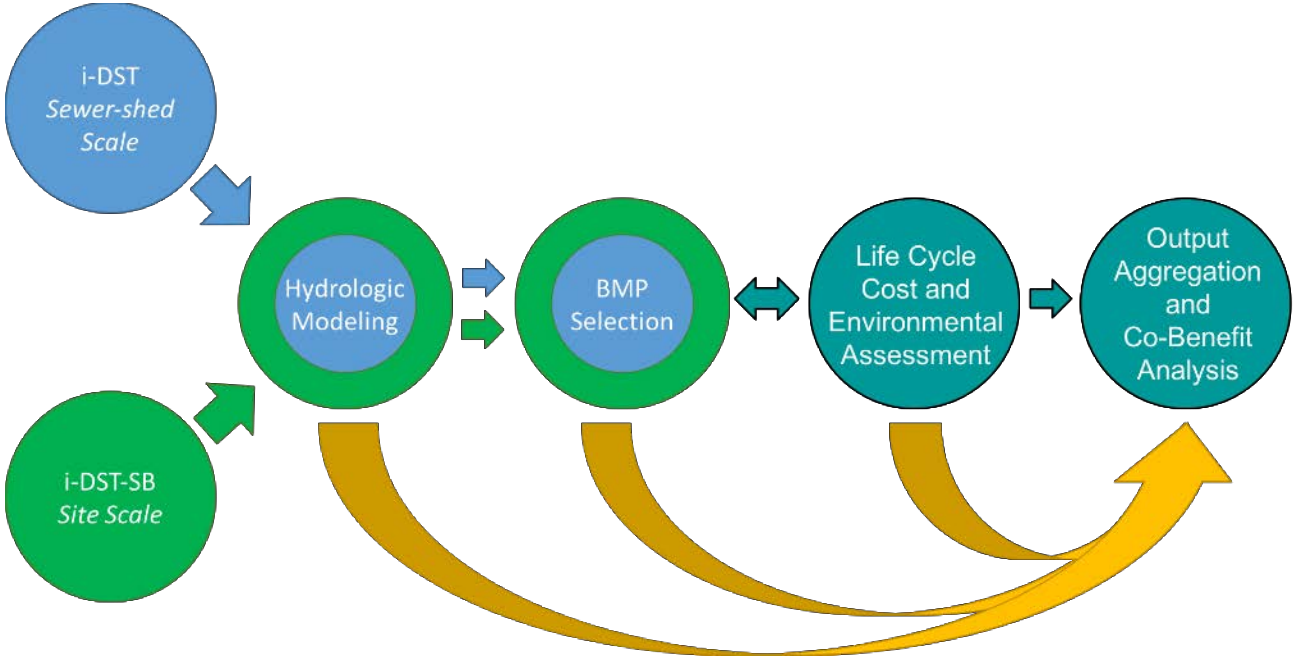
- Watershed Tool Background
- Updates to Front-end GUI
- Updates to EPA-SUSTAIN Code
- Test Site Modeling Example

i-DST Project Goals

- Develop an integrated, scalable, decision support tool (called **i-DST**) for grey, green, and hybrid infrastructure

- **Planning-level** tool – suitable for project prioritization (not design)

- Components:
  - Hydrology, water quality
  - BMP optimization and uncertainty estimation
  - Life cycle cost assessment (LCCA)
  - Life cycle assessment (LCA)
  - Quantification of co-benefits



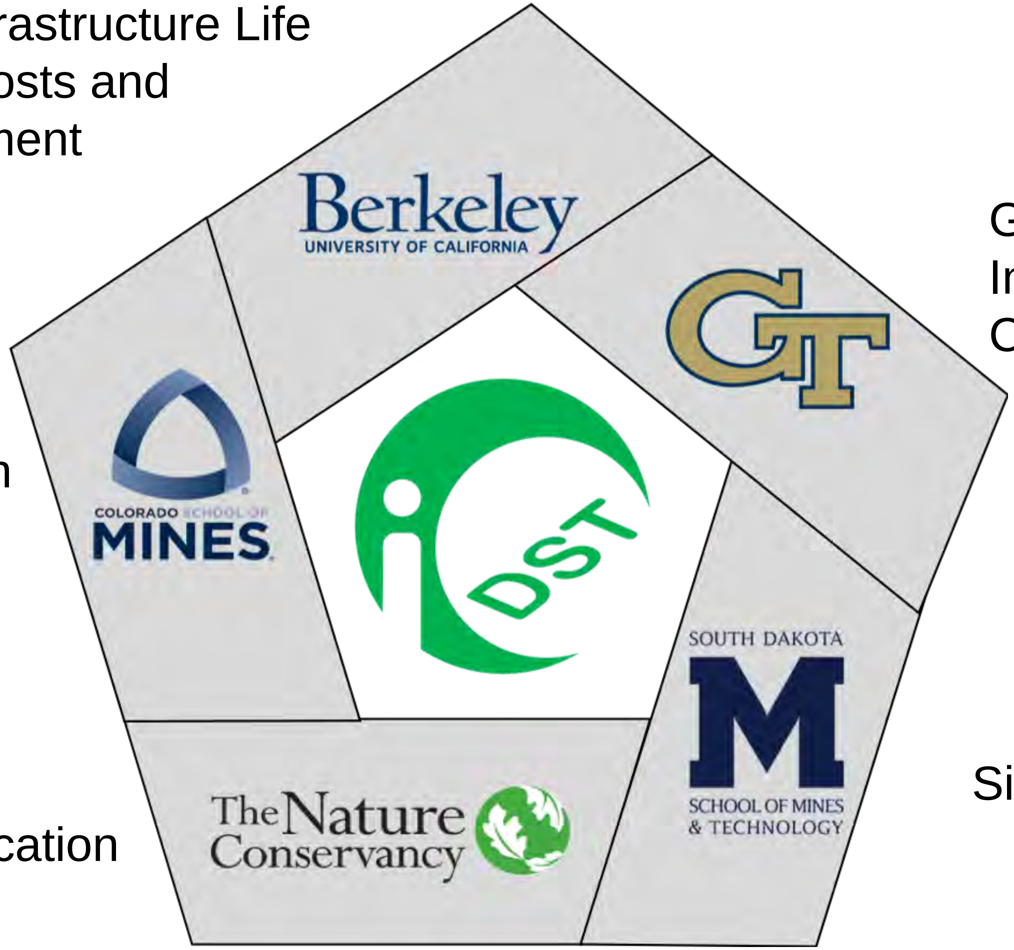
Conceptual model of tool components and the flow of information between them

i-DST Project Team

Grey Infrastructure Life Cycle Costs and Assessment

Green and Hybrid Infrastructure Life Cycle Costs and Assessment

Watershed Scale Tool & Co-benefit Quantification

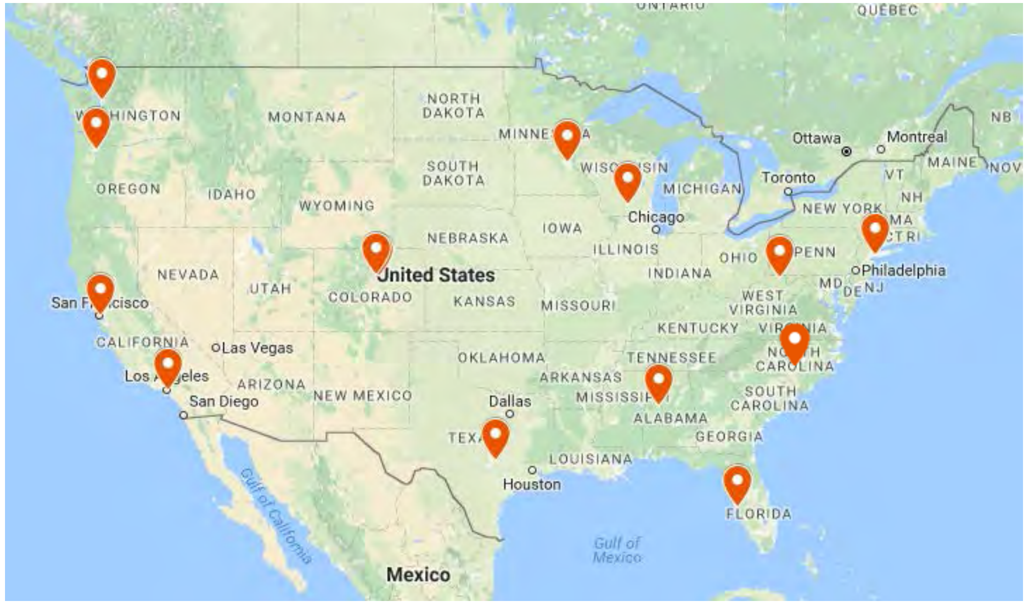


Site-scale Tool

Co-benefit Quantification

Science Advisory Board (SAB)

- Have a board of 21 urban water experts to help us:
  - Identify tool needs
  - Identify novel grey/green infrastructure techniques to include
  - Connect us with datasets
  - Provide feedback on the tool



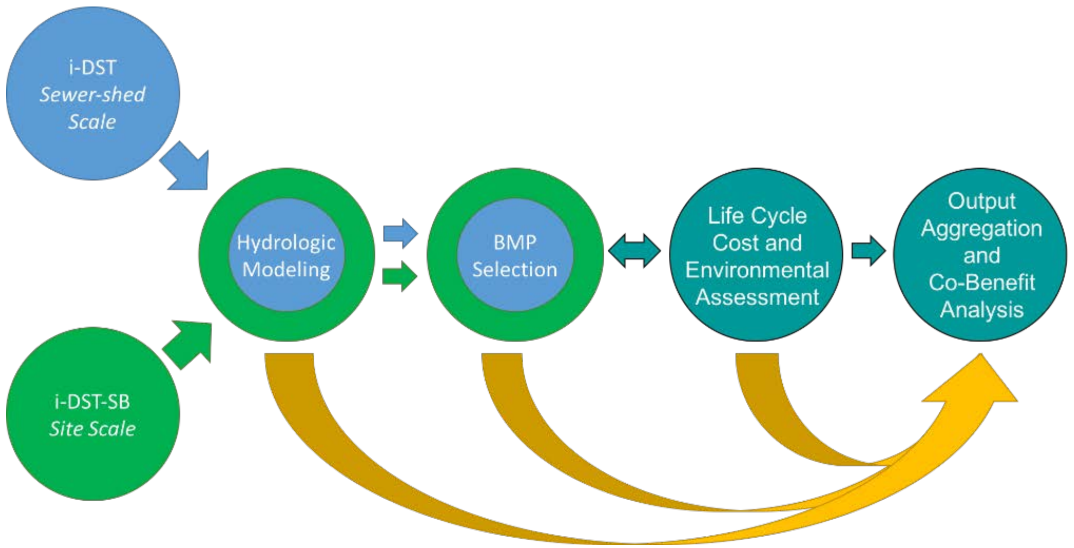
- NGOs
- Consultants
- City/county governments
- Federal agencies
- Academics

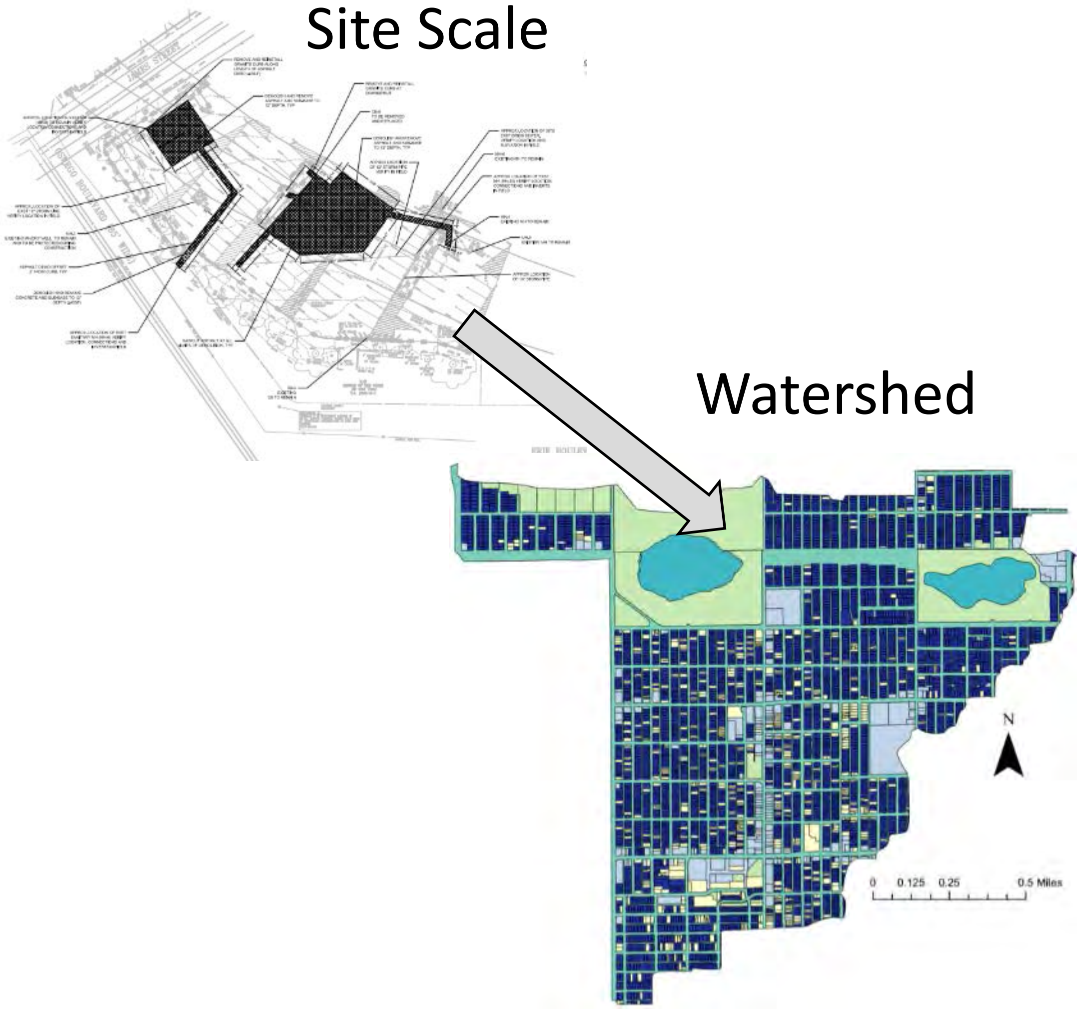
Science Advisory Board (SAB)

Member	Organization	State
Janet Clements	Corona Environmental Consulting	CO
Darren Mollendor	City of Denver	CO
Holly Piza	Denver Urban Drainage and Flood Control District	CO
Tracey Pond	City of Golden	CO
Scott Struck	Geosyntec Consultants	CO
Jeffrey Williams	City of Denver	CO
Colin Bell	City and County of Denver: Green Infrastructure Program	CO

Scalable

- Tool will be developed at:
  - Watershed level **(i-DST)**
  - Individual site scale **(i-DST-SB)**





Scalable

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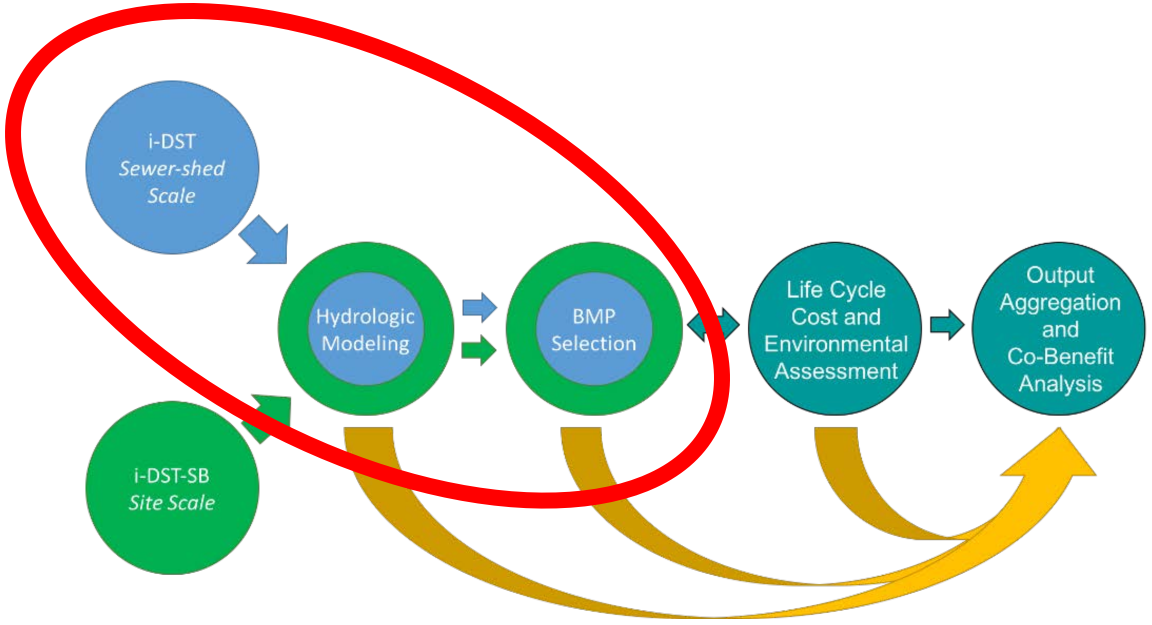
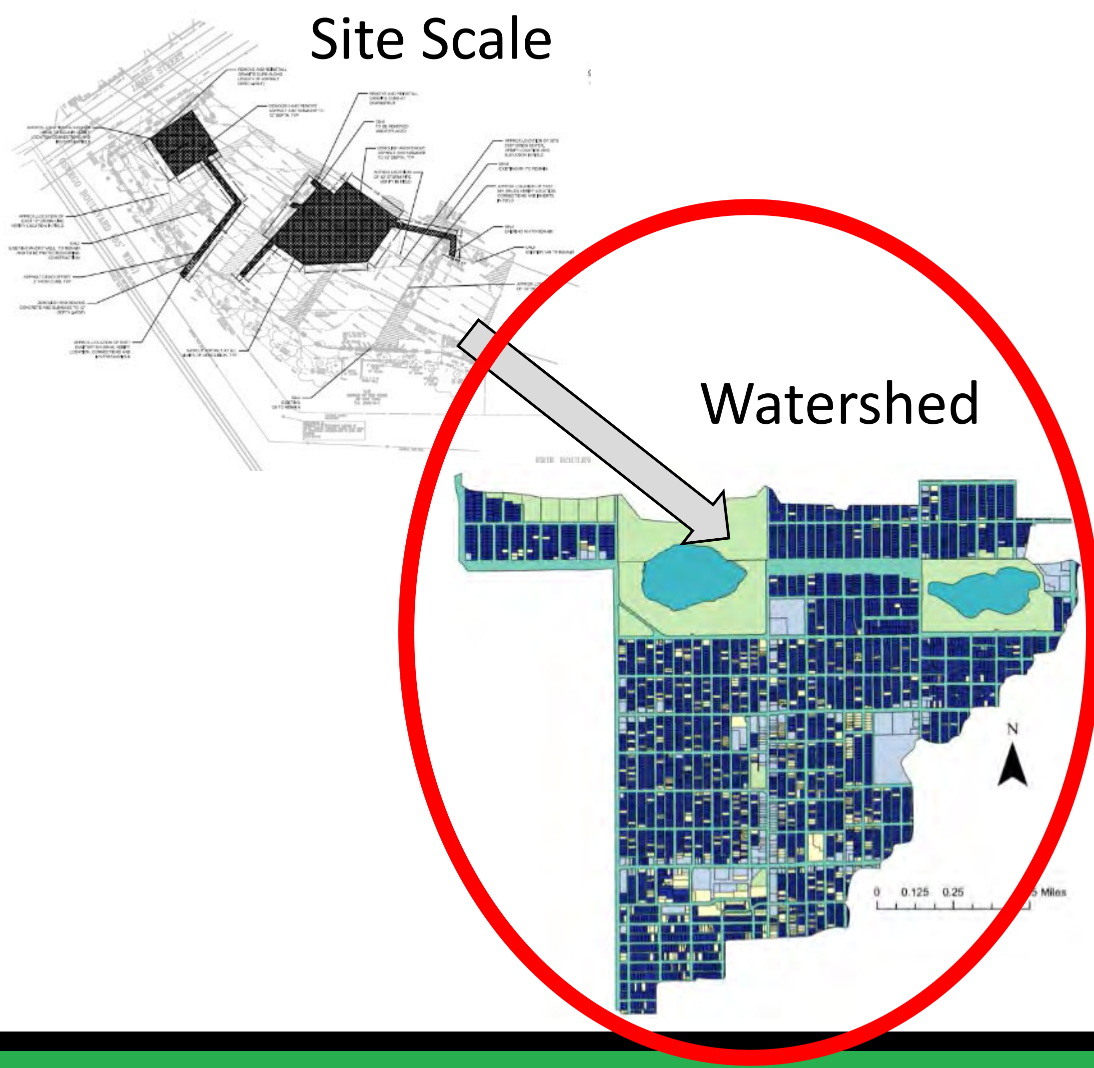
  - Watershed level **(i-DST)**
  - Individual site scale **(i-DST-SB)**





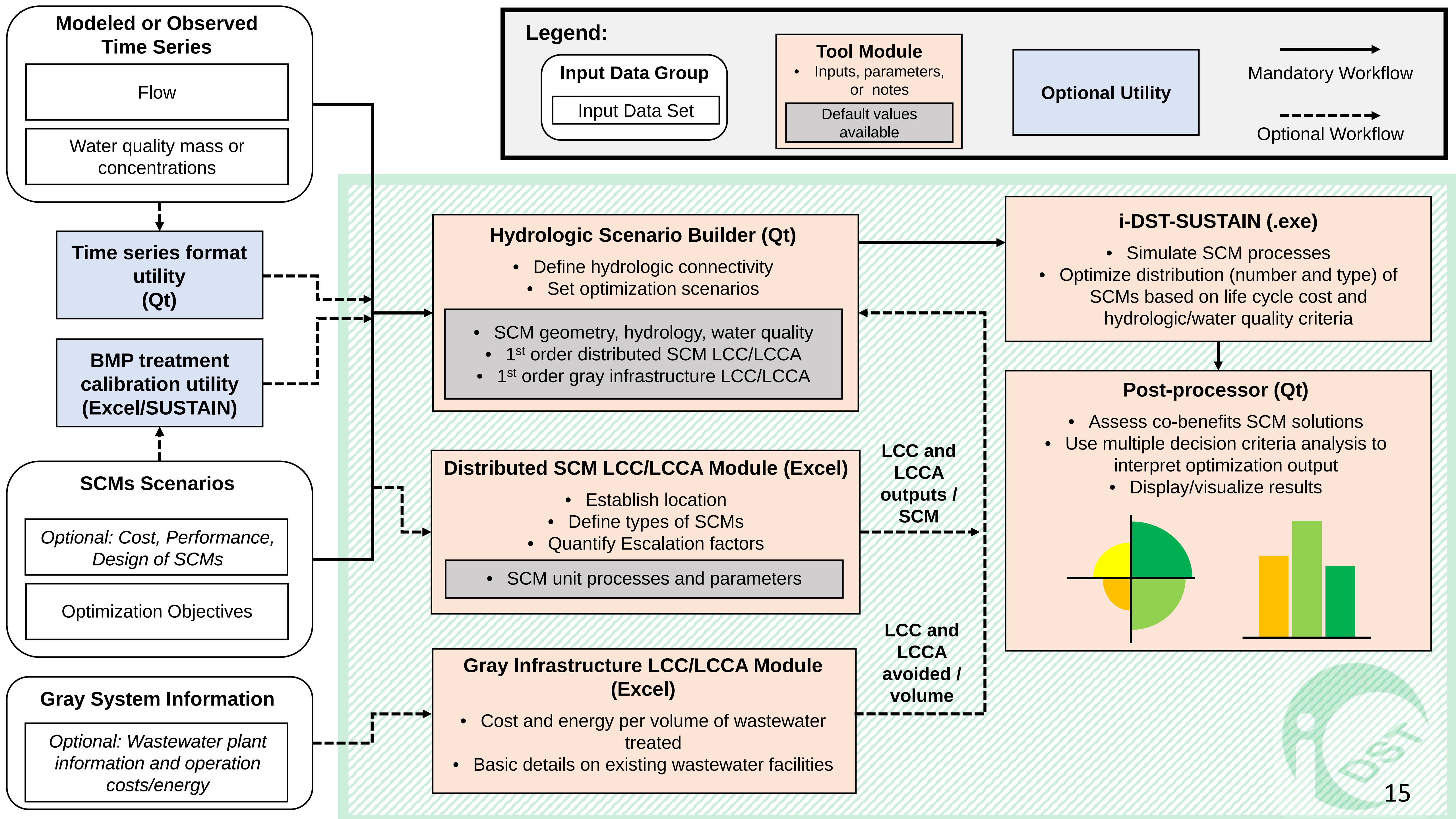
i-DST Tool Background

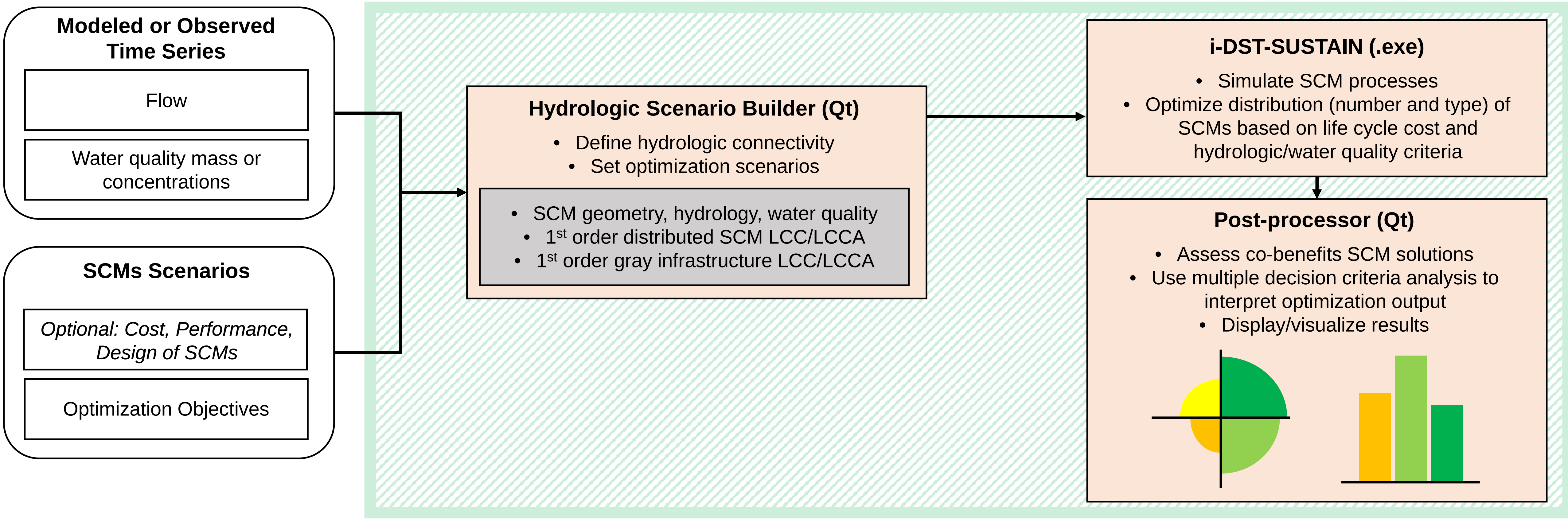
Watershed Tool Background

Updates to Front-end GUI

Updates to EPA-SUSTAIN Code

Test Site Modeling Example


Legend:
Input Data Group
Input Data Set
Tool Module
• Inputs, parameters, or notes
Default values available
Optional Utility
Mandatory Workflow
Optional Workflow
Modeled or Observed Time Series
Flow
Water quality mass or concentrations
Time series format utility (Qt)
BMP treatment calibration utility (Excel/SUSTAIN)
SCMs Scenarios
Optional: Cost, Performance, Design of SCMs
Optimization Objectives
Gray System Information
Optional: Wastewater plant information and operation costs/energy
Hydrologic Scenario Builder (Qt)
• Define hydrologic connectivity
• Set optimization scenarios
• SCM geometry, hydrology, water quality
• 1st order distributed SCM LCC/LCCA
• 1st order gray infrastructure LCC/LCCA
Distributed SCM LCC/LCCA Module (Excel)
• Establish location
• Define types of SCMs
• Quantify Escalation factors
• SCM unit processes and parameters
Gray Infrastructure LCC/LCCA Module (Excel)
• Cost and energy per volume of wastewater treated
• Basic details on existing wastewater facilities
LCC and LCCA outputs / SCM
LCC and LCCA avoided / volume
i-DST-SUSTAIN (.exe)
• Simulate SCM processes
• Optimize distribution (number and type) of SCMs based on life cycle cost and hydrologic/water quality criteria
Post-processor (Qt)
• Assess co-benefits SCM solutions
• Use multiple decision criteria analysis to interpret optimization output
• Display/visualize results


Modeled or Observed Time Series
Flow
Water quality mass or concentrations
SCMs Scenarios
Optional: Cost, Performance, Design of SCMs
Optimization Objectives
Hydrologic Scenario Builder (Qt)
• Define hydrologic connectivity
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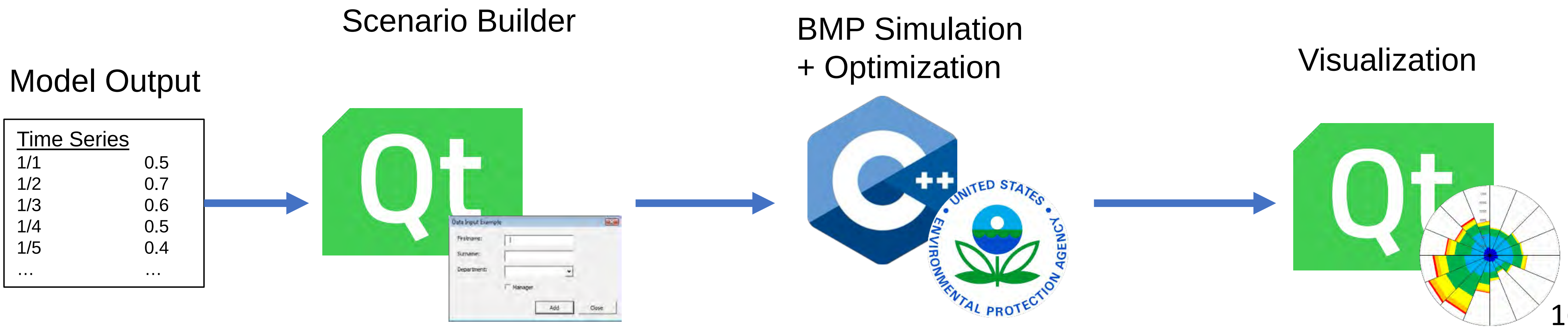
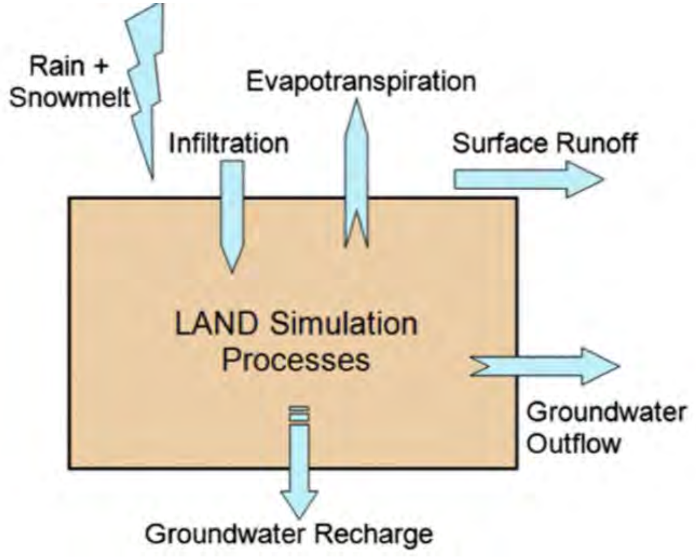
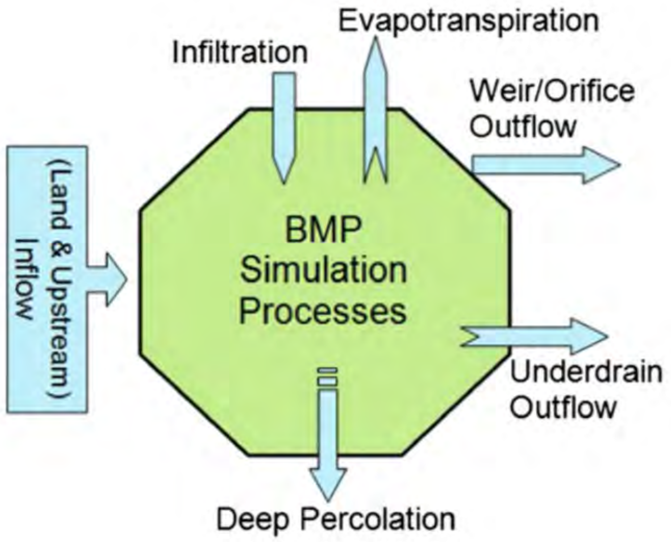
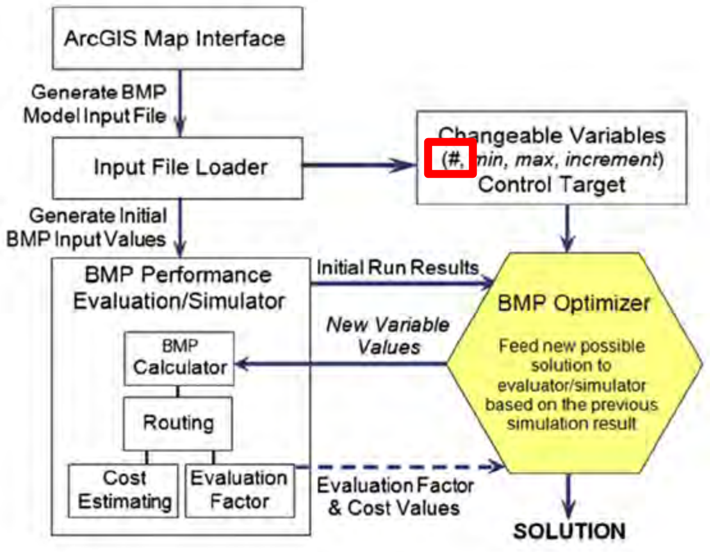

Model Output
Scenario Builder
BMP Simulation + Optimization
Visualization
Time Series
1/1 0.5
1/2 0.7
1/3 0.6
1/4 0.5
1/5 0.4
… …
Qt
Qt
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

EPA SUSTAIN Features







Also water quality treatment

$$\text{Cost} = a + b \cdot (\text{Length})^{c} + d \cdot (\text{Area})^{e} + f \cdot (\text{Volume})^{g}$$

Built In Evaluation Factors:*

- Peak Discharge
- Annual Average Volume
- Exceeding Frequency
- Annual Average Load
- Annual Average Concentration
- Maximum Days Average Concentration

i-DST Tool Background | Watershed Tool Background | **Updates to Front-end GUI** | Updates to EPA-SUSTAIN Code | Test Site Modeling Example

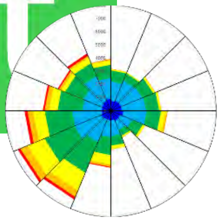
Model Output

Time Series	
1/1	0.5
1/2	0.7
1/3	0.6
1/4	0.5
1/5	0.4
…	…

Scenario Builder

BMP Simulation + Optimization

Visualization



Scenario Builder

Arc GIS 9.3

- Outdated
- Often Crashes

Excel VBA (Opti-Tool)

QT/C++

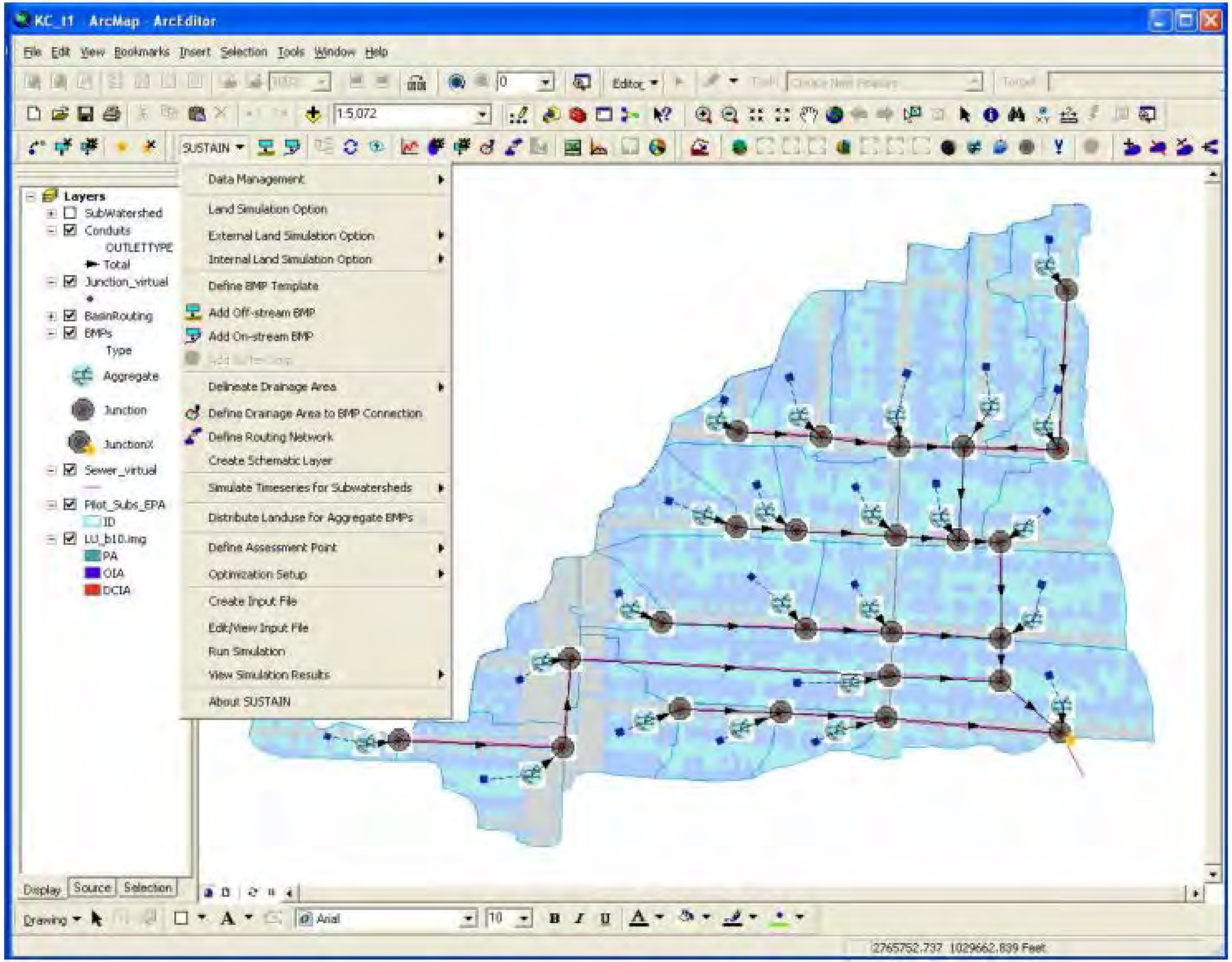


Image: Lee J., Riverson J.

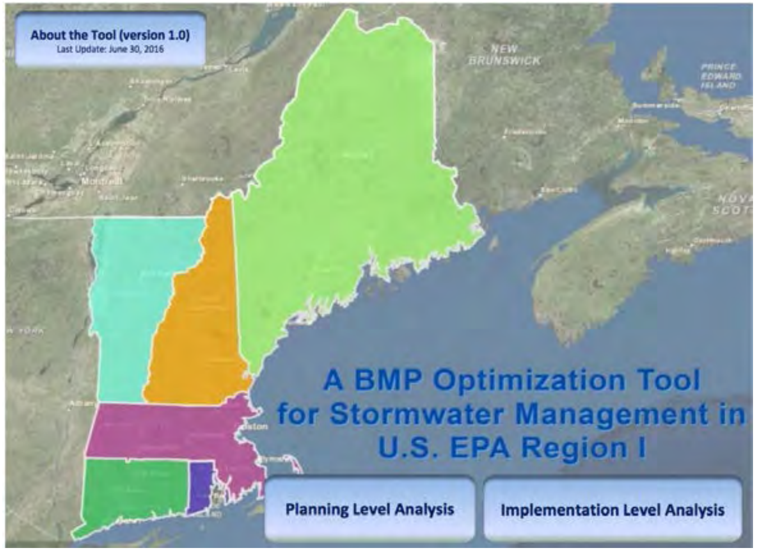
Scenario Builder

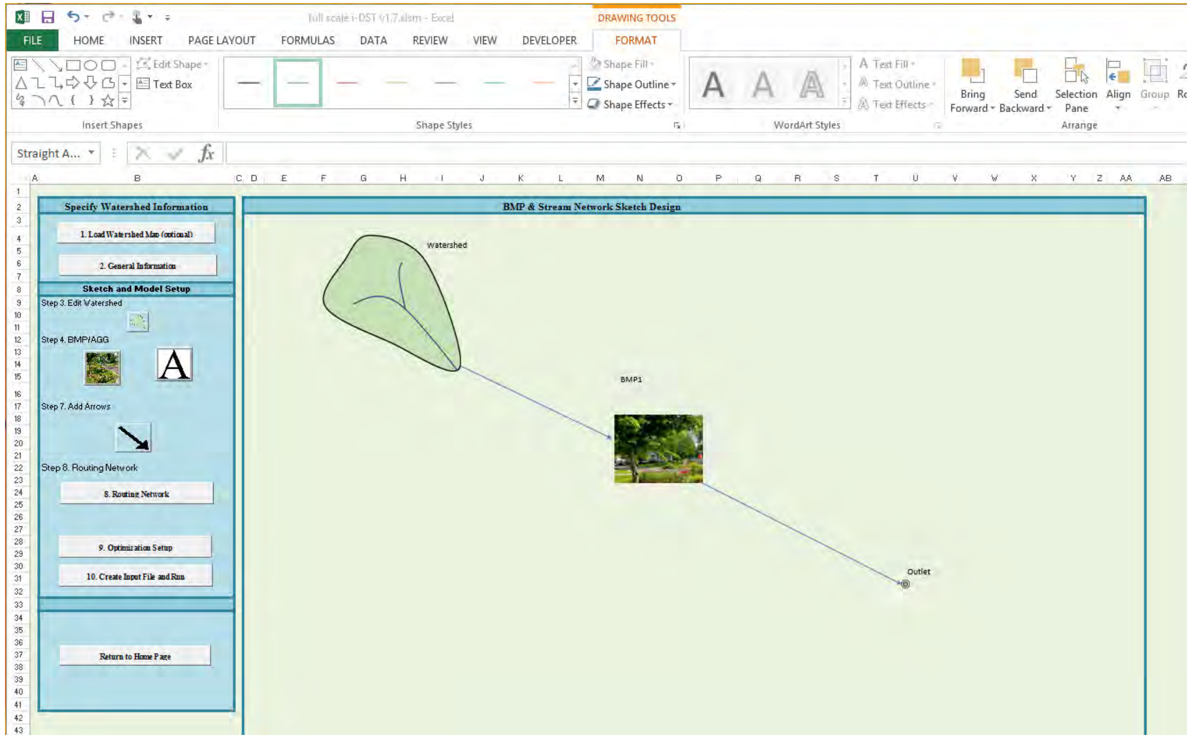
Arc GIS 9.3

Excel VBA (Opti-Tool)

- EPA Region 1 Tool
- TetraTech
- GUI to build input files

QT/C++





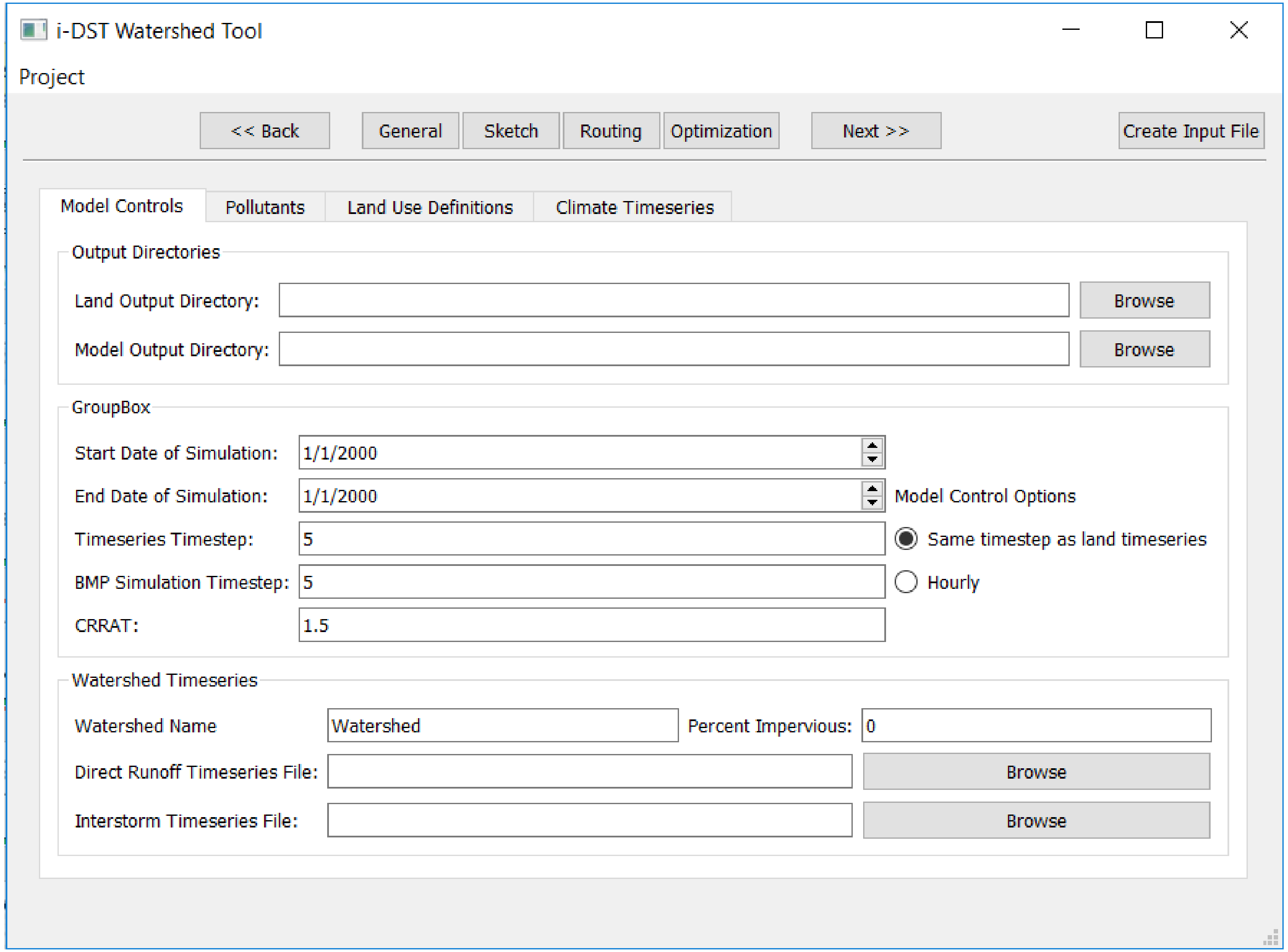
Scenario Builder

Arc GIS 9.3

Excel VBA (Opti-Tool)

QT/C++

- Easier and faster
- Less error prone
- More control
- Portability



i-DST Tool Background | Watershed Tool Background | Updates to Front-end GUI | **Updates to EPA-SUSTAIN Code** | Test Site Modeling Example

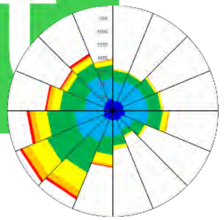
Model Output

Time Series	
1/1	0.5
1/2	0.7
1/3	0.6
1/4	0.5
1/5	0.4
…	…

Scenario Builder

BMP Simulation
+ Optimization

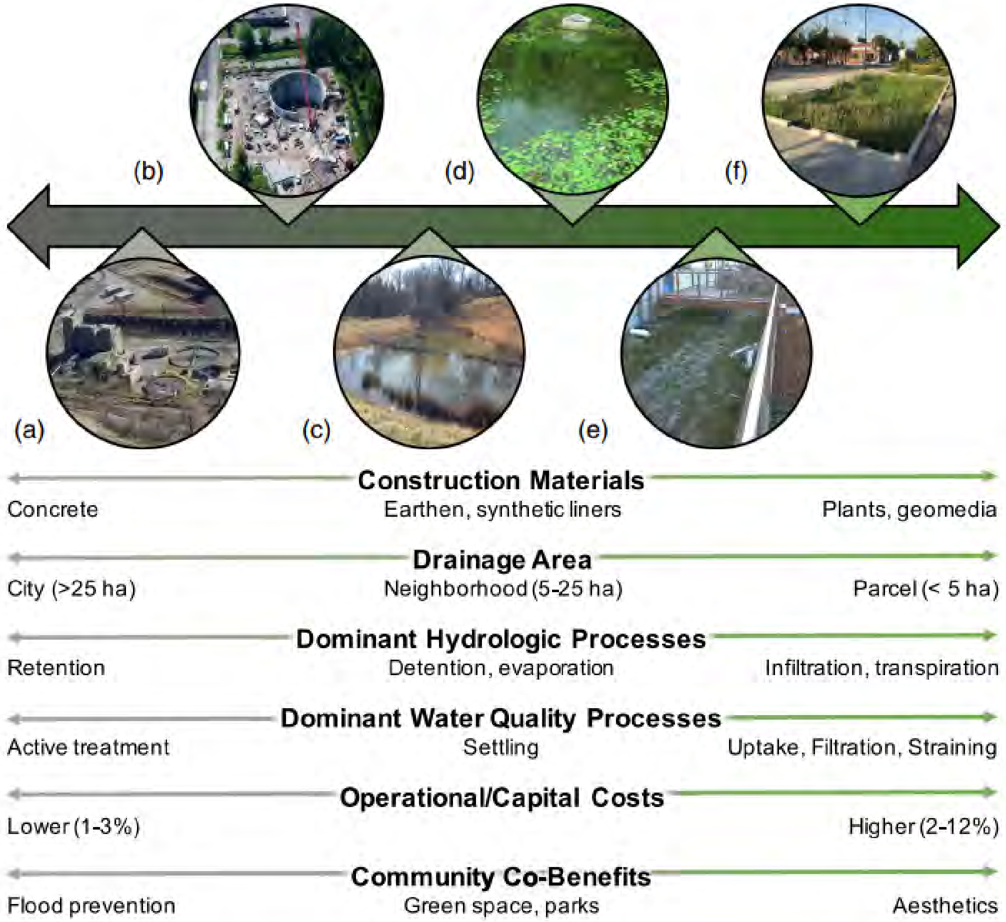
Visualization



Updates to SUSTAIN

1. Hybrid-Grey Infrastructure

Available SCM Types in SUSTAIN
Green Roof
Bio-retention
Infiltration Trench
Vegetated Swale
Dry Pond
Wet Pond
Buffer Strip
Porous Pavement
Rain Barrel
Cistern



Updates to SUSTAIN

1. Hybrid-Grey Infrastructure

Available SCM Types in SUSTAIN
Green Roof
Bio-retention
Infiltration Trench
Vegetated Swale
Dry Pond
Wet Pond
Buffer Strip
Porous Pavement
Rain Barrel
Underground Detention*
Underground Infiltration*
Underground Gravel Bed
Above Ground Storage

Underground Detention

Underground Infiltration

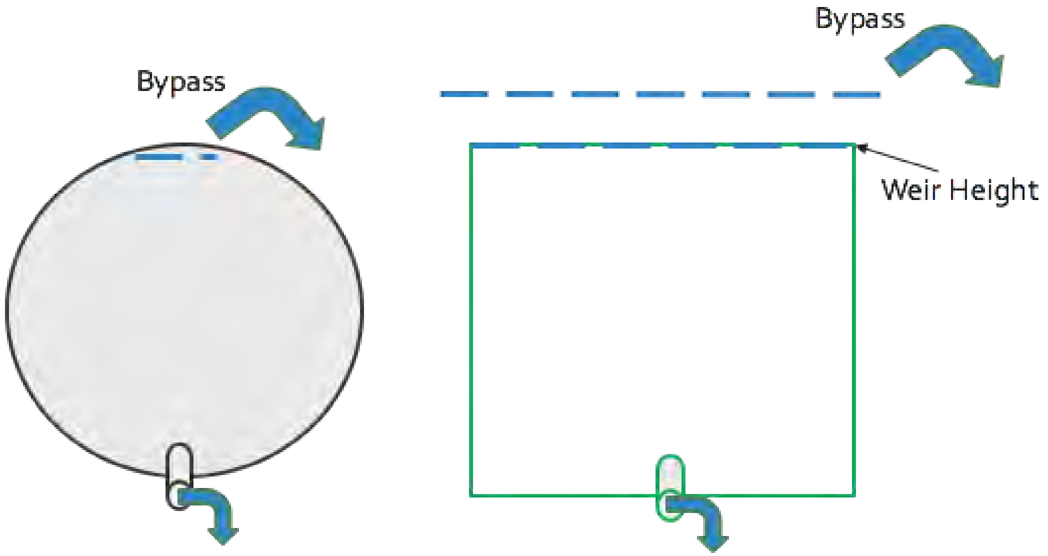
Underground Pipes

* Simulated as a pipe or a 'box'
SCM figures: StormTrap and Contech

Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

1. Bypass when reach max SCM volume capacity



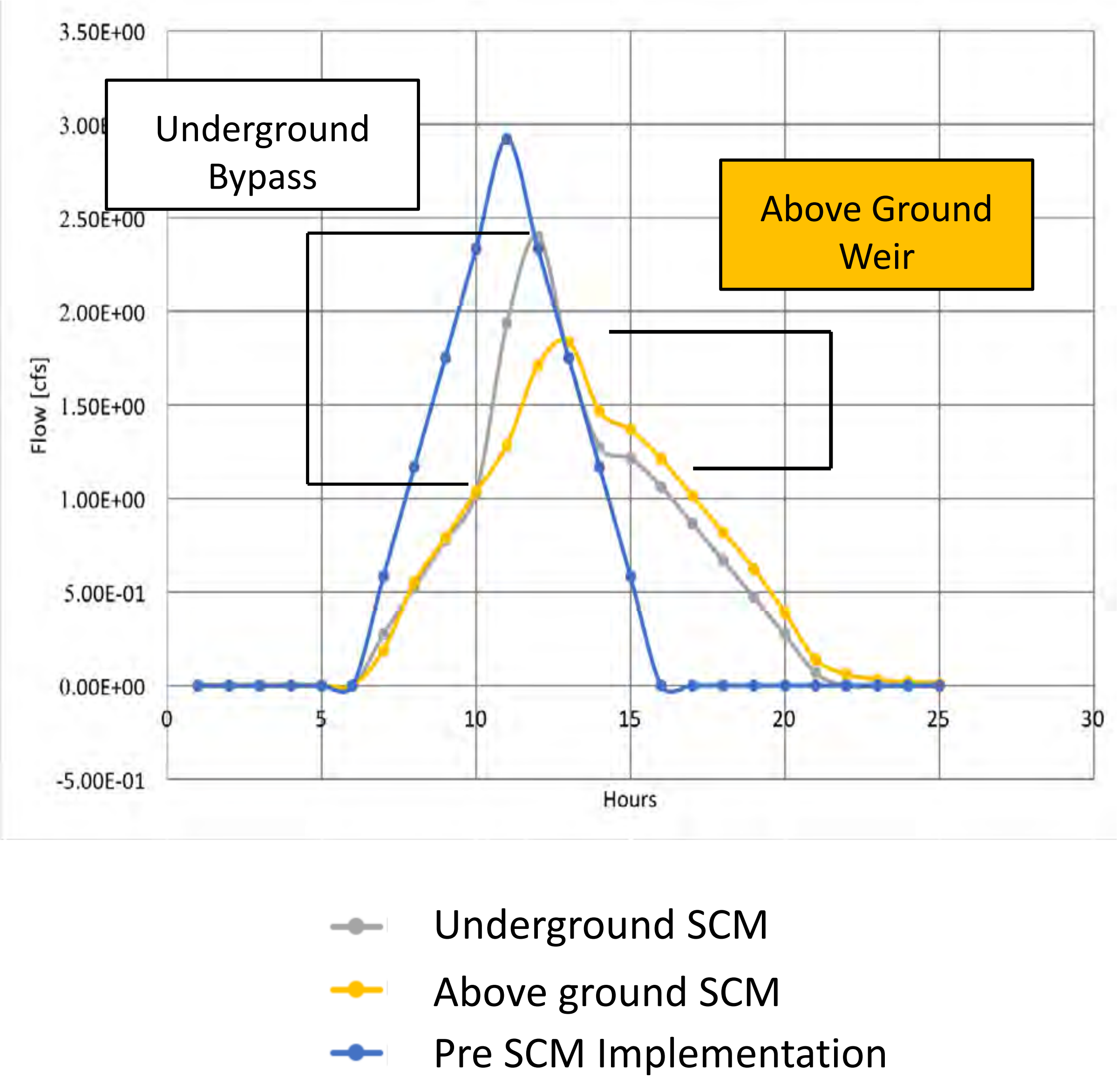
Underground pipe

Above ground “box”

Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

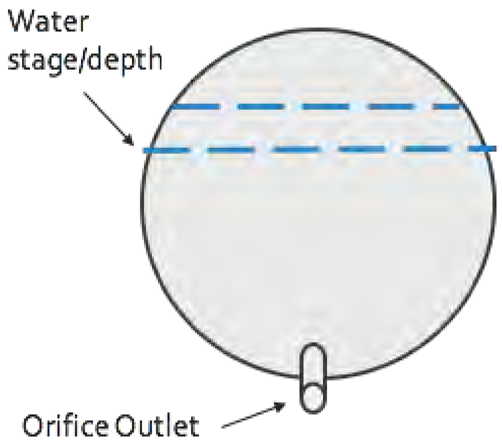
1. Bypass when reach max SCM volume capacity



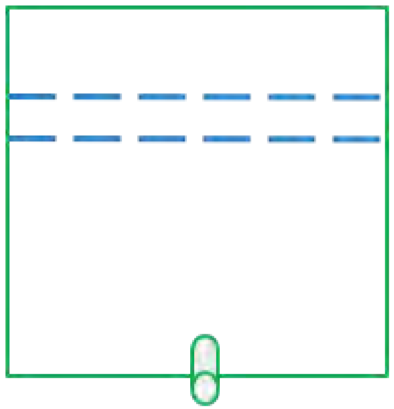
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

2. Accurate stage-surface area-volume relationship for pipes



Underground pipe



Above ground “box”

Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
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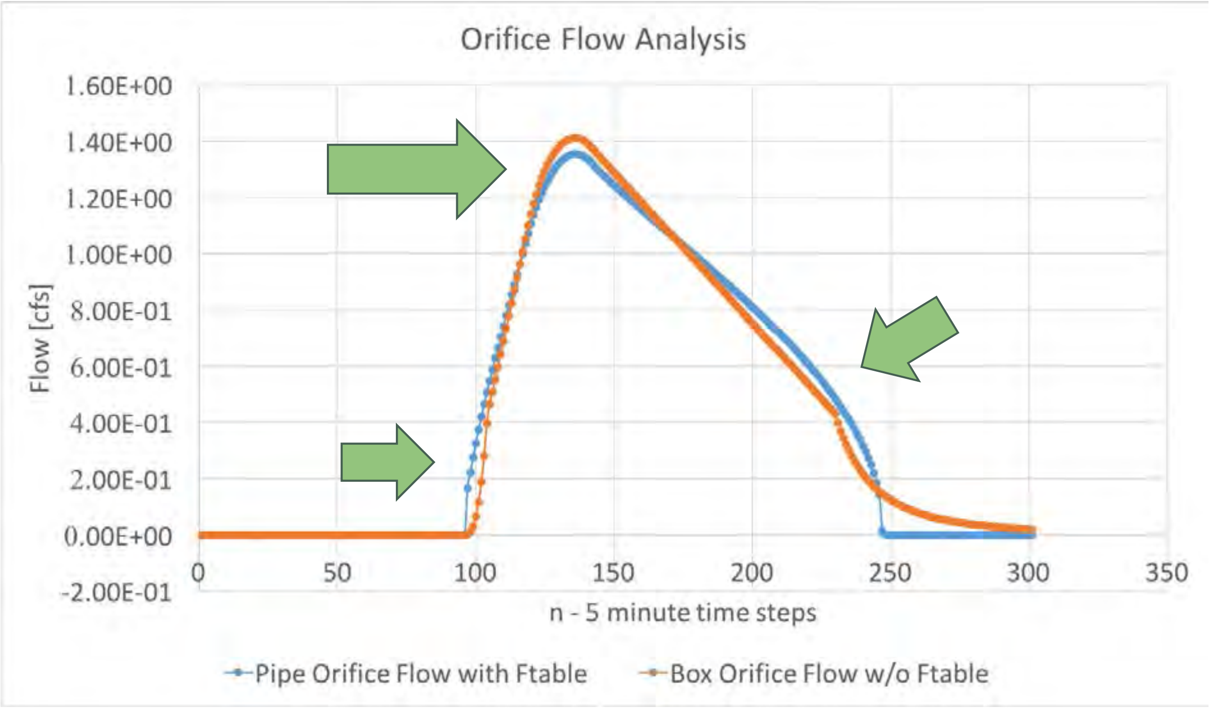
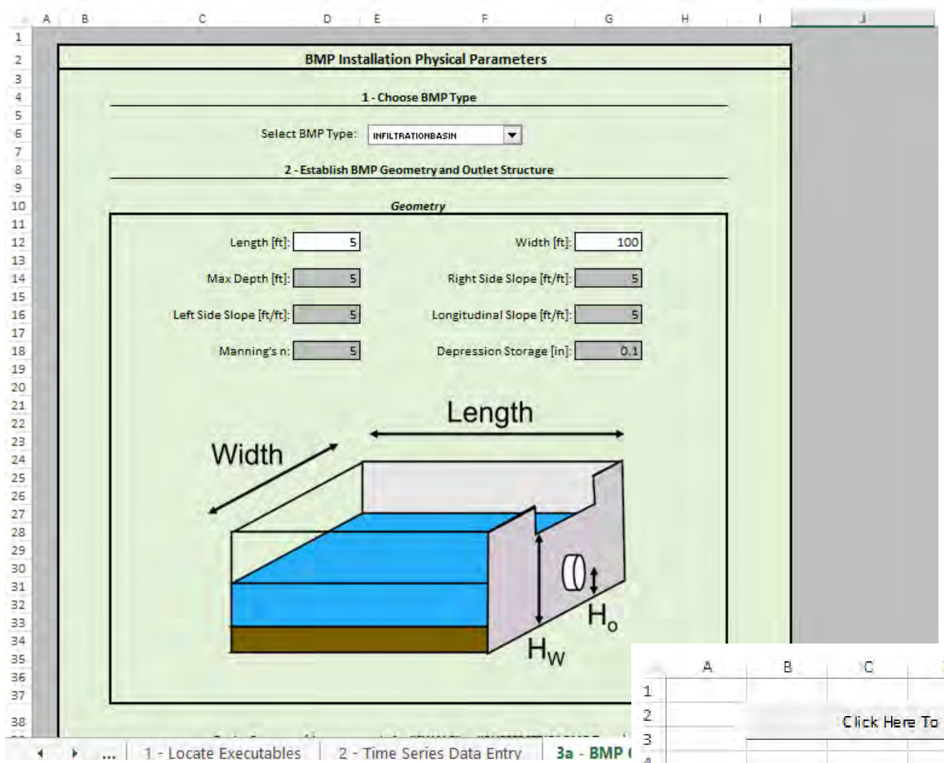
2. Accurate stage-surface area-volume relationship for pipes



Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool

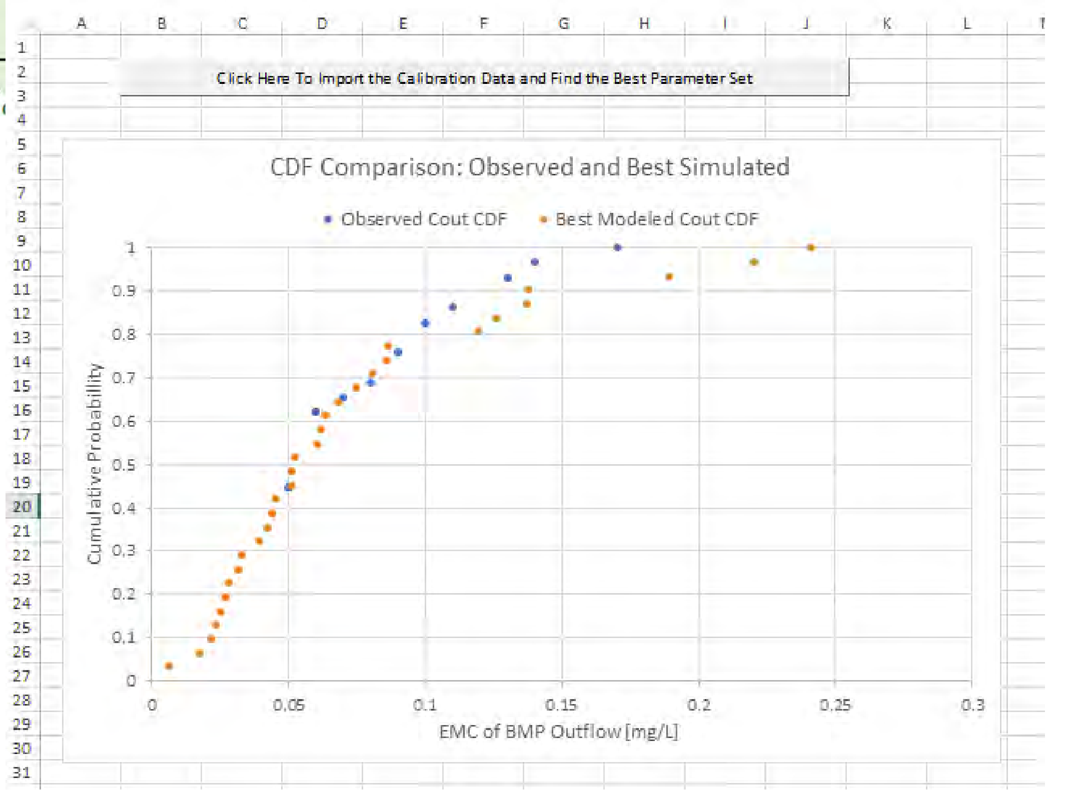


Inputs

- Precip time series
- Storm event SCM volumes, influent, and effluent data

Output

- Calibrated k or k-C* values



Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors

Water Quantity Benefits
Average Annual Flow Volume
Flow Exceedance Frequency
Flow Duration Curve
Peak Discharge Flow

Water Quality Benefits
Average Annual Load
Average Annual Concentration
Days above X Concentration

Updates to SUSTAIN

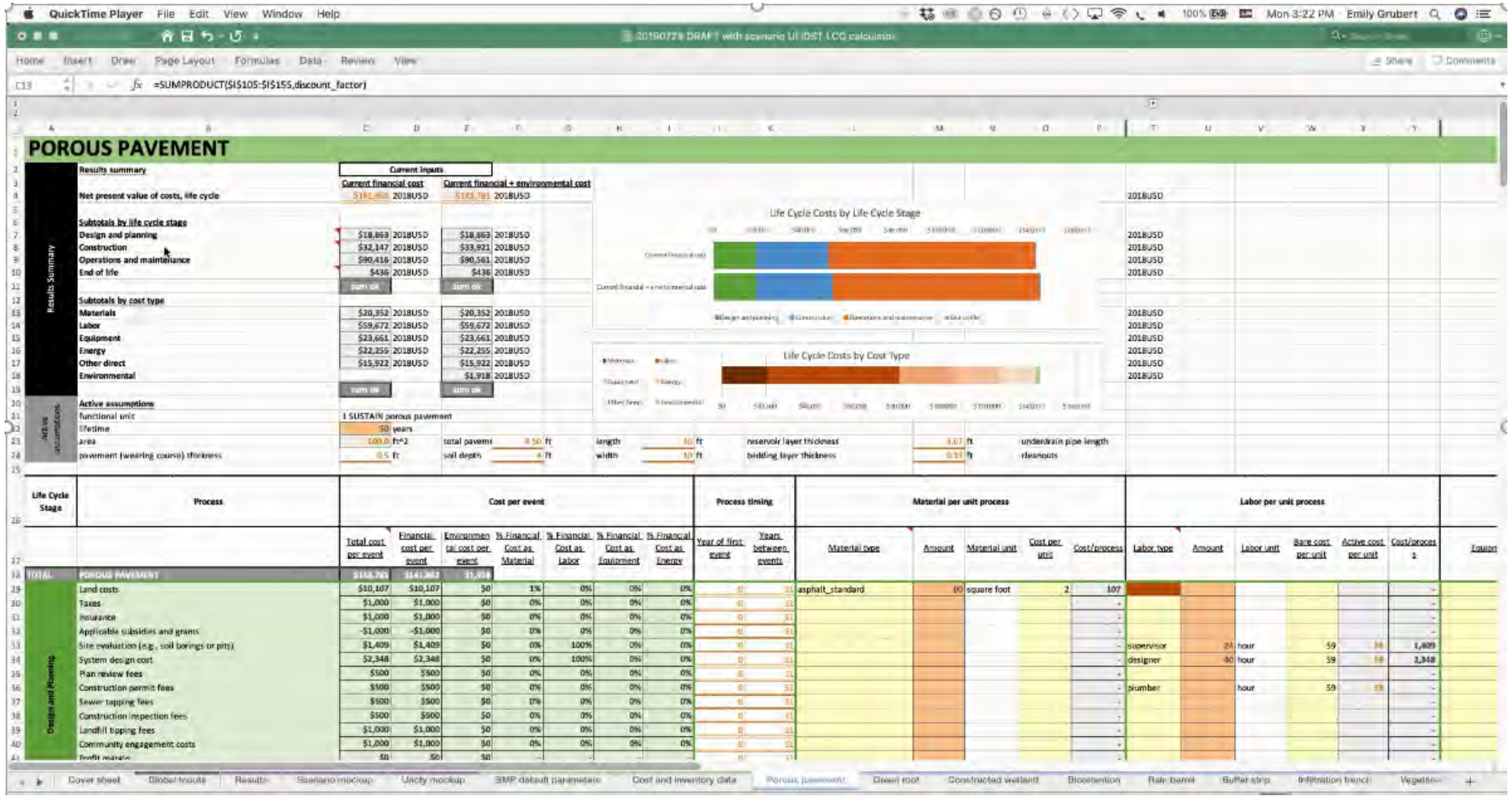
1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors

Water Quantity Benefits
Average Annual Flow Volume
Flow Exceedance Frequency
Flow Duration Curve
Peak Discharge Flow
Seasonal Average Flow Volume
Average Annual Groundwater Recharge
Seasonal Average Groundwater Recharge
Average Annual Evapotranspiration
Seasonal Average Evapotranspiration
New Peak Discharge Flow Calculations

Water Quality Benefits
Average Annual Load
Average Annual Concentration
Days above X Concentration
Seasonal Average Load
Seasonal Average Concentration

Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors
5. Life Cycle costs utilized in the Optimizer



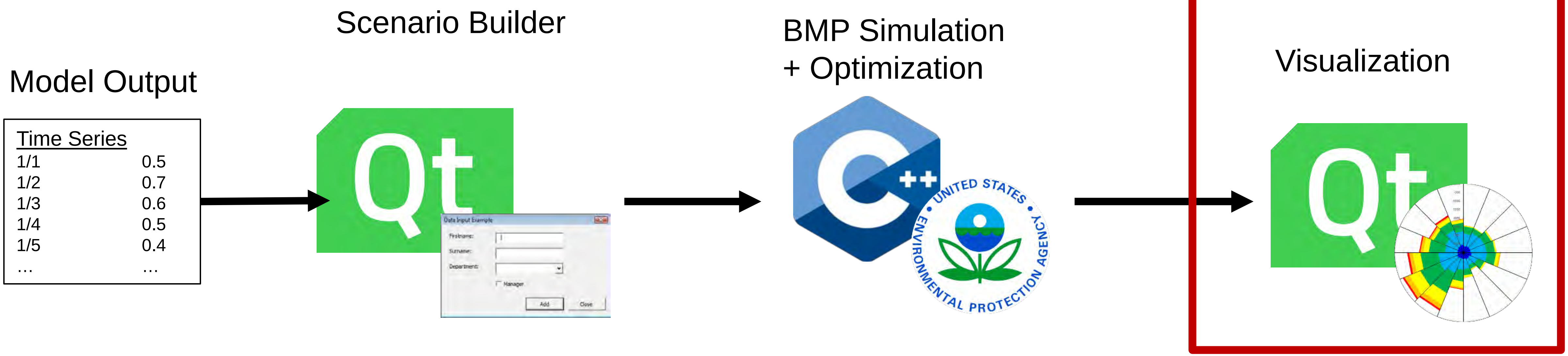
i-DST Tool Background

Watershed Tool Background

Updates to Front-end GUI

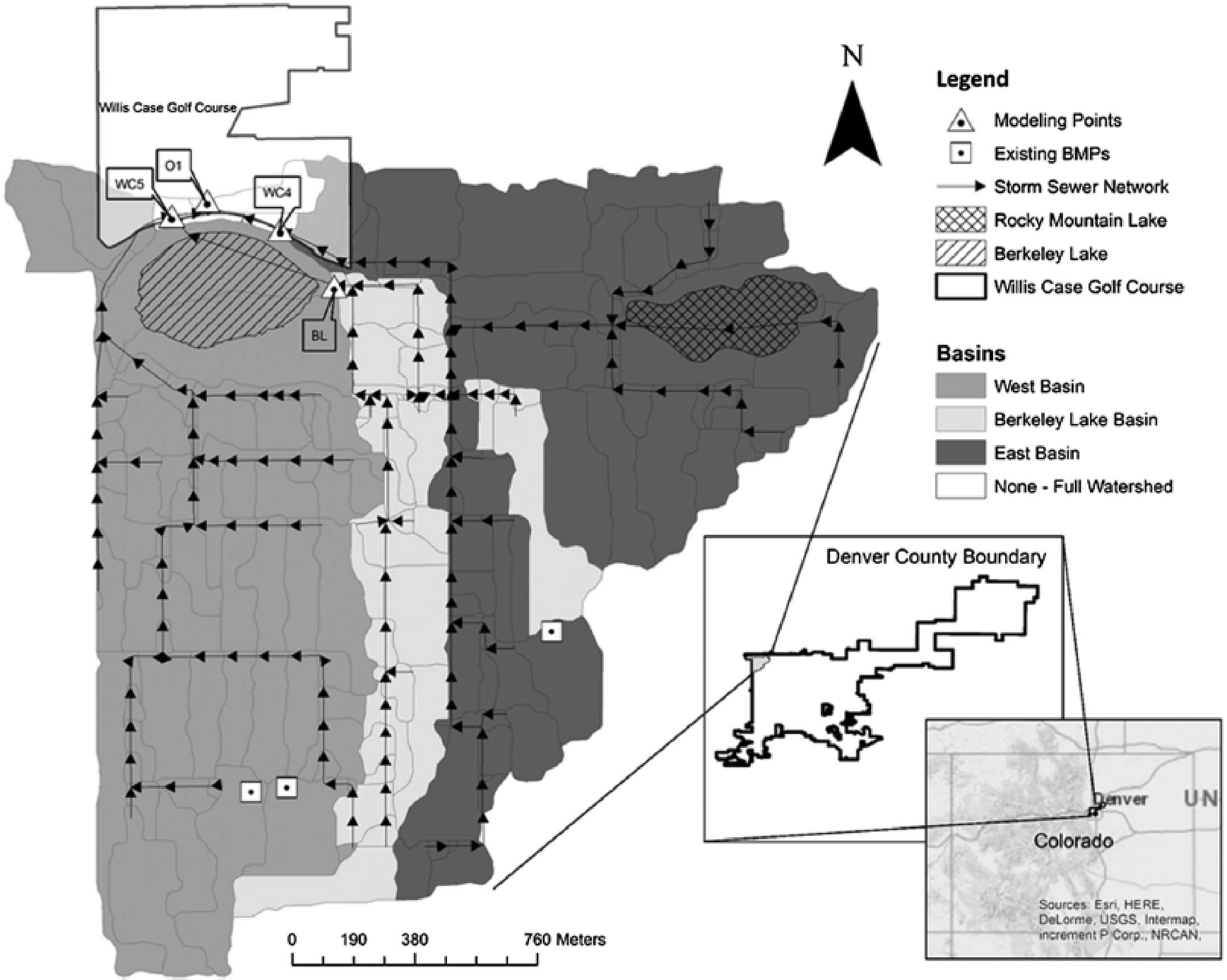
Updates to EPA-SUSTAIN Code

Test Site Modeling Example



Test Site: Berkeley Neighborhood Watershed

- 1,035 acres
- 53% impervious
- 15% of total area covered by future infil-redevelopment
- Concern of increase in surface water runoff



High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019

Test Site: Berkeley Neighborhood Watershed

What is the optimal suite and number of SCMs to reduce infil-redevelopment runoff back to pre-redevelopment flow?

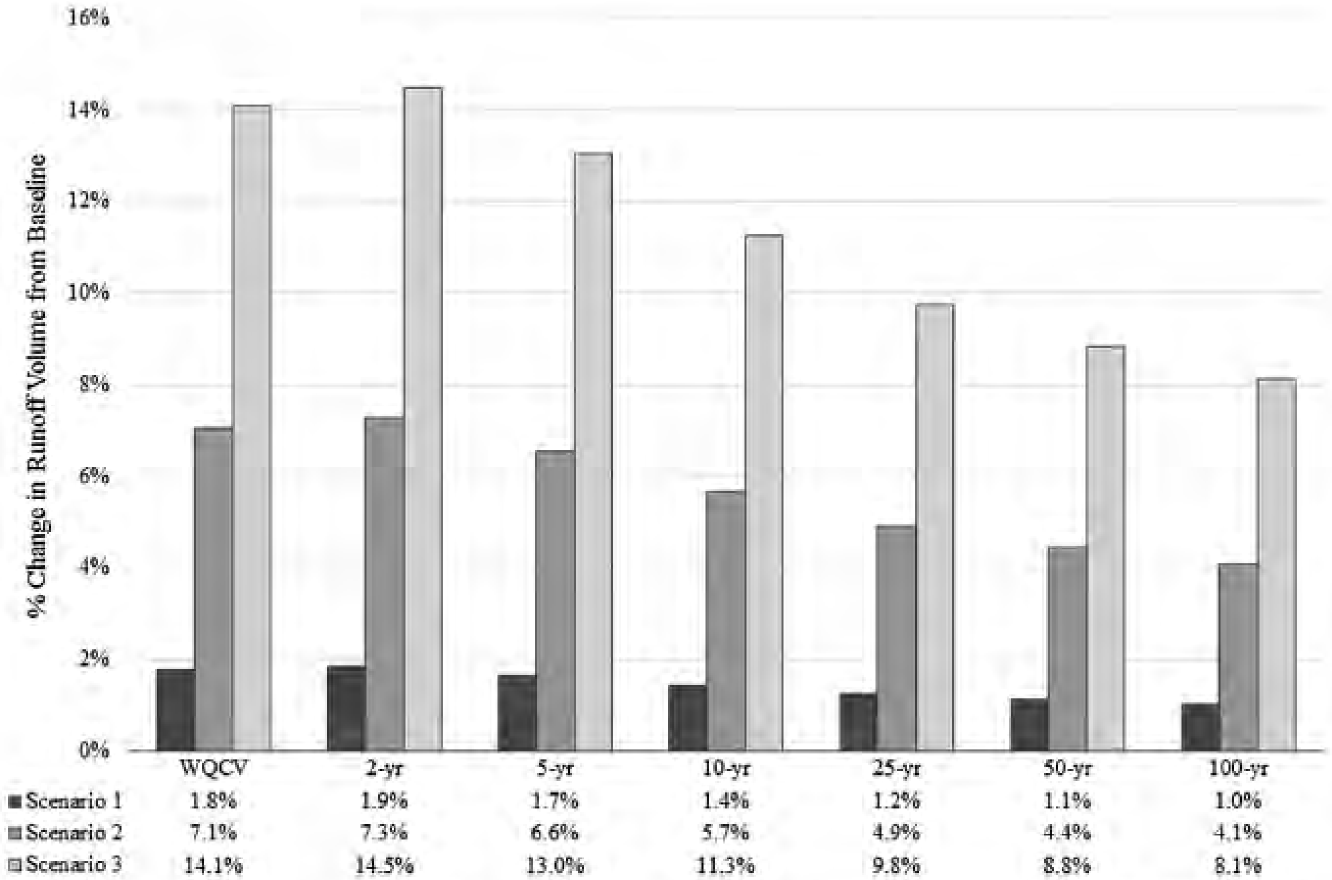


Fig. 6. Percent increase in total surface runoff volume from baseline for each design storm event by scenario. The WQCV is a 6-h event, while all others are 24-h.

- Scenario 1: +1.2% imp
- Scenario 2: +4.7% imp
- Scenario 3: +8.1% imp

High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019

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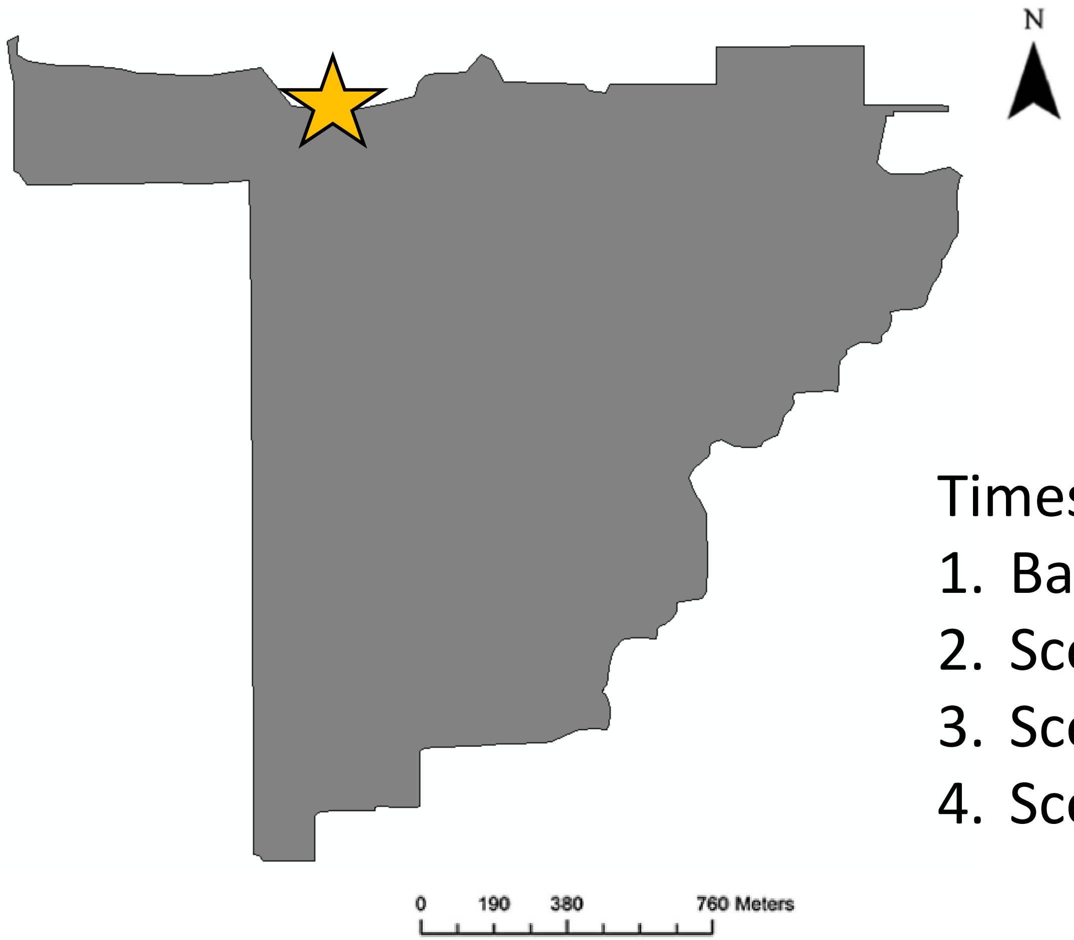

Timeseries ☆

1. Baseline/current flow
2. Scenario 1: +1.2% imp
3. Scenario 2: +4.7% imp
4. Scenario 3: +8.1% imp

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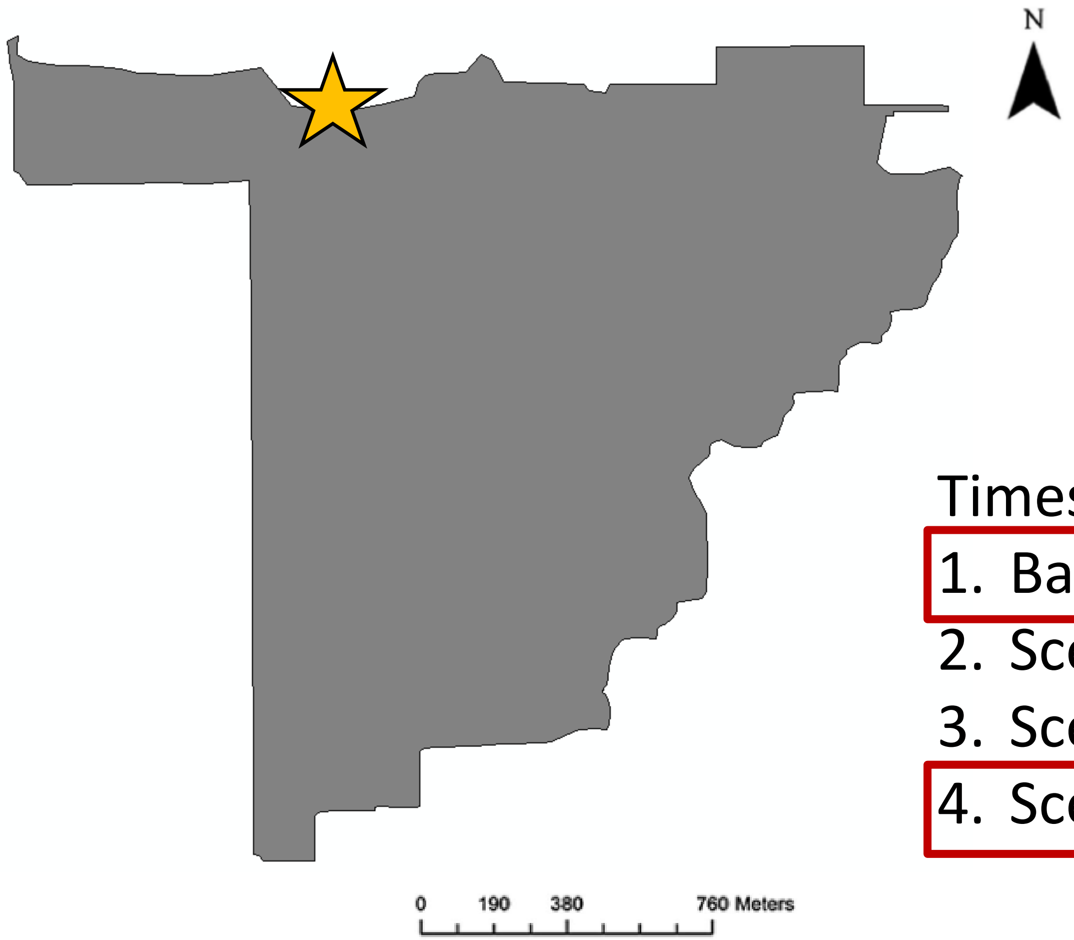

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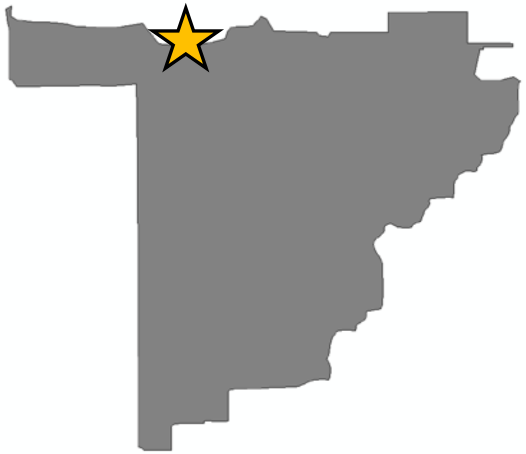
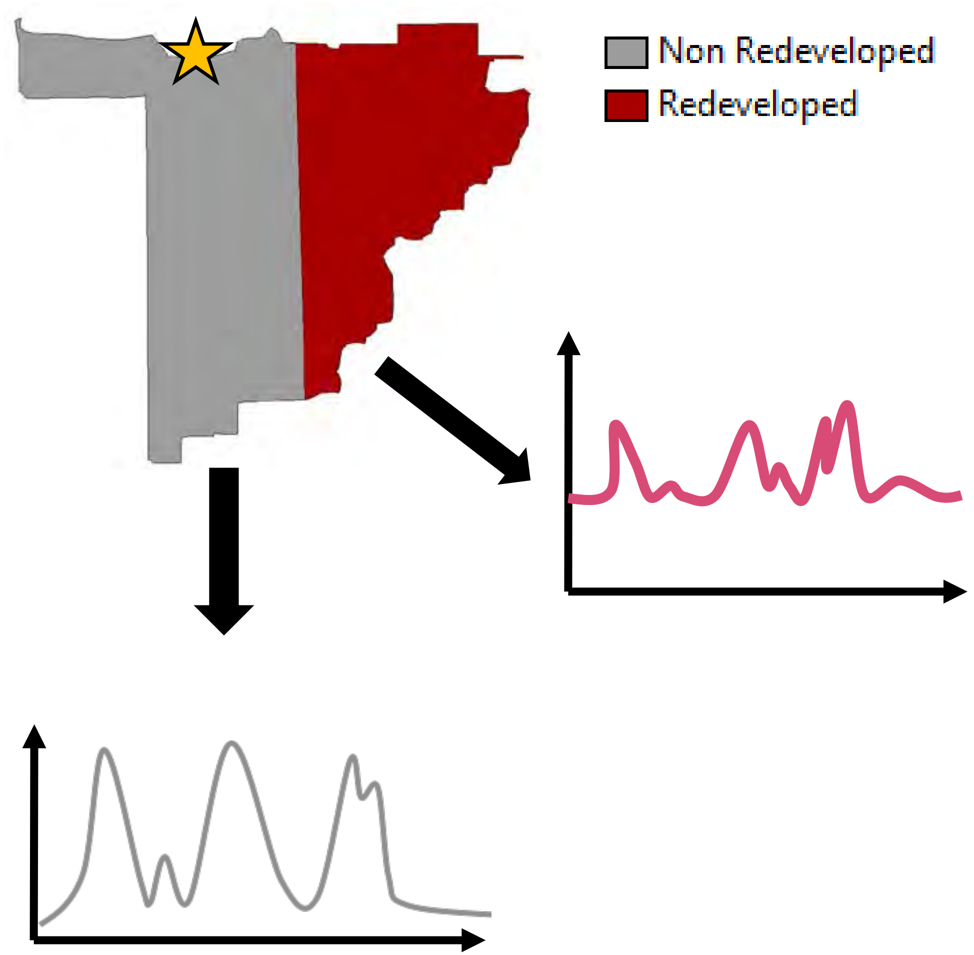
High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019

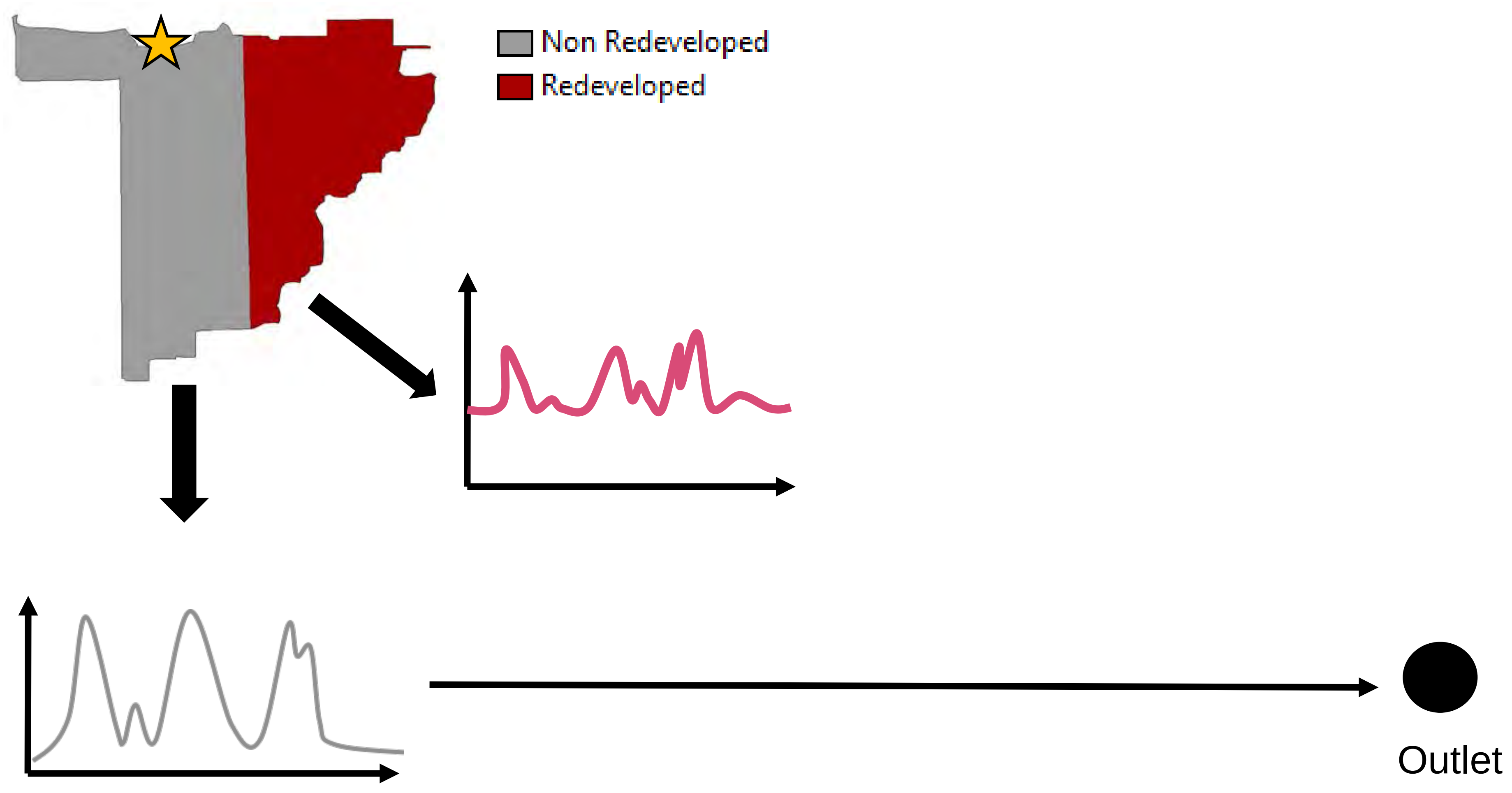
Workflow and Model Routing



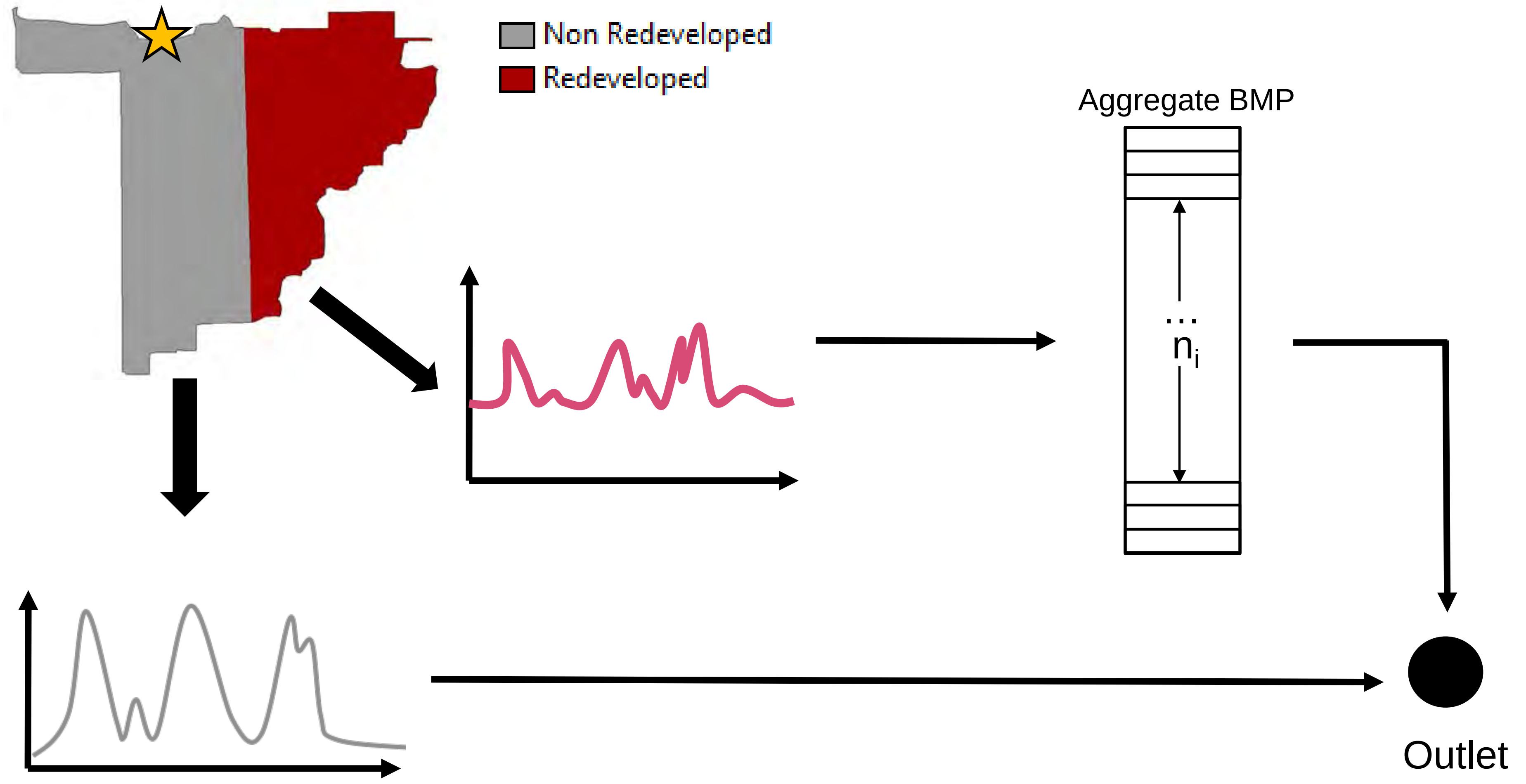
Workflow and Model Routing



Workflow and Model Routing

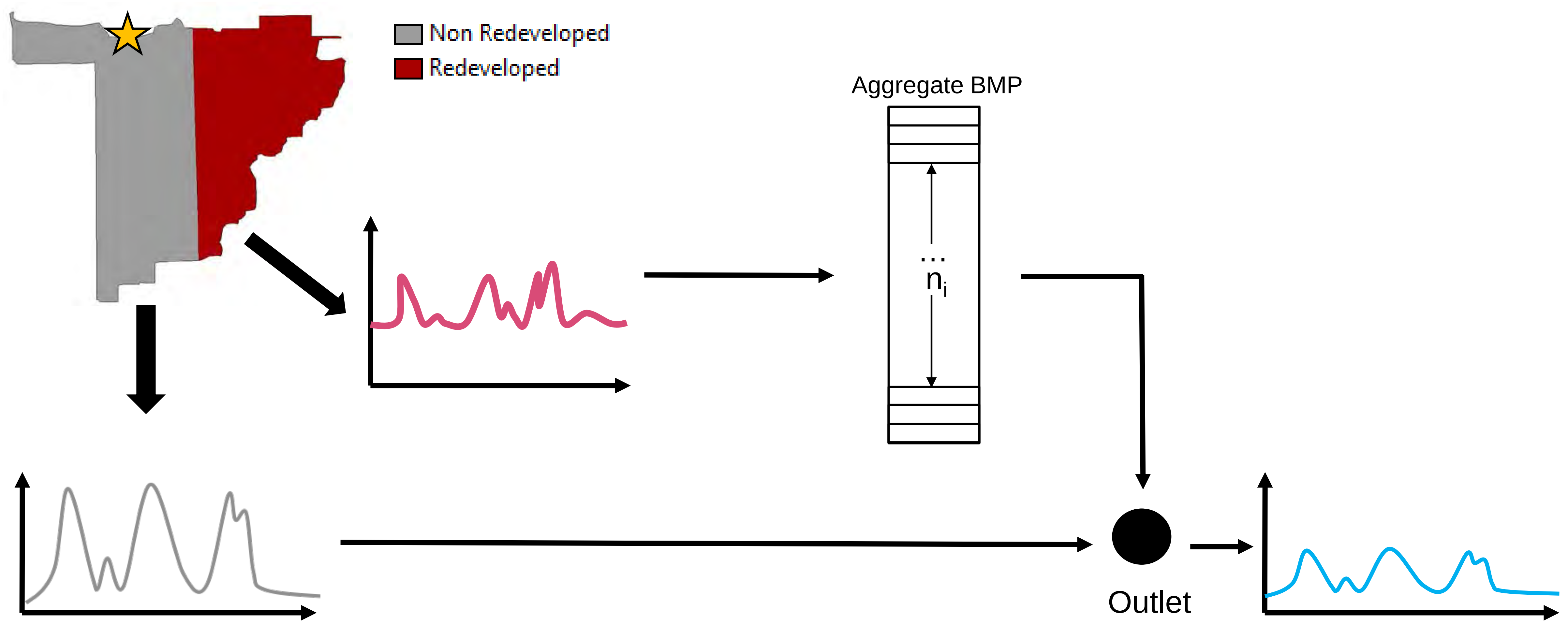


Workflow and Model Routing



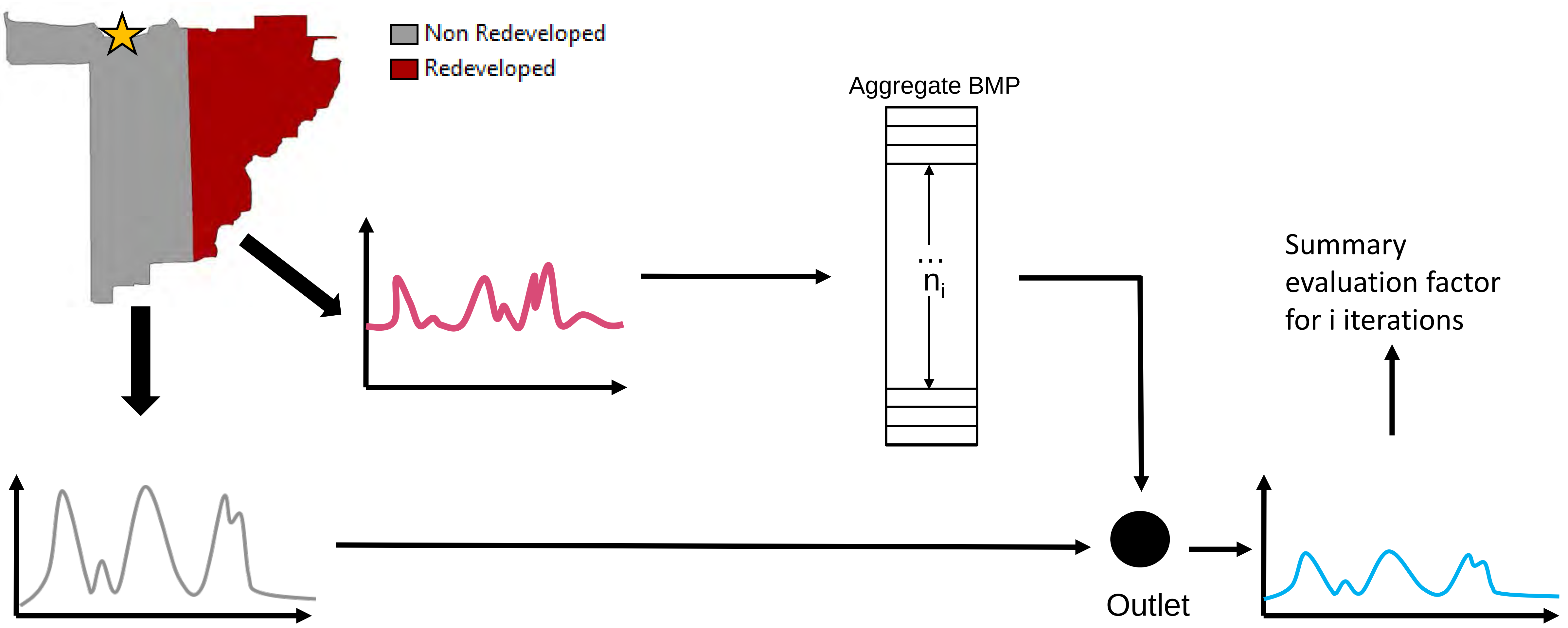
i = # of iterations

Workflow and Model Routing



i = # of iterations

Workflow and Model Routing



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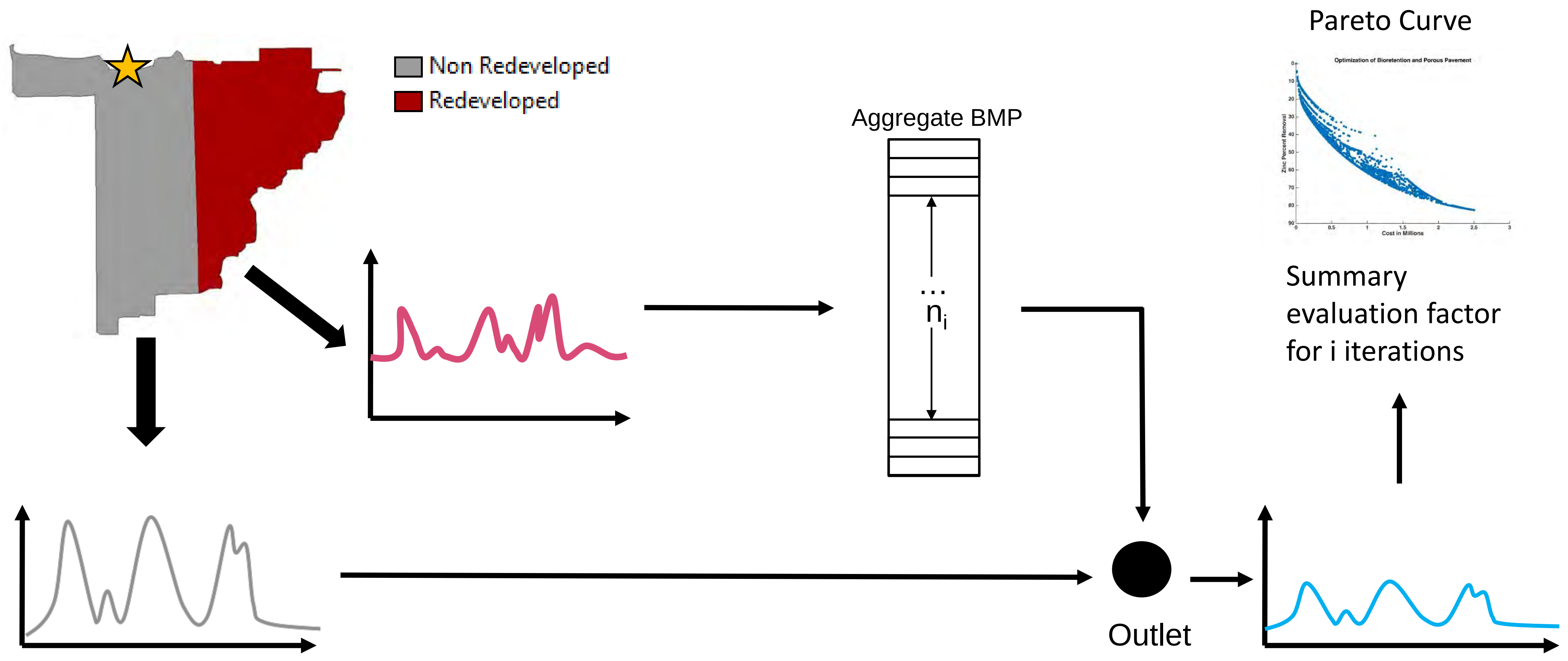
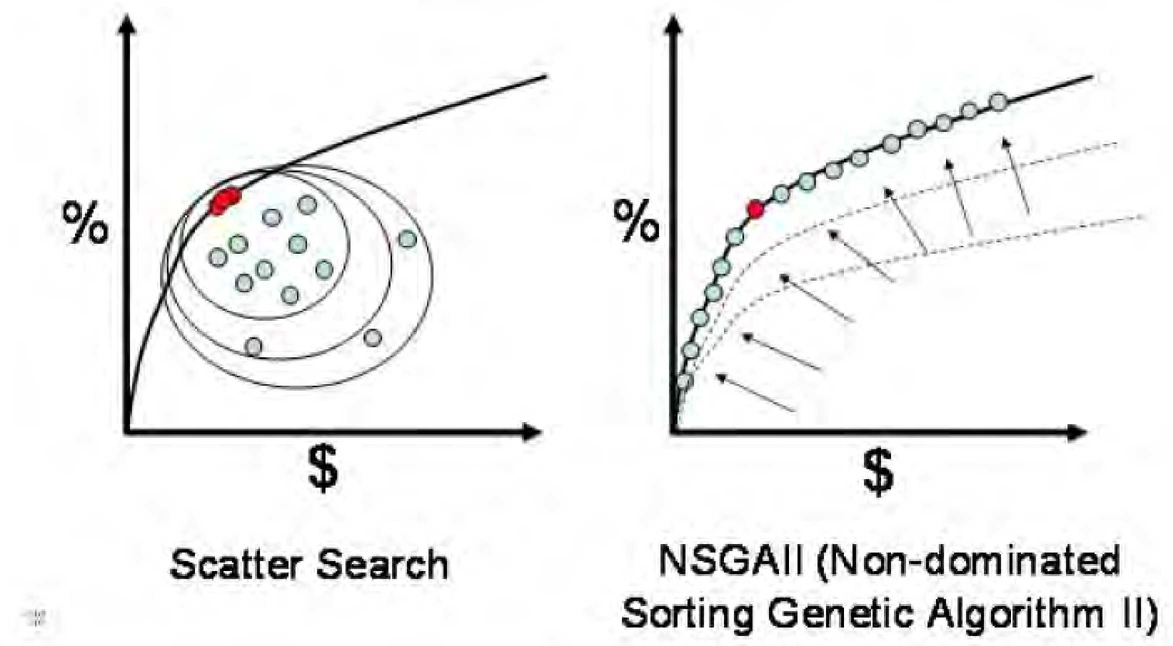
Workflow and Model Routing



i = # of iterations

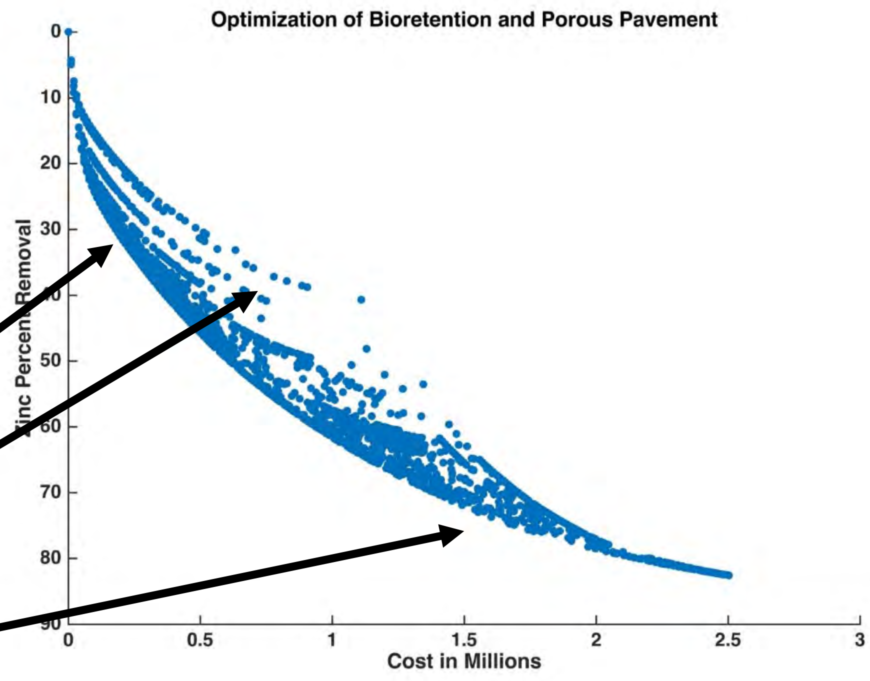
What is a pareto curve?

- Plotting cost vs evaluation factor during the optimization
- Evolutionary search technique
- Solve nonlinear, single or multi-objective, complex problems
- Find the optimal solution



Pareto Curve Example

	Porous Pavement Units	Bio-retention Units
Min number of SCMs	1	1
Max number of SCMs	60	33
Iteration 1	5	2
Iteration 2	40	10
Iteration 3	20	29



SCMs in the Berkeley Neighborhood model

	Los Angeles Capital Cost/ft^3	Area on Surface [ft^2]	Surface Storage Volume [ft^3]	Total Storage Volume [ft^3]	Maximum units to be optimized
Bio-retention	14.60	100	100	306	1300
Vegetated Swale	10.07	32	50	82	2600
Underground Infiltration	10.34	0	100	253	1300
Porous Pavement	15.69	100	100	204	1300

Optimization Set up

Individual SCM Comparison

- 4 pareto curves
- Optimize each SCM separately
- Routing 100% of infil-redevelopment to the SCM
- Evaluation factors:
    - average annual flow volume
    - groundwater recharge potential

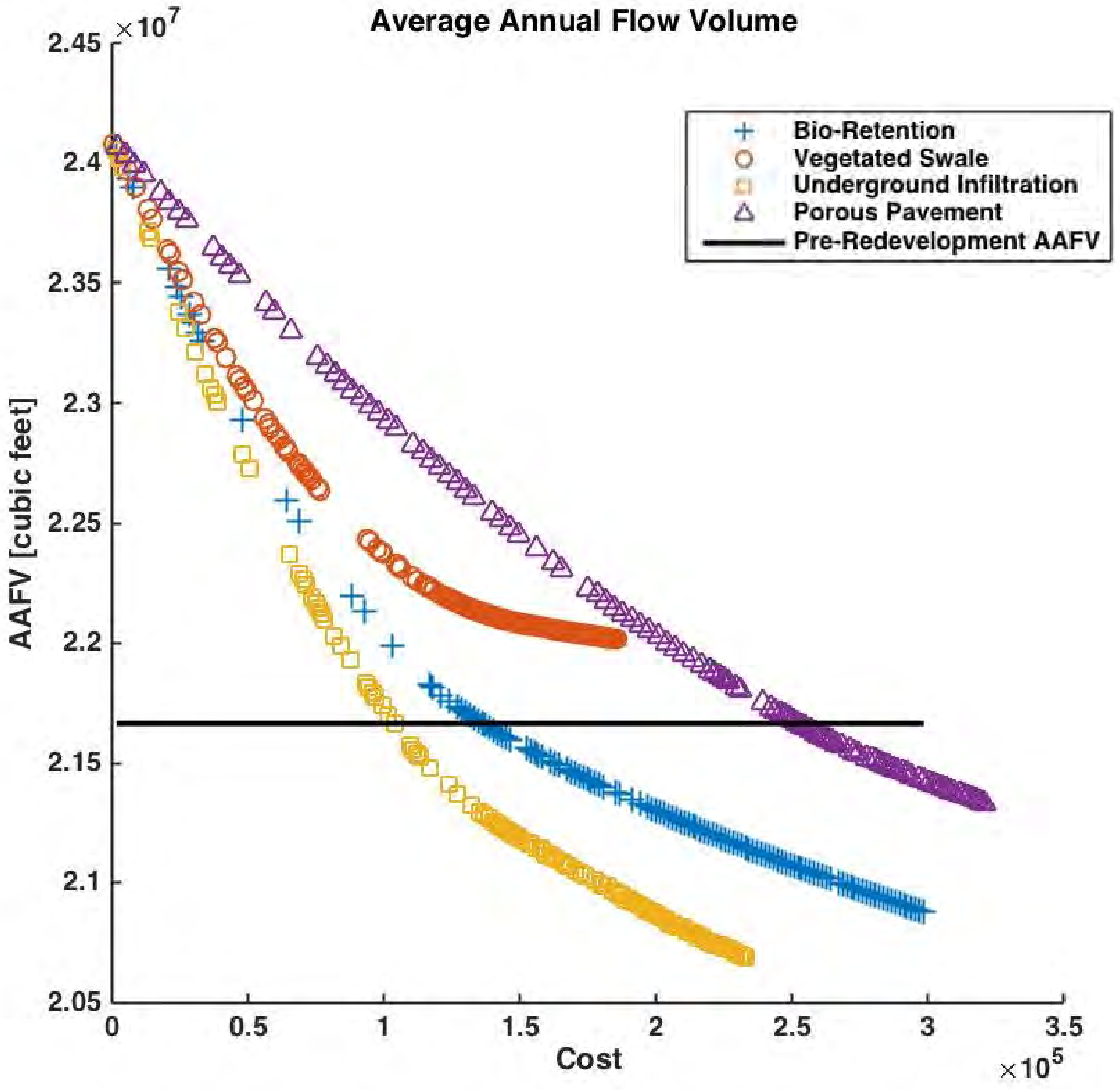
Full optimization

- 1 pareto curve
- Optimize all SCMs simultaneously
- Routing 25% of infil-redevelopment to each SCM type
- Evaluation factors:
    - average annual flow volume
    - groundwater recharge potential

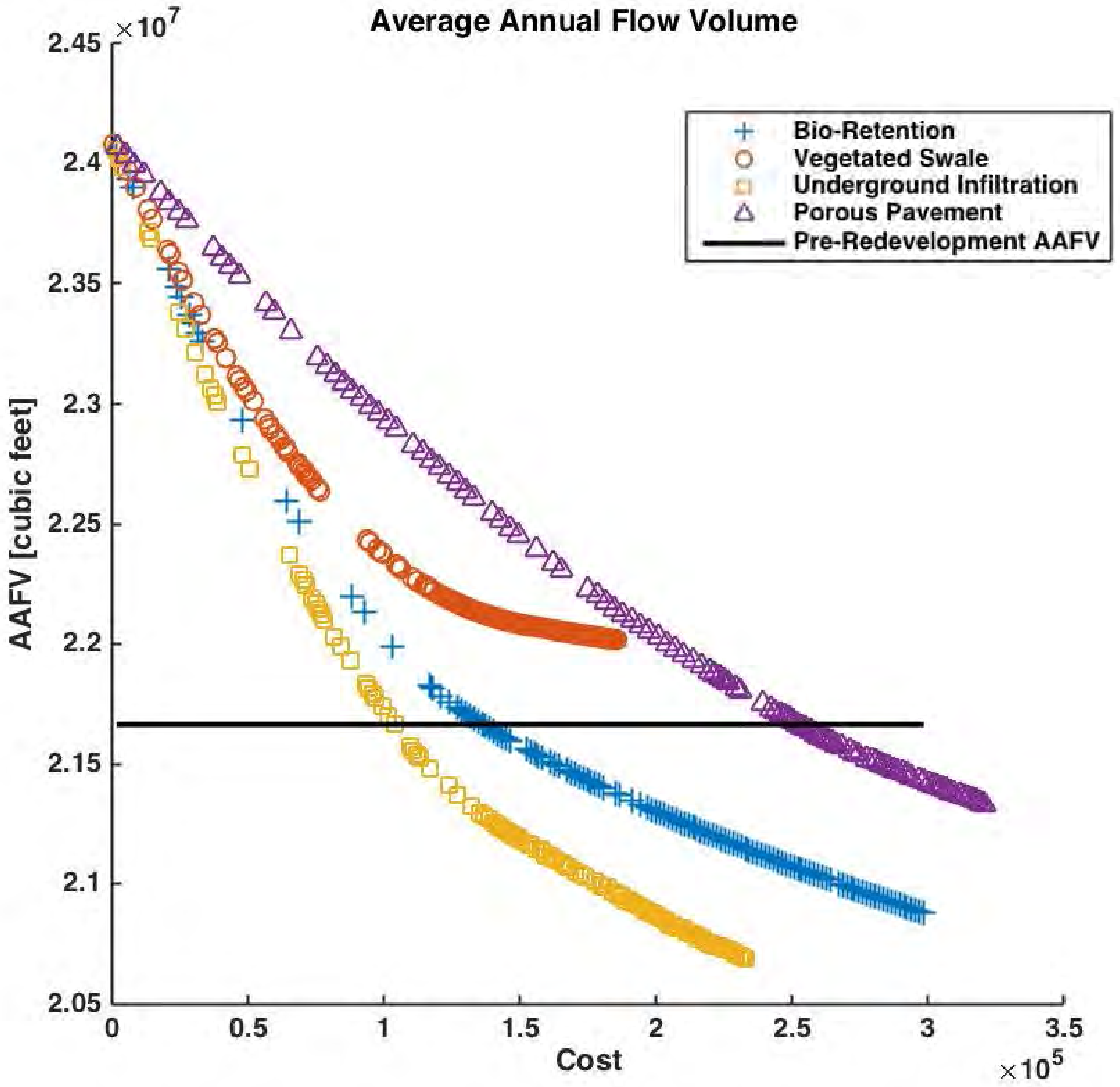
Results: Individual Optimizations

Individual SCM Comparison

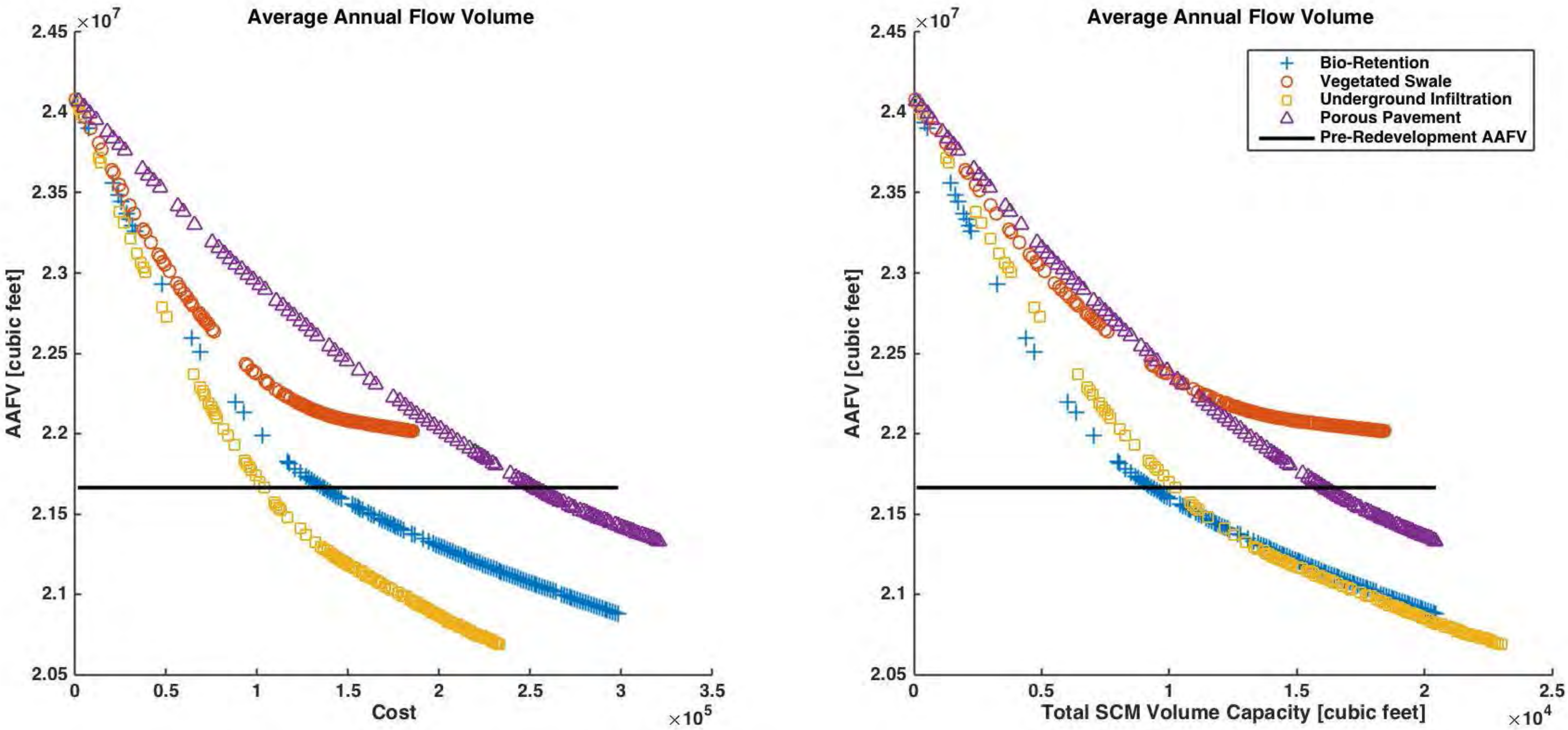
- 4 optimization curves
- Optimize each SCM separately
- Routing 100% of infil-redevelopment to the SCM



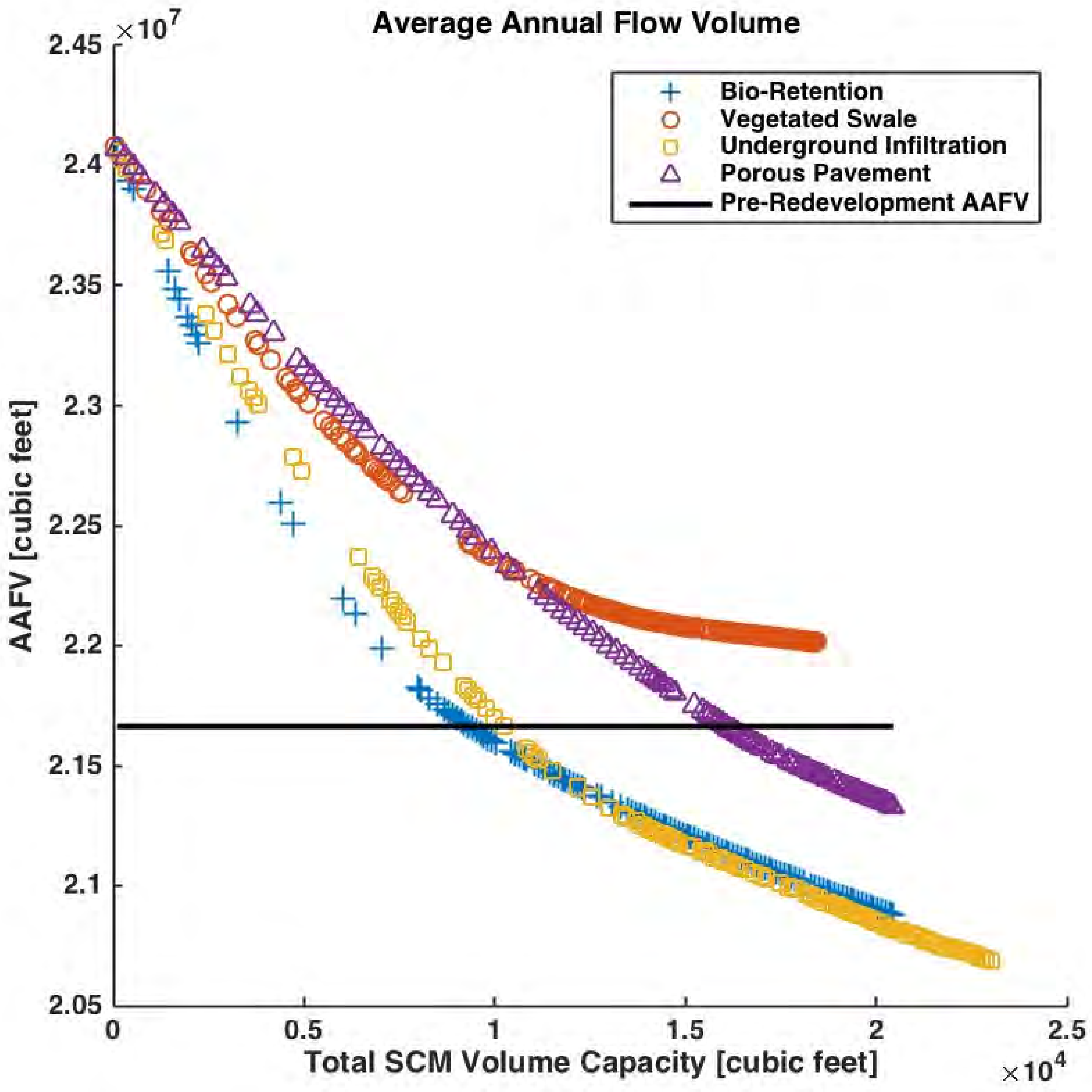
Underground infiltration reaches baseline conditions at the cheapest capital cost.



Tradeoff between cost and volume capacity



I argue that when comparing individual SCM pareto frontiers, displaying capture volume on the x-axis is efficient for planning level decisions.



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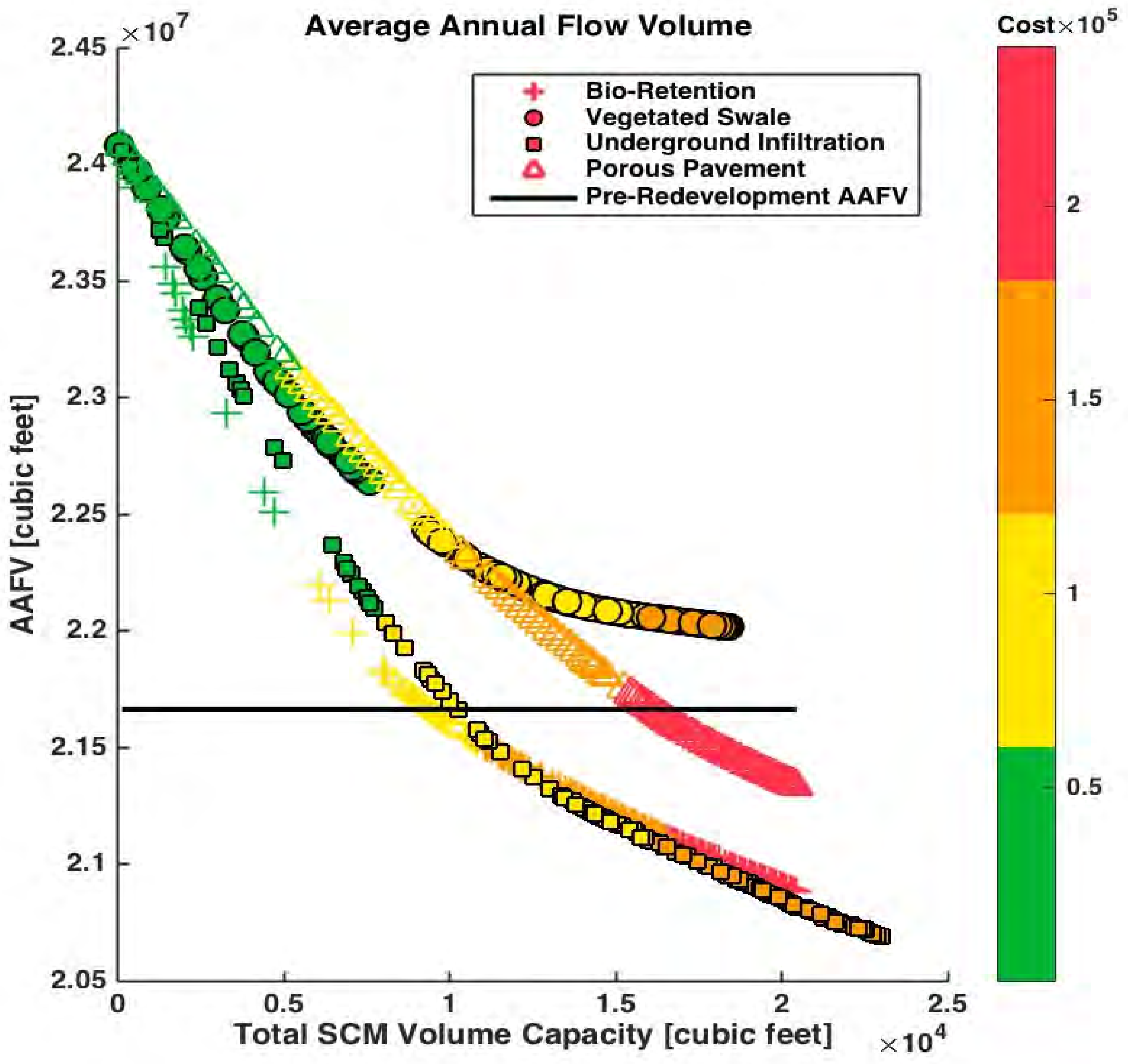
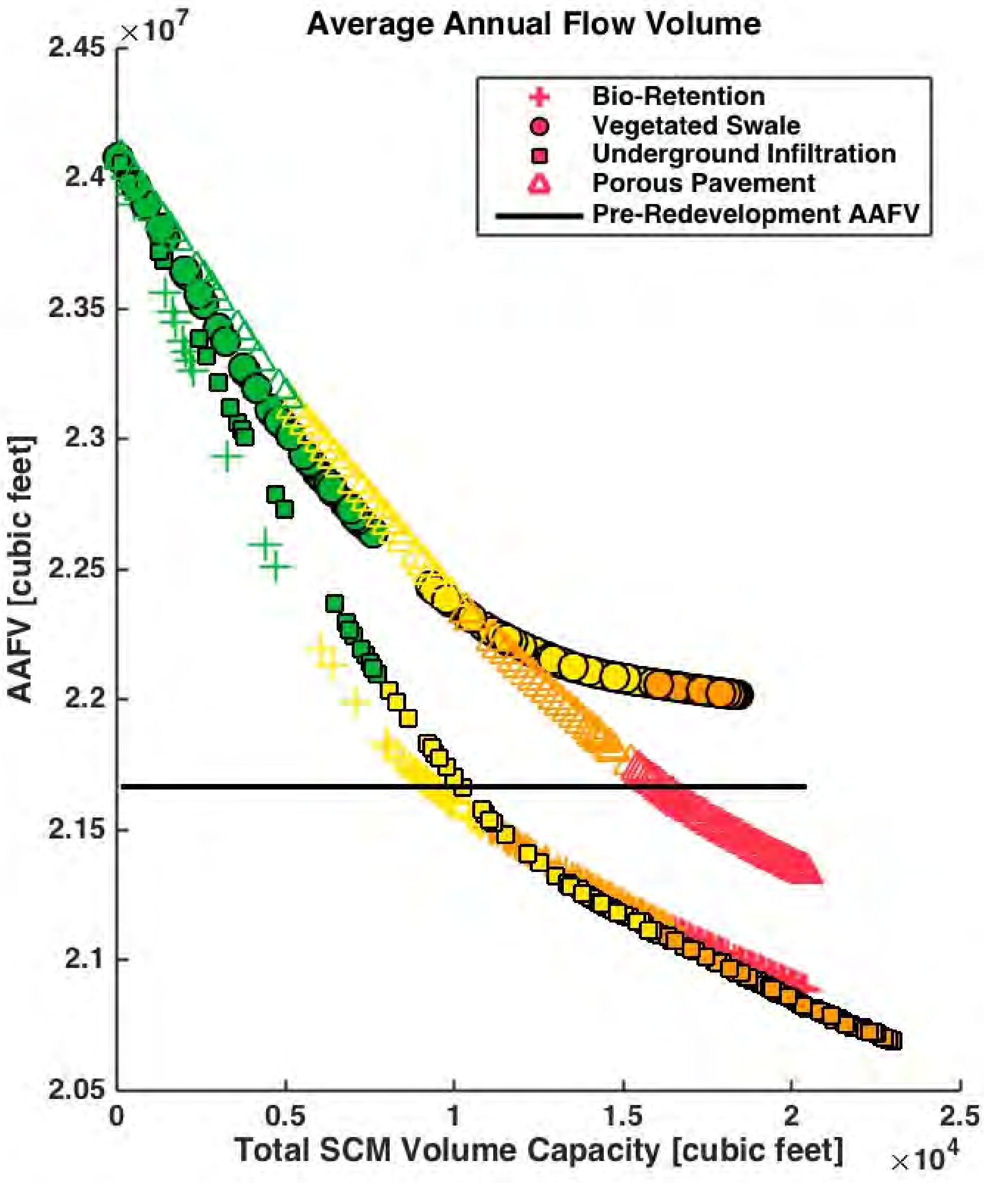
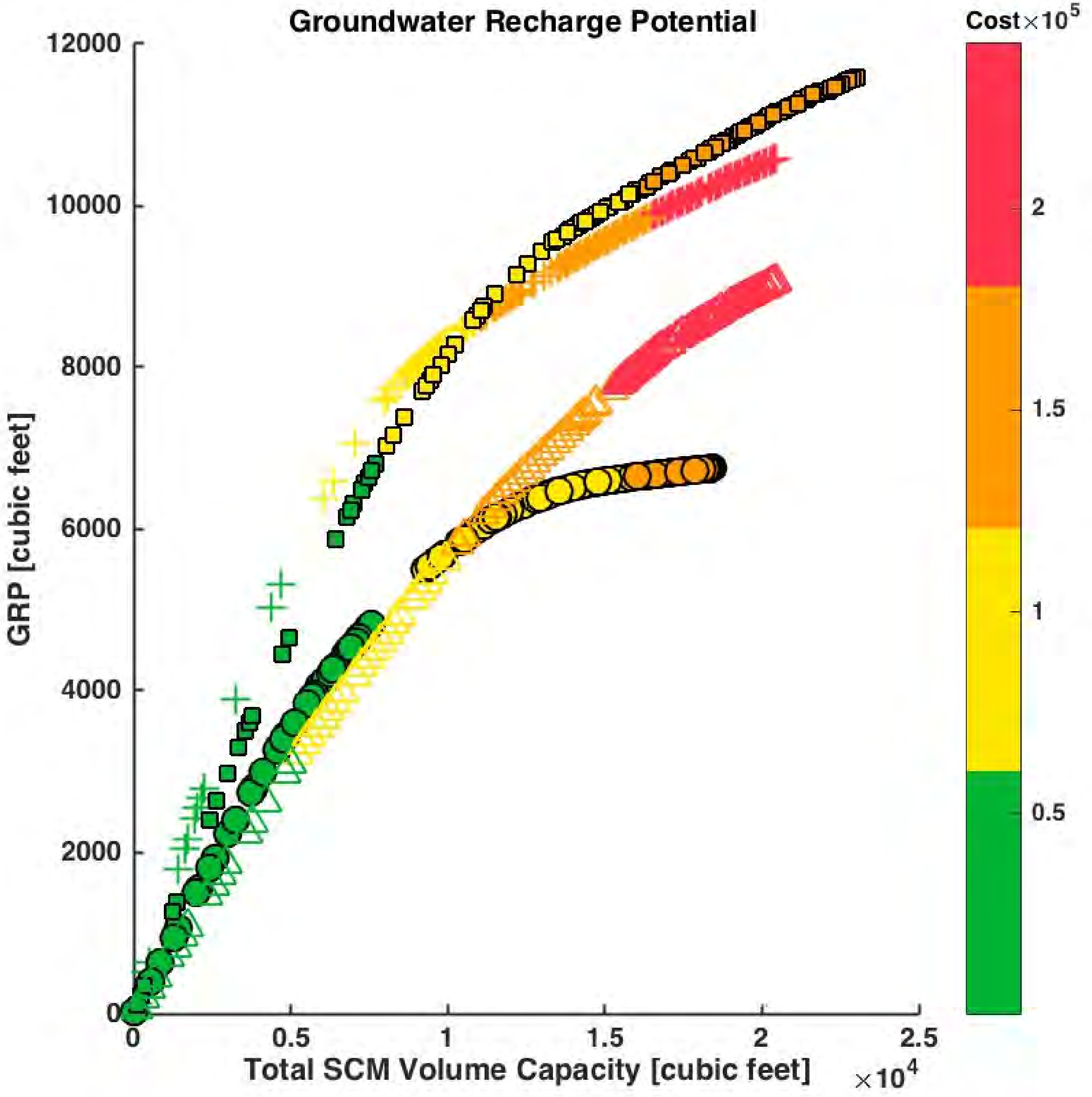


What about other benefits??


Average Annual Flow Volume
×10^7
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
AAFV [cubic feet]
Bio-Retention
Vegetated Swale
Underground Infiltration
Porous Pavement
Pre-Redevelopment AAFV
0
0.5
1
1.5
2
2.5
Total SCM Volume Capacity [cubic feet]
×10^4


Groundwater Recharge Potential
12000
10000
8000
6000
4000
2000
0
GRP [cubic feet]
0
0.5
1
1.5
2
2.5
Total SCM Volume Capacity [cubic feet]
×10^4
Cost ×10^5
2
1.5
1
0.5

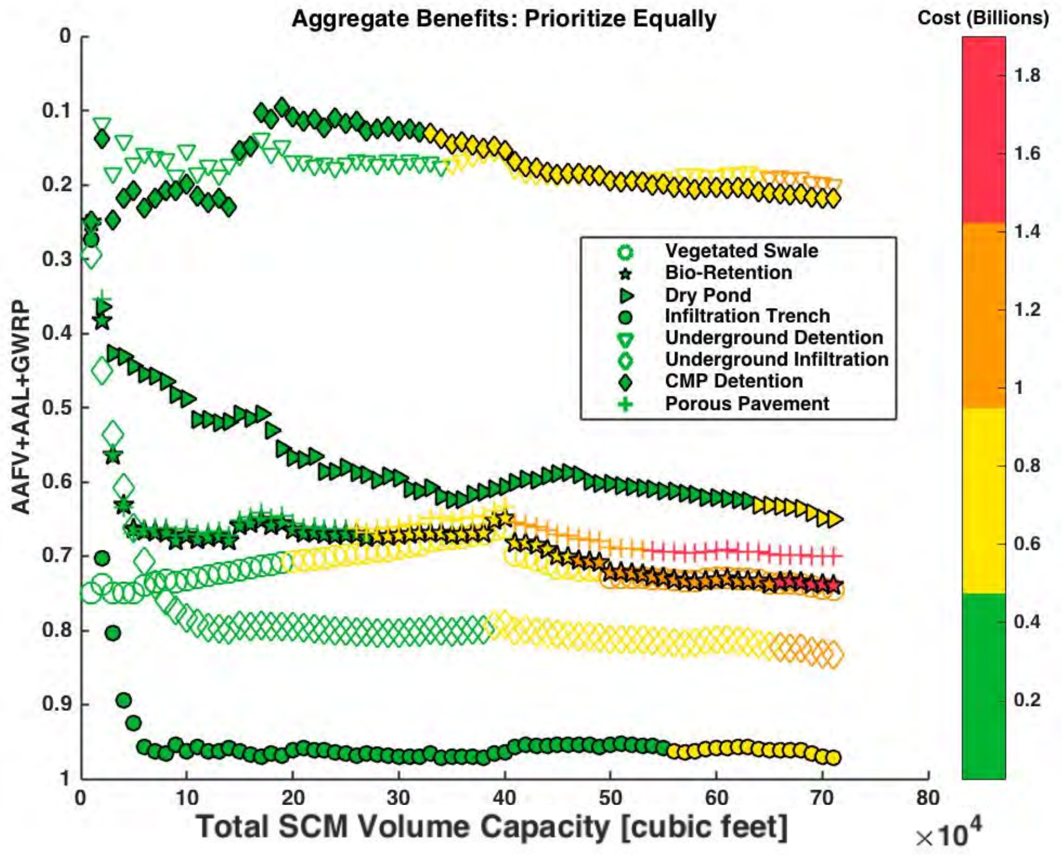
15+ pareto curve plots is a lot to look at and almost impossible to compare.

Water Quantity Benefits
Average Annual Flow Volume
Flow Exceedance Frequency
Flow Duration Curve
Peak Discharge Flow
Seasonal Average Flow Volume
Average Annual Groundwater Recharge
Seasonal Average Groundwater Recharge
Average Annual Evapotranspiration
Seasonal Average Evapotranspiration
New Peak Discharge Flow Calculations

Water Quality Benefits
Average Annual Load
Average Annual Concentration
Days above X Concentration
Seasonal Average Load
Seasonal Average Concentration

Can we summarize multiple evaluation factors in only one plot??

Example from Los Angeles modeling efforts



$$Benefit\ Score_{j,i} = \left[\frac{Benefit\ value_{j,i} - \min[Benefit\ Value_i]}{\max[Benefit\ Value_i] - \min[Benefit\ Value_i]}\right] * Ranking$$

$$Overall\ Score_{j,i} = \frac{\sum_m Benefit\ Score_{j,i}}{\sum rankings}$$

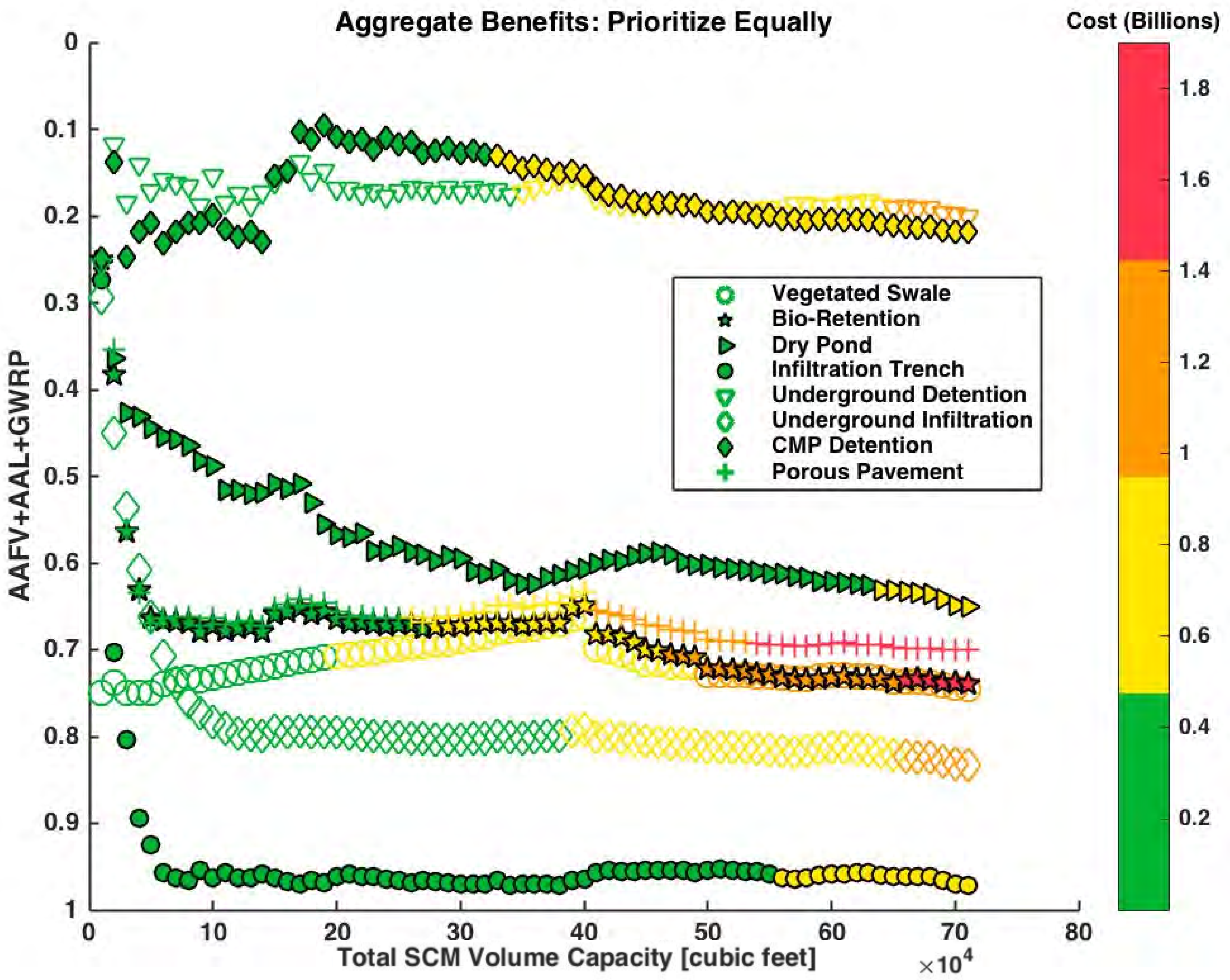
j = BMP Type

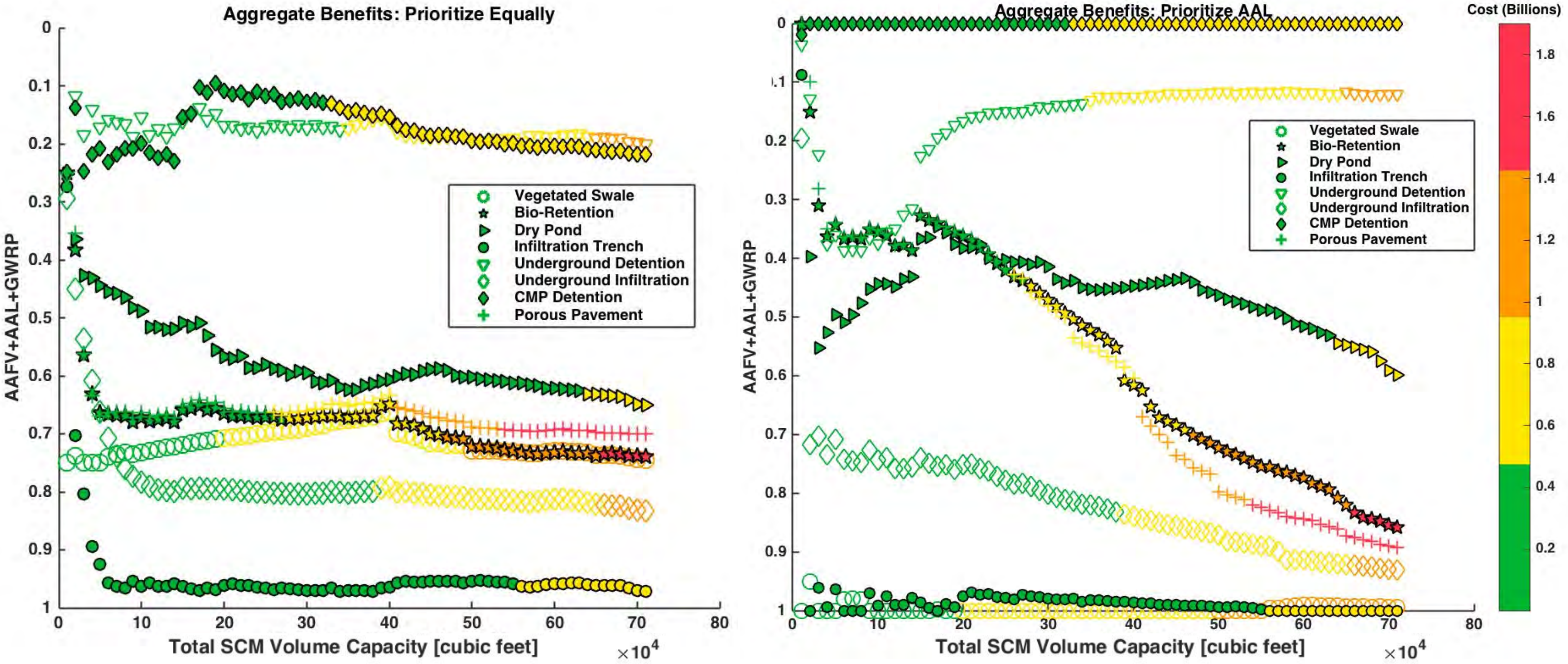
i = Treatment Volume

m = Evaluation factor

Can we summarize multiple evaluation factors in only one plot??

Example from Los Angeles modeling efforts

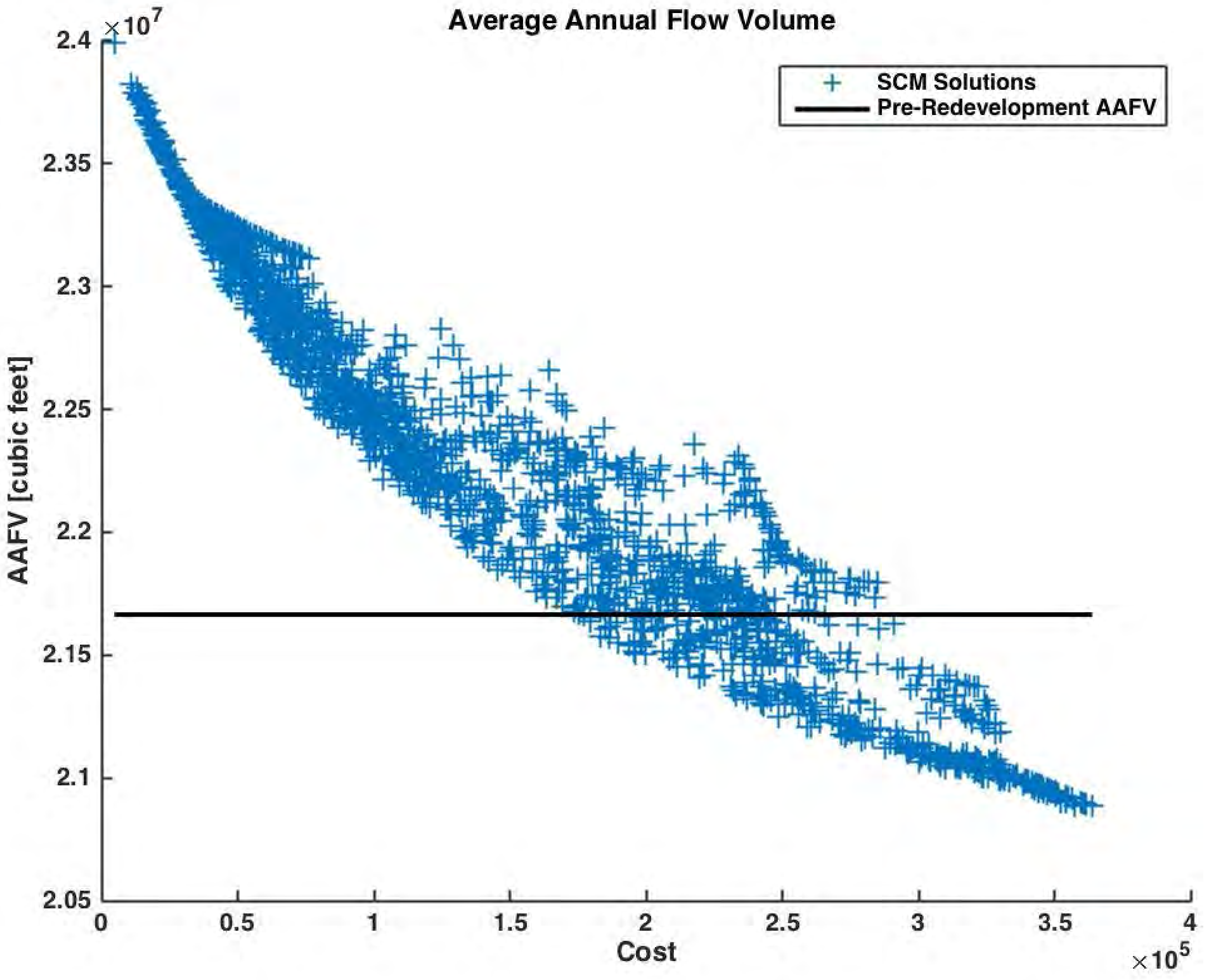



Aggregate Benefits: Prioritize Equally
AAFV+AAL+GWRP
Total SCM Volume Capacity [cubic feet]
×10^4
Vegetated Swale
Bio-Retention
Dry Pond
Infiltration Trench
Underground Detention
Underground Infiltration
CMP Detention
Porous Pavement
Aggregate Benefits: Prioritize AAL
AAFV+AAL+GWRP
Total SCM Volume Capacity [cubic feet]
×10^4
Cost (Billions)

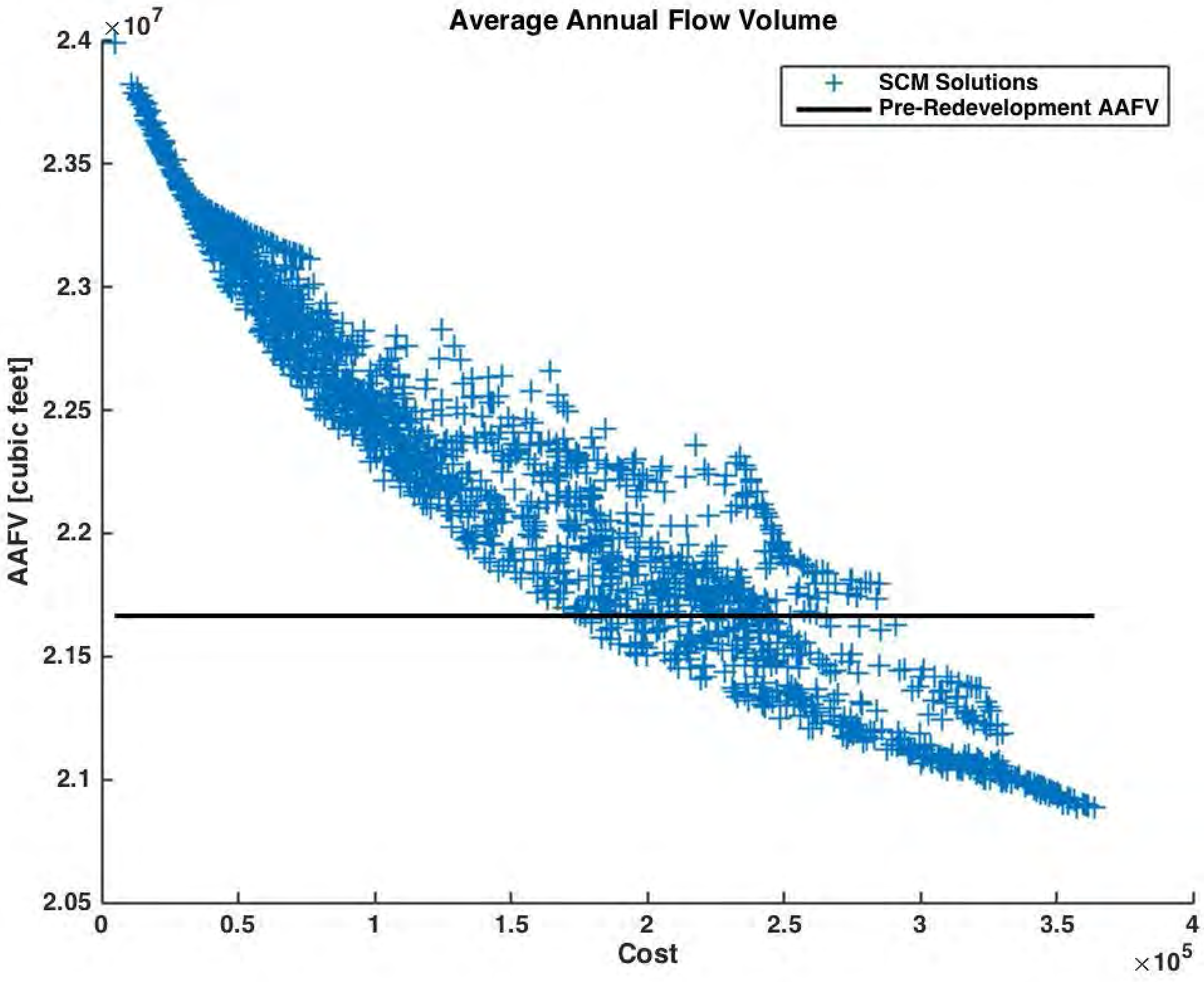
Results: Full Optimization

Full optimization

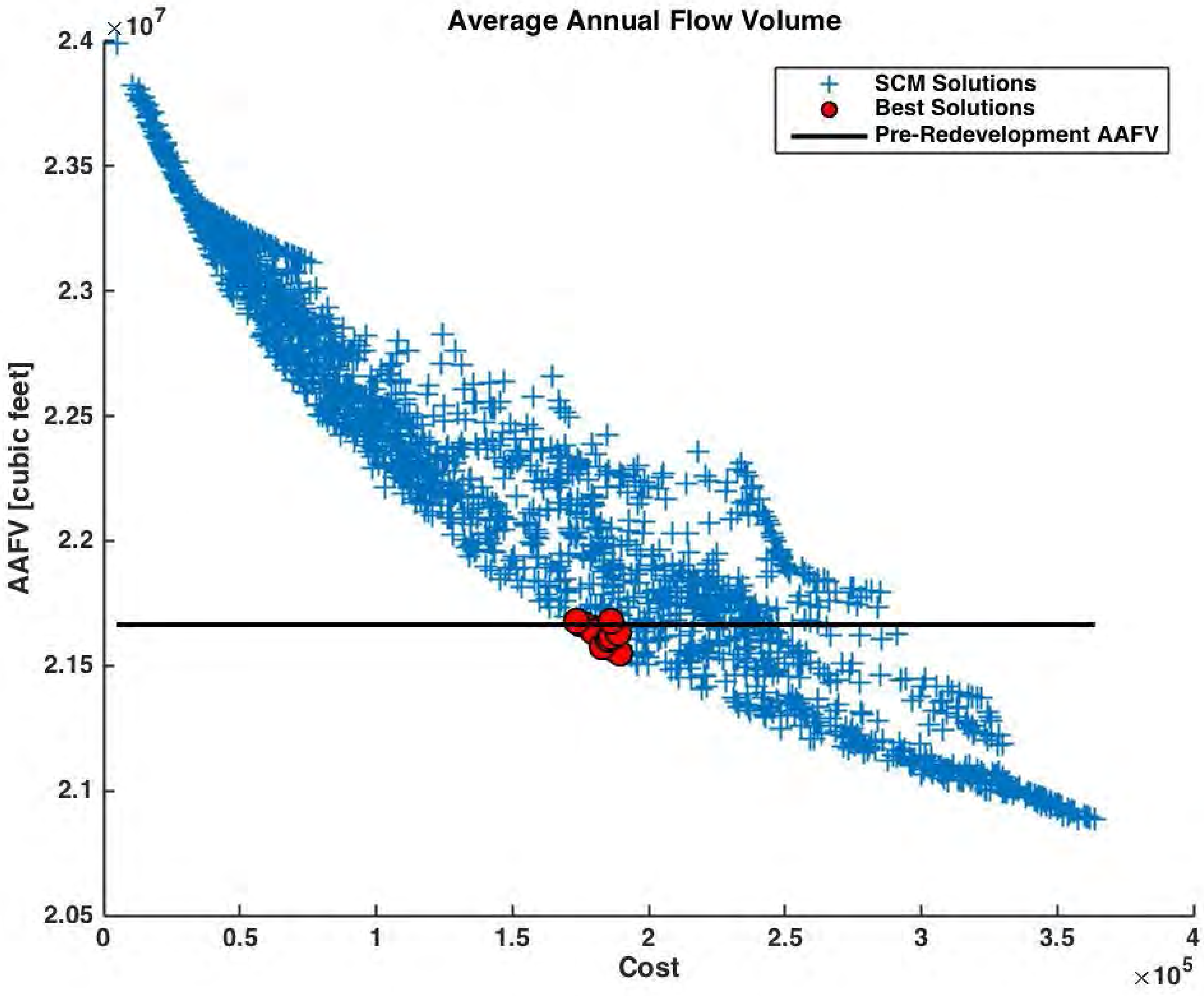
- 1 optimization curve
- Optimize all SCMs simultaneously
- Routing 25% of infil-redevelopment to each SCM type

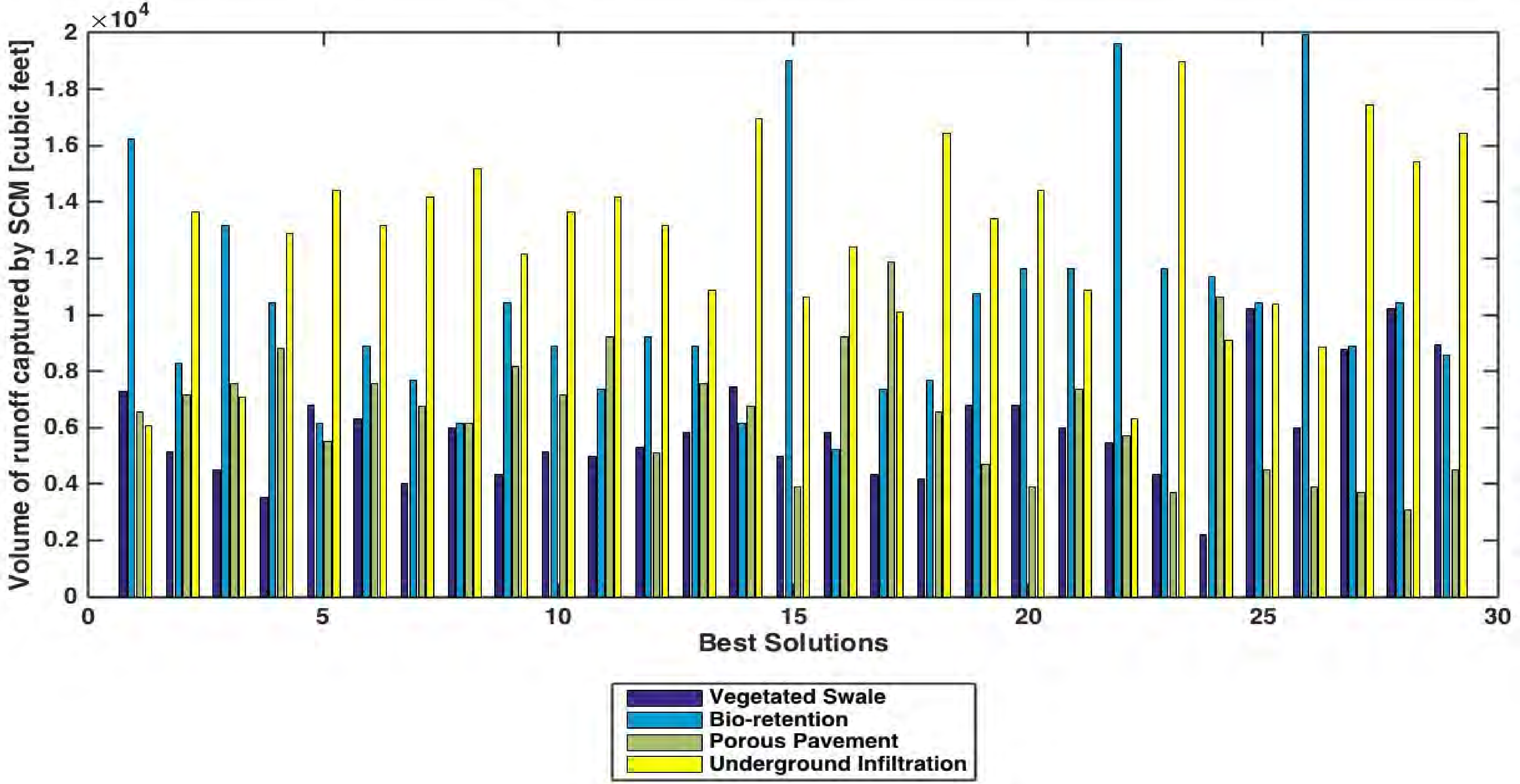


1000 Solutions across a range of AAFV and Costs

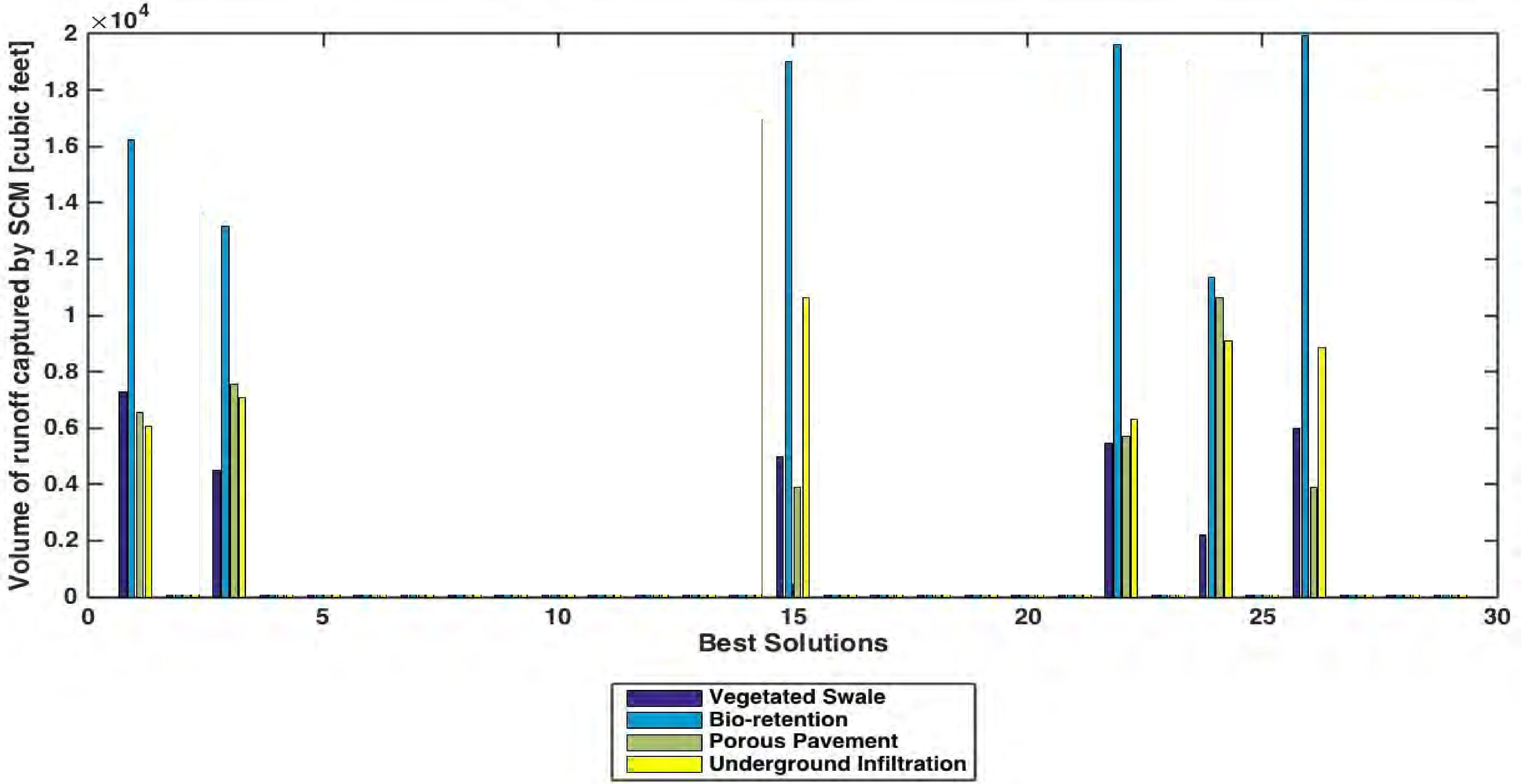


30 best solutions reach the AAFV target at the cheapest cost

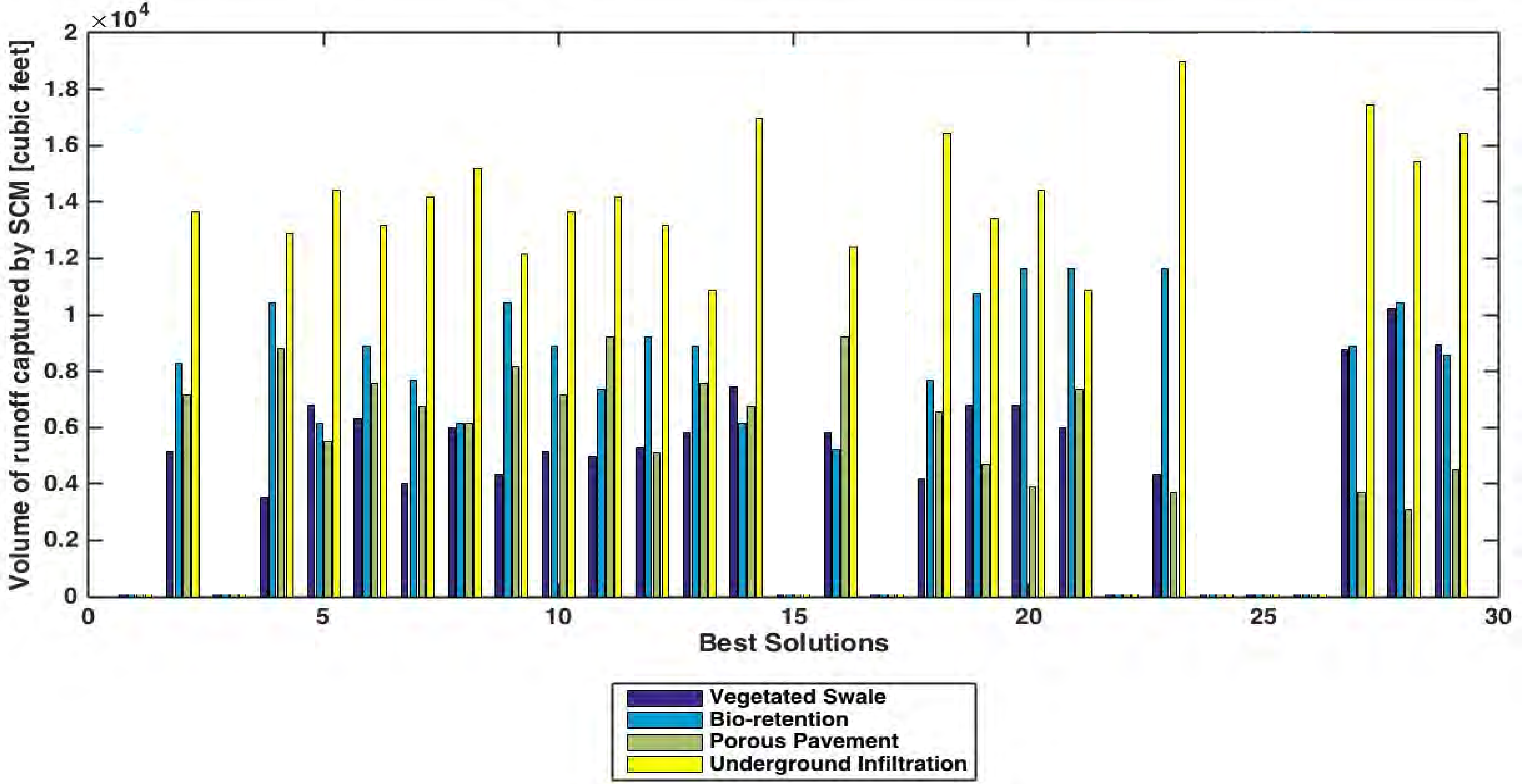



$\times 10^4$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Volume of runoff captured by SCM [cubic feet]
0
5
10
15
20
25
30
Best Solutions
Vegetated Swale
Bio-retention
Porous Pavement
Underground Infiltration

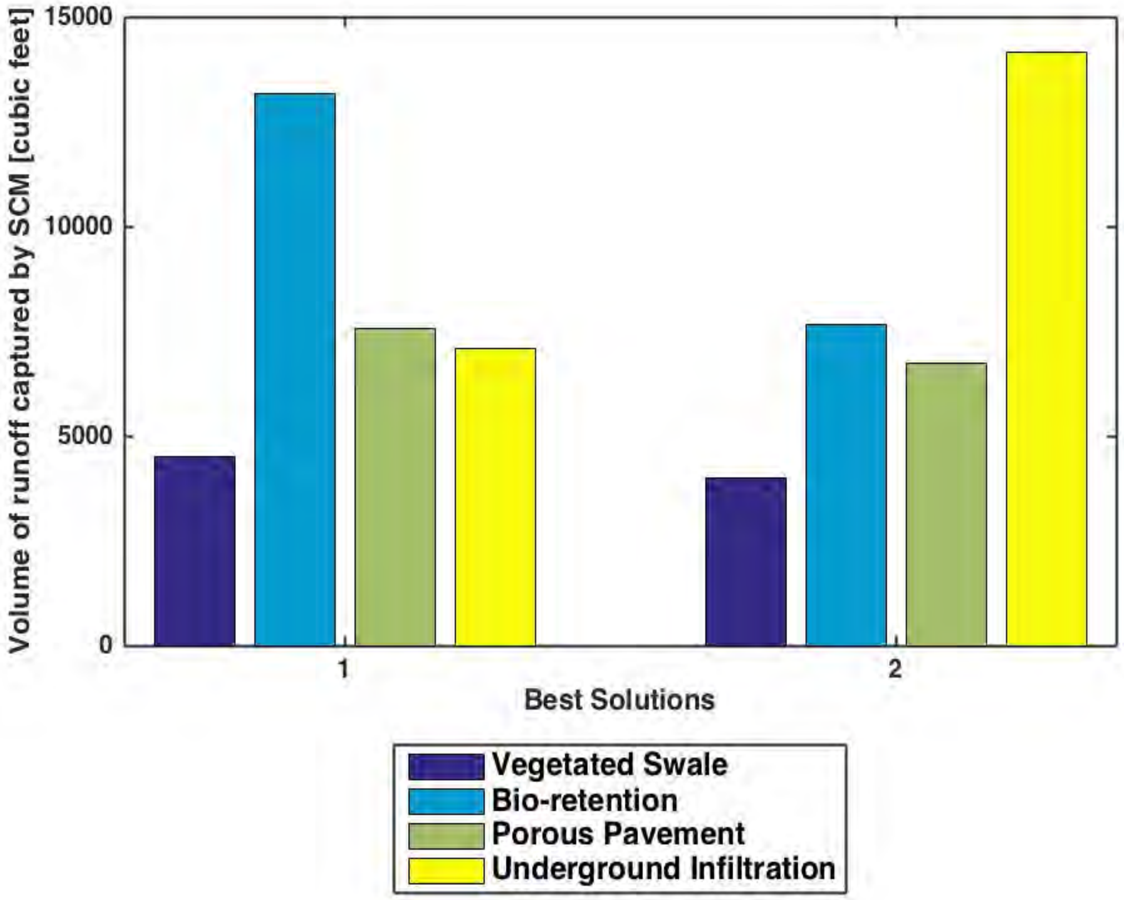
Best solutions favor 1) bio-retention



Best solutions favor 1) bio-retention and 2) underground infiltration



Future work and further analysis on two best solutions

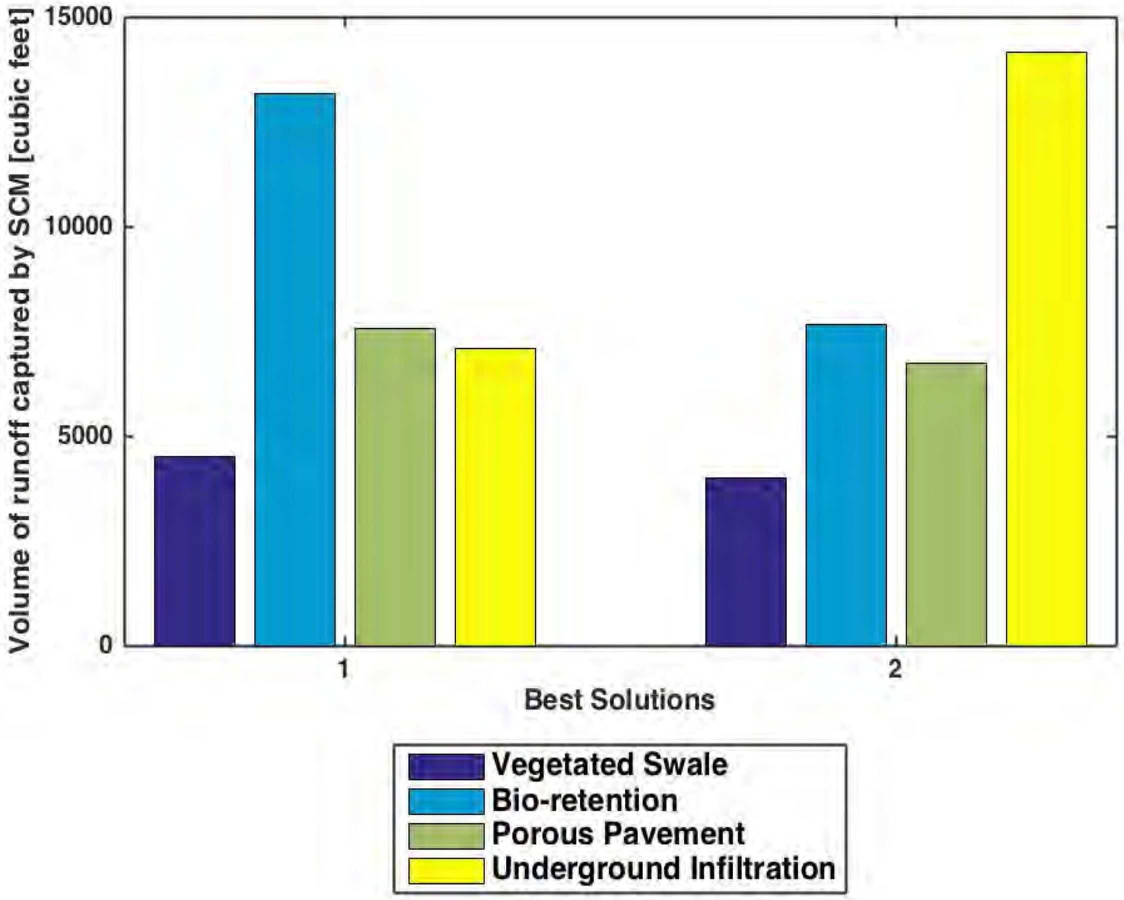


Two best solutions:

- Cheapest Cost
- Smallest total capture volume required to reach baseline flow conditions
- One solution that favors bio-retention
- One solution that favors underground infiltration

Which is the optimal solution??

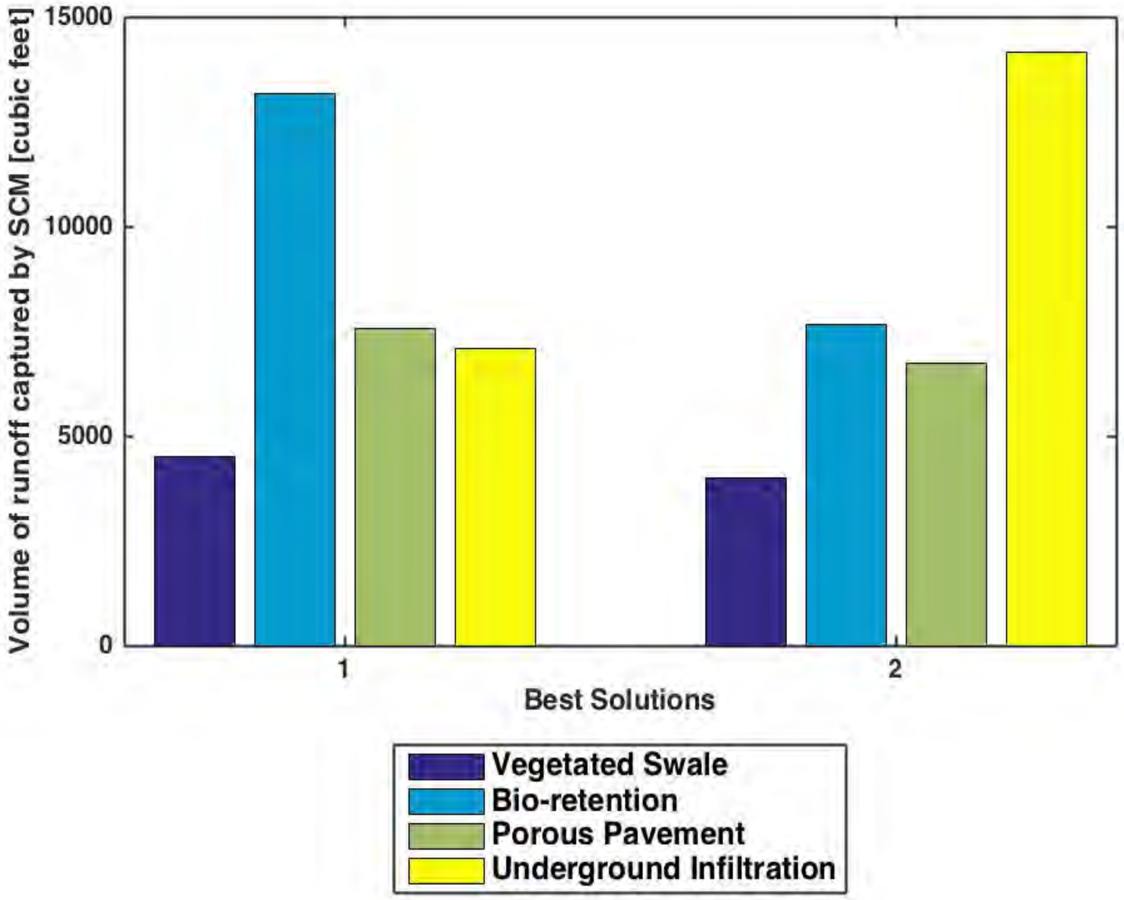
Future work and further analysis on two best solutions



Stormwater Capture Outputs	1	2
Dominant SCM type	Bio-retention	Underground Infiltration
Cost	179,450	176,910
AAFV $*10^7$ [ft^3]	2.1652	2.1665

Very similar cost and average annual flow volume..

Future work and further analysis on two best solutions



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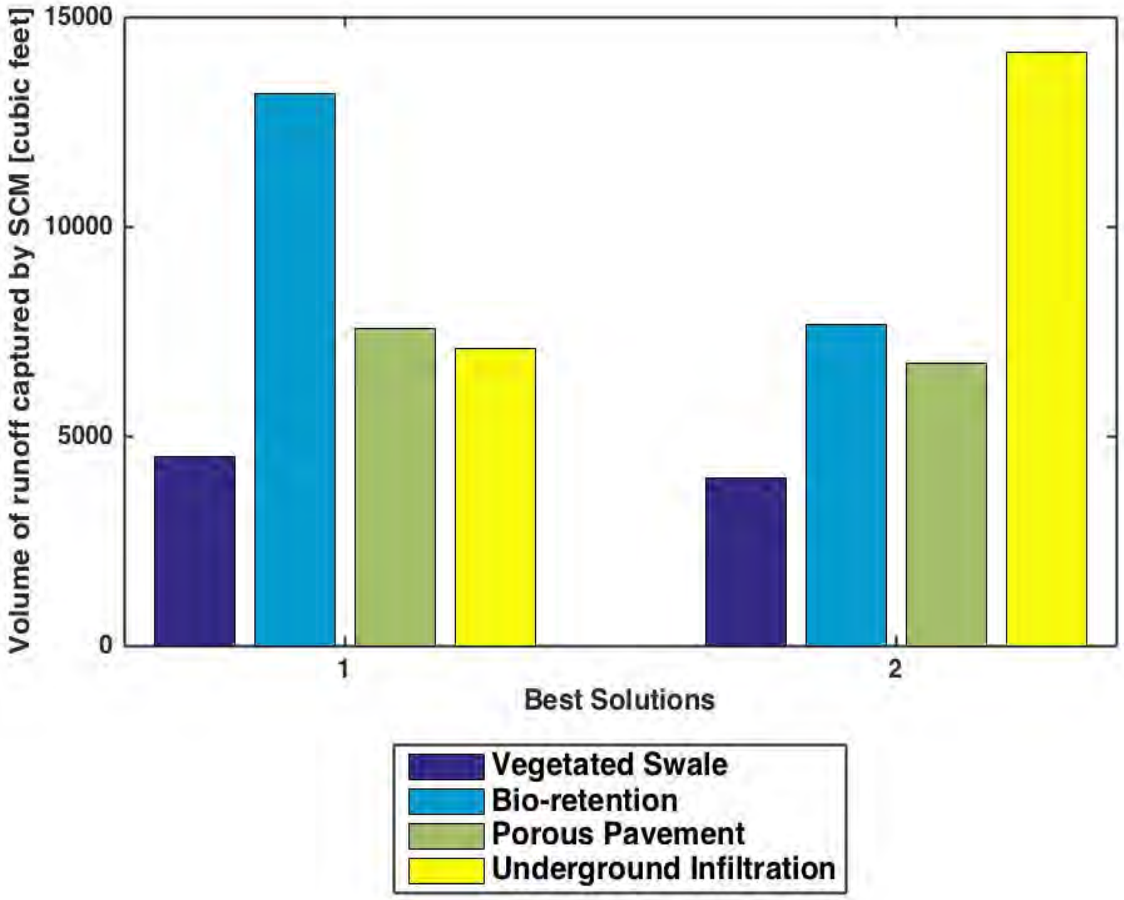
Dominant SCM type	Bio-retention	Underground Infiltration
Cost	179,450	176,910
AAFV $*10^7$ [ft^3]	2.1652	2.1665
Greener vs Greyer	Greener	Greyer
Volume Capture Required [ft^3]	32,333	32,589
Surface Area Required [ft^2]	9,928	7,491
GWRP$*10^7$ [ft^3]	0.2348	0.2335

Future work and further analysis on two best solutions



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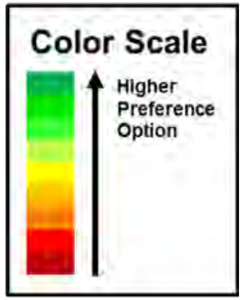
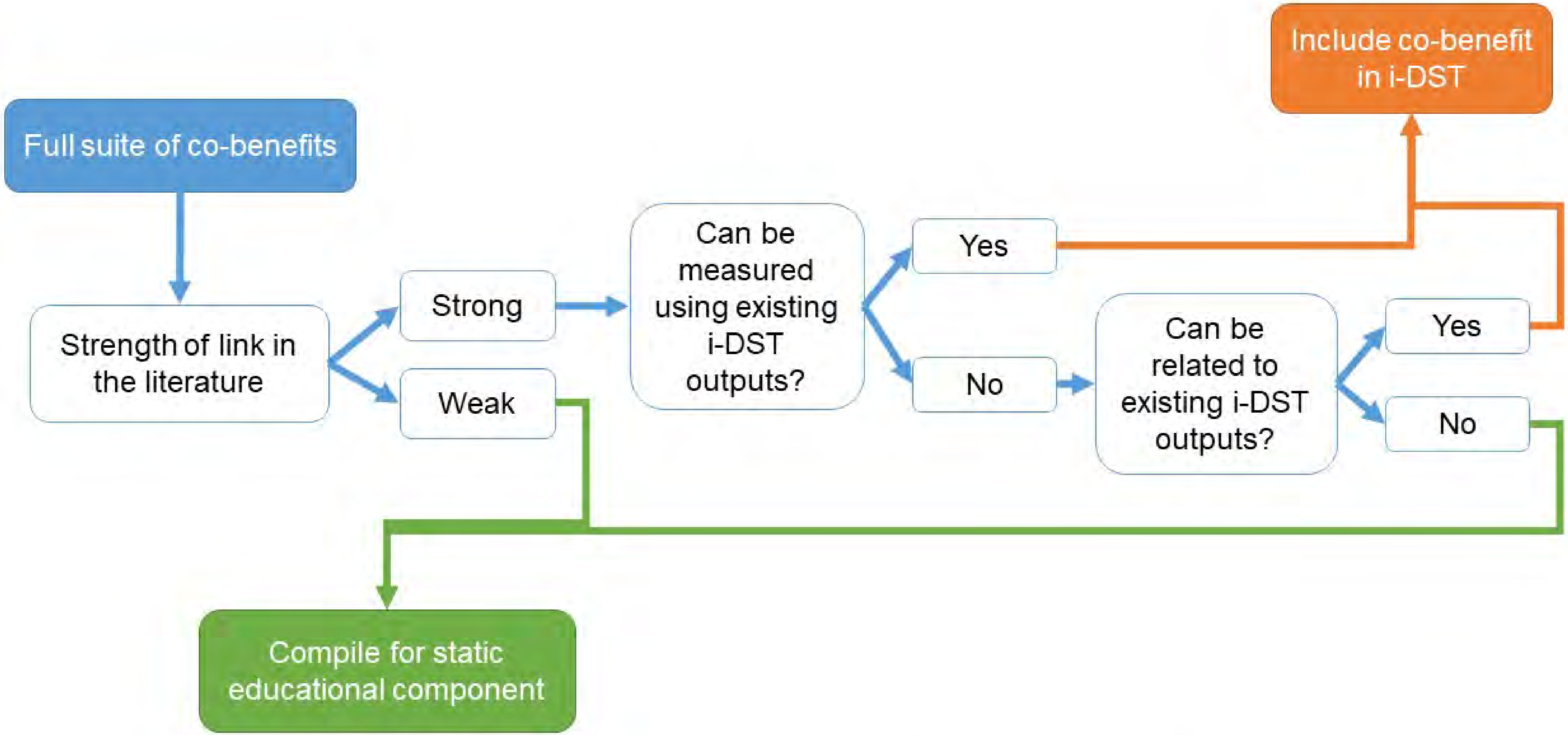
Stormwater Capture Score	66.6	33.3

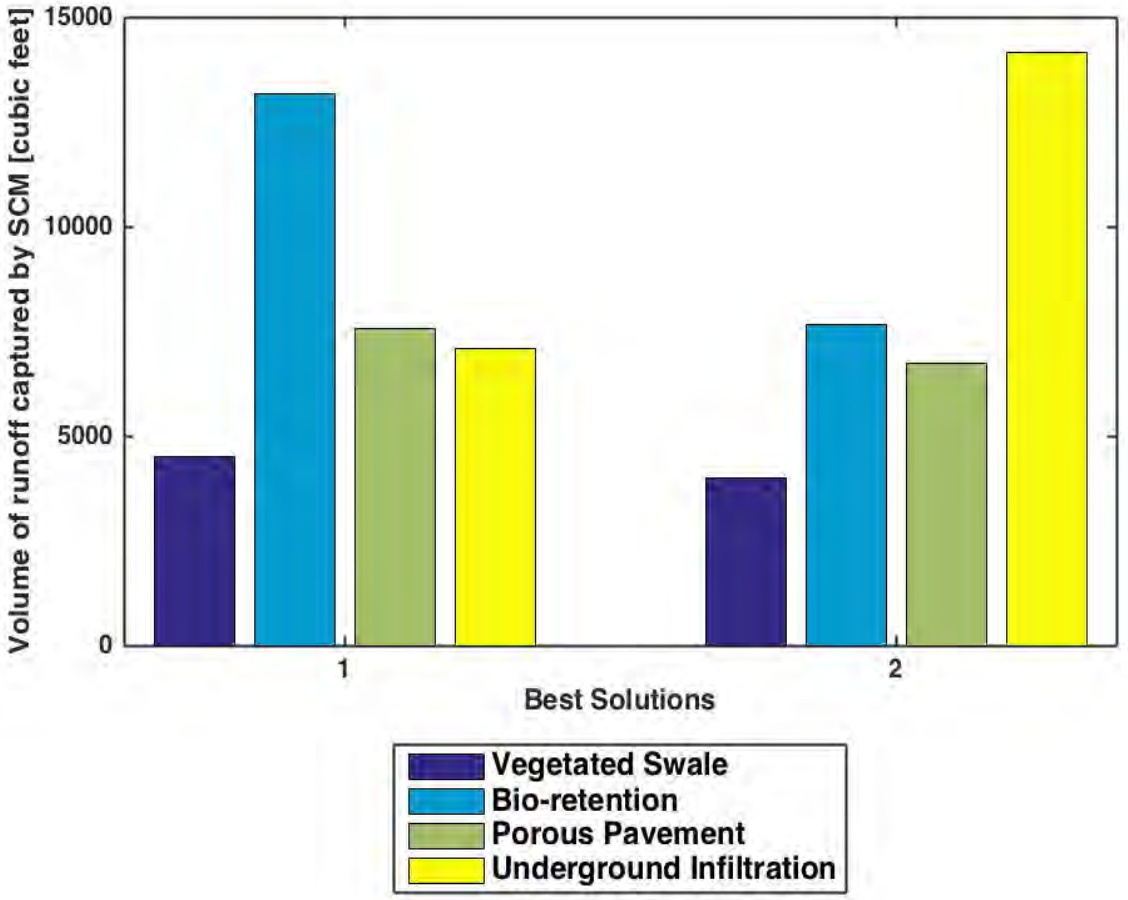


Life cycle costs and co-benefits may be the tipping point between SCM solutions.



Co-benefit Selection Process for i-DST

Future work and further analysis on two best solutions

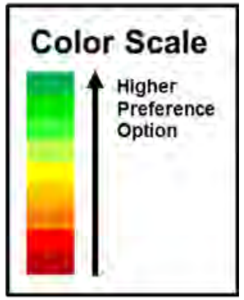


"Greyer" Underground Infiltration Solution

	Score
Stormwater Capture/LCC	33.3
Life Cycle Analysis	0
Co-benefits	0

"Greener" bio-retention Solution

	Score
Stormwater Capture/LCC	66.6
Life Cycle Analysis	100
Co-benefits	100



Thank you! Questions?

Email: emgallo@mines.edu

Email: idst@mines.edu

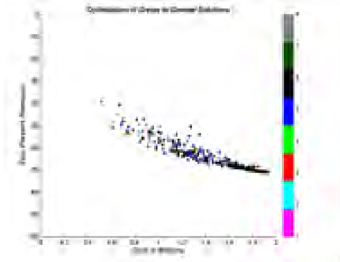
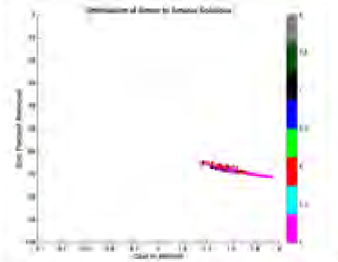
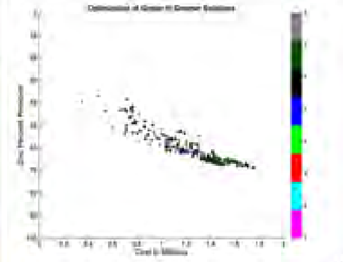
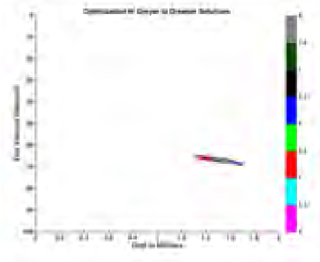
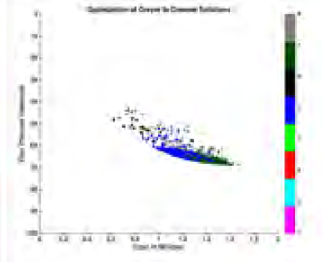
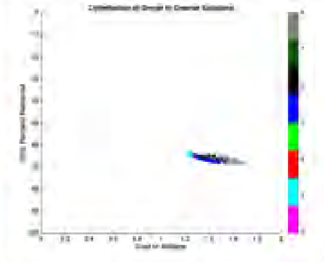
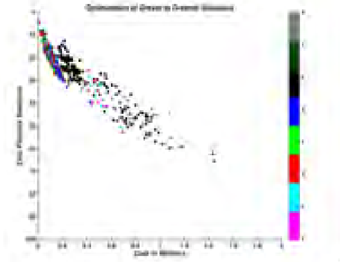
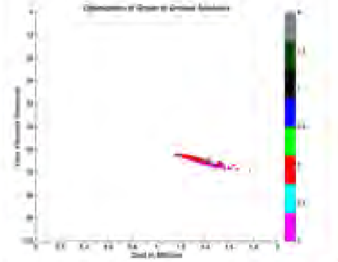
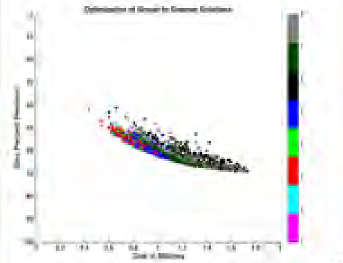
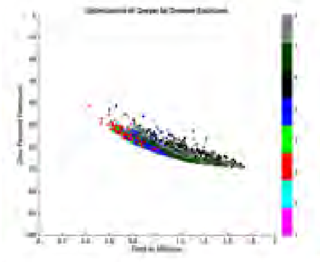
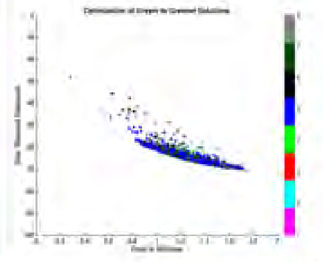
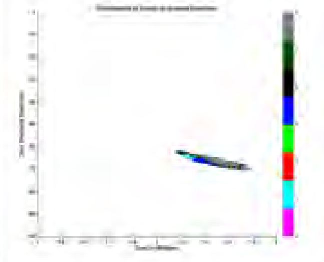
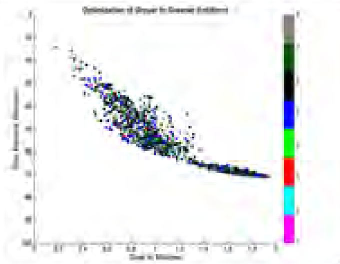
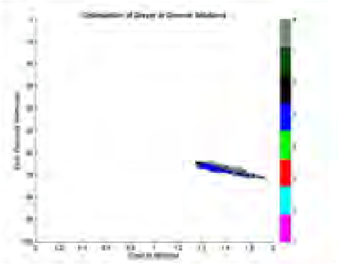
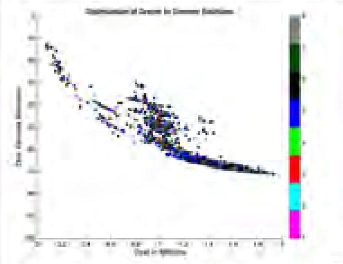
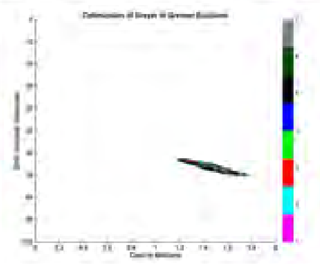
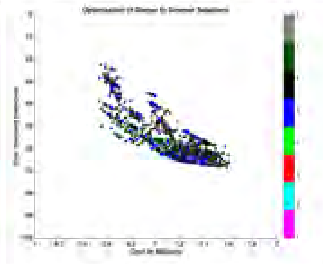
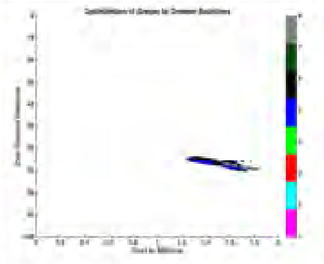
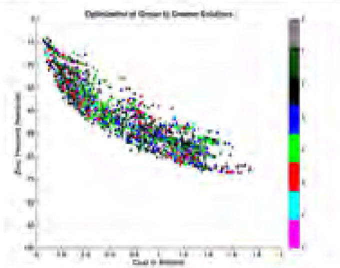
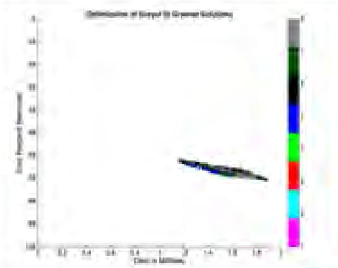
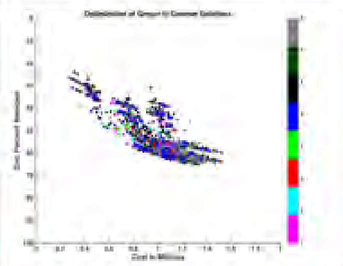
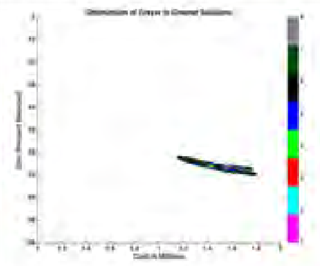
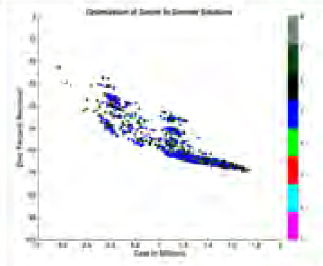
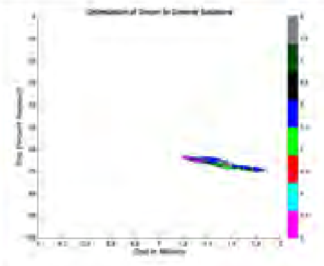
Website: https://idst.mines.edu/

Follow us: @iDST_Team

If you are interested in attending future workshops or beta testing the tool send us an email!!

idst@mines.edu

Matrix of all Optimization Controls

		Target Evaluation: X-X% Reduction	10 - 90%		60-70%		64 - 65%	
		BMP Units to capture X-X% of 85th	1 - 125%	75 - 125%	1 - 125%	75 - 125%	1 - 125%	75 - 125%
Optimization Search Algorthim Controls	NSGA II	Cost Effectiveness Curve	 4	 8	 12	 16	 20	 24
		Cost Minimization	 3	 7	 11	 15	 19	 23
	Scatter Search	Cost Effectiveness Curve	 2	 6	 10	 14	 18	 22
		Cost Minimization	 1	 5	 9	 13	 17	 21

Integrating LID into Municipal Design Criteria – A Colorado MS4 Perspective

CITY OF BOULDER

DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7

STORMWATER DESIGN

Effective: June 20, 2019

CASFM

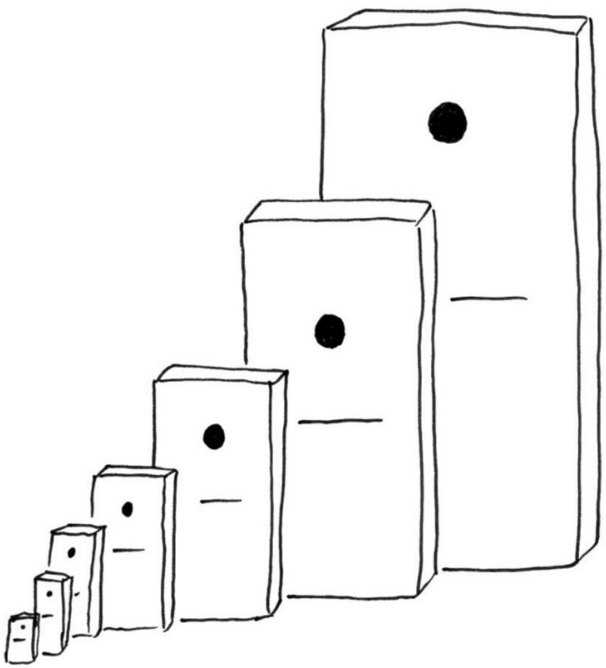
September 25th, 2019

Kevin Koryto, Stormwater Quality Engineer

City of Boulder

Municipal Design Criteria

Why talk about stormwater quality design criteria?



Background

Water Quality Design Standards Included in MS4 Phase II Revised Permit:

1. **Water Quality Capture Volume**
2. **Pollutant Removal**
3. **Runoff Reduction**

Treat runoff volume for 80th percentile, 0.6-in event

30 mg/L TSS effluent concentration

Infiltrate 60% of the WQCV

Boulder’s Design Criteria

The MS4 permit has new design standards…

Boulder's Design Criteria

Boulder Design and Construction Standards (DCS)

- Establishes technical requirements for infrastructure design & review
- Companion document to Boulder Revised Code (BRC)
- Not a manual, references external guidance documents
- First major revision in 20 years

CITY OF BOULDER
DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7
STORM WATER DESIGN

Effective: November 16, 2000

CITY OF BOULDER
DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7
STORMWATER DESIGN

Effective: June 20, 2019

Boulder's Design Criteria

- Implementation Timeline

MS4 Permit Deadline: July 1, 2019

Creation
Feb – Dec 2018

- *DCS Revisions*
- *Code Revisions*
- *Stakeholder Input*
- *Technical Review*
- *Legal Review*

Adoption
Jan – Jun 2019

- *Advisory Board Review*
- *Planning Board Review*
- *City Council*
- *Final Revisions*
- *Development Review Process Integration*

Implementation
Jul – Dec 2019

- *Outreach & Training*
- *Process Implementation*
- *Tracking Implementation*

Continuation
2020 and Beyond

- *Monitoring & Evaluation*
- *Feedback & Process Revision*

Formulating Criteria

The three elements of stormwater quality design criteria:

1. Implementation Threshold	**When** does stormwater quality have to be designed?
2. Design Standard	**What** is the metric for an adequate design?
3. Design Process	**How** are stormwater quality facilities designed?

Stormwater Quality Thresholds

Authority	Regulation	Specification
Federal, EPA	Clean Water Act: NPDES Phase II Stormwater Final Rule (2003)	Implement permanent stormwater controls when more than ***1 acre*** of land is disturbed
State, CDPHE	MS4 Permits	Replicate
Local	Local Ordinance	Replicate or go stricter

Boulder's Previous Requirement: For less than 1 acre, city "may" require

Does the 1-acre threshold make sense for our community?

What about in built-out communities where redevelopment is predominant?

Stormwater Quality Thresholds

Innovative and Integrated Stormwater Management

Date Published
JUN 26, 2019

Resource Type
SPECIAL REPORT

NYC Environmental Protection

THE Water Research FOUNDATION

- Survey of 34 community stormwater programs
- 2/3 of communities have a threshold lower than 1 acre
- Increased impervious area and other conditions, also commonly used

55%
Have a threshold < 10,890 sf

8%
Have a threshold from 10,890 sf to < 21,780 sf

5%
Have a threshold from 21,780 sf < 1 acre

27%
Have a threshold of 1 acre

5%
Have a threshold ≥ 1 acre

	Arlington County	City of Atlanta	City of Aurora	Baltimore County	City of Baltimore	City of Boston	City of Chicago	City of Cincinnati	City of Copenhagen	Fairfax County	City of Fort Lauderdale	City of Halifax	City of Houston	City of Indianapolis	King County	City of Lincoln	City of Los Angeles	City of Melbourne	City of Minneapolis	City of Milwaukee	City of Nashville	NEORSD	City of New Orleans	City of New York	Onondaga County	City of Philadelphia	City of Portland	City of Richmond	City of San Francisco	Port of San Francisco	City of Seattle	SD-1	City of Toronto	Washington, DC
Disturbed Area	●		●	●	●	●	●	●	NA	●			●		●	●		●	●		●	NA		●	NA	●		●			●	●	●	●
Increased Impervious Area		●					●	●	NA	●	●		●	●			●			●		NA	●		NA		●		●	●	●	●	●	
Other Conditions							●		NA	●	●	●								●		NA	●		NA						●			

Stormwater Quality Thresholds

Boulder's Approach

- Maintain 1-acre threshold
- Demonstration of LID required for all sites, including < 1 ac
- Collect development data to support future evaluation and revision

Low Impact Development (LID) Checklist

LID techniques, as defined below shall be implemented for all new development and redevelopment

LID techniques have been investigated and implemented to the maximum extent practical for this site.	☐ Yes	☐ No

Conserve Existing Amenities: Planning efforts shall account for and, where practicable, preserve or restore existing site features that naturally retain stormwater on site, including vegetated areas, high infiltrating soils, and natural surface drainage patterns, such as meadows and trees.

Minimize Impacts: Planning efforts shall account for and minimize, where practicable, land disturbance, impervious surface addition, and soil compaction. This may include removing unnecessary impervious areas, minimizing driveway and sidewalk widths, and sequencing construction to minimize compacted areas

Minimize Directly Connected Impervious Areas (MDCIA): Planning efforts shall account for and minimize impervious areas, such as rooftops and pavement, that directly drain to the stormwater utility system or a local stream without prior stormwater control. This may include using or integrating receiving pervious areas into the site landscape, such as vegetated swales and buffers. Where practicable, site drainage patterns shall be designed to promote sheet flow to vegetated area and roof downspouts shall be disconnected from direct discharge to the storm sewer. Receiving pervious areas shall be designed to slow run-off and promote infiltration.

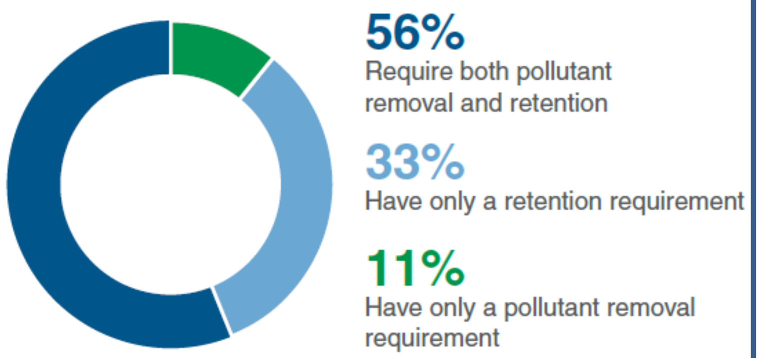
Design Standards

Authority	Regulation	Specification
Federal, EPA	NPDES Phase II Stormwater Final Rule (2003)	No specification
State, CDPHE	MS4 Permits	Establishes base design standards
Local	Local Ordinance	Replicate, select from, or go stricter

Design Standard Approaches:

- Pollutant Removal Requirement
  - **Capture volume (WQCV*)**
  - **Effluent concentration limit**
  - Percent removal
  - Load reduction
- Retention Requirement
  - **Volume infiltrated** or reused
  - Match pre-development hydrograph

NYC (2017) Survey of 34 Municipalities:



Design Standards

MS4 Permit Design Standards:

1. **Water Quality Capture Volume**
2. **Pollutant Removal**
3. **Runoff Reduction**

Treat runoff volume for 80th percentile, 0.6-in event

30 mg/L TSS effluent concentration

Infiltrate 60% of the WQCV

For TSS Load Reduction: 60% infiltrated ≈ WQCV

Retention Design Standard Comparison

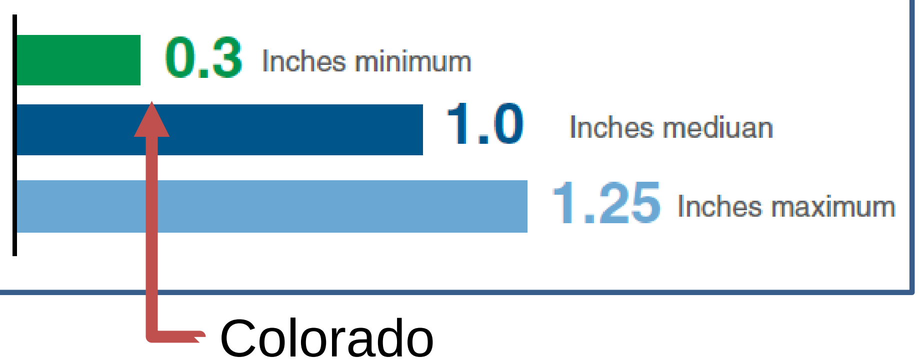
Colorado's Phase II Permit Retention Requirement:

0.36 in = 60% of 0.6 in (roughly not accounting for WQCV calc)

National Survey (NYC, 2017):

1.0 in = Median retention requirement

NYC (2017) Survey
of 34 Municipalities:



Design Process

Authority	Regulation	Specification
Federal, EPA	NPDES Phase II Stormwater Final Rule (2003)	None
State, CDPHE	MS4 Permits	Review requirement
Local	Local Ordinance	Open ended

Local Criteria Building Blocks

Local Design Criteria [Boulder DCS]

- Requires Standards & Methods
- Implements Process

MS4 Permit [CO Phase II]

- Design Standards
- Recordkeeping/Review Requirements

Regional Manual [UDFCD Vol. 3]

- Technical Methods & Sizing Criteria
- Implementation Guidance

Boulder's Design Process Objectives

Objective	Driver
1. Meet Permit Requirements	Colorado Phase II MS4 Permit CDPS GENERAL PERMIT CORO09000 STORMWATER DISCHARGES ASSOCIATED WITH MUNICAL SEPARATE STORM SEWER SYSTEMS (MS4s) EFFECTIVE JULY 1, 2016
2. Promote Infiltration with GI/LID	Bacteria primary pollutant of concern ***E. coli* TMDL Implementation Plan** **City of Boulder** 
3. Guide effective designs	Lessons learned from design and maintenance failures

Boulder Design Standard Hierarchy

Boulder Specified Design Approach		Infiltration Conditions
Tier 1 – Runoff Reduction	**Full Infiltration** *Ex.: Bioretention without underdrain*	HSG A/B and No Risk
Tier 2 – WQCV	**Partial Infiltration/Filtration** *Ex.: Bioretention with underdrain*	HSG C/D and No Risk
	No Infiltration *Ex.: Bioretention with underdrain and liner*	Identified Infiltration Risk
Tier 3 – Pollutant Removal	**Alternative Design** *Ex.: Media Filter*	Site Specific Constraint

Evaluating Infiltration

Selection Process

Treatment Approach	Step 1. Feasibility Screening	Step 2. Field Test Requirements
Full Infiltration (Runoff Reduction)	HSG A or B, No soil, groundwater, or geological risk factors.	Required, Infiltration rate tested at ≥ 1 in/hr OR For RPAs topsoil texture analysis
Partial Infiltration (WQCV)	HSG C or D, No soil, groundwater, or geological risk factors.	Optional, Infiltration rate tested at < 1 in/hr OR For RPAs topsoil texture analysis
No Infiltration (WQCV)	Lined system required due to risk factors.	N/A
Alternative Design (Pollutant Removal/ Constrained Site)	Proof of physical site constraints/risk factor preventing other design.	N/A

Boulder Infiltration Conditions

Legend

Boulder Creek

Boulder Creek Drainage Area

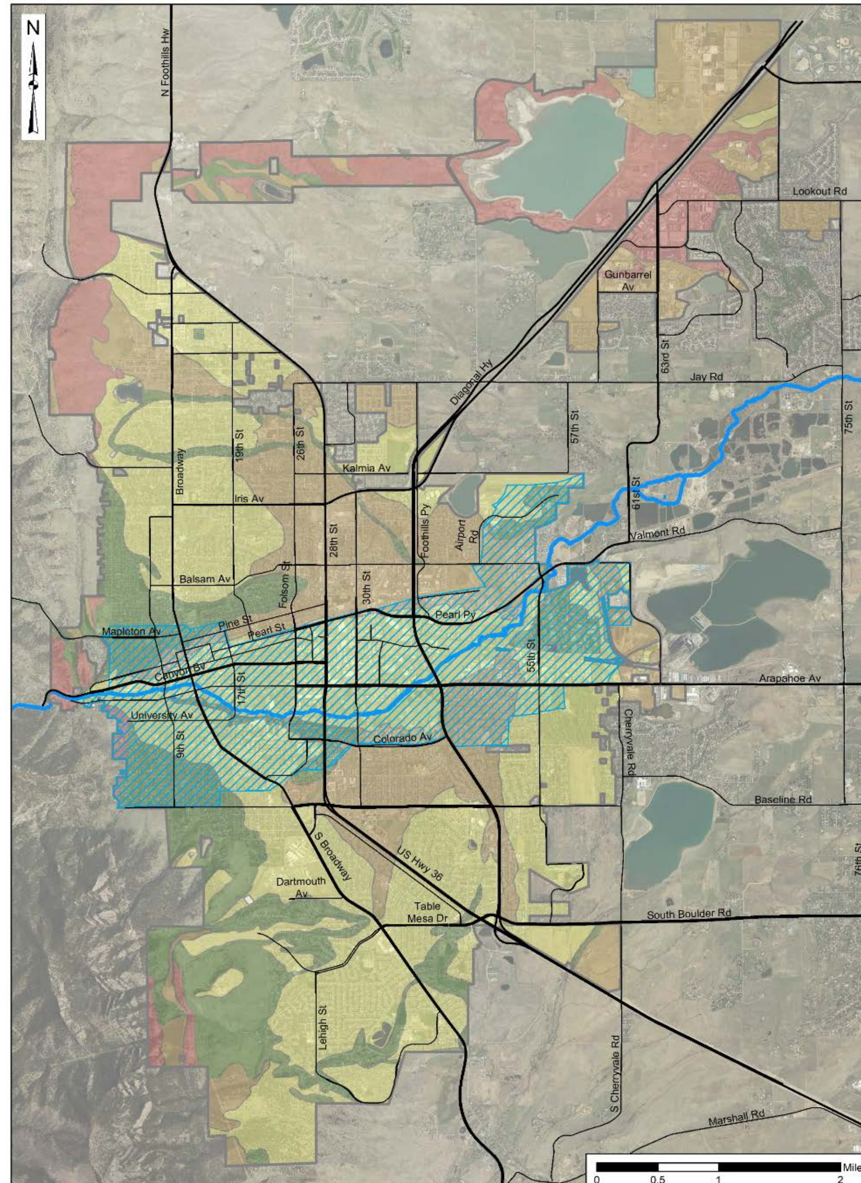
Hydrologic Soil Group

A

B

C

D



- HSG used only as a first look
- Differentiated soil conditions
  - HSG A: 16%
  - HSG B: 44%
  - HSG C: 28%
  - HSG D: 12%
- Boulder Creek Drainage: 80% HSG A/B

Process

Post-Construction Water Quality Design Form

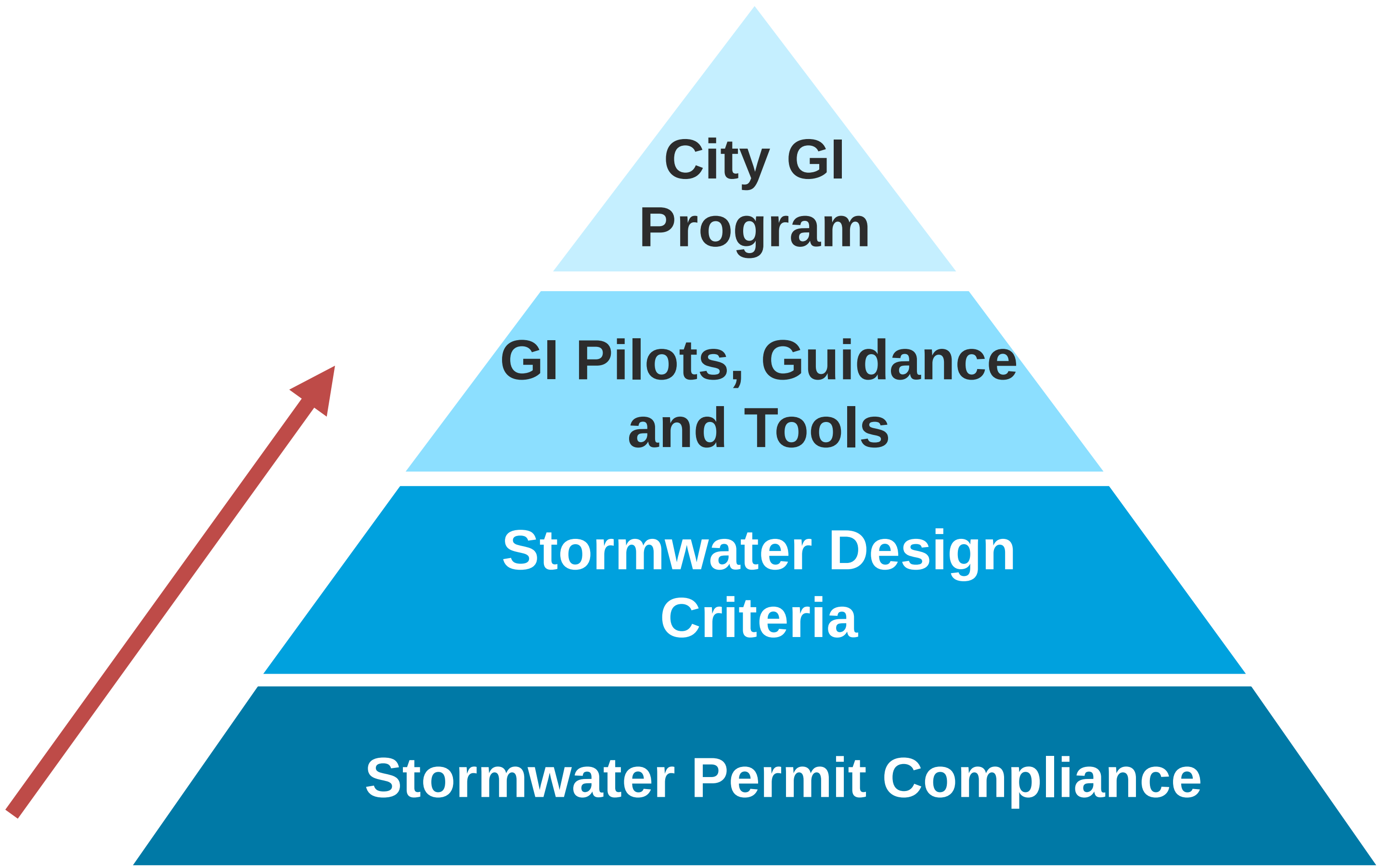
4. Full Infiltration – Runoff Reduction Criteria		
Runoff Reduction Design Standard: SCMs are selected, designed, and constructed to infiltrate into the ground where site geology permits, evaporate, or evapotranspire a quantity of water equal to 60% of what the WQCV would be if all impervious area for the applicable development site discharged without infiltration. None of the applicable development area may be excluded when using the Runoff Reduction Standard.		
Design Criteria[a]	**Yes**	**No**
1. Preliminary infiltration feasibility screening has been completed and documented in the drainage report with a rational conclusion for full infiltration.	☐	☐
2. The Runoff Reduction Design Standard has been met for the treatment area.	☐	☐
3. Required sizing criteria for full infiltration has been achieved and documented in the drainage report.	☐	☐
4. Field infiltration test requirements have been met and documented in the drainage report.	☐	☐

SCM Name[b]	SCM Type[c]	Drainage Area (ac)	WQ Event Runoff Volume (ft^3)	WQ Event Infiltrated Volume (ft^3)	Percent Infiltrated (%)	Detention Storage (yes/no)
	Treatment Area Not Routed to SCM:			0	0%	N/A
	Total:					

[a]Refer to D.C.S. Section 7.16(D)(1) for full infiltration treatment approach criteria.
[b]SCM Name shall match drainage report and plan designation. Attach additional table if more than three SCMs are planned.
[c]SCM Type shall match USDCM Volume 3, Treatment BMP Factsheet nomenclature.

Building Blocks

Building a green infrastructure (GI) program



Acknowledgements

wood.

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Elizabeth Judd
Kevin Koryto
Scott Kuhna
Brett Linenfelser
Candice Owen
Hella Pannewigh
Jessica Pault-Altiase
Edward Stafford

Thank You!

References:

Boulder Design and Construction Standards,
Search: “Boulder DCS”
https://bouldercolorado.gov/plan-develop/design-construction-standards

Innovative and Integrated Stormwater Management,
Search: “NYC Stormwater Report”
https://www.waterrf.org/resource/innovative-and-integrated-stormwater-management

Contacts:

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Beneficial Use of Water Treatment Residuals as a Bioretention Media Amendment for Phosphorus Removal

2019 CASFM Annual Conference

September 24-27, 2019

- *Basil Hamdan, P.E., CFM – City of Fort Collins - Utilities*
- *Tyler Dell – Colorado State University –*

  Colorado Stormwater Center

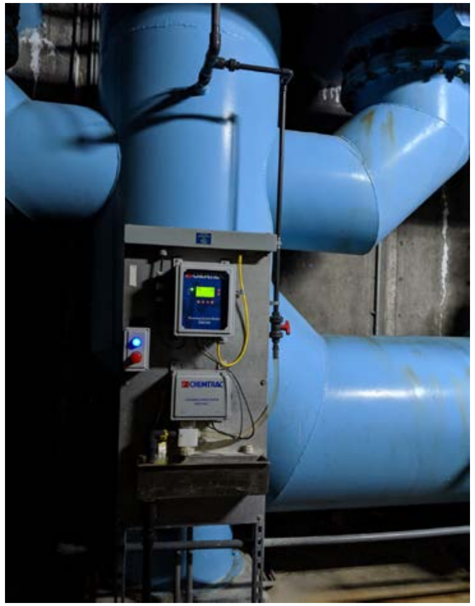
What are Water Treatment Residuals (WTRs)?

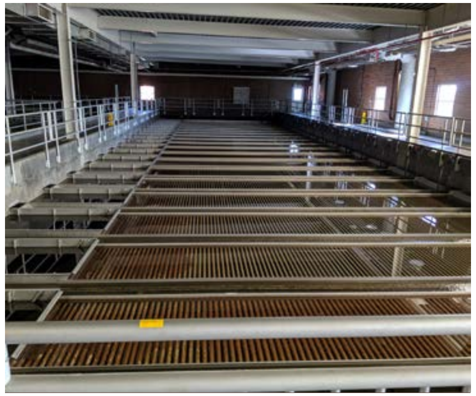
What are WTRs?

- The flocculating agent of water treatment
- Fort Collins Utilities uses Aluminum Sulfate
  $Al_2(SO_4)_3$
- Delivered as a liquid
- Stored in large tanks and added to the water

What are WTRs?

- Calculated, added, monitored for the source water
- Causes flocculation
- Removed in the sediment from water treatment residuals





What are WTRs?

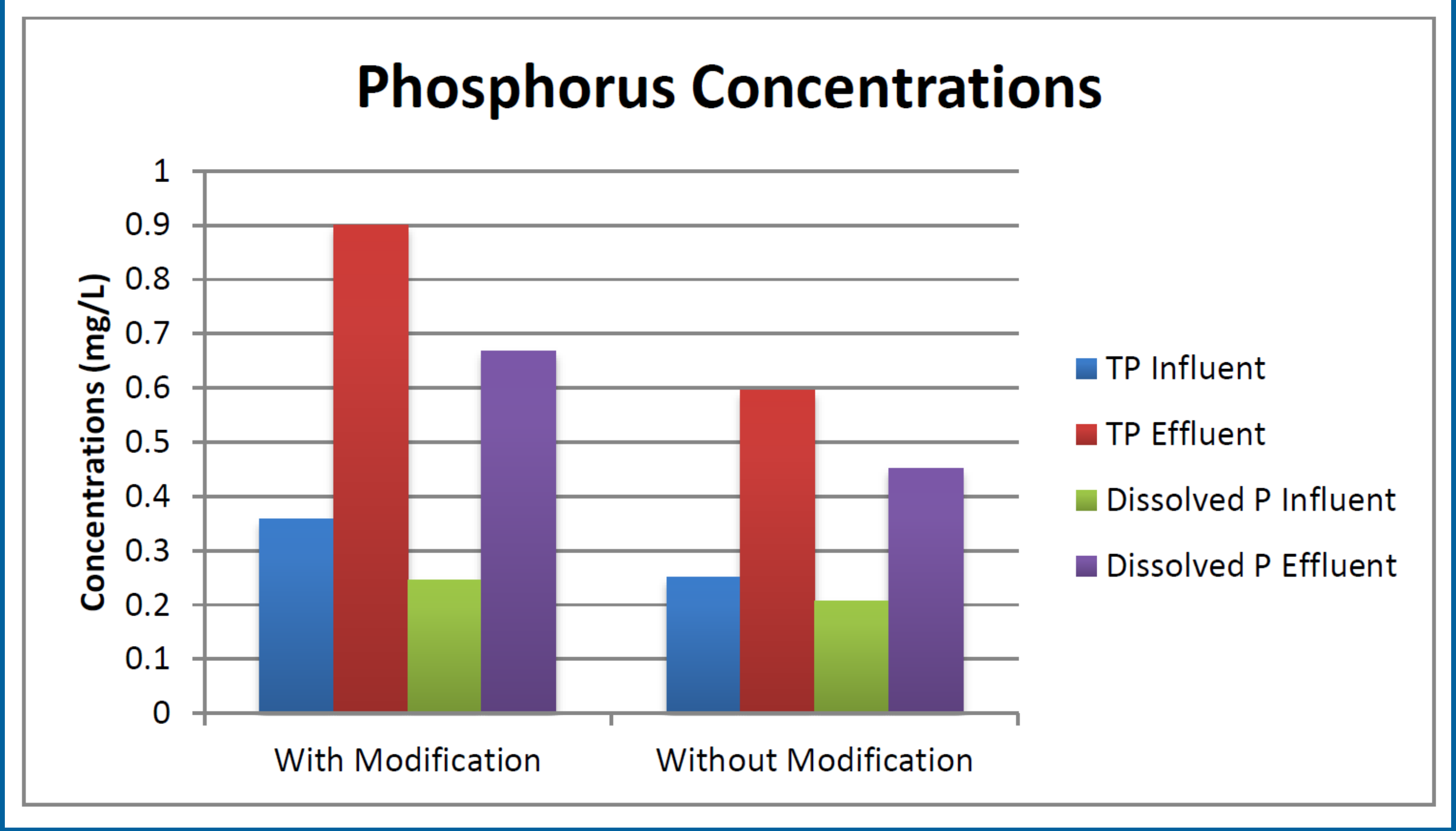
- Sediment containing the aluminum sulfate as well as particles removed from water treatment needs to be managed (full-time position)
  1. Dewatering
  2. On-site Management
  3. Landfill Issues (Costs + Life Cycle)

zero waste
FORT COLLINS

Fort Collins Zero Waste Initiative

Meanwhile Back At The Ranch…

- Stormwater nutrients and current practices
- Regulation 85
- Lead pipes and phosphate
- COFC Climate Action Plan
- Innovate Fort Collins
- Colorado State University – Stormwater Center - COFC Collaboration
- CSU- City Sustainability Network

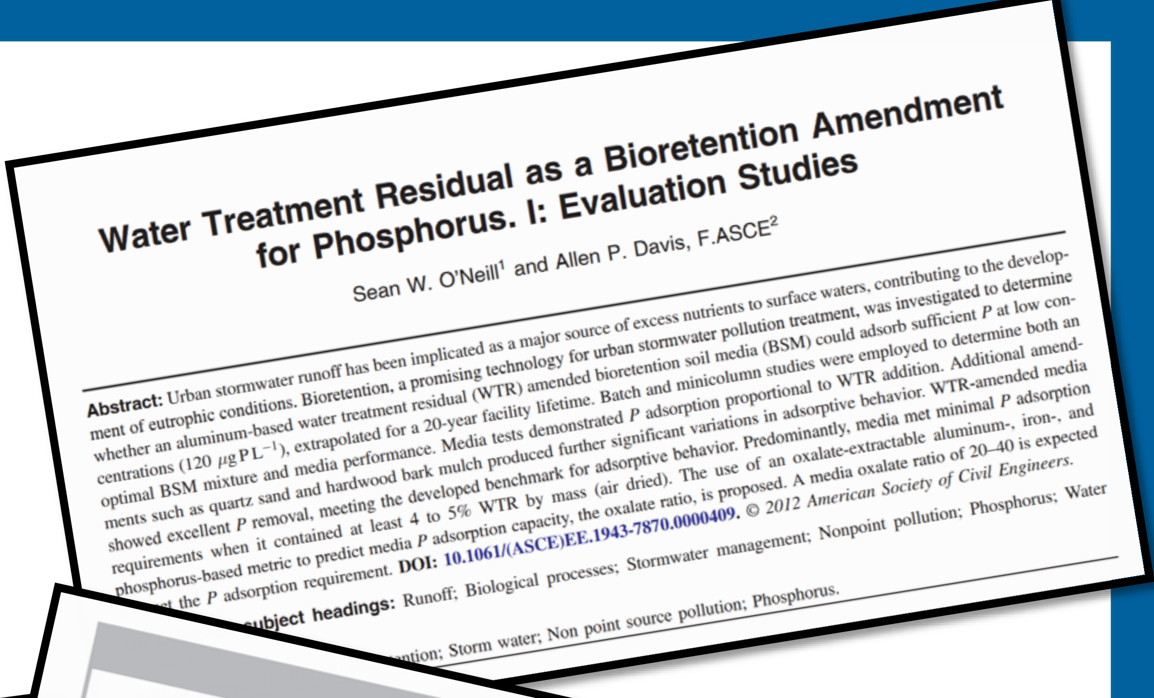


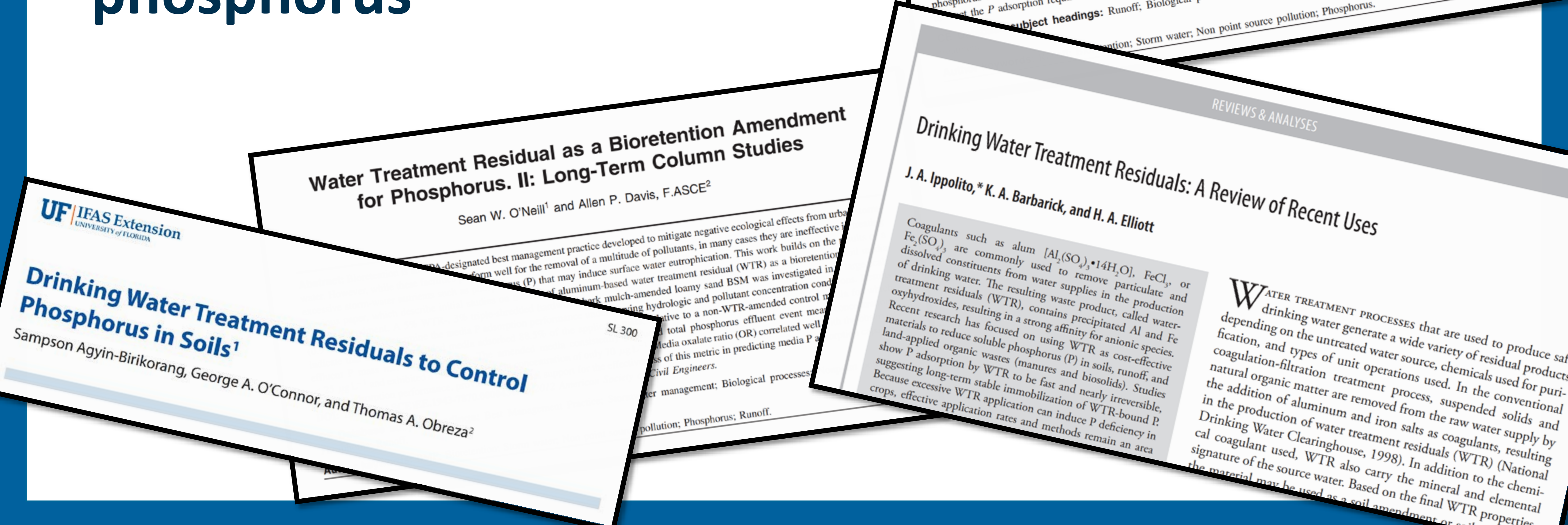
WASTE

RESOURCE

- Fort Collins Water Treatment Plant produces over 1,000 tons of WTRs/yr
- Larimer County Landfill originally scheduled to be closed within 5-10 years
- Regulation 85 sets new TMDLs for streams and phosphorus
- Current stormwater practices export phosphorus

We want to use WTRs as a media amendment to reduce waste and treat phosphorus





WTR Column Study

- Wanted to test the concept and mixing strategy
- 4 different configurations
  - Top Applied – 0.5”
  - Top Applied – 1.0”
  - Bottom Applied – 1.0”
  - Mixed Application – 1.0”

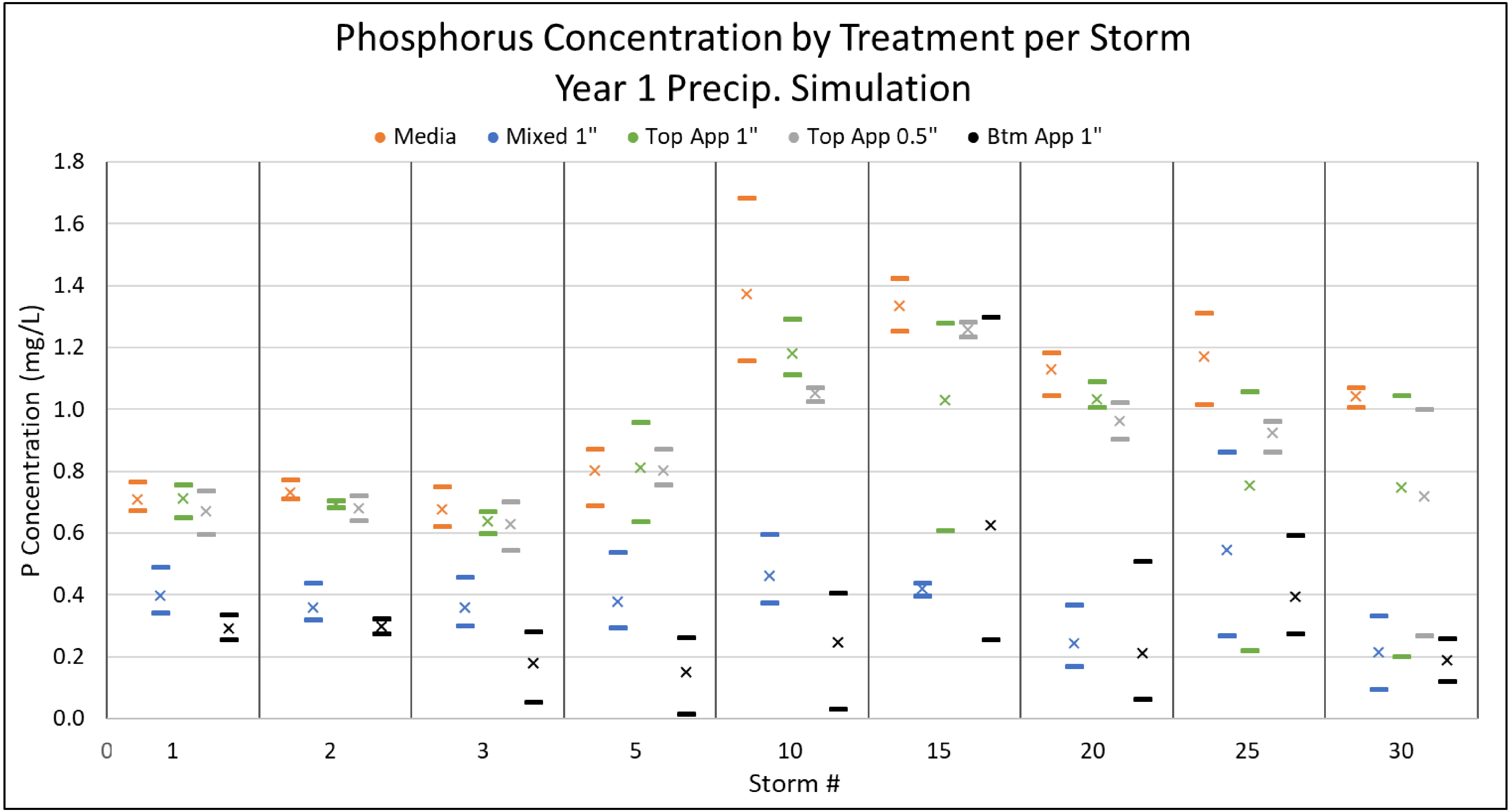
Hydrology Summary

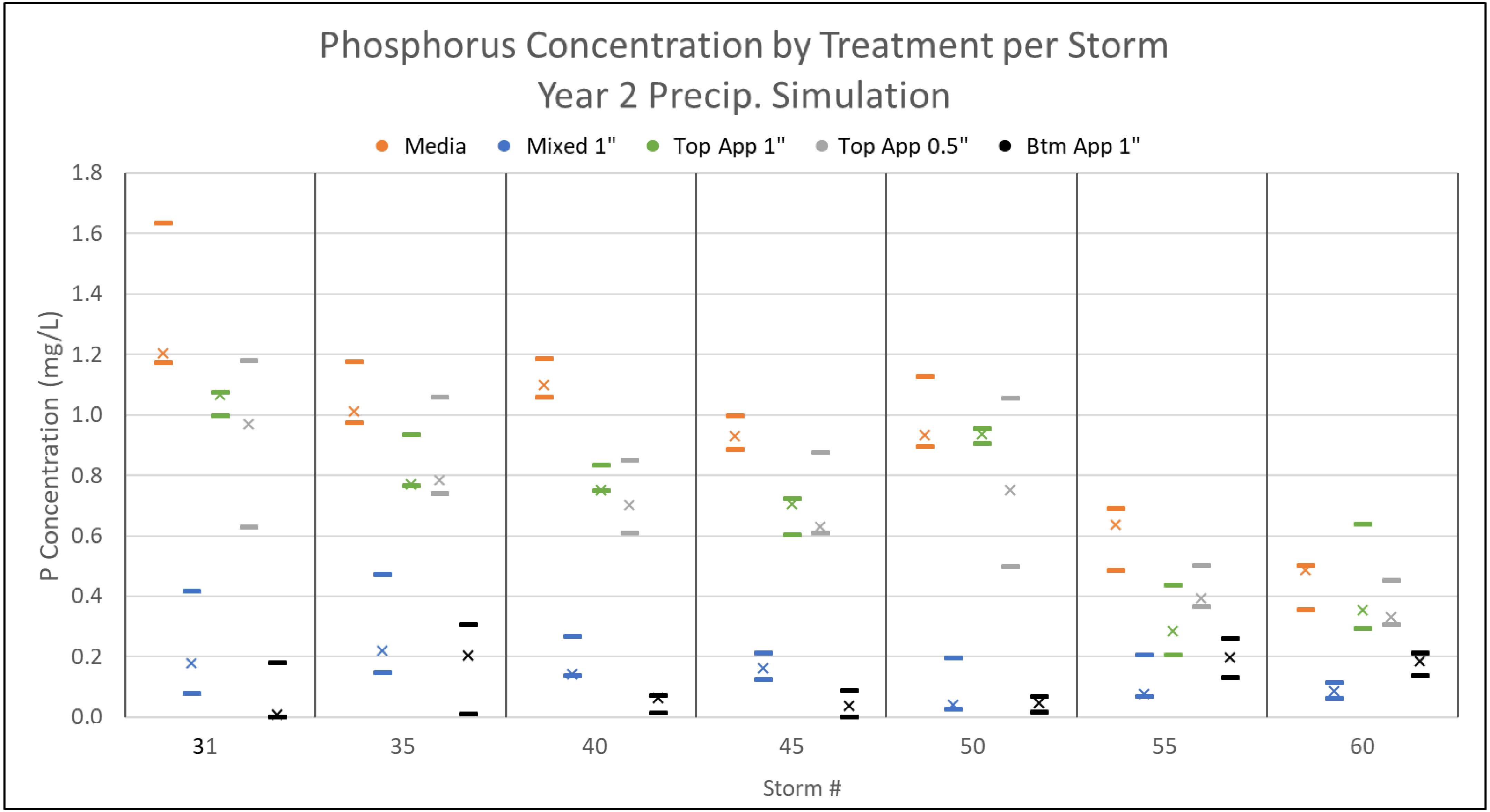
Year	# of Sig Events (> 0.1 in)	Water Volume ft^3			
		Total Precip	*Sig. Event Precip*	*Total Estimated Runoff*	*Limited Estimated Runoff*
2007	21	104,280	83,490	66,165	17,753
2008	22	110,220	98,670	80,520	24,405
2009	41	173,333	155,760	121,935	41,310
2010	28	115,253	101,805	78,705	26,175
2011	32	143,633	127,958	101,558	33,735
2012	18	72,765	59,483	44,633	17,940
2013	33	143,055	127,793	100,568	34,680
2014	33	131,753	107,828	80,273	32,970
2015	38	155,595	134,558	103,208	36,435
2016	27	93,473	75,983	53,708	23,348
2017	36	139,343	117,398	88,110	33,383
Average	30	125,700	108,248	83,580	29,285

Hydrology Summary

Based on previous rain gage analysis

- Fort Collins experiences an average of 30 runoff producing storms/year
- The average depth contained by the rain garden from those storms is 6.2”
- The 95th confidence interval 7.0”
- The average dissolved phosphorus EMC from the parking lot is approximately 0.228 mg/L


Phosphorus Concentration by Treatment per Storm
Year 1 Precip. Simulation
Media
Mixed 1"
Top App 1"
Top App 0.5"
Btm App 1"
P Concentration (mg/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
5
10
15
20
25
30
Storm #



Phosphorus Concentration by Treatment per Storm
Year 2 Precip. Simulation
Media
Mixed 1"
Top App 1"
Top App 0.5"
Btm App 1"
P Concentration (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
31
35
40
45
50
55
60
Storm #

Performance of WTR Columns

- Bottom application performed the best followed closely by mixed
- The top applied did provide some removal but not much
- Application rates of top application did not impact performance
    - Time of exposure
    - Picking up pollutants from media beneath

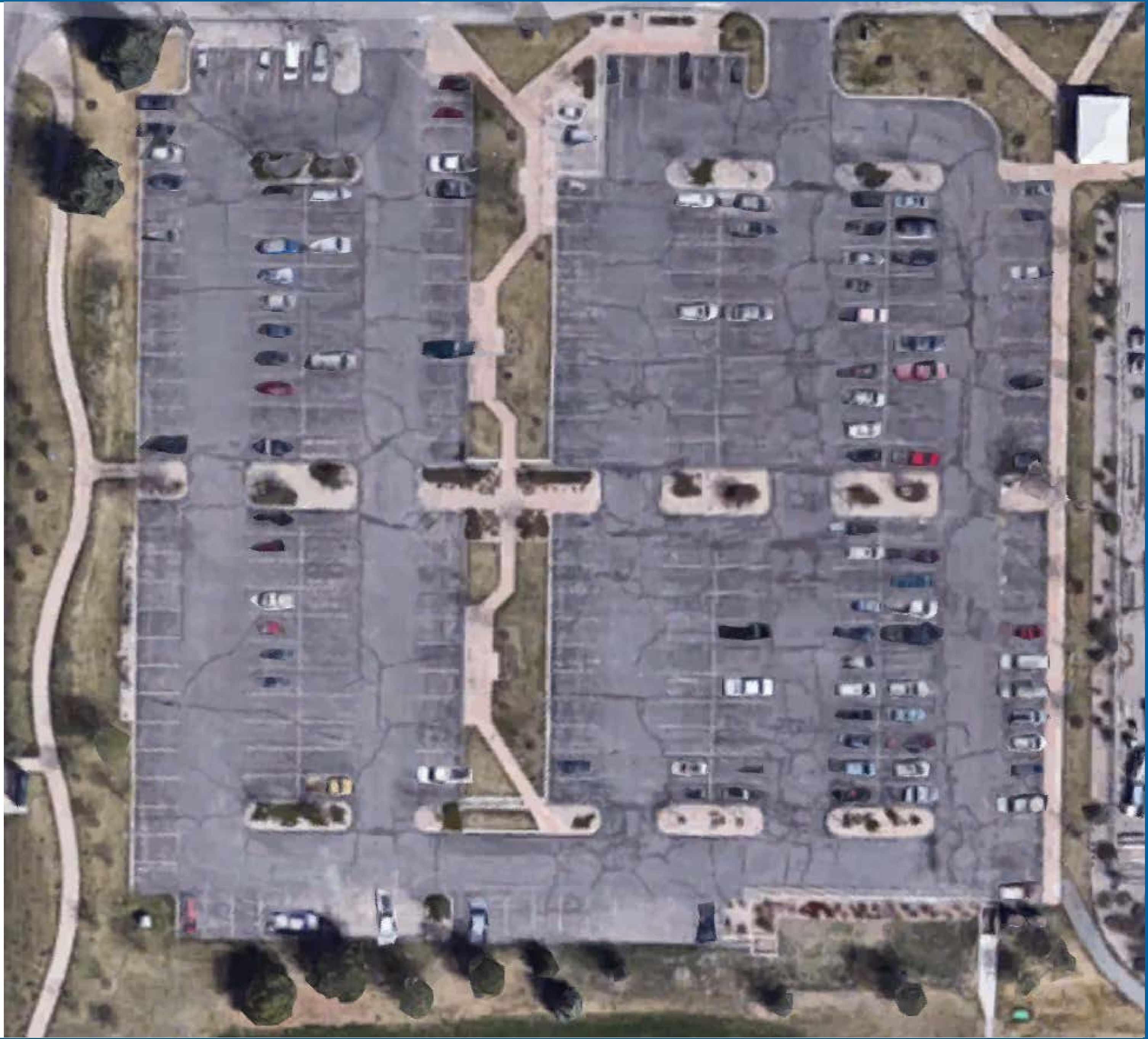
Mix Type	Average Reduction
Mixed 1"	71.9%
Top Applied 1"	19.0%
Top Applied 0.5"	19.3%
Bottom Applied 1 "	77.1%

WTR Pilot Project: 700 Wood Street

Site Background

Rain Garden (Bioretention)

- Installed in 2012
- 2.25 acre parking lot
- Rain Garden Area: 1,900 ft^2
- Rain Garden Volume: 1,400 ft^3



Stormwater Monitoring

Monitored site since 2013

Pilot Project Application

- Used a top application of approximately 0.5”
  - This should handle at least 10 years of phosphorus loading
- Installed sampling equipment to capture influent and effluent water quality samples
  - Looking primarily for dissolved P, aluminum, and potential radioactive particulate from the WTRs
- Collected a sample on 9/8/2019, results should be in soon…

Conclusions

- Mixed application appears to be the optimal application that would yield the least amount of risk
- Continuation of column study for 30 rainfall years
- Expansion to additional types of technologies
  - Wetlands
  - Extended Detention Basins
- Elimination/re-use of Fort Collins water treatment residuals waste

Thank you!

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Contact: Basil Hamdan

970.224.6035

bhamdan@fcgov.com

COLORADO STORMWATER CENTER

Educate, Enhance, Explore

City of Fort Collins

SUBWATERSHED WATER QUALITY BMP RETROFIT ANALYSIS

CASFM 2019

HRGreen

Watershed Management

Stormwater Retrofits

Stream Management

Riparian Corridor Management

Forest Management

Source/Discharge Controls

Process Overview

- Target
- Measure
- Prioritize

Process Overview

Municipal Challenges

- Staffing resources
- Implementation funding
- Water quality/TMDL
- Fully built landscape

Process Overview

Solutions

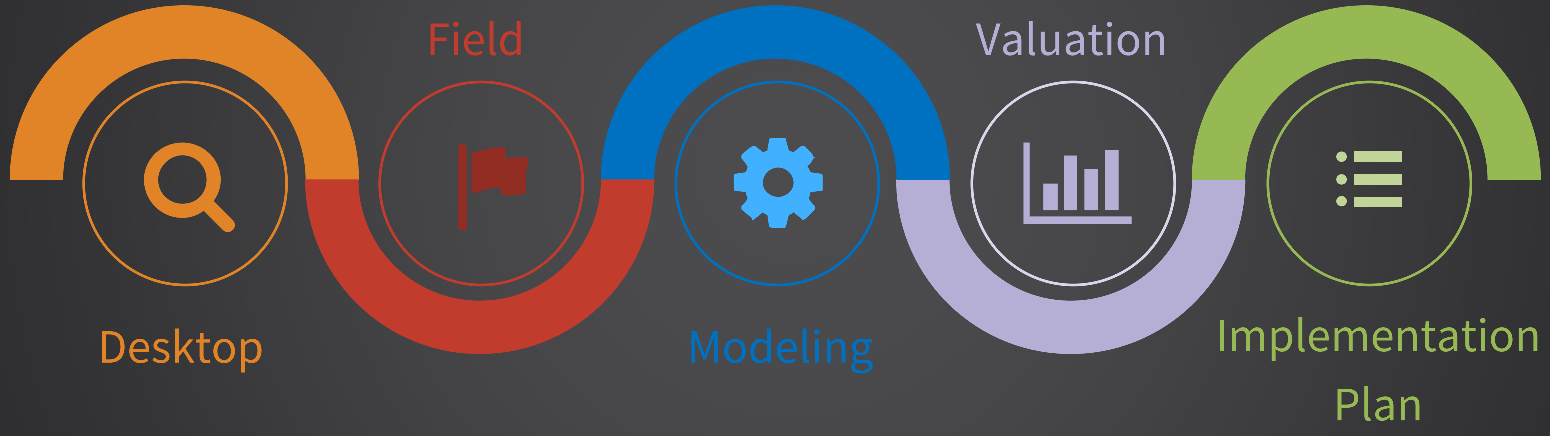
- Optimized BMP targeting
- Optimized BMPs by location
- Measurable, defensible outcomes

Process Overview

Benefits

- Comprehensive planning
- Apples-to-apples vetting
- CIP planning
- NPDES reporting support
- Powerful grant writing

Process Overview



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Process Overview

Desktop Analysis: potential retrofit location screening

- Outfalls
- Pond mod's
- Open space
- Parking lots
- Rural
- Residential
- Urban
- Underground
- Base WQ Model

Process Overview

Field Analysis: site validation and data collection

- Confirm data
- Site constraint identification
- BMP alternatives identification
- Spot invert survey
- Infiltration testing
- Base model update

Process Overview

Treatment Analysis

- Subwatershed WQ modeling of alternatives
- 30-year, continuous modeling
- Incremental treatment (%) sizing runs
- TP, TKN, TSS, CU, PB, ZN, Hydrocarbons
- Water balance
- Treatment train effects
- WQ effects by outfall

Process Overview

Value Analysis

- Apples-to-apples comparison of alternatives
- 30-year Present Day Values (PDV)
- PDV / 30-year treatment = value
- Incremental cost analysis
- Triple Bottom Line analysis by subwatershed
- Alternative ranking by subwatershed
- Comprehensive mapping and database development

Potential Locations

- Existing pond modification potential
- Above roadway culverts
- Below stormwater outfalls
- Within the conveyance system
- Transportation right of ways
- Large parking lots
- Hotspot operations
- Small parking lots
- Residential streets/blocks
- Open space/pervious areas for disconnecting pervious areas
- Large rooftops
- Underground treatment

BMP-Function Groups

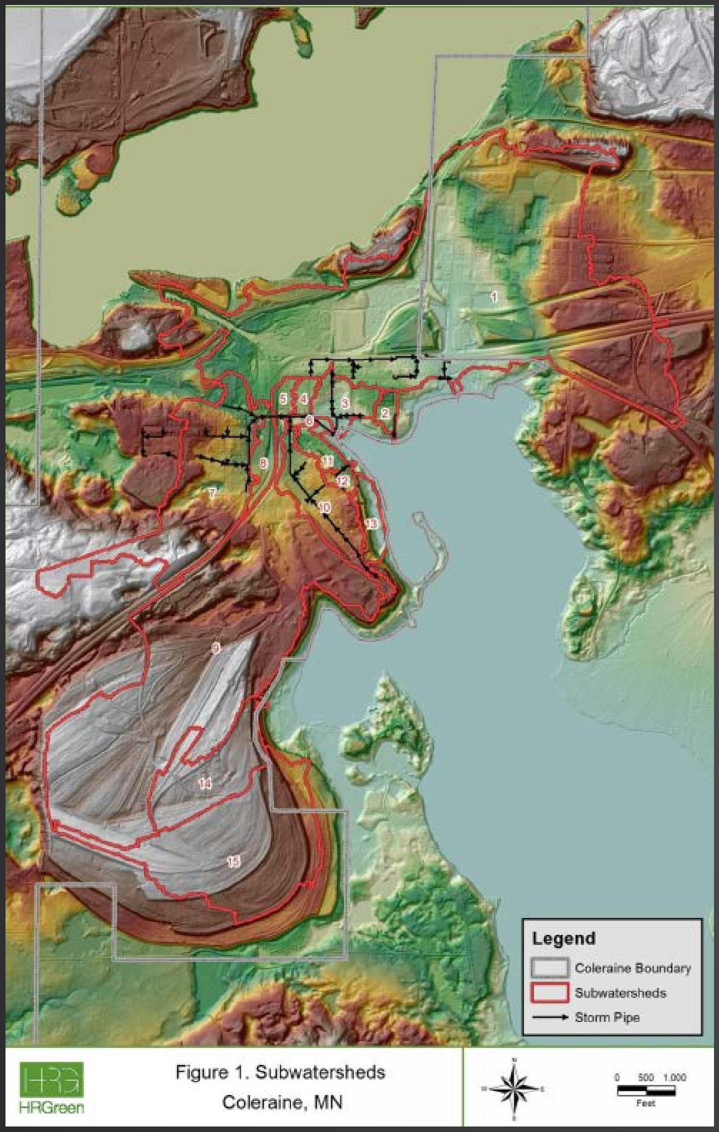
- Extended Detention (Full Spectrum)
- Stormwater Wetlands
- Infiltration
- Bioretention
- Filtration
- Swales
- Stormwater Harvesting
- Chemical Reaction

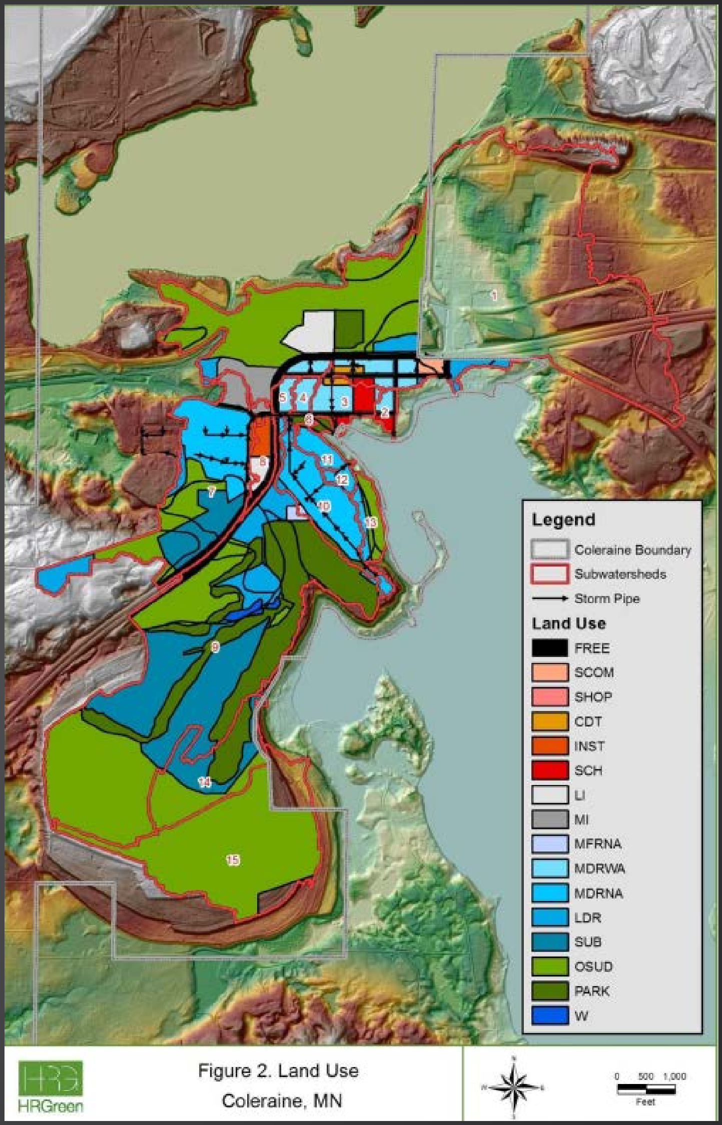
BMP Groups by Location

	Stormwater Treatment Option (BMP)						
Location	**Extended Detention**	**Wet Ponds**	**Stormwater Wetlands**	**Bioretention**	**Filtration**	**Infiltration**	**Swales**
Existing pond modification	●	●	●	▲	▲	○	○
Above roadway culverts	●	▲	●	○	○	○	○
Below stormwater outfalls	●	●	●	▲	▲	○	○
Within the conveyance system	▲	○	●	●	○	○	●
Transportation right of ways	●	●	●	●	▲	○	▲
Large parking lots	●	●	●	▲	▲	▲	○
Hotspot operations	○	○	○	●	●	X	○
Small parking lots	○	○	○	●	●	●	●
Residential streets/blocks	○	○	○	●	▲	▲	○
Open space	○	○	○	●	▲	●	●
Urban hardscape	○	○	▲	●	▲	▲	▲
Large rooftops	○	○	○	●		▲	●
Underground treatment	▲	○	○	▲	●	▲	○

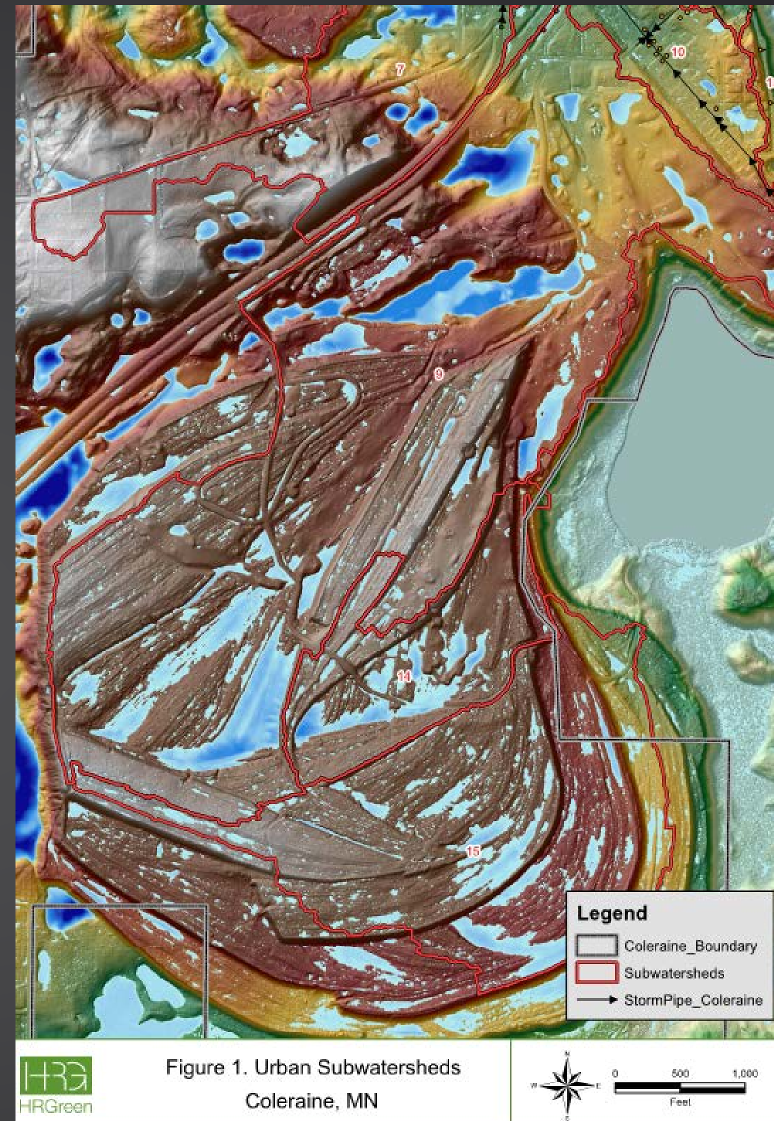
● = Preferred stormwater treatment option
▲ = Feasible in some circumstances
○ = Seldom used for the retrofit
X = Not recommended under any circumstances

Source: Center for Watershed Protection

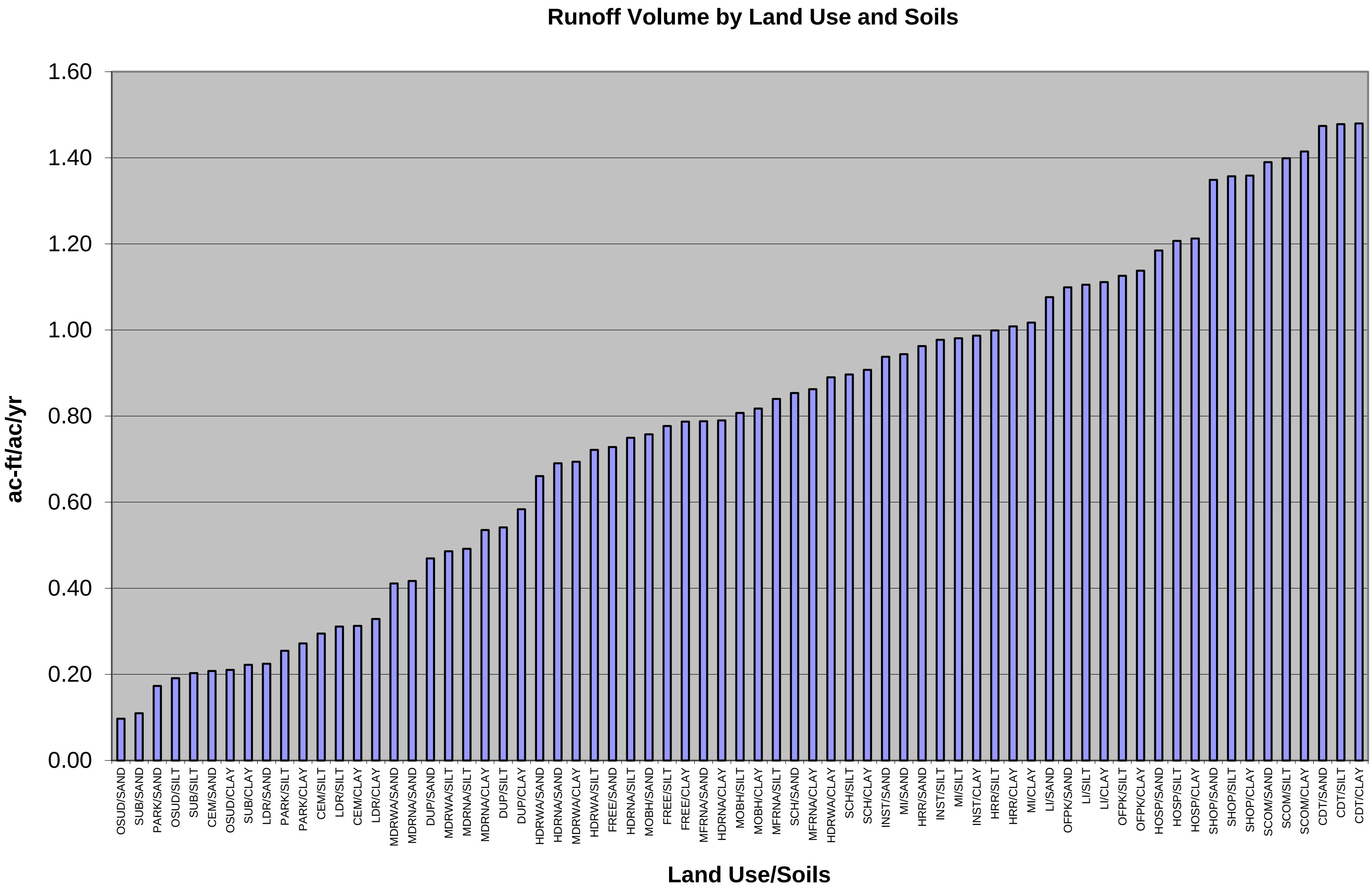

Legend
Coleraine Boundary
Subwatersheds
Storm Pipe
HRGreen
Figure 1. Subwatersheds
Coleraine, MN
0 500 1,000
Feet


Legend
Coleraine Boundary
Subwatersheds
Storm Pipe
Land Use
FREE
SCOM
SHOP
CDT
INST
SCH
LI
MI
MFRNA
MDRWA
MDRNA
LDR
SUB
OSUD
PARK
W
HRGreen
Figure 2. Land Use
Coleraine, MN
0 500 1,000
Feet

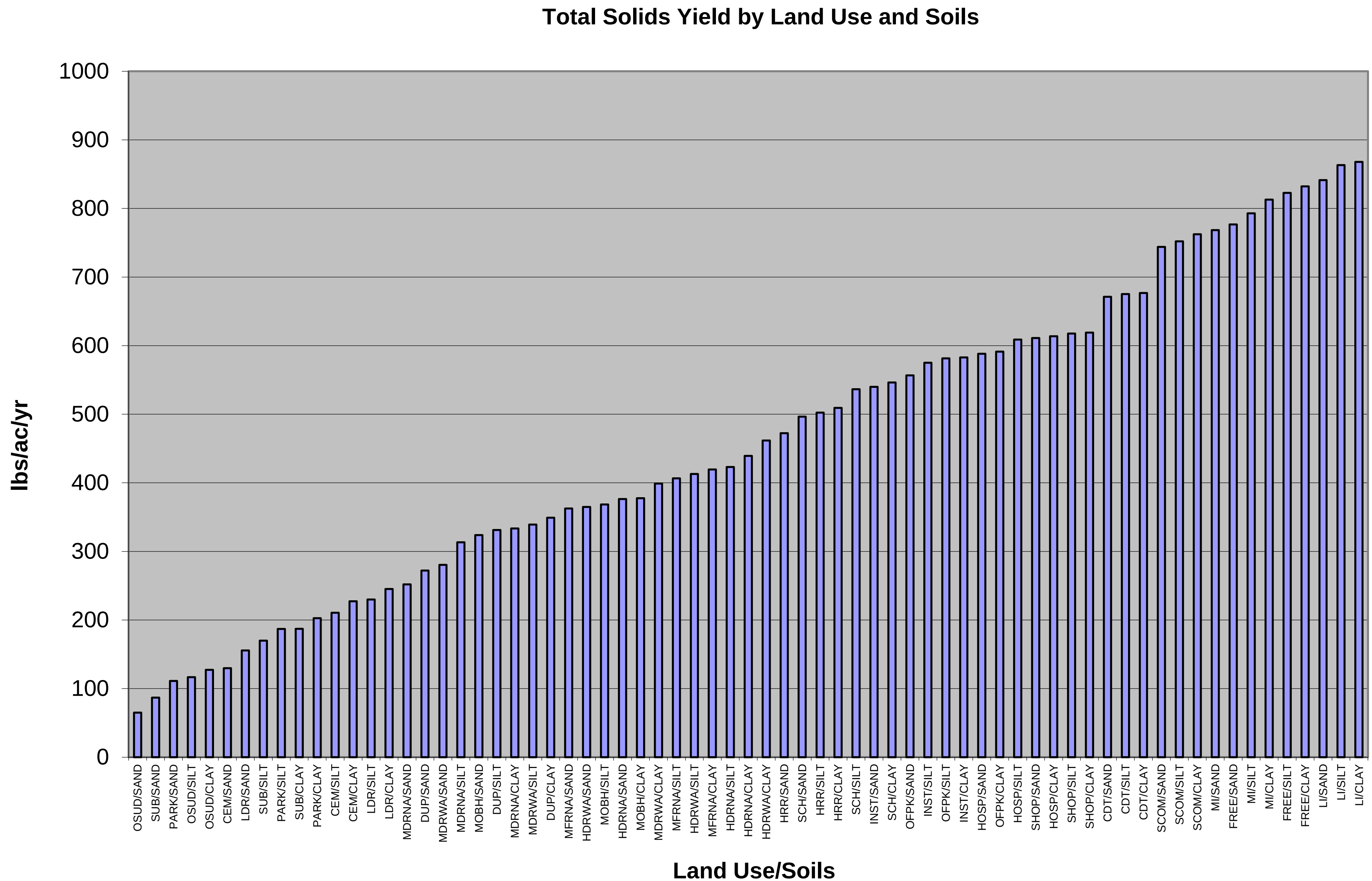

Legend
Coleraine Boundary
Storm Pipe
Subwatersheds
SW9 Flow Lines
Figure 4. SW 9
Flow Paths
Coleraine, MN
HRGreen
0
500
1,000
Feet


Legend
Coleraine_Boundary
Subwatersheds
StormPipe_Coleraine
Figure 1. Urban Subwatersheds
Coleraine, MN
HRGreen
0
500
1,000
Feet

HRGreen


Runoff Volume by Land Use and Soils
ac-ft/ac/yr
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
OSUD/SAND
SUB/SAND
PARK/SAND
OSUD/SILT
SUB/SILT
CEM/SAND
OSUD/CLAY
SUB/CLAY
LDR/SAND
PARK/SILT
PARK/CLAY
CEM/SILT
LDR/SILT
CEM/CLAY
LDR/CLAY
MDRWA/SAND
MDRNA/SAND
DUP/SAND
MDRWA/SILT
MDRNA/SILT
MDRNA/CLAY
DUP/SILT
DUP/CLAY
HDRWA/SAND
HDRNA/SAND
MDRWA/CLAY
HDRWA/SILT
FREE/SAND
HDRNA/SILT
MOBH/SAND
FREE/SILT
FREE/CLAY
MFRNA/SAND
HDRNA/CLAY
MOBH/SILT
MOBH/CLAY
MFRNA/SILT
SCH/SAND
MFRNA/CLAY
HDRWA/CLAY
SCH/SILT
SCH/CLAY
INST/SAND
MI/SAND
HRR/SAND
INST/SILT
MI/SILT
INST/CLAY
HRR/SILT
HRR/CLAY
MI/CLAY
LI/SAND
OFPK/SAND
LI/SILT
LI/CLAY
OFPK/SILT
OFPK/CLAY
HOSP/SAND
HOSP/SILT
HOSP/CLAY
SHOP/SAND
SHOP/SILT
SHOP/CLAY
SCOM/SAND
SCOM/SILT
SCOM/CLAY
CDT/SAND
CDT/SILT
CDT/CLAY
Land Use/Soils

HRGreen


Total Solids Yield by Land Use and Soils
lbs/ac/yr
0
100
200
300
400
500
600
700
800
900
1000
OSUD/SAND
SUB/SAND
PARK/SAND
OSUD/SILT
OSUD/CLAY
CEM/SAND
LDR/SAND
SUB/SILT
PARK/SILT
SUB/CLAY
PARK/CLAY
CEM/SILT
CEM/CLAY
LDR/SILT
LDR/CLAY
MDRNA/SAND
DUP/SAND
MDRWA/SAND
MDRNA/SILT
MOBH/SAND
DUP/SILT
MDRNA/CLAY
MDRWA/SILT
DUP/CLAY
MFRNA/SAND
HDRWA/SAND
MOBH/SILT
HDRNA/SAND
MOBH/CLAY
MDRWA/CLAY
MFRNA/SILT
HDRWA/SILT
MFRNA/CLAY
HDRNA/SILT
HDRNA/CLAY
HDRWA/CLAY
HRR/SAND
SCH/SAND
HRR/SILT
HRR/CLAY
SCH/SILT
INST/SAND
SCH/CLAY
OFPK/SAND
INST/SILT
OFPK/SILT
INST/CLAY
HOSP/SAND
OFPK/CLAY
HOSP/SILT
SHOP/SAND
HOSP/CLAY
SHOP/SILT
SHOP/CLAY
CDT/SAND
CDT/SILT
CDT/CLAY
SCOM/SAND
SCOM/SILT
SCOM/CLAY
MI/SAND
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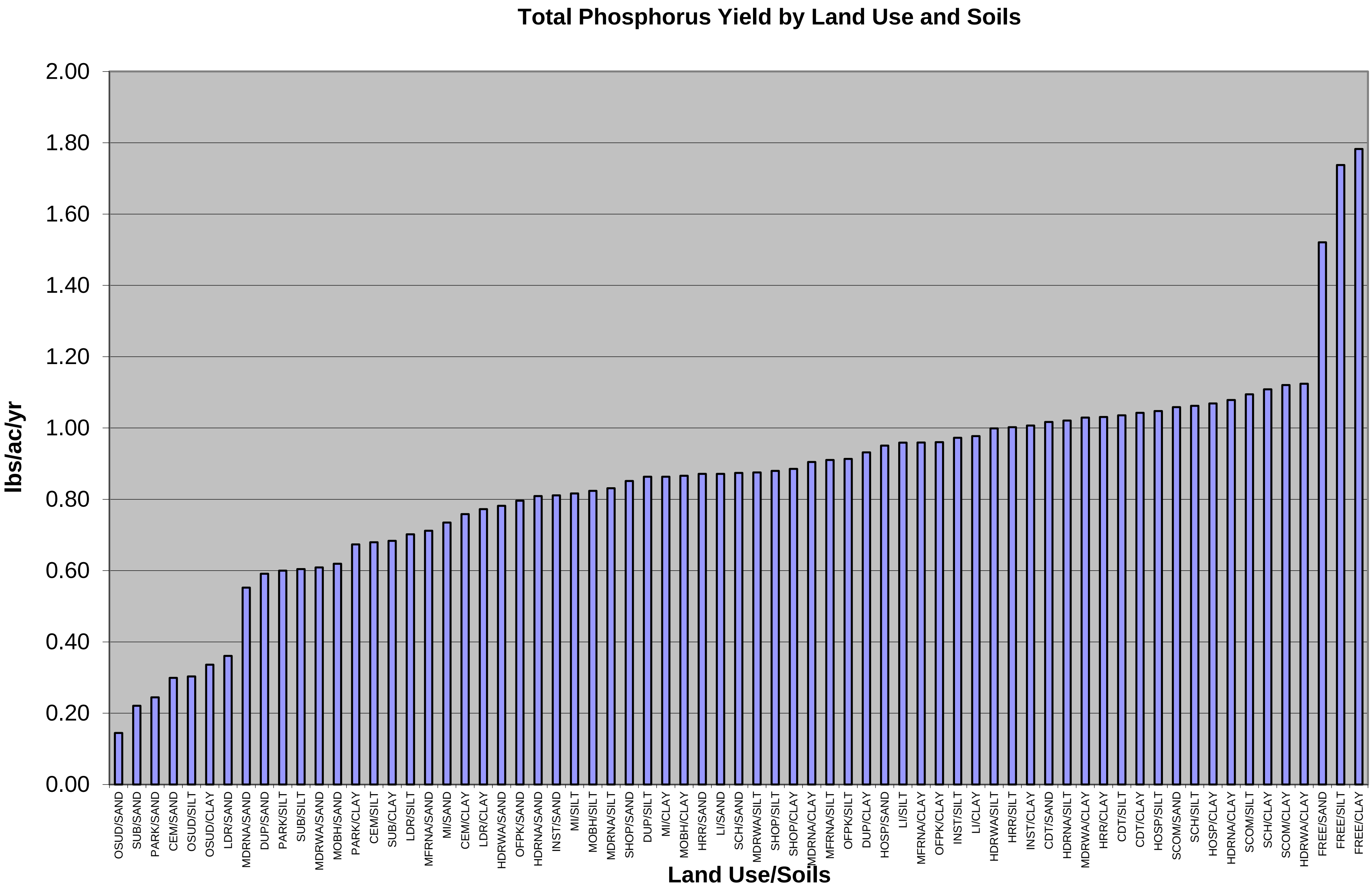
FREE/SILT
FREE/CLAY
LI/SAND
LI/SILT
LI/CLAY
Land Use/Soils


Total Phosphorus Yield by Land Use and Soils
lbs/ac/yr
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
OSUD/SAND
SUB/SAND
PARK/SAND
CEM/SAND
OSUD/SILT
OSUD/CLAY
LDR/SAND
MDRNA/SAND
DUP/SAND
PARK/SILT
SUB/SILT
MDRWA/SAND
MOBH/SAND
PARK/CLAY
CEM/SILT
SUB/CLAY
LDR/SILT
MFRNA/SAND
MI/SAND
CEM/CLAY
LDR/CLAY
HDRWA/SAND
OFPK/SAND
HDRNA/SAND
INST/SAND
MI/SILT
MOBH/SILT
MDRNA/SILT
SHOP/SAND
DUP/SILT
MI/CLAY
MOBH/CLAY
HRR/SAND
LI/SAND
SCH/SAND
MDRWA/SILT
SHOP/SILT
SHOP/CLAY
MDRNA/CLAY
MFRNA/SILT
OFPK/SILT
DUP/CLAY
HOSP/SAND
LI/SILT
MFRNA/CLAY
OFPK/CLAY
INST/SILT
LI/CLAY
HDRWA/SILT
HRR/SILT
INST/CLAY
CDT/SAND
HDRNA/SILT
MDRWA/CLAY
HRR/CLAY
CDT/SILT
CDT/CLAY
HOSP/SILT
SCOM/SAND
SCH/SILT
HOSP/CLAY
HDRNA/CLAY
SCOM/SILT
SCH/CLAY
SCOM/CLAY
HDRWA/CLAY
FREE/SAND
FREE/SILT
FREE/CLAY
Land Use/Soils

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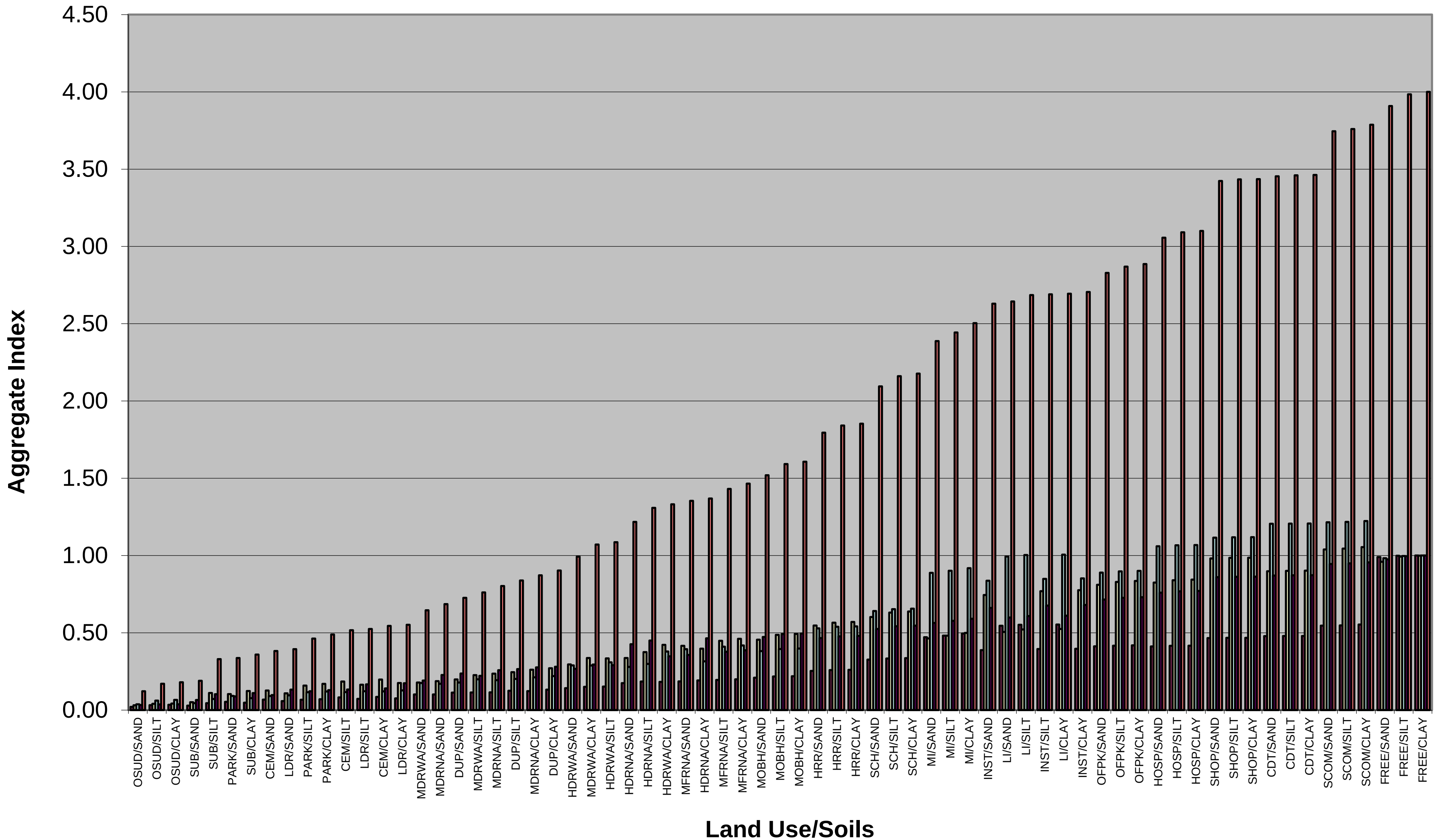
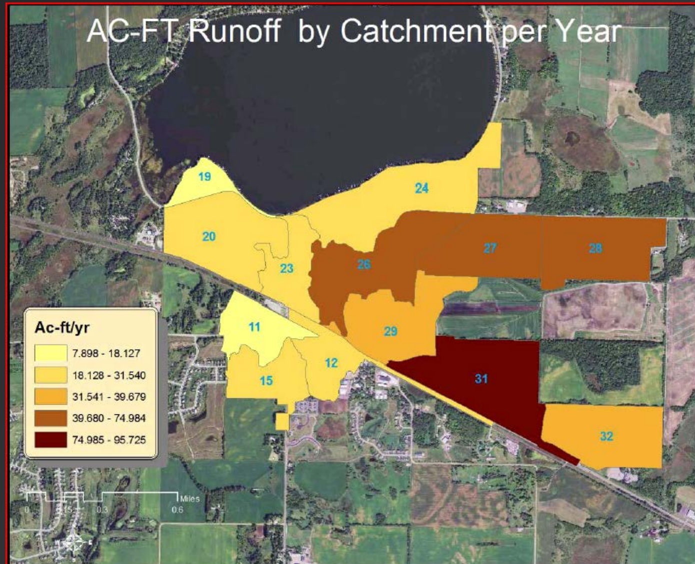
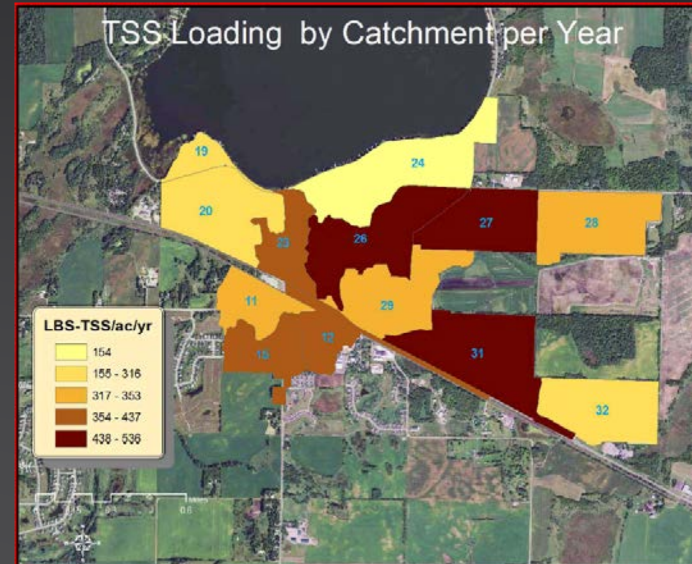
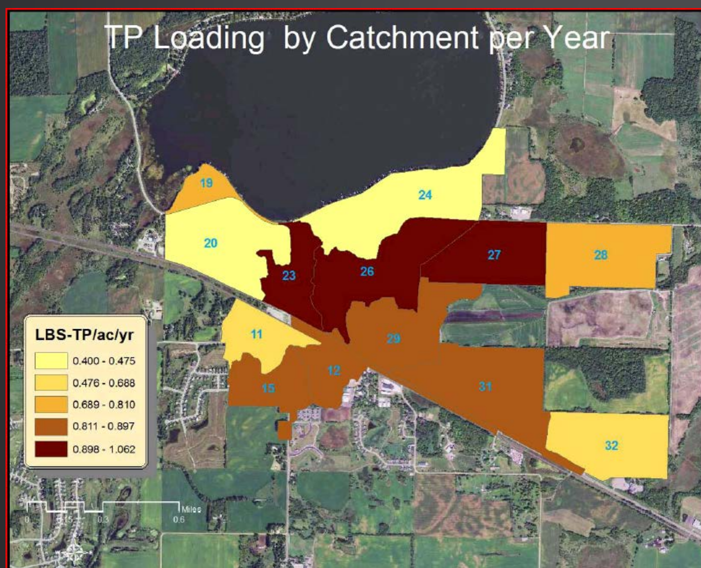
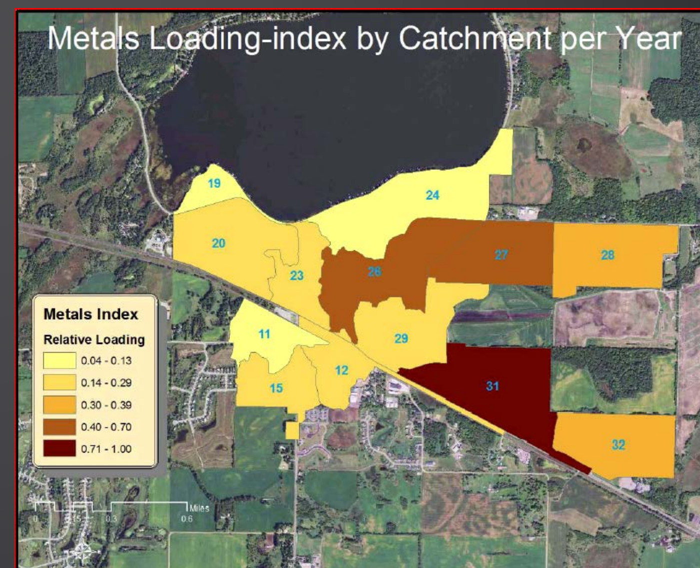
Metals Yield Index by Land use and Soils




AC-FT Runoff by Catchment per Year
Ac-ft/yr
7.898 - 18.127
18.128 - 31.540
31.541 - 39.679
39.680 - 74.984
74.985 - 95.725
19
20
23
24
26
27
28
11
29
12
15
31
32


TSS Loading by Catchment per Year
LBS-TSS/ac/yr
154
155 - 316
317 - 353
354 - 437
438 - 536
19
24
20
23
26
27
28
11
29
12
15
31
32


TP Loading by Catchment per Year
LBS-TP/ac/yr
0.400 - 0.475
0.476 - 0.688
0.689 - 0.810
0.811 - 0.897
0.898 - 1.062
19
24
20
23
26
27
28
11
29
12
15
31
32


Metals Loading-index by Catchment per Year
Metals Index
Relative Loading
0.04 - 0.13
0.14 - 0.29
0.30 - 0.39
0.40 - 0.70
0.71 - 1.00
19
24
20
23
26
27
28
11
29
12
15
31
32

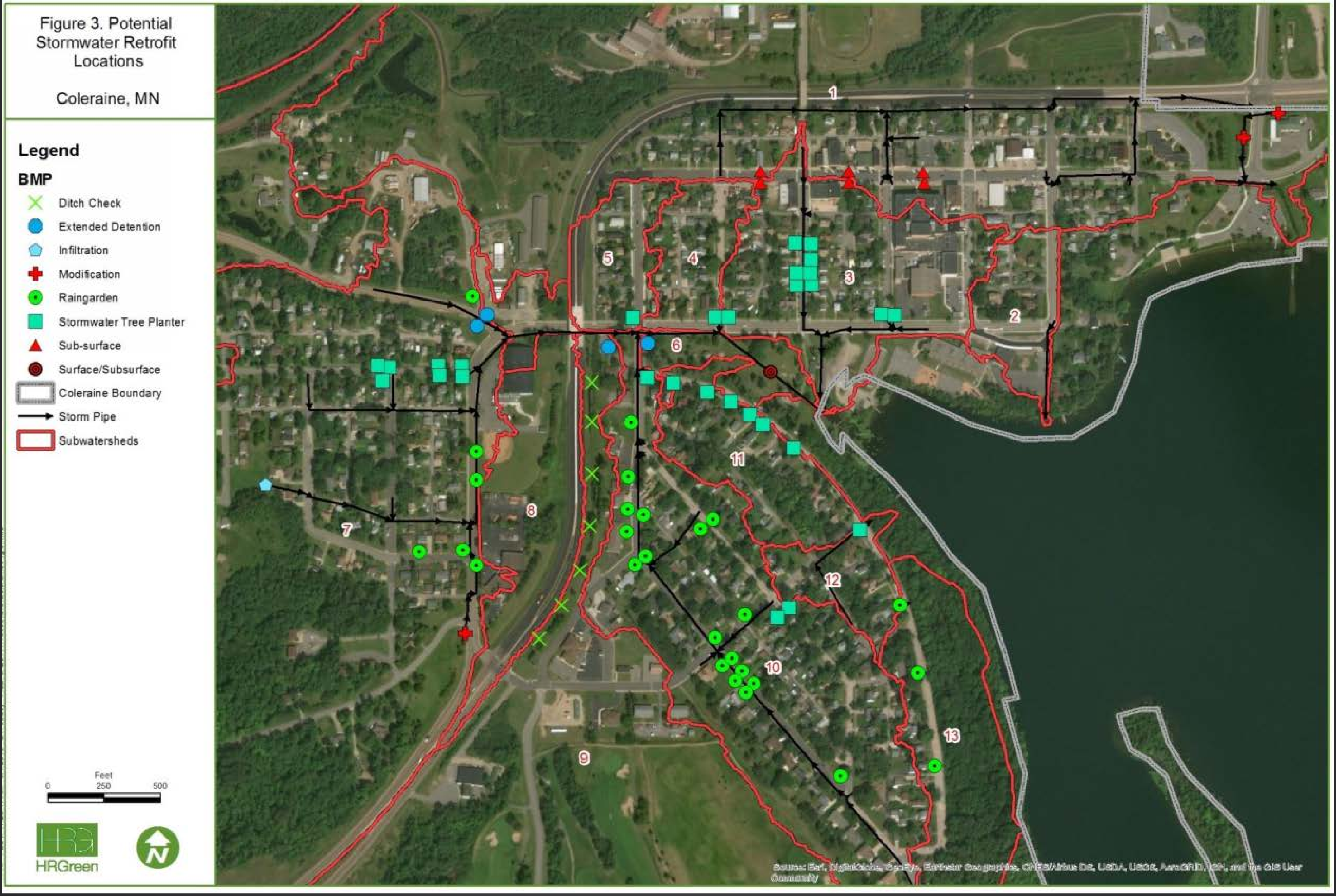
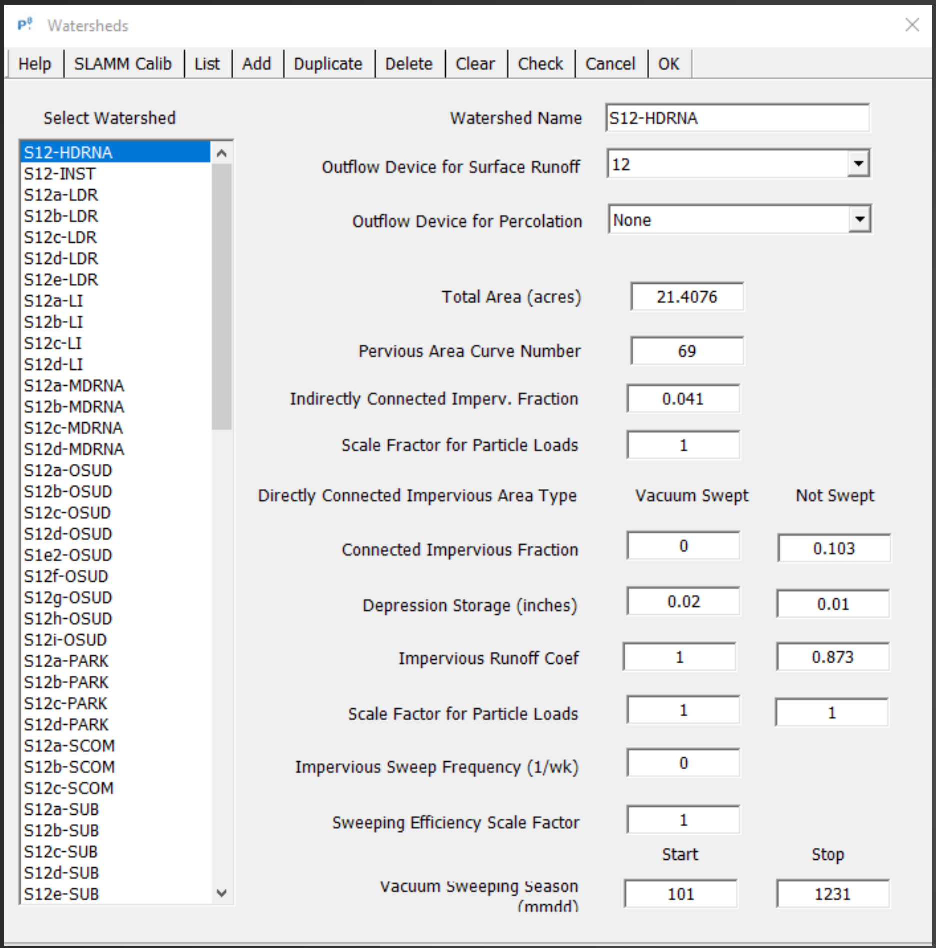
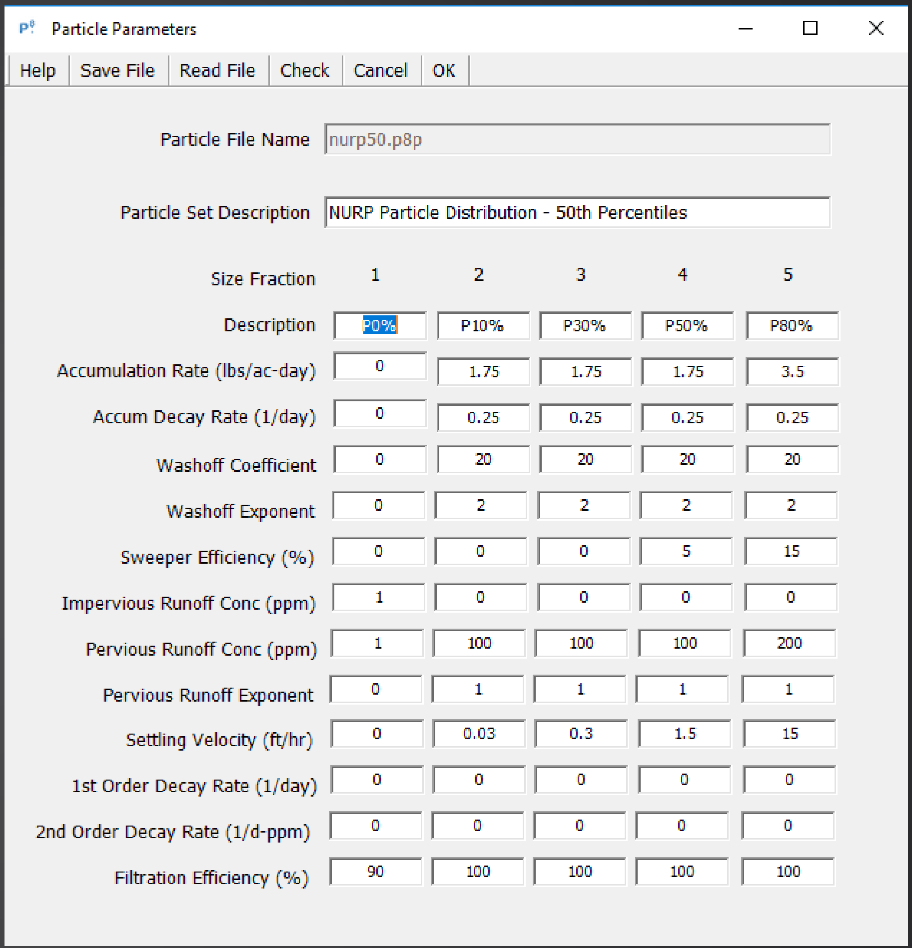


Figure 3. Potential Stormwater Retrofit Locations
Coleraine, MN
Legend
BMP
Ditch Check
Extended Detention
Infiltration
Modification
Raingarden
Stormwater Tree Planter
Sub-surface
Surface/Subsurface
Coleraine Boundary
Storm Pipe
Subwatersheds
Feet
0
250
500
1
2
3
4
5
6
7
8
9
10
11
12
13

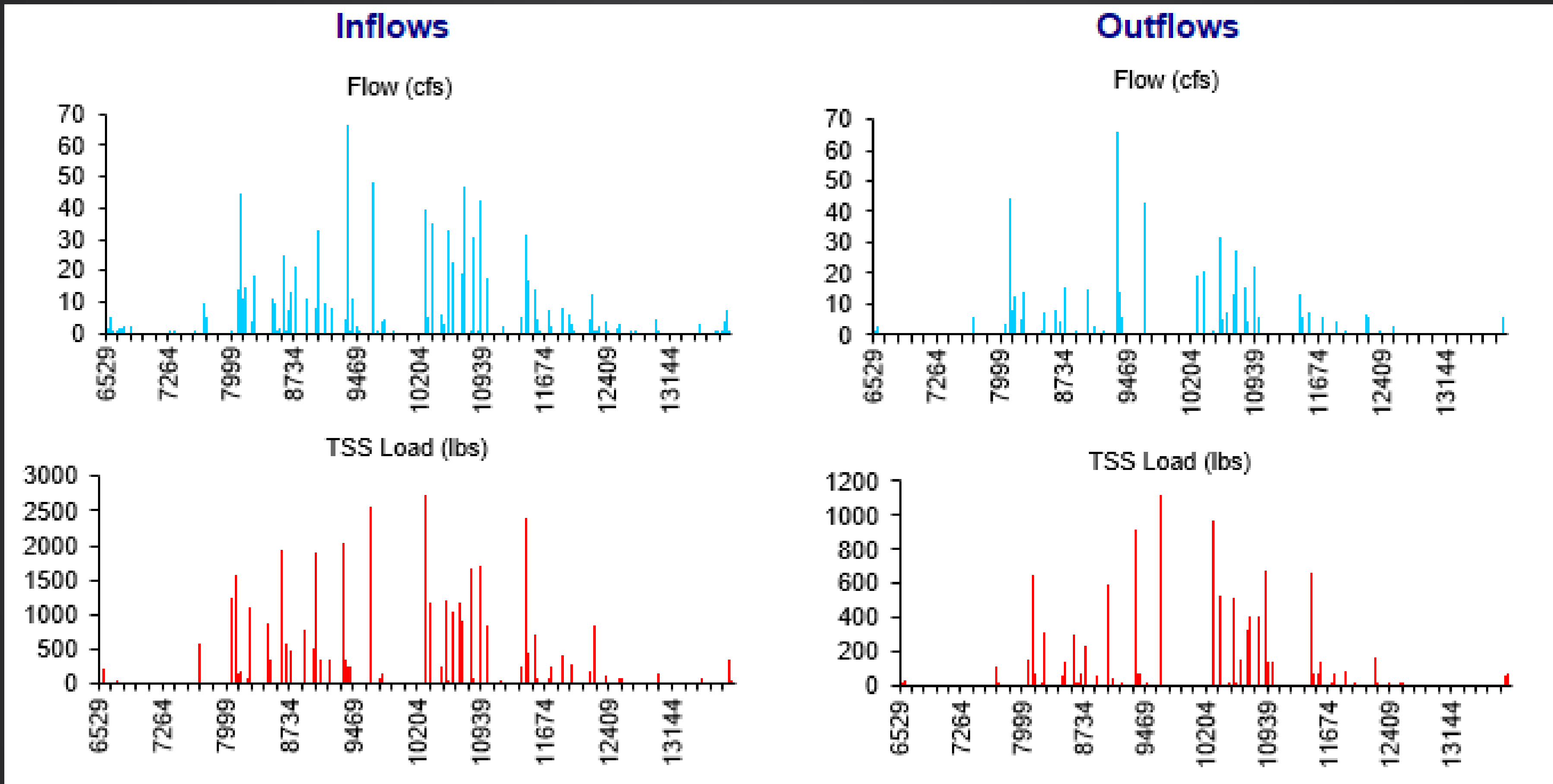
HRGreen


Watersheds
Help | SLAMM Calib | List | Add | Duplicate | Delete | Clear | Check | Cancel | OK
Select Watershed
S12-HDRNA
S12-INST
S12a-LDR
S12b-LDR
S12c-LDR
S12d-LDR
S12e-LDR
S12a-LI
S12b-LI
S12c-LI
S12d-LI
S12a-MDRNA
S12b-MDRNA
S12c-MDRNA
S12d-MDRNA
S12a-OSUD
S12b-OSUD
S12c-OSUD
S12d-OSUD
S1e2-OSUD
S12f-OSUD
S12g-OSUD
S12h-OSUD
S12i-OSUD
S12a-PARK
S12b-PARK
S12c-PARK
S12d-PARK
S12a-SCOM
S12b-SCOM
S12c-SCOM
S12a-SUB
S12b-SUB
S12c-SUB
S12d-SUB
S12e-SUB
Watershed Name S12-HDRNA
Outflow Device for Surface Runoff 12
Outflow Device for Percolation None
Total Area (acres) 21.4076
Pervious Area Curve Number 69
Indirectly Connected Imperv. Fraction 0.041
Scale Fractor for Particle Loads 1
Directly Connected Impervious Area Type Vacuum Swept Not Swept
Connected Impervious Fraction 0 0.103
Depression Storage (inches) 0.02 0.01
Impervious Runoff Coef 1 0.873
Scale Factor for Particle Loads 1 1
Impervious Sweep Frequency (1/wk) 0
Sweeping Efficiency Scale Factor 1
Start Stop
Vacuum Sweeping Season (mmdd) 101 1231

Particle Parameters
Help | Save File | Read File | Check | Cancel | OK
Particle File Name nurp50.p8p
Particle Set Description NURP Particle Distribution - 50th Percentiles
Size Fraction 1 2 3 4 5
Description P0% P10% P30% P50% P80%
Accumulation Rate (lbs/ac-day) 0 1.75 1.75 1.75 3.5
Accum Decay Rate (1/day) 0 0.25 0.25 0.25 0.25
Washoff Coefficient 0 20 20 20 20
Washoff Exponent 0 2 2 2 2
Sweeper Efficiency (%) 0 0 0 5 15
Impervious Runoff Conc (ppm) 1 0 0 0 0
Pervious Runoff Conc (ppm) 1 100 100 100 200
Pervious Runoff Exponent 0 1 1 1 1
Settling Velocity (ft/hr) 0 0.03 0.3 1.5 15
1st Order Decay Rate (1/day) 0 0 0 0 0
2nd Order Decay Rate (1/d-ppm) 0 0 0 0 0
Filtration Efficiency (%) 90 100 100 100 100

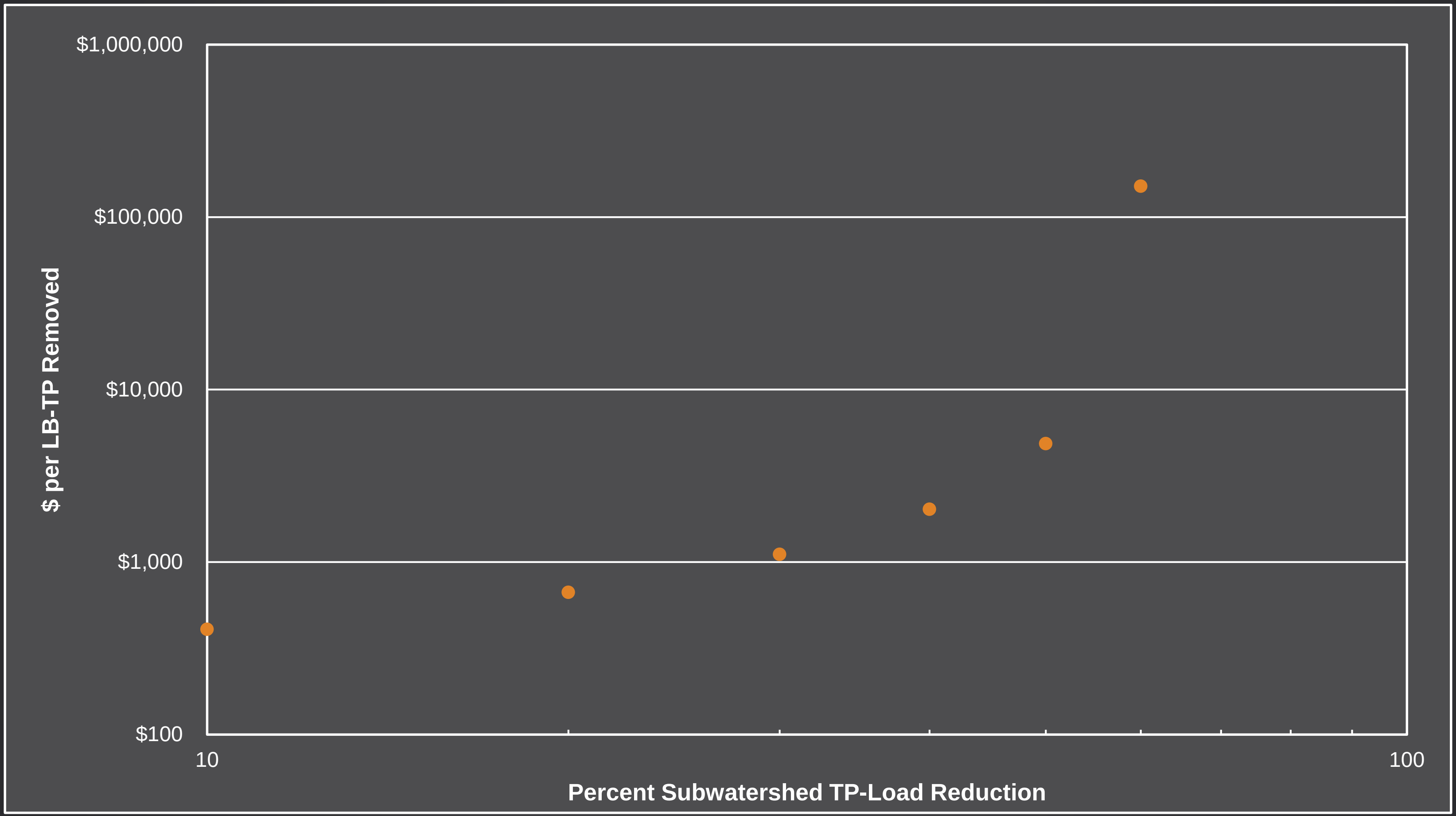
Report: Mass Balance Term: 10 surface outflow Dec: 1

Device: SS Treat-Infil Var: TSS Transpose Copy Help

Term	Flow ac-ft	Load lbs	Conc ppm	Flow cfs	Load lbs/yr
01 watershed inflows	167.9	52198.9	114.4	0.3	62306.0
03 infiltrate	54.8	4209.8	28.3	0.1	5024.9
04 exfiltrate	54.8	0.0		0.1	0.0
05 filtered	0.0	4209.8		0.0	5024.9
06 normal outlet	91.6	15222.7	61.1	0.2	18170.2
07 spillway outlet	21.5	3677.3	62.8	0.0	4389.3
08 sedimen + decay	0.0	29087.4		0.0	34719.5
09 total inflow	167.9	52198.9	114.4	0.3	62306.0
10 surface outflow	113.2	18900.0	61.4	0.2	22559.5
11 groundw outflow	54.8	0.0		0.1	0.0
12 total outflow	167.9	18900.0	41.4	0.3	22559.5
13 total trapped	0.0	33297.2		0.0	39744.5
14 storage increase	0.0	0.0		0.0	0.1
15 mass balance check	0.0	1.6		0.0	2.0
Load Reduction %	0.0	63.8			
Mass Balance Error %	0.0	0.0			


Inflows
Flow (cfs)
70
60
50
40
30
20
10
0
6529
7264
7999
8734
9469
10204
10939
11674
12409
13144
TSS Load (lbs)
3000
2500
2000
1500
1000
500
0
Outflows
Flow (cfs)
TSS Load (lbs)
1200
1000
800
600
400
200
0

Incremental Cost of Treatment



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Within Subwatershed Value by Strategy

Alternative	Install Cost	Annual O&M	D.A. Load[1] (TP-LB/YR)[2]	TP Removed (%/YR)[2]	TP Removed (LB/YR)[2]	30-Year Treatment Value ($/LB/YR)[2]
Permeable Parking[3]	$140,400	$200	10.6	78	9.8	$14,347
Stormwater Planters[4]	$45,745	$250	10.6	45	4.8	$9,582
Sub-sidewalk Storage[5]	$195,000	$250	10.6	42	4.4	$44,375
Raingardens[2]	$15,000	$250	8.3	34	2.8	$5,446
Stormwater Planter Boxes[3]	$42,000	$250	4.2	56	2.3	$18,370
Infiltration Trench[4]	$2,500	$0	2.1	79	1.3	$1,923
H169 Detention[5]	$135,000	$750	13.4	59	7.5	$8,500
Extended Detention[2]	$225,000	$750	67	46	31	$2,299

Between Subwatershed Value by Strategy

Subwatershed	BMP	Install Cost	TP lb/yr	30-yr TP value	Values Addressed: Manage Stormwater	Surface WQ	Enhance Public Space	Infrastr. Integration
7	Infiltration Trench	$2,500	1.3	$1,923	Y	Y	N	N
6	Extended Detention	$105,000	46	$2,299	Y	Y	Y	Y
10	Raingardens	$24,000	5.8	$4,181	Y	Y	Y	Y
13	Raingardens	$9,000	2.1	$4,406	Y	Y	Y	Y
7	Raingardens	$15,000	2.8	$5,446	Y	Y	Y	Y
11	Stormwater Planters	$14,000	1.8	$7,917	Y	Y	Y	Y
7	H169 Detention	$63,000	7.5	$8,500	Y	Y	Y	Y
1	Stormwater Planters	$45,745	4.8	$9,582	Y	Y	Y	Y
12	Stormwater Planters	$7,000	0.7	$10,360	Y	Y	Y	Y
3	Stormwater Planters	$49,000	4.6	$10,707	Y	Y	Y	Y
1	Permeable Paving	$140,400	9.8	$14,347	Y	Y	N	Y
7	Stormwater Planters	$42,000	2.3	$18,370	Y	Y	Y	Y
1	Sub-Sidewalk Storage	$195,000	4.4	$44,375	Y	Y	N	Y

Contact Information

HRGreen

Shawn Tracy
763.248.0134
stracy@hrgreen.com

Greg Panza
720.602.4939
gpanza@hrgreen.com

Reimagining a Denver Landmark
City Park Golf Course

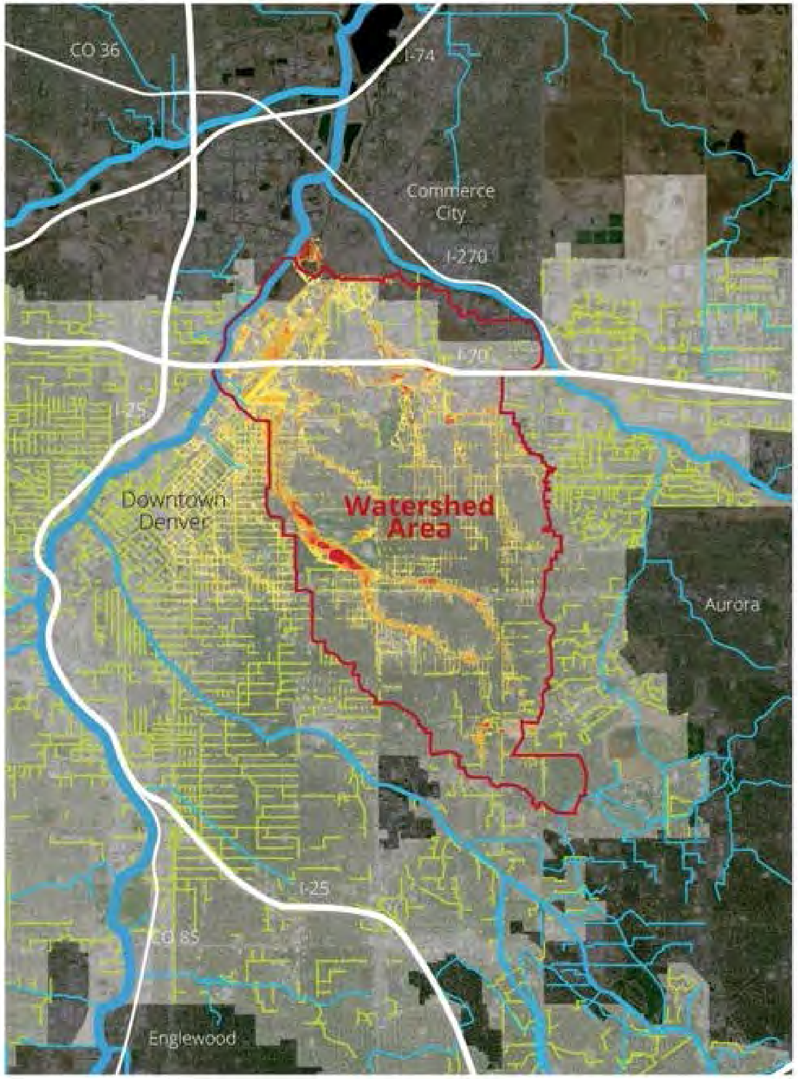
CASFM

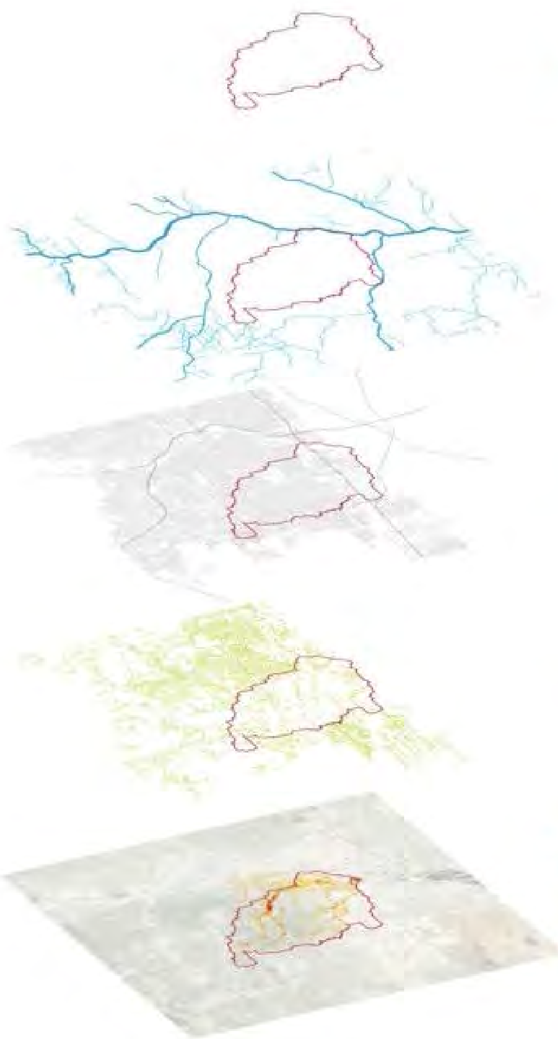
September 25, 2019

Matrix

MARTIN/MARTIN
CONSULTING ENGINEERS

Background





15.25 SQUARE MILE COLLECTION AREA

\+

NO NATURAL DRAINAGE WAY

\+

DENSE URBAN FABRIC

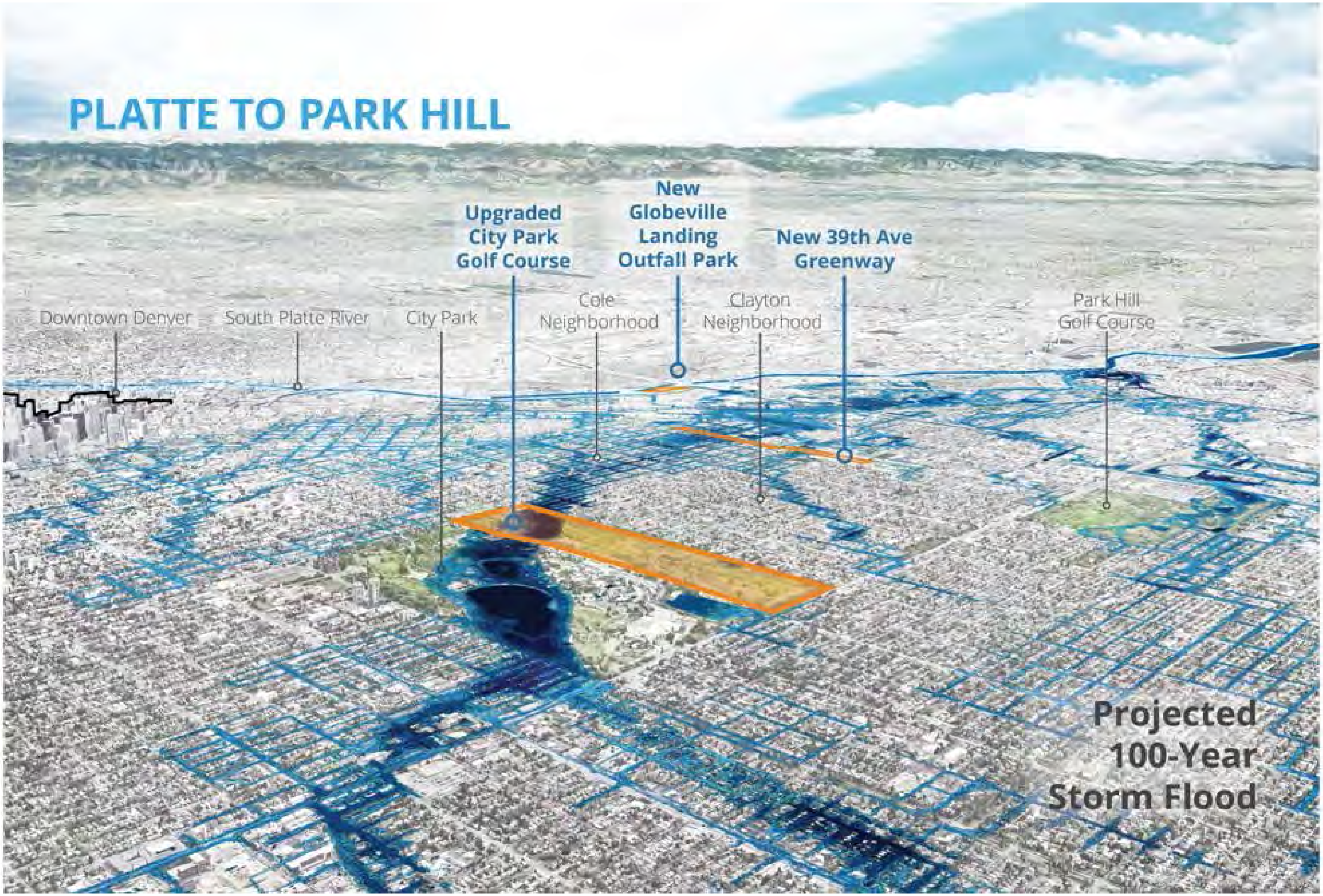
\+

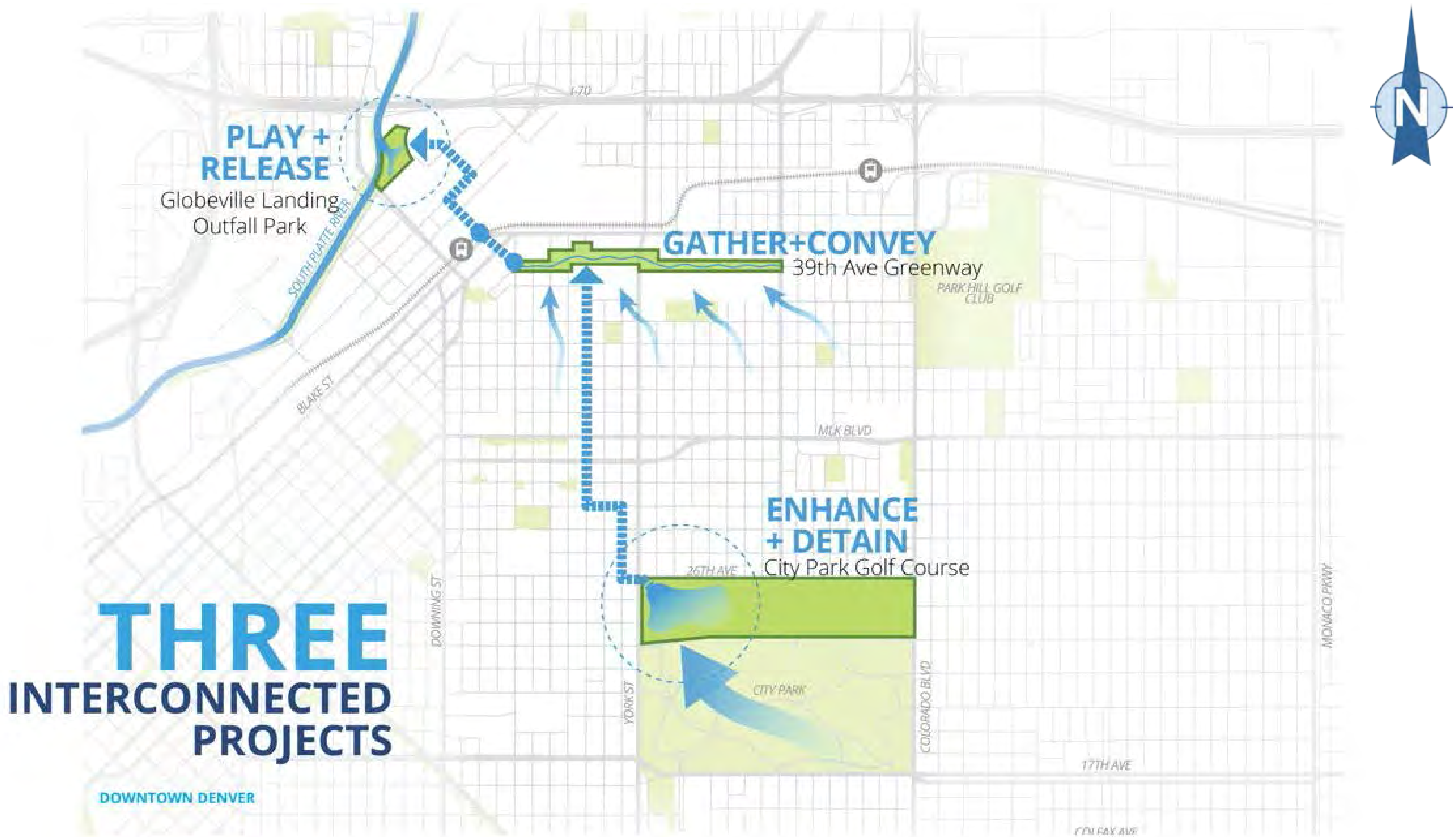
AGING AND UNDERSIZED PIPES

=

SIGNIFICANT FLOODING CHALLENGES

Background


PLATTE TO PARK HILL
New Globeville Landing Outfall Park
Upgraded City Park Golf Course
New 39th Ave Greenway
Downtown Denver
South Platte River
City Park
Cole Neighborhood
Clayton Neighborhood
Park Hill Golf Course
Projected 100-Year Storm Flood


PLAY + RELEASE
Globeville Landing Outfall Park
SOUTH PLATTE RIVER
I-70
GATHER+CONVEY
39th Ave Greenway
PARK HILL GOLF CLUB
BLAKE ST
MLK BLVD
ENHANCE + DETAIN
City Park Golf Course
26TH AVE
DOWNING ST
YORK ST
CITY PARK
COLORADO BLVD
MONACO PKWY
17TH AVE
COLFAX AVE
THREE
INTERCONNECTED
PROJECTS
DOWNTOWN DENVER
N

A Community Approach

AN ENGAGED CITY

THE CLIENT
City & County of Denver

- Mayor's Office
- Parks and Recreation
- Public Works
- Community Planning and Development

EXPERTISE

- Landscape Architects
- Civil Engineers
- Urban Designers
- Geotech Engineers
- Planners
- Public Outreach
- Drainage Engineers

KEY PARTNERS

- Colorado Department of Transportation
- Urban Drainage & Flood Control District
- Regional Transportation District
- US Army Corps of Engineers

To date, there have been

250+ Public and stakeholder meetings

PROBLEM DEFINITION
Summer 2015
- 1 Public & Community Meetings
- 2 Design Workgroups
- 15 Small Groups & 1-on-1 Meetings

IDENTIFICATION OF ALTERNATIVES
Fall 2015
- 2 Public & Community Meetings
- 1 Design Workgroups
- 21 Small Groups & 1-on-1 Meetings

ANALYSIS & FEASIBILITY
Winter 2015
- 2 Public & Community Meetings
- 2 Design Workgroups
- 25 Small Groups & 1-on-1 Meetings

PREFERRED ALTERNATIVES
Spring 2016
- 1 Public & Community Meetings
- 2 Design Workgroups
- 19 Small Groups & 1-on-1 Meetings

PRELIMINARY DESIGN
Summer 2016
- 4 Public & Community Meetings
- 6 Design Workgroups
- 32 Small Groups & 1-on-1 Meetings

FINAL DESIGN & CONSTRUCTION
Start Fall 2016
- 8 Public & Community Meetings
- 8 Design Workgroups
- 47 Small Groups & 1-on-1 Meetings

STRATEGIES FOR PUBLIC ENGAGEMENT

STRATEGY

- Public Open Houses
- Public Presentations
- Site Tours
- Neighborhood Meetings
- Design Work Group Meetings
- Stakeholder Presentations
- Planning Charrettes
- One-on-One Meetings

STAKEHOLDER

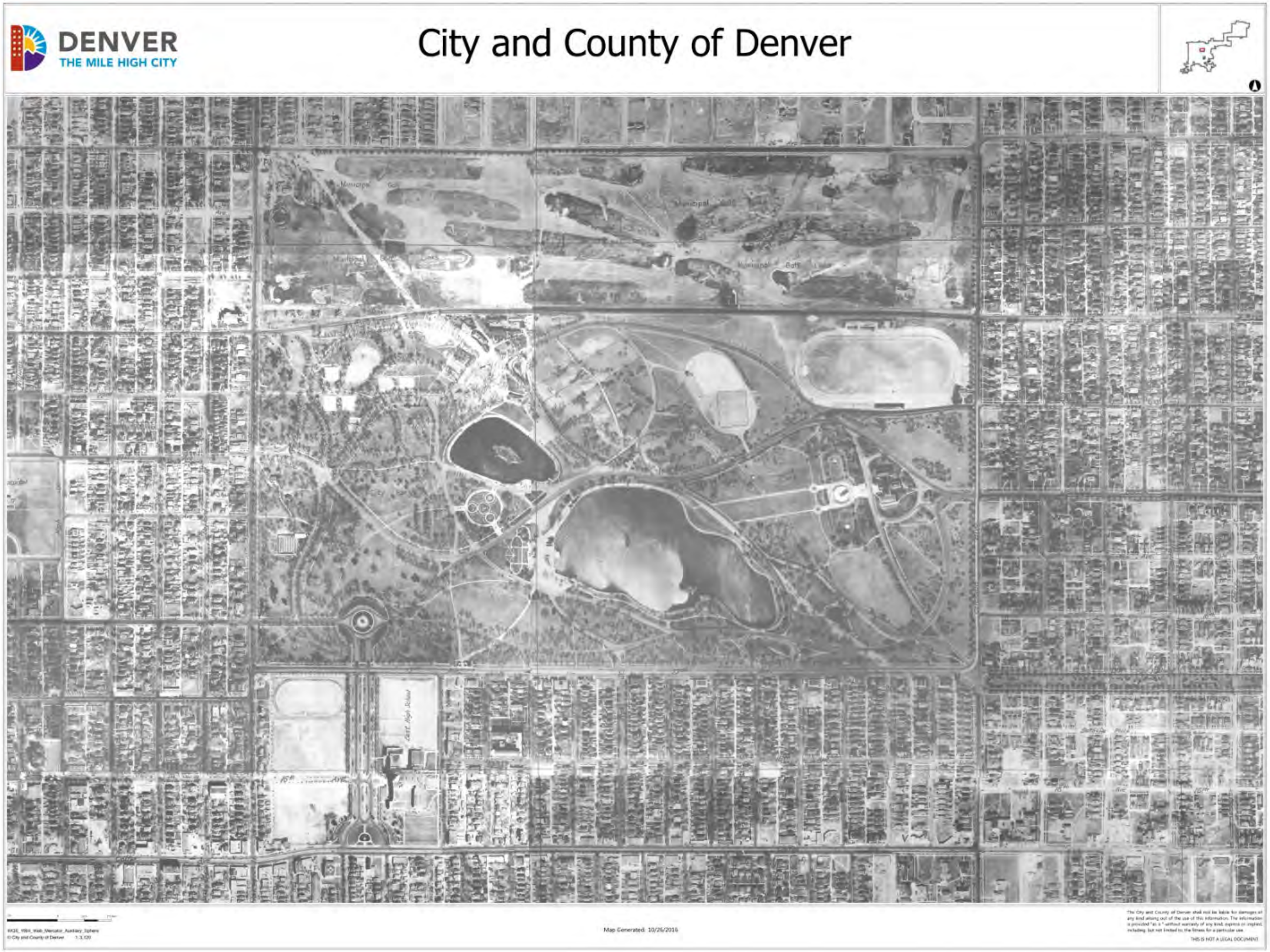
- Government Agencies
- Media
- Schools
- Special Interest Groups
- Local Leaders
- Industry Experts
- Business Owners
- Property Owners
- Neighborhood Residents
- Non-English Speakers
- General Public



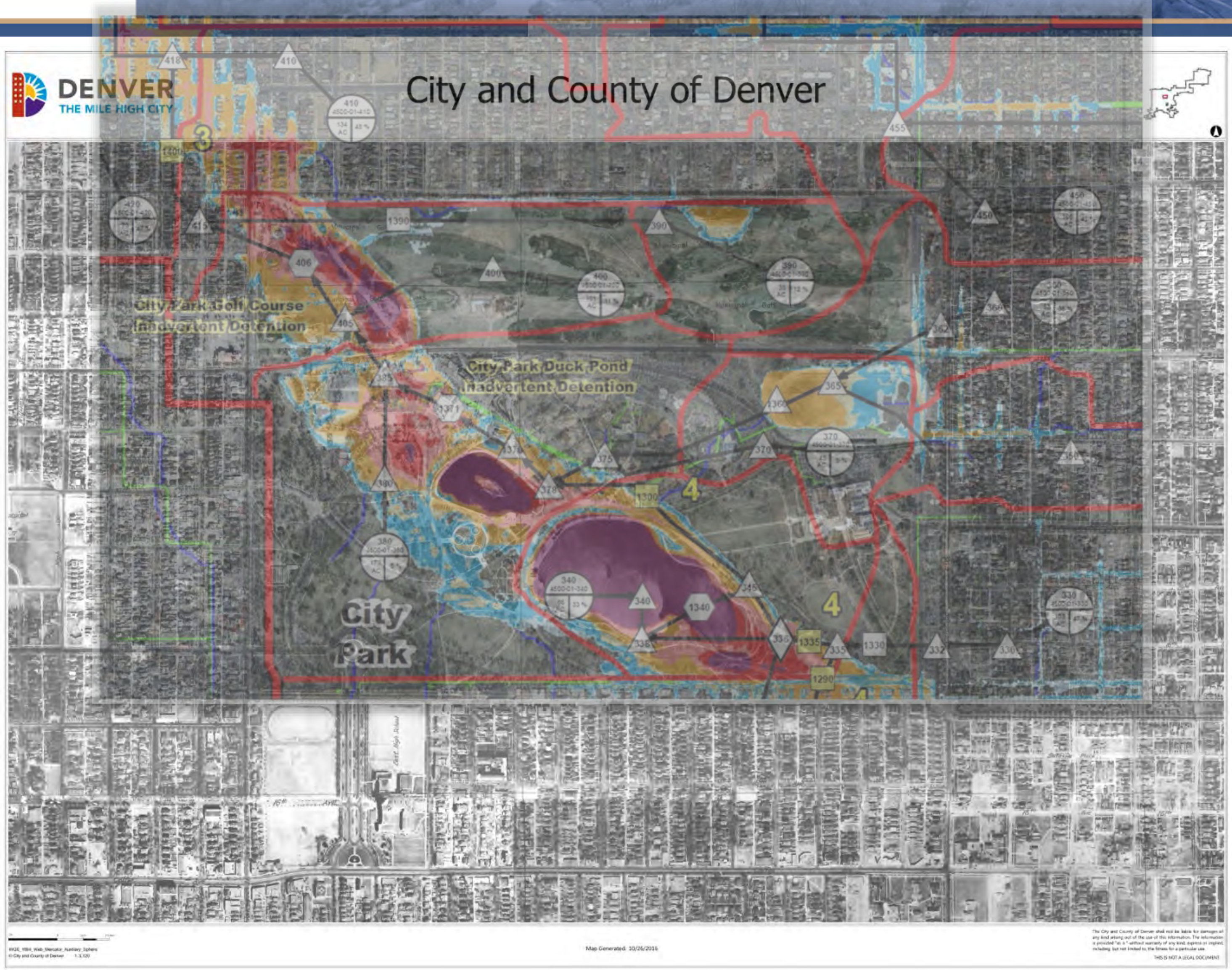


Community Goals

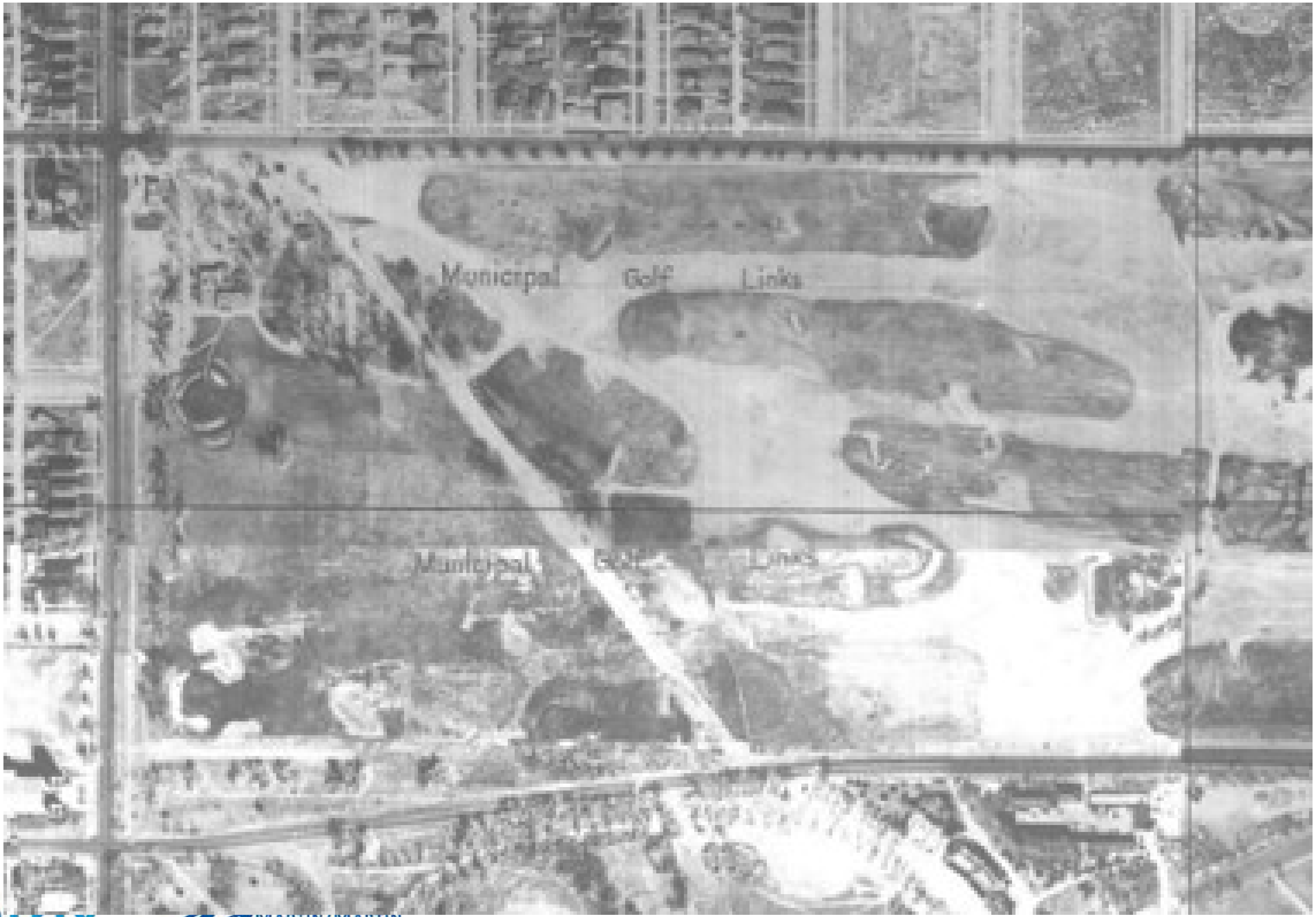
Preliminary design



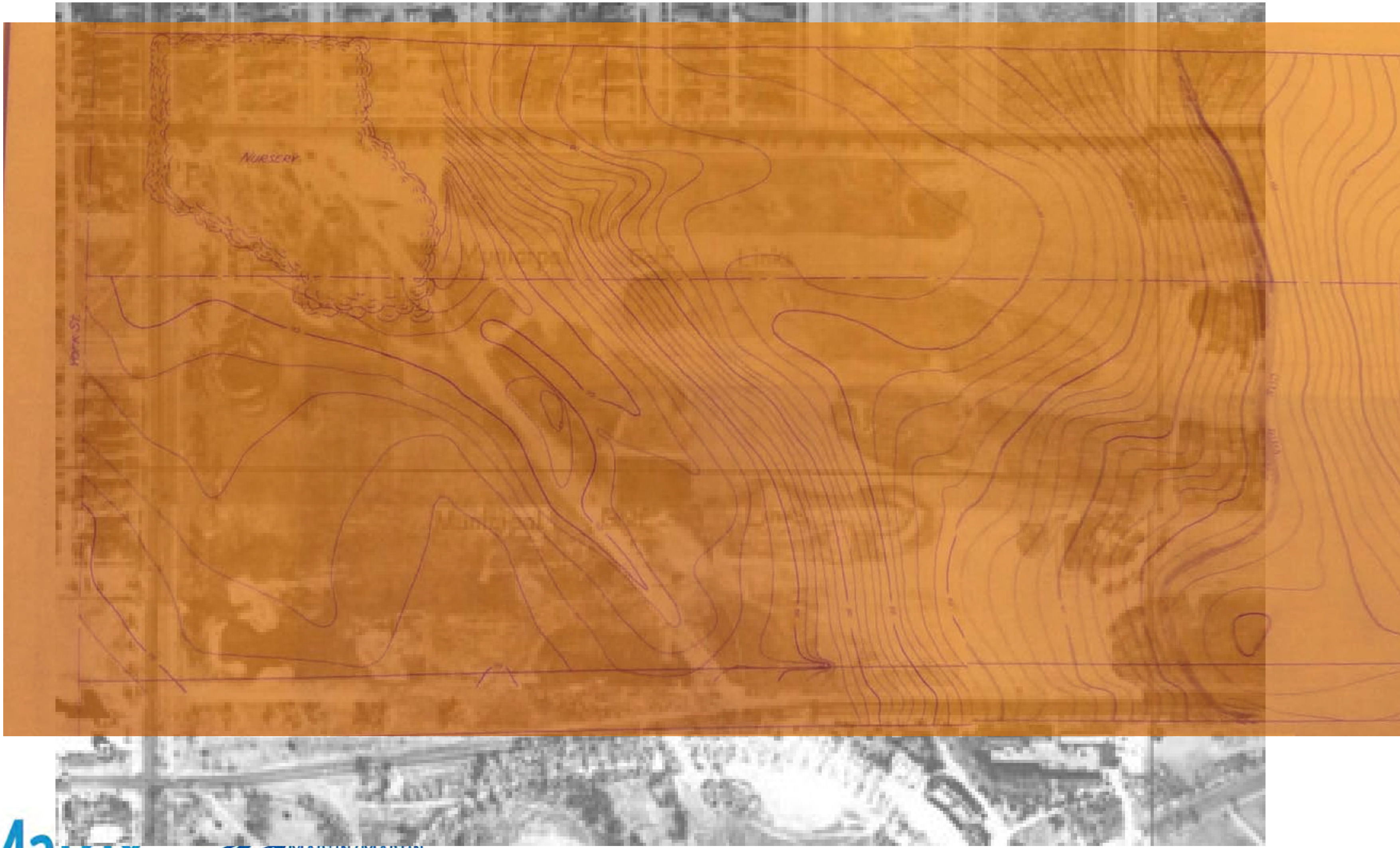
Preliminary design



Preliminary design



Preliminary design



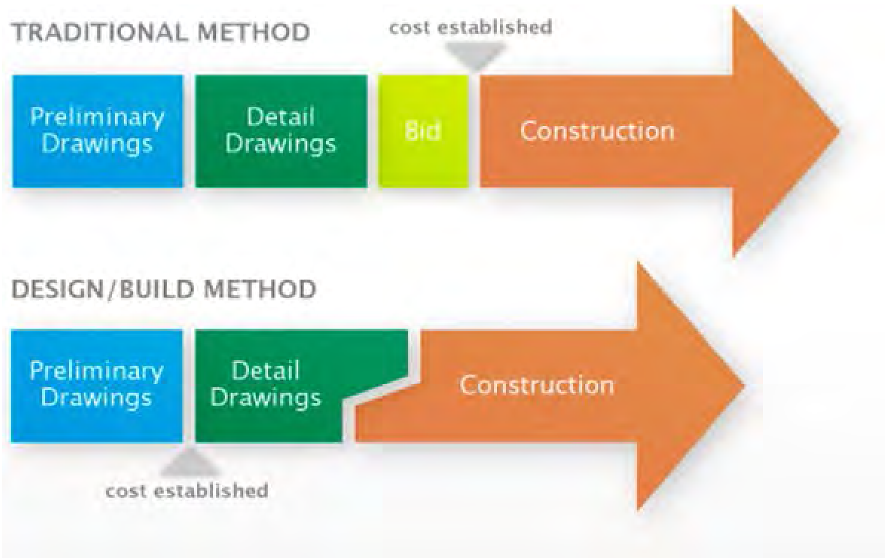
Constraints

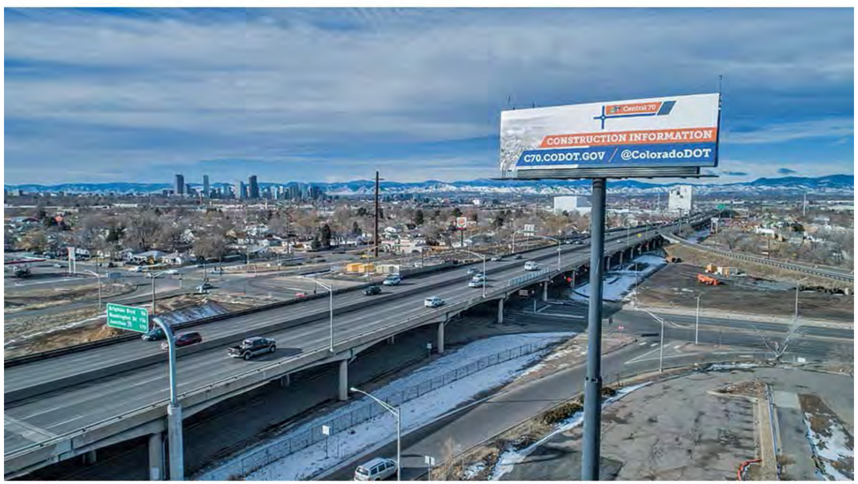
- Groundwater
- Earthwork/Soil Suitability
- Hydrology
- Embankment
- Golf
- Trees
- Views
- Historic
- Schedule

Preliminary design

Design Build Procurement

- Why Design Build?
  - Schedule
  - Innovation
  - One point of Contact





Technical requirements

- 100-yr Storm detention
  - Q_{max}= 3,275 cfs (227 ac-ft)
  - 8hr max detention time
  - No adverse effects to golf in storm events
  - Integrated into golf course
- 10-yr storm impacts
- Mile High Flood District Maintenance Eligibility
- Water Quality – residence time
- Trash Vaults - offline

Final Design

- Design Overview
- Designing to the TR's
- Unique Design Features
- Construction Phasing
- 2D Model
- Lessons Learned

Design Build Team

SAUNDERS

JNS JOHNSON NATHAN STROHE

Hale Irwin GOLF DESIGN

iConGolf STUDIO

MARTIN / MARTIN CONSULTING ENGINEERS

SSG MEP

JFS&A JF SATO AND ASSOCIATES

ASPEN

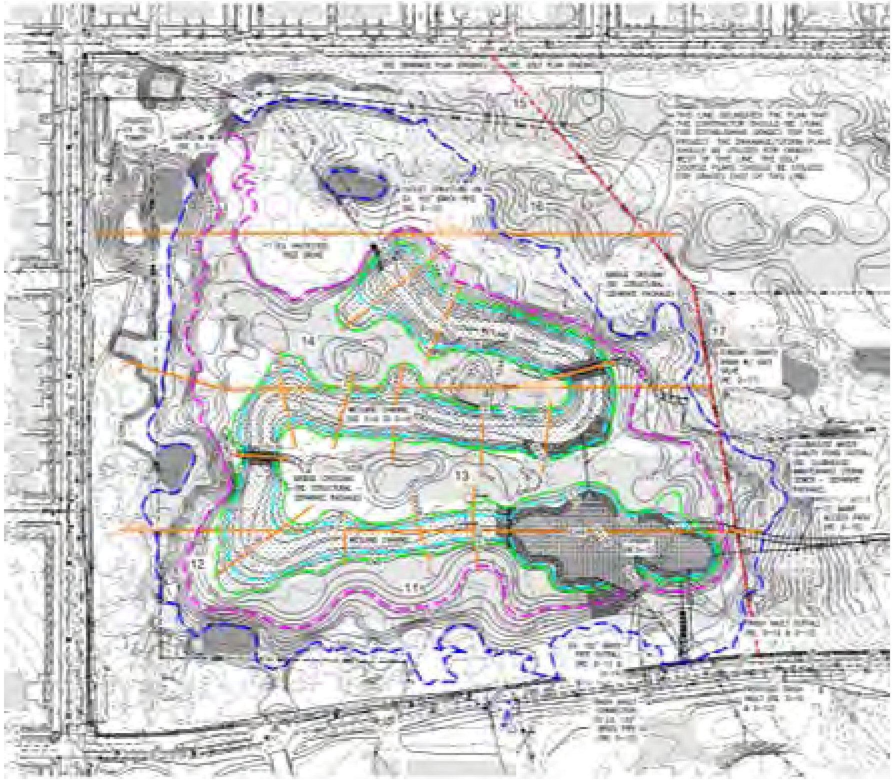
LRDG

shrewsberry

ZOELLER

digstudio

Design Overview



Meeting the Technical Requirements

CPGC SWMM Model Comparison Table			Return Period		
			WQ	10-Year	100-Year
RFP	Qin	(cfs)	411	825	4398
	Qout	(cfs)	294	419	3725
	Volume	(ac-ft)	21	73	227
	WSEL	(ft)	-	5241.1	5248.0
Design	Qin	(cfs)	411	825	4398
	Qout	(cfs)	276	419	3724
	Volume	(ac-ft)	23.9	76.9	213.5
	WSEL	(ft)	5239.1	5243.6	5251.0

RFP Criteria Comparison		RFP	Design
Non-Jurisdictional Dam Surface Area **	(acres)	20	14.2
Non-Jurisdictional Dam Volume Above Natural Grade **	(acre-ft)	100	8.4
Non-Jurisdictional Dam Berm Height **	(ft)	10.0	0.6
Maximum Embankment Slope	(h:v)	4:1	4:1
Wetland Channel Length	(ft)	2000	2018
Max Wetland Channel Slope	(%)	0.3% - 0.7%	0.3%
Max Wetland Channel Velocity (Normal Depth) *	(ft/s)	3.5	3.5
Residence Time *	(min)	7-10	9.6
Maximum Forebay Depth	(ft)	4.0	3.0
Minimum Forebay Depth	(ft)	3.0	3.0
Forebay Sediment Depth	(ft)	1.5	1.5
Forebay Footprint	(acres)	1.0	1.2

*MAXIMUM WETLAND CHANNEL VELOCITY AND RESIDENCE TIME CALCULATED BASED ON NORMAL DEPTH CONDITIONS WITHIN THE TYPICAL WETLAND CHANNEL SECTION.

**MAXIMUM NON-JURISDICTIONAL DAM CRITERIA PER STATE OF COLORADO RULES AND REGULATIONS FOR DAM SAFETY AND DAM CONSTRUCTION. THE DAM CRITERIA IS MEASURED RELATIVE TO THE OVERFLOW WEIR CREST.

NOTES:

1. CONTOURS SHOWN ARE ONE FOOT INTERVAL. EXISTING TOPOGRAPHY SHOWN WAS PROVIDED BY SAUNDERS CONSTRUCTION COMPANY.

2. HYDROLOGIC ANALYSIS IS BASED ON THE TWO BASINS DRAINAGE PLAN SWMM MODELING PROVIDED BY MATRIX DESIGN GROUP ON SEPTEMBER 28, 2017. THE SWMM MODELING PROVIDED BY MATRIX IS THE BASIS FOR RFP ADDENDUM 3 AND WAS ADAPTED FROM THE MATT UDSWMM MODEL WITH CORRECTIONS BY ENGINUITY. PROPOSED POND ANALYSIS IS OUTLINED IN THE CITY PARK GOLF COURSE – REGIONAL DETENTION POND FINAL DRAINAGE REPORT, BY MARTIN/MARTIN, INC., DATED FEBRUARY 12, 2018.

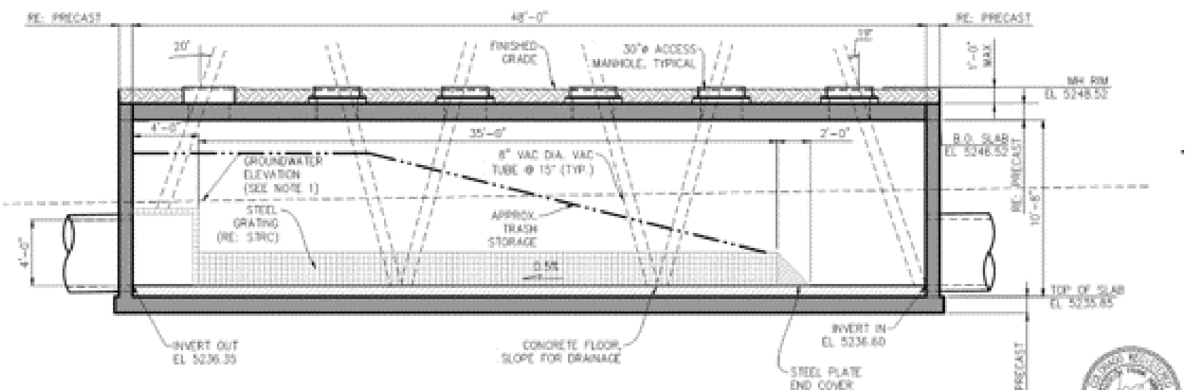
3. THE ADDENDUM 3, SECTION 12.2.4.11, AREA SPECIFIC DRAINAGE REQUIREMENTS THAT IDENTIFY PLAYABLE GOLF FACILITY CRITERIA, ARE SUMMARIZED AS FOLLOWS:

   3.1. NO PONDING GREATER THAN EIGHT HOURS OR ADVERSE IMPACTS SHALL OCCUR DURING THE 10-YEAR OR 100-YEAR RECURRENCE INTERVAL STORM EVENTS, ON ANY NON-GREEN PLAYABLE GOLF FACILITIES (FAIRWAYS, TEE BOXES, BUNKERS, CHIPPING AREA, PUTTING PRACTICE AREA, CART PATHS, GOLF CART BRIDGES, FIRST TEE FACILITIES, ETC.). ADVERSE IMPACTS ARE DEFINED AS EROSION, DAMAGE TO TURF, WASHING AWAY OF MATERIAL, OR ANY OTHER DAMAGE THAT WOULD REQUIRE MORE THAN MINIMAL MAINTENANCE. CONSIDERATIONS TO DETERMINE ADVERSE IMPACTS SHOULD INCLUDE DEPTH OF WATER, VELOCITY OF FLOW, AND TYPE OF FACILITY BEING INUNDATED.

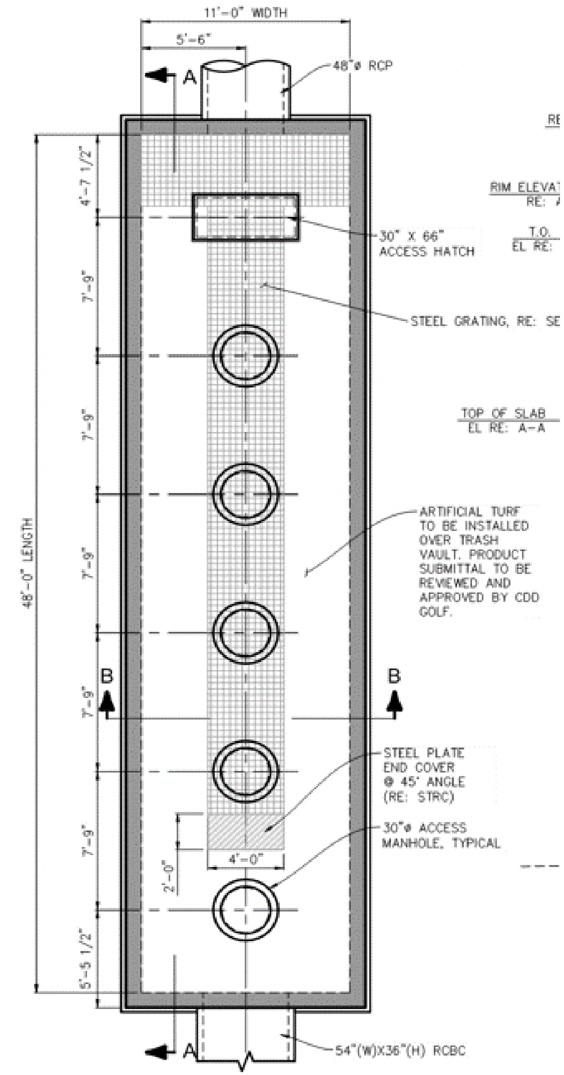
   3.2. GREENS SHALL NOT BE INUNDATED DURING THE 10-YEAR NOR THE 100-YEAR EVENT.

4. GROUNDWATER SURFACE ELEVATIONS ARE BASED ON DATA FROM THE INTERIM DRAFT GEOTECHNICAL INVESTIGATION REPORT. CITY PARK INVESTIGATION, BY YEH AND ASSOCIATES, INC. JANUARY 11, 2017.

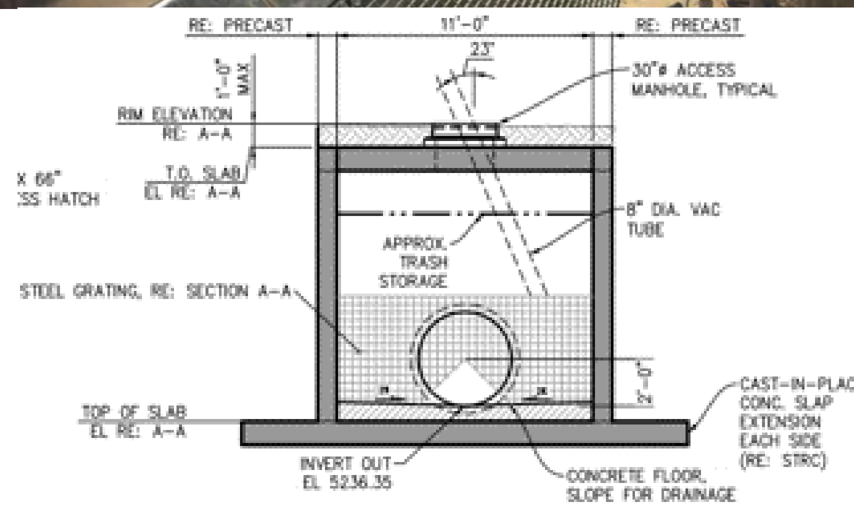
Trash Vault



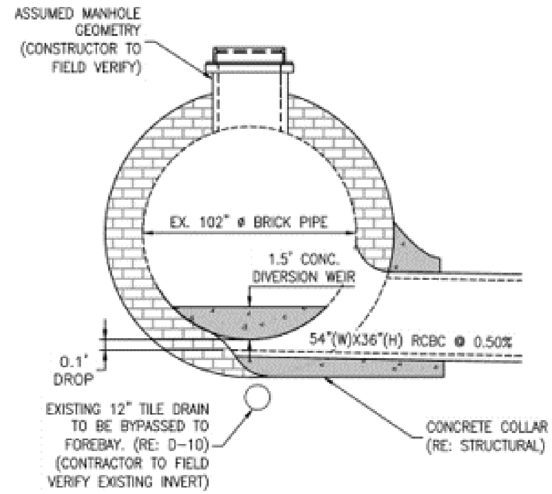
TRASH VAULT SECTION A-A
SCALE: ¼"=1.0'



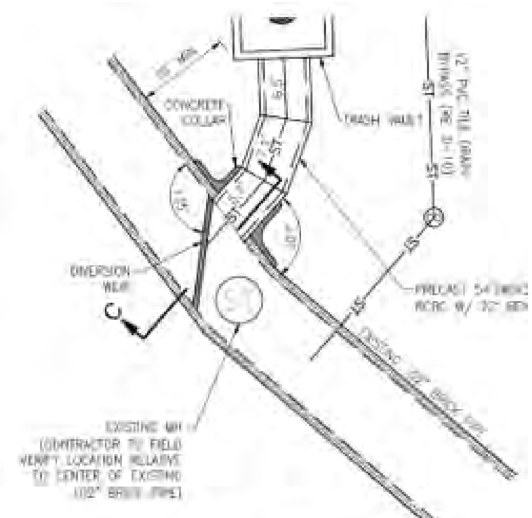
TRASH VAULT PLAN
SCALE: ¼"=1.0'


RE: PRECAST
11'-0"
RE: PRECAST
23"
1'-0" MAX
30"ø ACCESS MANHOLE, TYPICAL
RIM ELEVATION RE: A-A
X 66"
SS HATCH
T.O. SLAB EL RE: A-A
8" DIA. VAC TUBE
APPROX. TRASH STORAGE
STEEL GRATING, RE: SECTION A-A
2'-0"
TOP OF SLAB EL RE: A-A
CAST-IN-PLACE CONC. SLAP EXTENSION EACH SIDE (RE: STRC)
INVERT OUT EL 5236.35
CONCRETE FLOOR, SLOPE FOR DRAINAGE

Trash Vault Diversion



BRICK PIPE CONNECTION – SECTION C
N.T.S



TRASH VAULT DIVERSION – PLAN
SCALE 1"=10'

Construction Phasing

Construction Phasing

Lessons learned

- Trash Grate diversion
  - Maximize grate area
- Neighboring projects
- Balancing stakeholder goals
  - Communication
- Phasing