Holistic Watershed Management for Existing and Future Land Use Development Activities: Opportunities for Action for Local Decision Makers

a.k.a. Flow Duration Curve (FDC) Project

Prepared for EPA Region 1

In Cooperation with

Taunton Watershed Municipalities and other project participants

Prepared by

Paradigm Environmental

Great Lakes Environmental Center

Waterstone Engineering

JLBPlanning

A Technical Direct Assistance Project funded by the USEPA Southeast New England Program (SNEP)

WISHING THE BEST FOR PEOPLE IMPACTED BY HURRICANE IAN

“If there is magic on this planet, it is contained in water.” — Loren Eiseley

- The ***Next-Generation Watershed Management Practices for Conservation Development*** project is about envisioning a ***different future of watershed management***.

- This project examines the use of ***Conservation Development Practices*** to achieve a ***Watershed Protection Standard*** that maintains ***predevelopment hydrology, predevelopment nutrient load***, and ***landscape resiliency.***

WATER SMART PLAYGROUND, BEFORE AND AFTER, BOERUM HILL PUBLIC SCHOOL, BROOKLYN, NY

AGENDA

10:00-10:05 | Introduction

10:05-10:25 | Project Background and Objectives
Ray Cody, EPA Region 1, Boston

10:25–10:55 | Technical Introduction and Implication for the Use of FDCs for Stormwater Management
Mark Voorhees, EPA Region 1, Boston

10:55-11:00 | Break

11:00-11:45 | Modeling and Development of the FDC: Phases 1 and 2
Khalid Alvi, Paradigm, Inc.

11:45-12:40 | Application of Next Generation Stormwater Management at the Site-Scale
Robert Roseen, Waterstone Engineering

12:40-12:45 | Break

12:45- 1:05 | Recommendations for Municipal Bylaws
Julie LaBranche, Planning Consultant

1:05-1:15 | Outreach Materials
Michelle Vuto, EPA Region 1, Boston

1:15-1:50 | Discussion / Q&A

1:50–2:00 | Wrap up and closing / Next Steps

A Direct Assistance, Applied Research Project in the Taunton River Watershed. 2 phases:

- FDC1 – Modeling and Development of Watershed-scale FDC
- FDC2 – Application of FDC at Watershed, Site and Stormwater Control Measure (SCM)-scales + Municipal Outreach and Coordination

FDC Project Objectives

- exploration of the use and feasibility of flow duration curves (FDC) for informing next-generation development practices – termed, "Conservation Development" - for achieving a predevelopment hydrological condition for new development and redevelopment (nD/rD);
- mitigating the effect of cumulative increases in impervious cover (IC) across the watershed; and
- communicating the FDC as a concept using real world nD/rD examples.

Executive Summary

Incorporating next-generation Conservation Development Practices (incl. SCM) may achieve resilient predevelopment hydrology with little to no net increase in nutrient loads. Currently, existing practices and standards do not achieve this outcome.

Today's results indicate such CD practices may be implemented economically and practicably as compared to existing practices, all things considered (O&M, long-term offsets, etc.).

The Problem with Impervious Cover (IC) - Relationship between IC and Surface Runoff

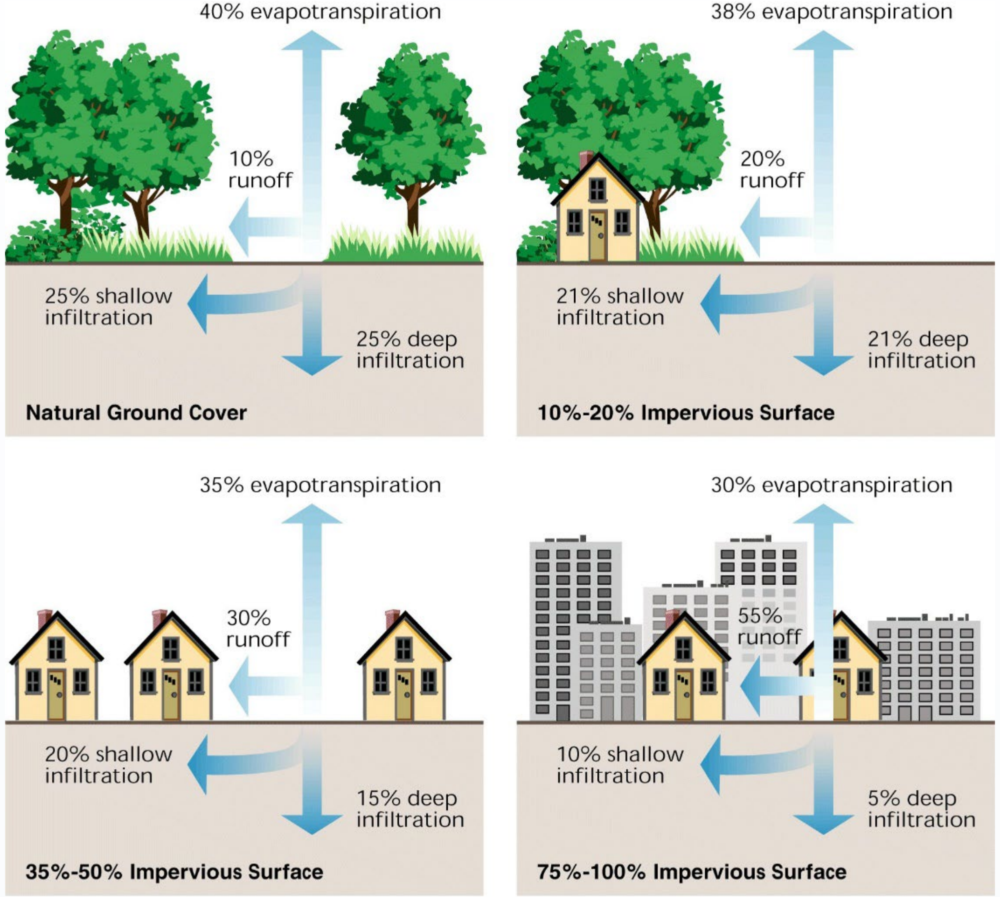


Fig. 3.21 -- Relationship between impervious cover and surface runoff. Impervious cover in a watershed results in increased surface runoff. As little as 10 percent impervious cover in a watershed can result in stream degradation.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
By the Federal Interagency Stream Restoration Working Group (FISRWG) (15 Federal agencies of the U.S.)

Reference: Federal Interagency Stream Corridor Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. PB98-158348LUW.

Flooding

Tisbury, Massachusetts
Refer to https://www.epa.gov/snep/tisbury-ma-impervious-cover-disconnection-icd-project-integrated-stormwater-management

Drought

Bloomberg
US Edition

Sign In | Subscribe

● Live Now | Markets | Industries | Technology | Politics | Wealth | Pursuits | Opinion | Businessweek | Equality | **Green** | CityLab | Crypto | More

Green
Weather & Science

N.Y. to Maine Hit by Rare Drought Killing Crops, Sparking Fires

US Northeast farmers are warning of a 'desperate time'

The Charles River in Massachusetts *Photographer: Brian K. Sullivan/Bloomberg*

By Will Wade and Elizabeth Elkin
September 8, 2022, 11:00 AM EDT

Listen to this article
▶ 5:39

● LIVE ON BLOOMBERG
Watch Live TV >
Listen to Live Radio >

It's barely September, but crops are withering and brown leaves carpet the ground. Forests are bursting into flames. An iconic river is, in some places, little more than a mud-choked stream.

Water Quality

Reference: Mystic River, BostonGlobe.com, July 30, 2017

Some Terms and Concepts

Conservation Development Practices – next-generation new development and redevelopment (nD/rD) site-scale practices, including SCM and practices that promote evapotranspiration (ET) (e.g., green roof), ‘conserve’ / ‘preserve’ - even restore - the hydrological and ecological condition / health of land; and mitigate, if not reverse the impact of cumulative increases in IC across the watershed / landscape.

Soils. The United States Department of Agriculture (USDA) developed a simple classification schema for soils. According to this schema, **soils may be classified as A, B, C or D**. As a general rule, the infiltration rate (related: permeability, hydraulic conductivity) decreases from A to D.

That is, **A soils (sands) have the highest infiltration rate capacity** and **D soils (clays) have the lowest**.

For more information, refer to the USDA National Resources Conservation Service's (NRCS) May 2007 publication entitled "Part 630 Hydrology National Engineering Handbook, Chapter 7: Hydrologic Soil Groups" available here: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba

Hydrologic Response Unit (HRU).

Hydrologists need a way to express stormwater runoff that occurs over large areas of land composed of differing land types (e.g., residential, commercial, industrial, forest) having different soil types (e.g., A, B, C, D) and characteristics (e.g., percent slope; percent impervious cover (%IC), etc.). Hydrologists use the hydrologic response unit – or HRU.

The combinations of these different land characteristics result in multiple unique HRUs. E.g.,

Examples: Land Use - Soil - Slope - Land Cover (pervious or impervious)

1. Residential - A soil – 5% slope – impervious;
2. Residential - B soil – 10% slope – pervious;
3. Commercial - C soil – 15% slope – impervious
4. Industrial – D soil - 5% - pervious . .. and so on.

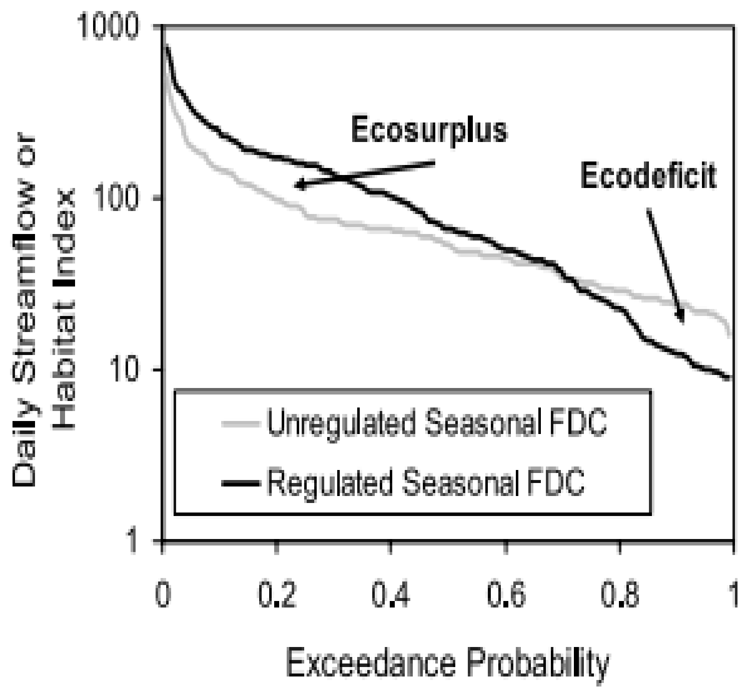
Because each of these HRU combinations describe an existing discrete land use type, they become the hydrologic 'building blocks' for evaluating stormwater runoff for a given community.

Flow Duration Curve (FDC). An FDC is a cumulative probability distribution of storm events over time in the stream (includes baseflow). EPA used a USGS flow gauge in the Wading River over a period of decades to calibrate a watershed model and then to simulate future land use and climate change FDC scenarios.

In this FDC figure:

- "Unregulated" (light grey line) is predevelopment condition;
- "Regulated" (dark line) is post-development condition.

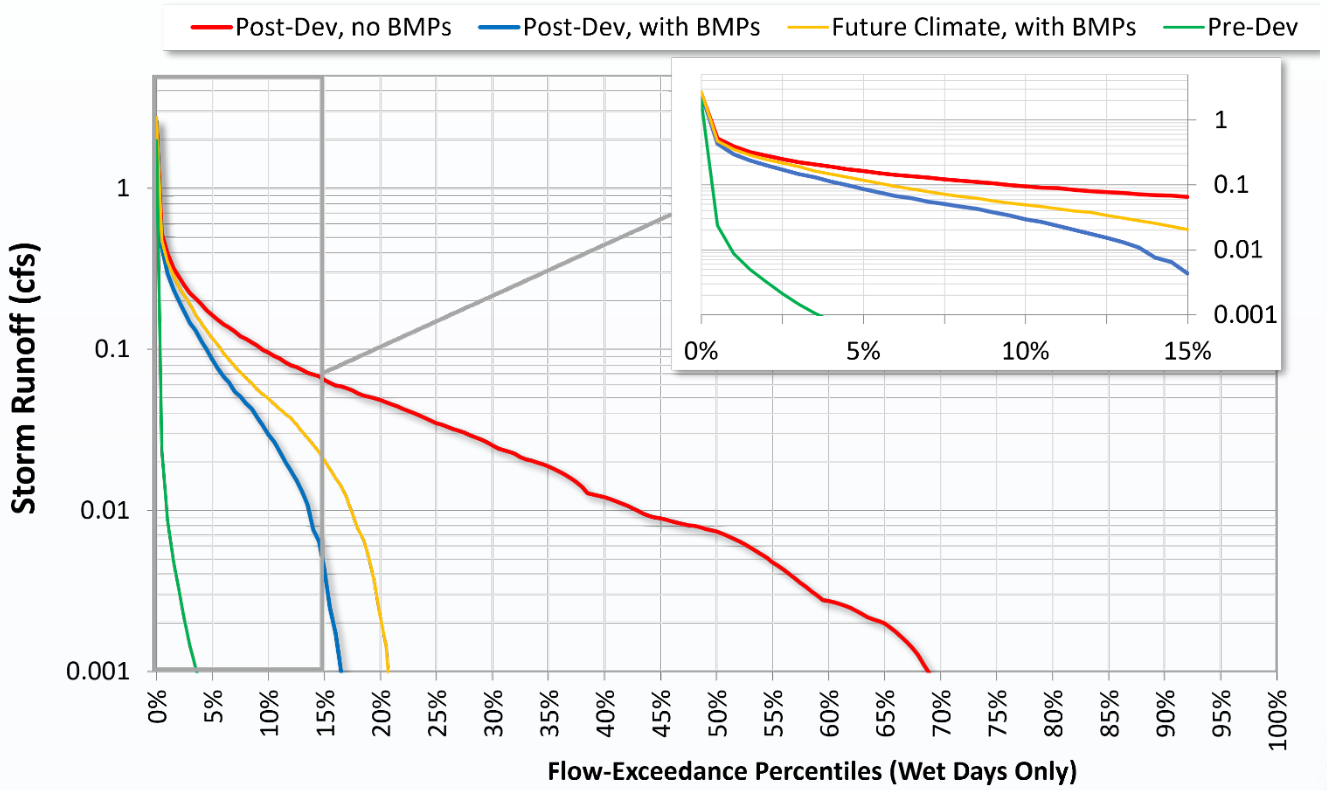
As development occurs, the high flows become higher (ecosurplus = flooding) and the low flows become lower (ecodeficit = drought)



Ecodeficit and ecosurplus regions between an unregulated (predevelopment) and regulated (post-development) FDC. Source: (Vogel et al., 2007).

Incorporating specific development and management practices normalizes the FDC towards the natural hydrologic condition of the predevelopment (forested) state.

Runoff Duration Curve (RDC). Application of FDC Project-calibrated models at site and SCM-scales results in a representation of surface runoff to an assessment point (e.g., site-scale or SCM). This is an RDC for one (1) SCM (infiltration basin).



Ex. This is an RDC for and SCM (infiltration basin on HSG C with infiltration rate of 0.17 in/hr).

Objective: In GENERAL, move red line to green line.

Note: multiple SCMs help move the red line to the green AT THE SITE SCALE

Next-Gen CD Practices and SCM resulting in a site-scale RDC

This is an RDC for one of the FDC Projects' real world Conservation Development (CD) Concept Designs (CD) this presentation will showcase. ..

CDCD Plan showing Runoff Volume for a High-density Commercial Development

CD2.3 LID Basic Commercial Redevelopment

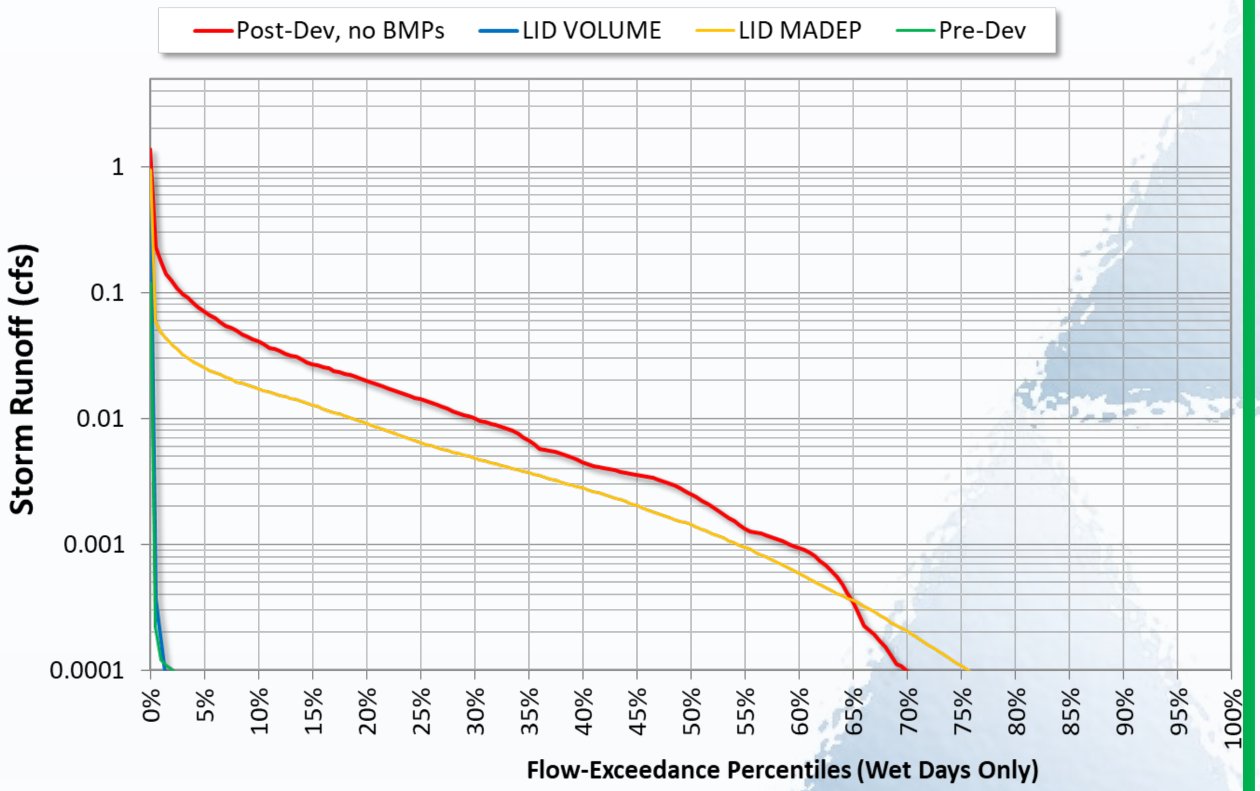
LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD2.4 LID Volume Commercial Redevelopment

LID VOLUME

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY



Acknowledgements

FDC Technical Steering Committee (Phase 1)

- Boston Society of Landscape Architects
- EPA Contractor, Great Lakes Environmental Center
- EPA Contractor, Paradigm Environmental, Inc.
- EPA Contractor, Waterstone Engineering, PLLC
- EPA Region 1 Water Division's Stormwater Permitting and NonPoint Source Unit
- EPA's Office of Research and Development's Atlantic and Ecology Division, Narragansett, RI
- Fluvial Matters Consulting, University of Vermont
- Scott Horsley Consulting
- Kimberly Groff Consulting
- Massachusetts Department of Environmental Protection
- Rensselaer Polytechnic Institute
- The Nature Conservancy / Ducks Unlimited
- Southeastern Regional Planning and Economic Development District
- University of Massachusetts, Amherst, MA
- University of New Hampshire Stormwater Center
- United States Geological Survey, and
- Vermont Department of Environmental Conservation

Acknowledgements [cont.]

Taunton Municipalities (Phase 2)

- Easton
- Mansfield
- Middleborough
- Norton

Southeast New England Program (SNEP)

Shout Outs

- Sara Burns, TNC / Ducks Unlimited
- Jeff Barbaro, USGS

EPA Contractors

- Great Lakes Environmental Center (GLEC)
- Paradigm Environmental, Inc.
- Waterstone Engineering
- JVLPlanning

Project Webpage:

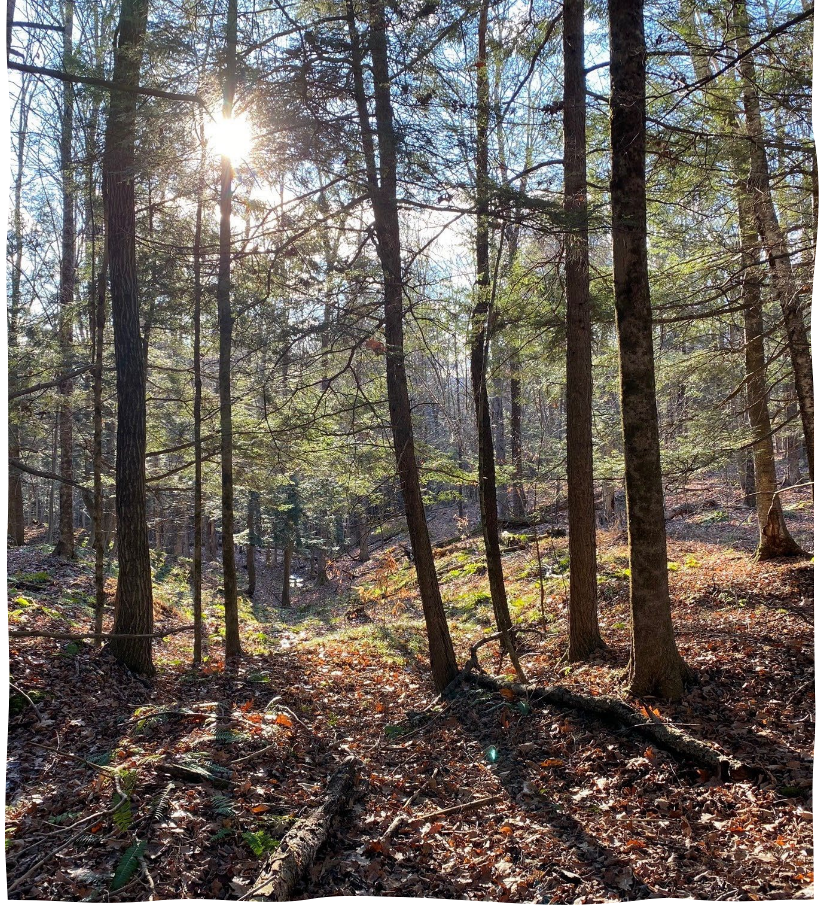
https://www.epa.gov/snep/holistic-watershed-management-existing-and-future-land-use-development-activities

Google: “EPA SNEP FDC”

SNEP: https://www.epa.gov/snep

Sound Future Land Development & Stormwater Management

- Development of a ***Conservation Development Control Level Standard*** to maintain ***predevelopment hydrology*** and ***nutrient load***, and ***resilient landscapes***
- Evaluate performance and cost based on real projects that have been permitted and built
- Examine and model projects at 3 scales 1) BMP/HRU system scale, 2) project scale, 3) watershed scale
- Demonstrate through outreach info on cost avoidance of watershed protection standards
- Enable municipalities through recommendations for next-generation municipal bylaws/ordinances.



Applying Advances in EPA Region 1 Analytical Tools to Quantify

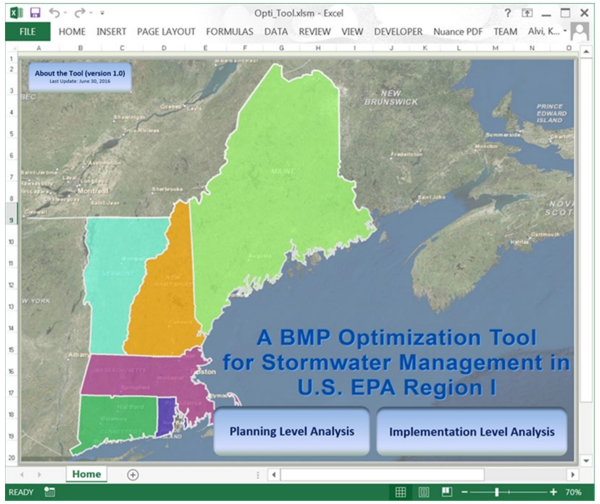
- Cumulative impacts of future IC
- Benefits of Resilient Site-Development Performance Standards
- Right sizing stormwater controls
- Future Cost Burden and Cost Avoidance Opportunities

EPA R1 Applied Research and Development of SW Tools, (2007 to 2022)

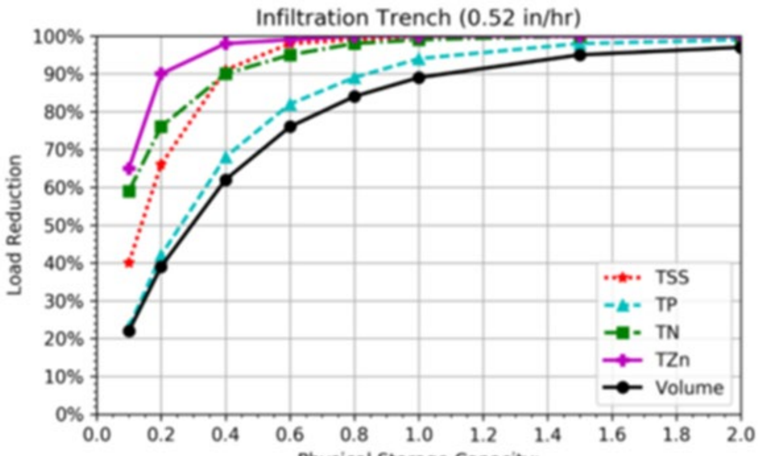
Research and Tools include:

- Regionally representative SW source pollutant load export rates by land use and cover type (e.g., IC)
- Stormwater Control Measure (SCM) Performance Curves
- Applied research validating modelling tools & SCM performance estimates
- Regional calibrated continuous simulation SWMM hydrologic source area models and SCM SUSTAIN models
- Publicly available SW Management Optimization Tool (Opti-Tool)
- Regional SCM unit cost data

Phosphorus Source Category by Land Use	Land Surface Cover	P Load Export Rate, lbs./acre/year
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78
	Pervious	See* DevPERV
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32
	Pervious	See* DevPERV
Medium -Density Residential (MDR)	Directly connected impervious	1.96
	Pervious	See* DevPERV
Low Density Residential (LDR) - "Rural"	Directly connected impervious	1.52
	Pervious	See* DevPERV
Highway (HWY)	Directly connected impervious	1.34
	Pervious	See* DevPERV



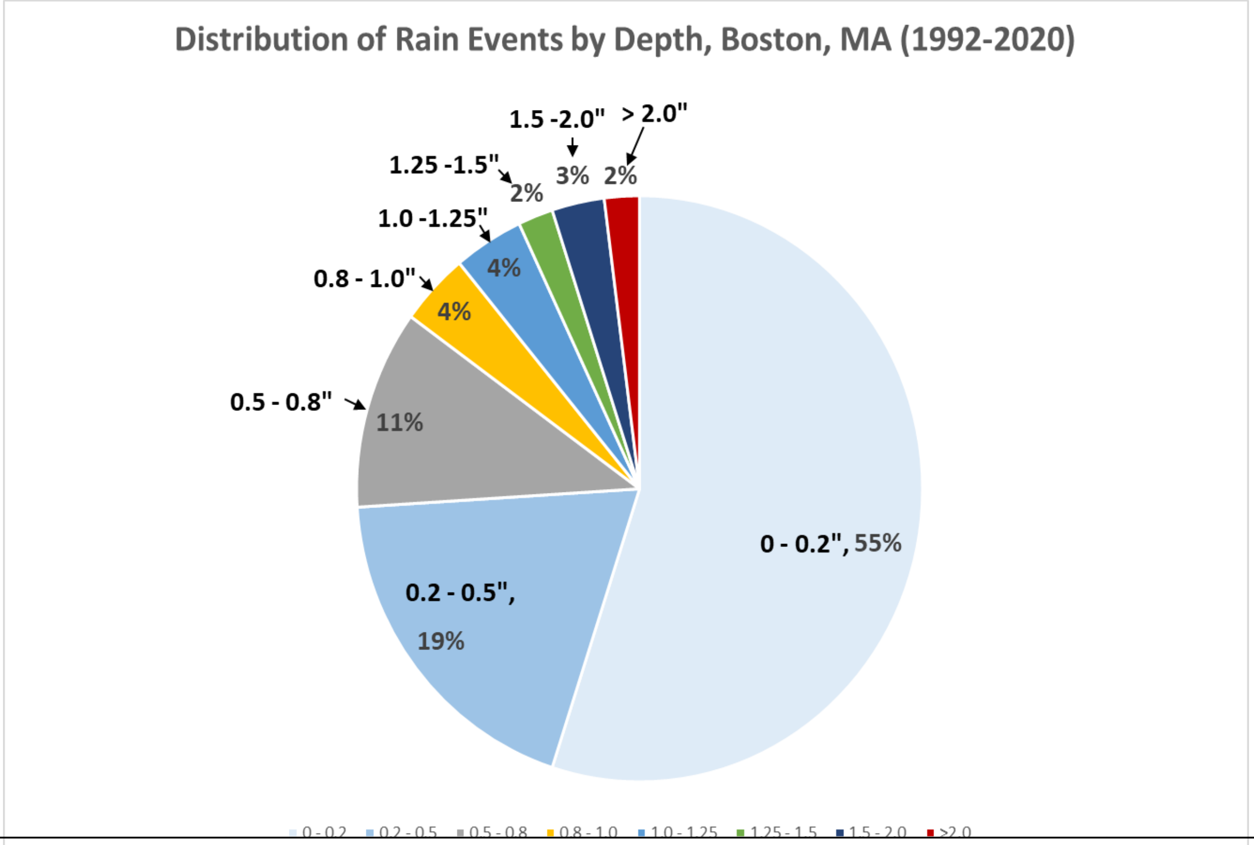
https://www.epa.gov/tmdl/opti-tool-epa-region-1s-stormwater-management-optimization-tool



https://www.unh.edu/unhsc/sites/default/files/media/ms4_permit_nomographs_sheet_final_2020.pdf

New England Region Rainfall Patterns Important Points

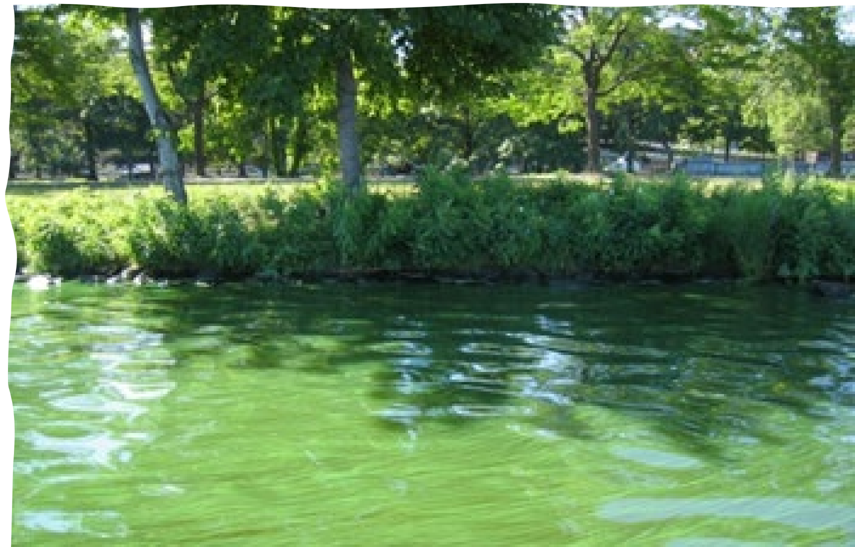
- Most rain events are small
- The total volume and event size distribution are relatively consistent across New England Region
- Small sized events are entirely captured through natural processes on pervious areas (recharge and evapotranspiration)
- Small sized events wash-off significant proportion of annual pollutant load from impervious surfaces

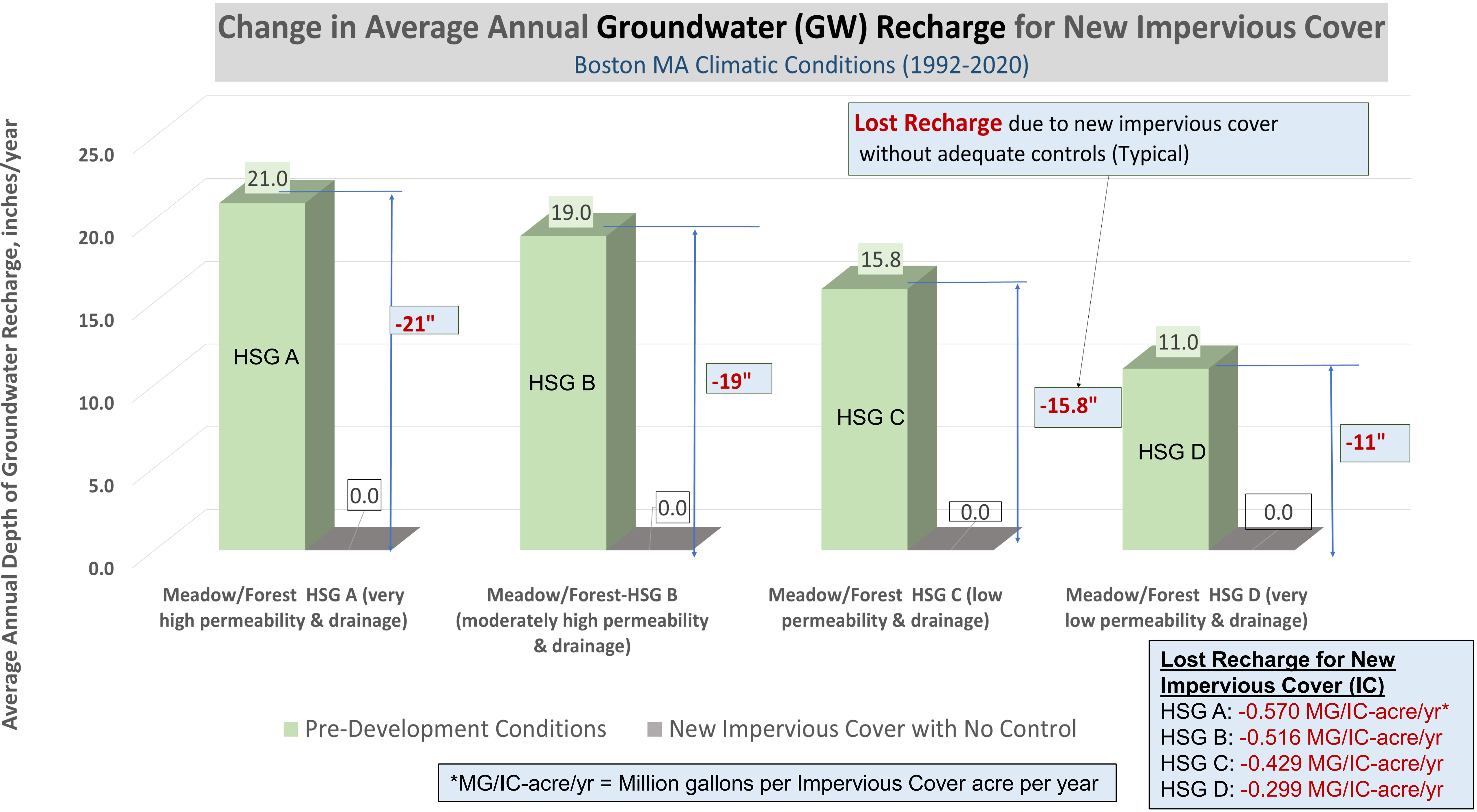


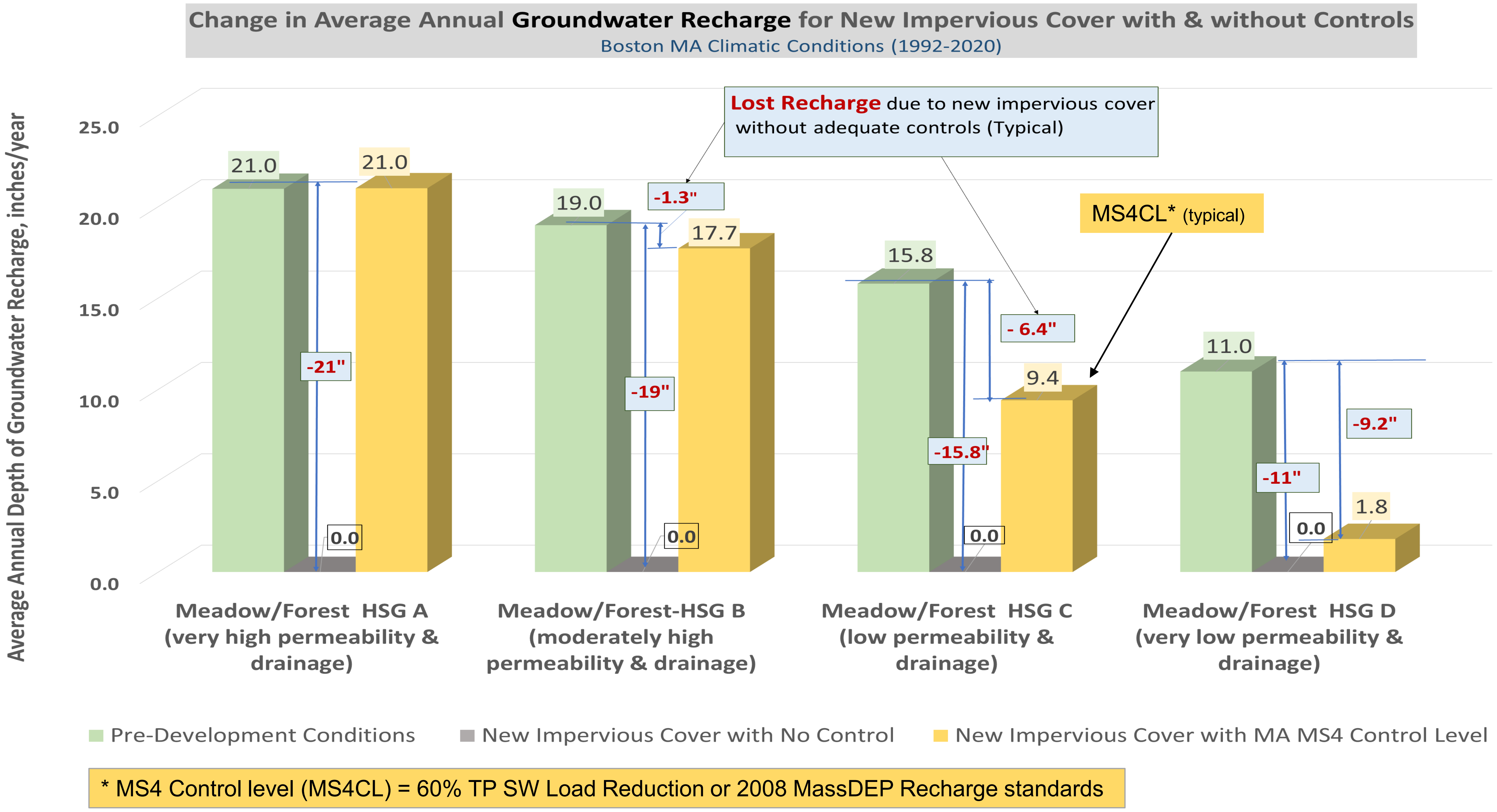
Summary of Precipitation and Simualted Runoff Events for Impervious Cover and Predevelopment Pervious Conditions						
Metric	Precipitation	Runoff Events				
		IC	HSG A	HSG B	HSG C	HSG D
Average annual number of events	78	70	1	5	10	19
Minimum depth triggering runoff, inches	NA	0.05	1.72	1.17	0.64	0.56
Average annual total depth, inches	42.31	39.60	0.42	2.38	5.55	10.34
Average annual total volume, MG/ac/yr	1.15	1.08	0.01	0.06	0.15	0.28
Notes: Results from calibrated continuous simulation SWMM HRU models for impervius cover and predevelopment pervious conditions for Boston, MA climatic conditions, 1992 - 2022., NA= not applicable						

Converting Natural Land to Impervious Cover: Site Scale

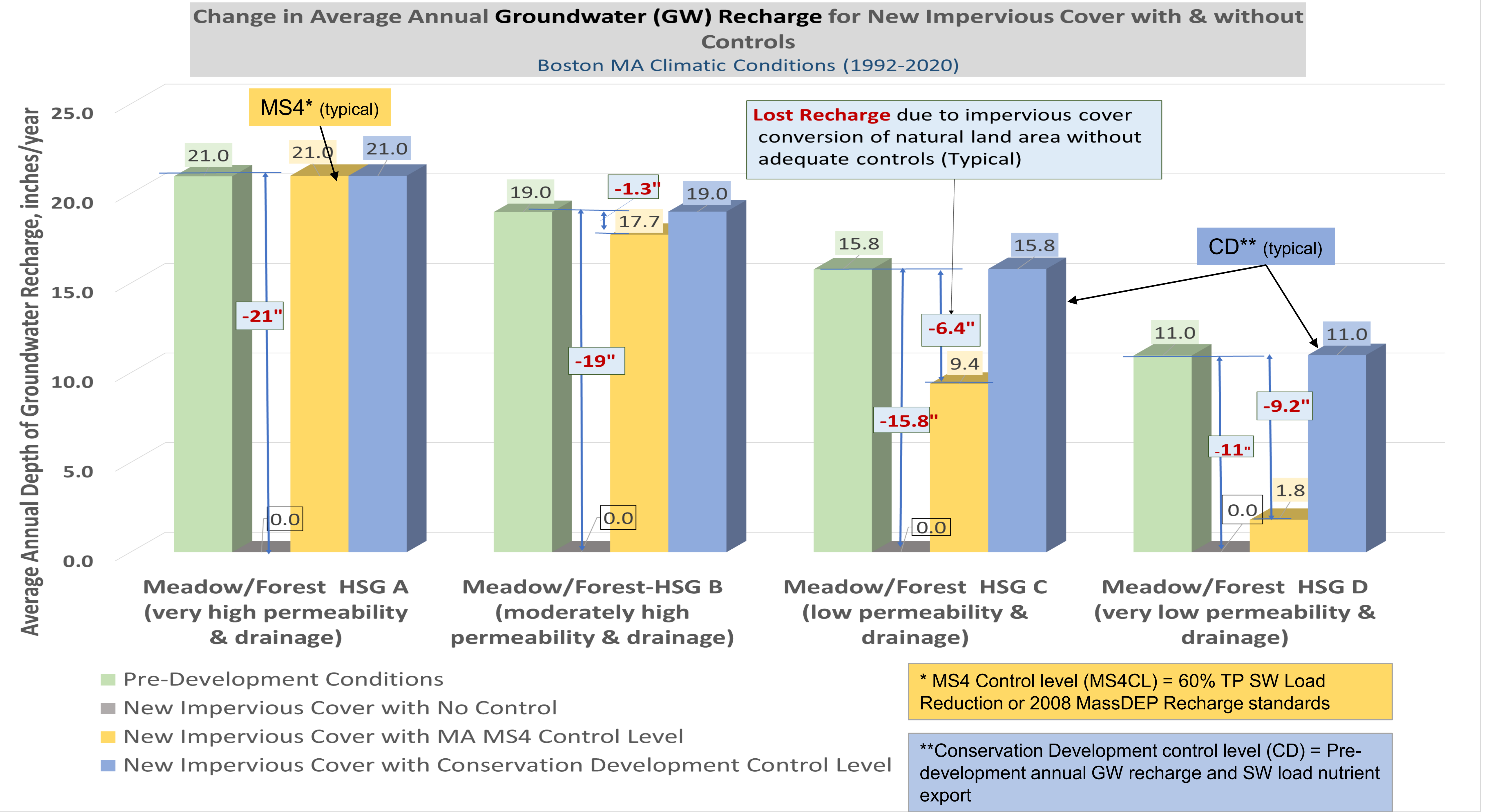
- **Increased** Annual Runoff Volume
  - **~+300% to +10,000%** increase (0.5 to 1.1 Million-Gallons/acre/year)
- **Lost** Annual Groundwater Recharge
  - **~0.30 to 0.57 million-gallons/acre/year**
- **Increased** Annual SW **Phosphorus** Load
  - **~+400% to +6,500%** (1.5 to 1.9 pounds/acre/year)
- **Increased** Annual SW **Nitrogen** Load
  - **~+400% to +13,000%** increase (11 to 13 pounds/acre/year)




Change in Average Annual Groundwater (GW) Recharge for New Impervious Cover
Boston MA Climatic Conditions (1992-2020)
Average Annual Depth of Groundwater Recharge, inches/year
25.0
20.0
15.0
10.0
5.0
0.0
Lost Recharge due to new impervious cover without adequate controls (Typical)
21.0
HSG A
-21"
0.0
19.0
HSG B
-19"
0.0
15.8
HSG C
-15.8"
0.0
11.0
HSG D
-11"
0.0
Meadow/Forest HSG A (very high permeability & drainage)
Meadow/Forest-HSG B (moderately high permeability & drainage)
Meadow/Forest HSG C (low permeability & drainage)
Meadow/Forest HSG D (very low permeability & drainage)
Pre-Development Conditions
New Impervious Cover with No Control
*MG/IC-acre/yr = Million gallons per Impervious Cover acre per year
Lost Recharge for New Impervious Cover (IC)
HSG A: -0.570 MG/IC-acre/yr*
HSG B: -0.516 MG/IC-acre/yr
HSG C: -0.429 MG/IC-acre/yr
HSG D: -0.299 MG/IC-acre/yr



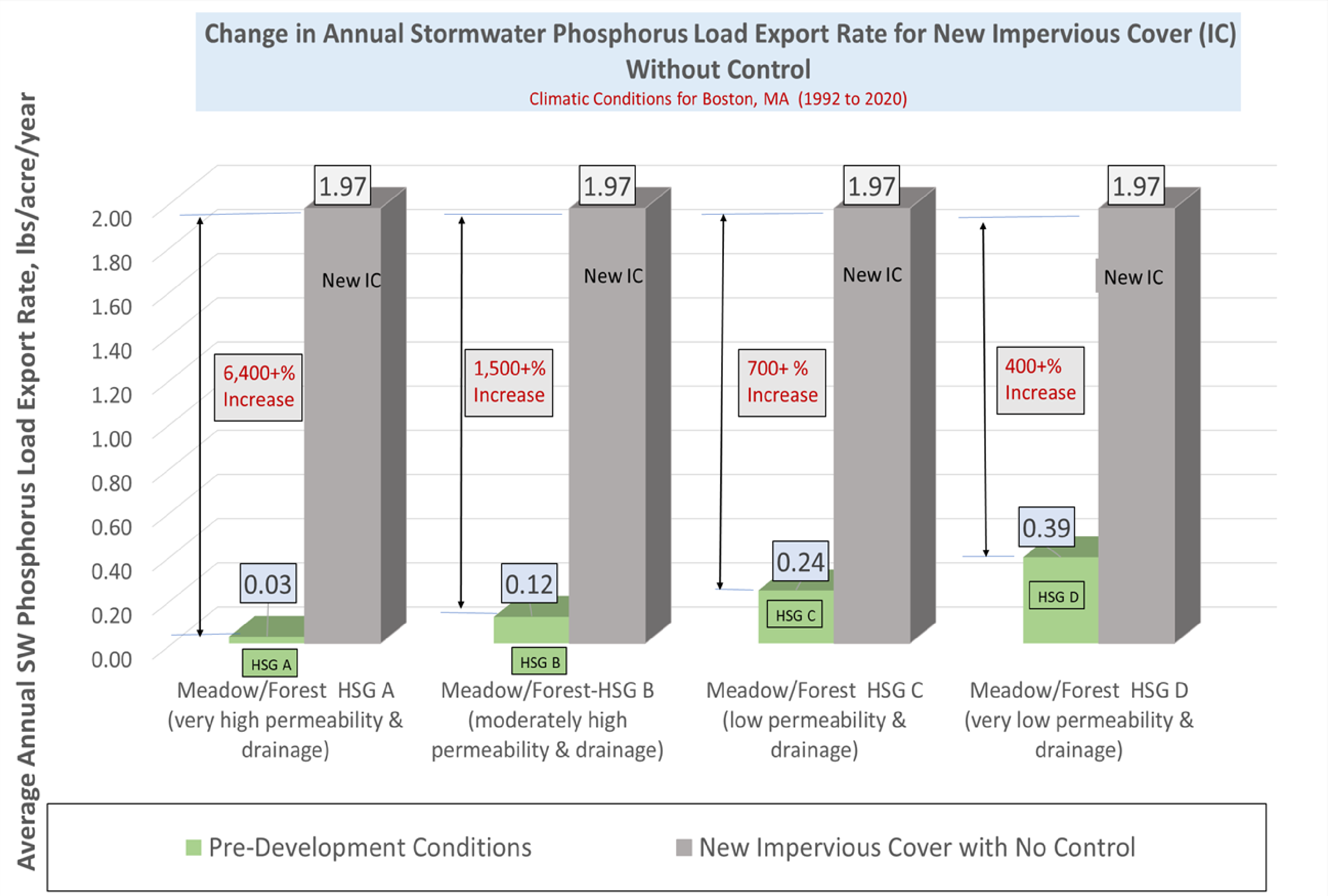
Change in Average Annual Groundwater Recharge for New Impervious Cover with & without Controls
Boston MA Climatic Conditions (1992-2020)
Average Annual Depth of Groundwater Recharge, inches/year
25.0
20.0
15.0
10.0
5.0
0.0
Lost Recharge due to new impervious cover without adequate controls (Typical)
MS4CL* (typical)
21.0
21.0
-21"
0.0
19.0
-1.3"
17.7
-19"
0.0
15.8
- 6.4"
9.4
-15.8"
0.0
11.0
-9.2"
-11"
1.8
0.0
Meadow/Forest HSG A (very high permeability & drainage)
Meadow/Forest-HSG B (moderately high permeability & drainage)
Meadow/Forest HSG C (low permeability & drainage)
Meadow/Forest HSG D (very low permeability & drainage)
Pre-Development Conditions
New Impervious Cover with No Control
New Impervious Cover with MA MS4 Control Level
* MS4 Control level (MS4CL) = 60% TP SW Load Reduction or 2008 MassDEP Recharge standards


Change in Average Annual Groundwater (GW) Recharge for New Impervious Cover with & without Controls
Boston MA Climatic Conditions (1992-2020)
MS4* (typical)
Lost Recharge due to impervious cover conversion of natural land area without adequate controls (Typical)
CD** (typical)
Average Annual Depth of Groundwater Recharge, inches/year
25.0
20.0
15.0
10.0
5.0
0.0
21.0
0.0
21.0
21.0
-21"
19.0
0.0
17.7
19.0
-1.3"
-19"
15.8
0.0
9.4
15.8
-15.8"
-6.4"
11.0
0.0
1.8
11.0
-11"
-9.2"
Meadow/Forest HSG A (very high permeability & drainage)
Meadow/Forest-HSG B (moderately high permeability & drainage)
Meadow/Forest HSG C (low permeability & drainage)
Meadow/Forest HSG D (very low permeability & drainage)
Pre-Development Conditions
New Impervious Cover with No Control
New Impervious Cover with MA MS4 Control Level
New Impervious Cover with Conservation Development Control Level
* MS4 Control level (MS4CL) = 60% TP SW Load Reduction or 2008 MassDEP Recharge standards
**Conservation Development control level (CD) = Pre-development annual GW recharge and SW load nutrient export

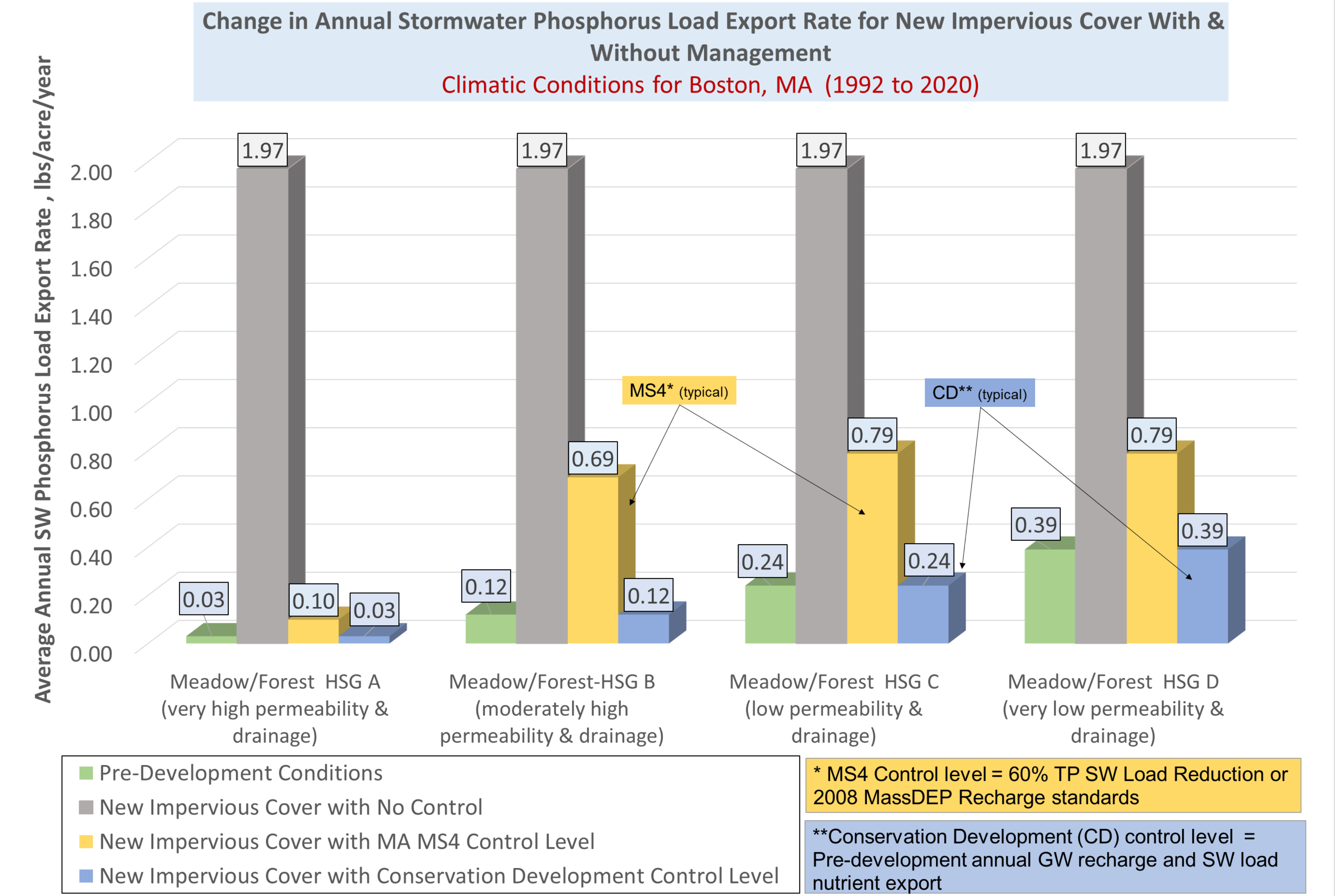
The Nutrient Challenge & SW Permitting

- Nationally 45% to 65% of assessed waters are impaired by nutrients
- Stormwater is a major contributor of Phosphorus and Nitrogen
- Land conversion to impervious cover increases stormwater flow and nutrient delivery
- Changing climate leads to warmer waters and increased stormwater flow – exacerbating the issue

Change in SW Nutrient Export Due to Impervious Cover



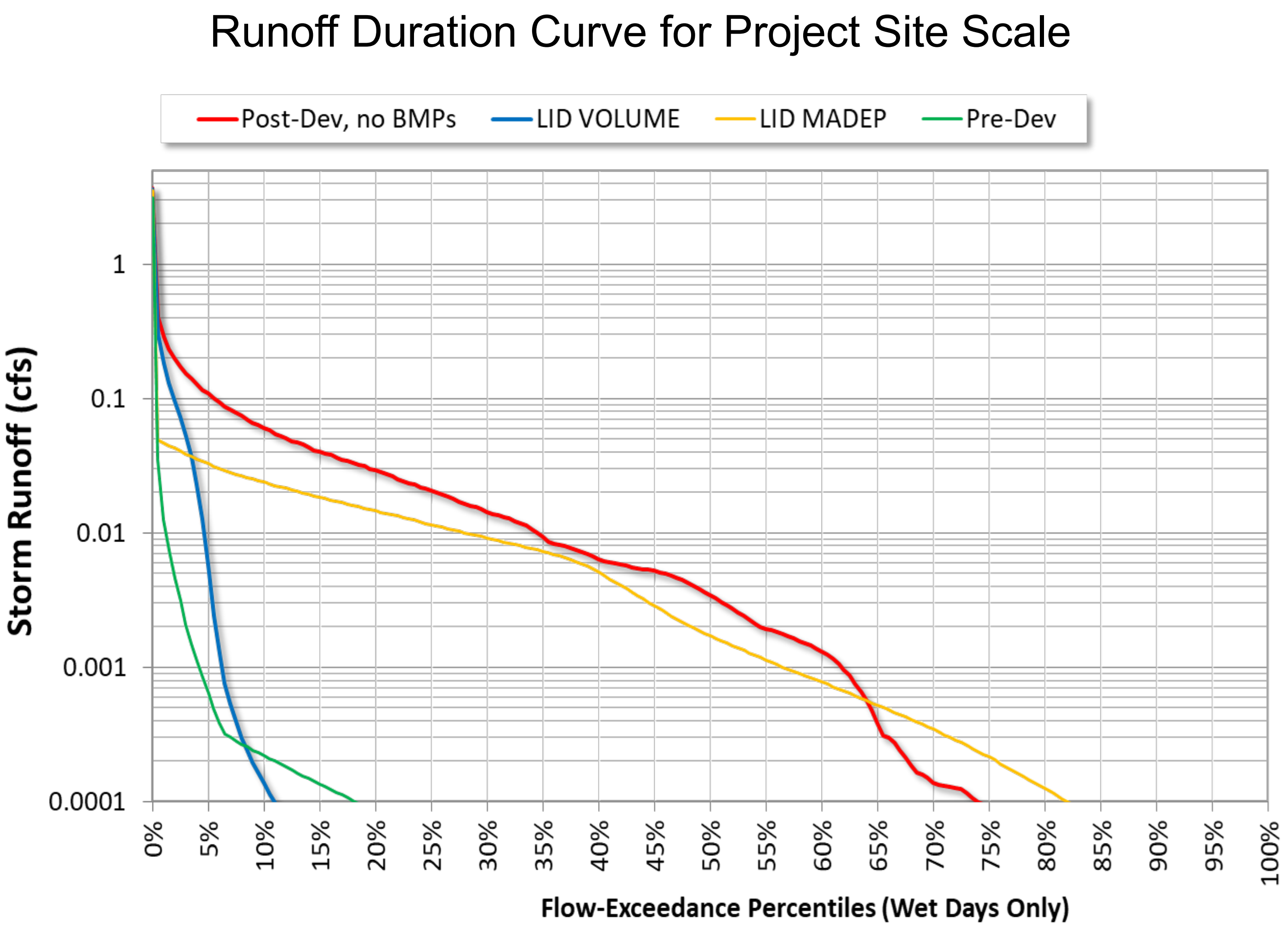
SW Nutrient Control for New Impervious Cover



The Power of Continuous Simulation, Flow Duration and Runoff Duration Curves

Takeaway Points:

- Nature is resilient
- Evaluating impacts and management solutions across the full range of instream flow & runoff flow regimes empowers us to better mimic natural conditions post-development and maintain resiliency
- How? Conservation Development Standards using dispersed green infrastructure for IC while preserving predevelopment natural drainage patterns on site



Minimizing Future Retrofit Needs

- Next generation stormwater permits now require SW load reductions from existing development
- Municipal retrofit programs require substantial investment from the community
- Retrofit stormwater controls can cost up to 4x the equivalent control during new or re-development

Protective Post Construction Stormwater Requirements For New and Re-Development are a MUST for Resiliency

$ Cost Avoidance or Cost Burden for SW Nutrient Control $

Cost to offset increased SW nutrient load from new impervious cover:

- No Control: $54,000 – $76,000* per new acre of impervious cover
- MS4 Control Level**:$11,000 - $22,000 per new acre of impervious cover
- Conservation Development Control Level***:$0

Notes: *Cost estimates are for construction of SW retrofit controls for existing impervious cover in year 2020 dollars.

**MS4 control level is the more stringent of either 60% SW phosphorus load reduction or MassDEP's 2008 groundwater recharge SW standards.

***Conservation Development control level is achieving predevelopment annual recharge and nutrient export through dispersed green infrastructure and environmentally sensitive site designs.

Other Considerations for Local SW Regulations

Regulatory SW management triggers matter

- Area of disturbance should be as low as feasible
  - NH Study estimates: 1 acre threshold will capture 30% of IC whereas 5000 sq. ft. (~1/8th acre) will capture 80% of IC
- Note watershed modeling results of future development conditions with varying amounts of IC being covered by SW regulations - 30%, 80%, and 100%.
  - Consider impacts of conversion of natural land to developed pervious landscapes (e.g., lawns) on future nutrient export
  - Require restoration of hydrologic function for disturbed soils on site.
  - Consider requiring offsetting pervious nutrient load at time of development

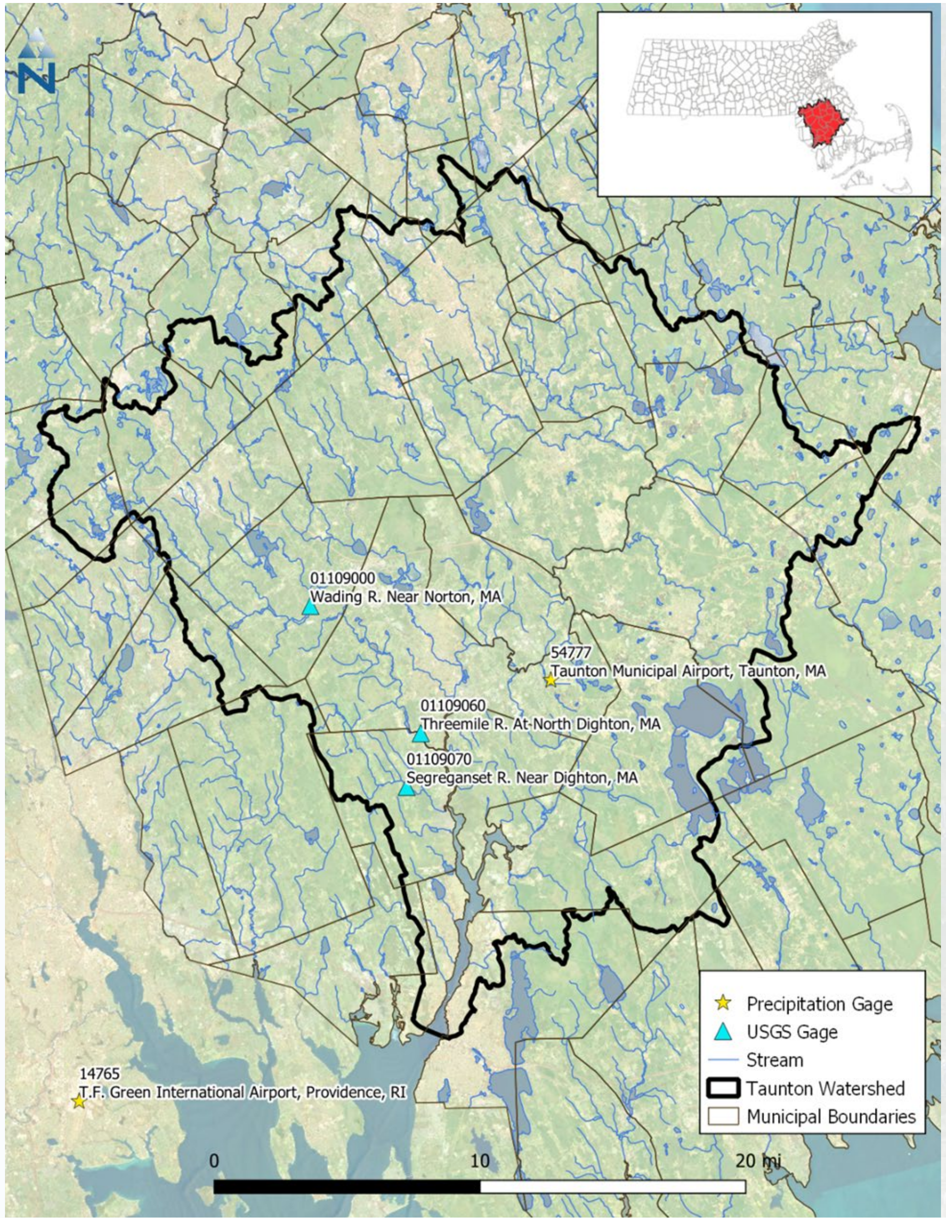
Summary & Take Away Information

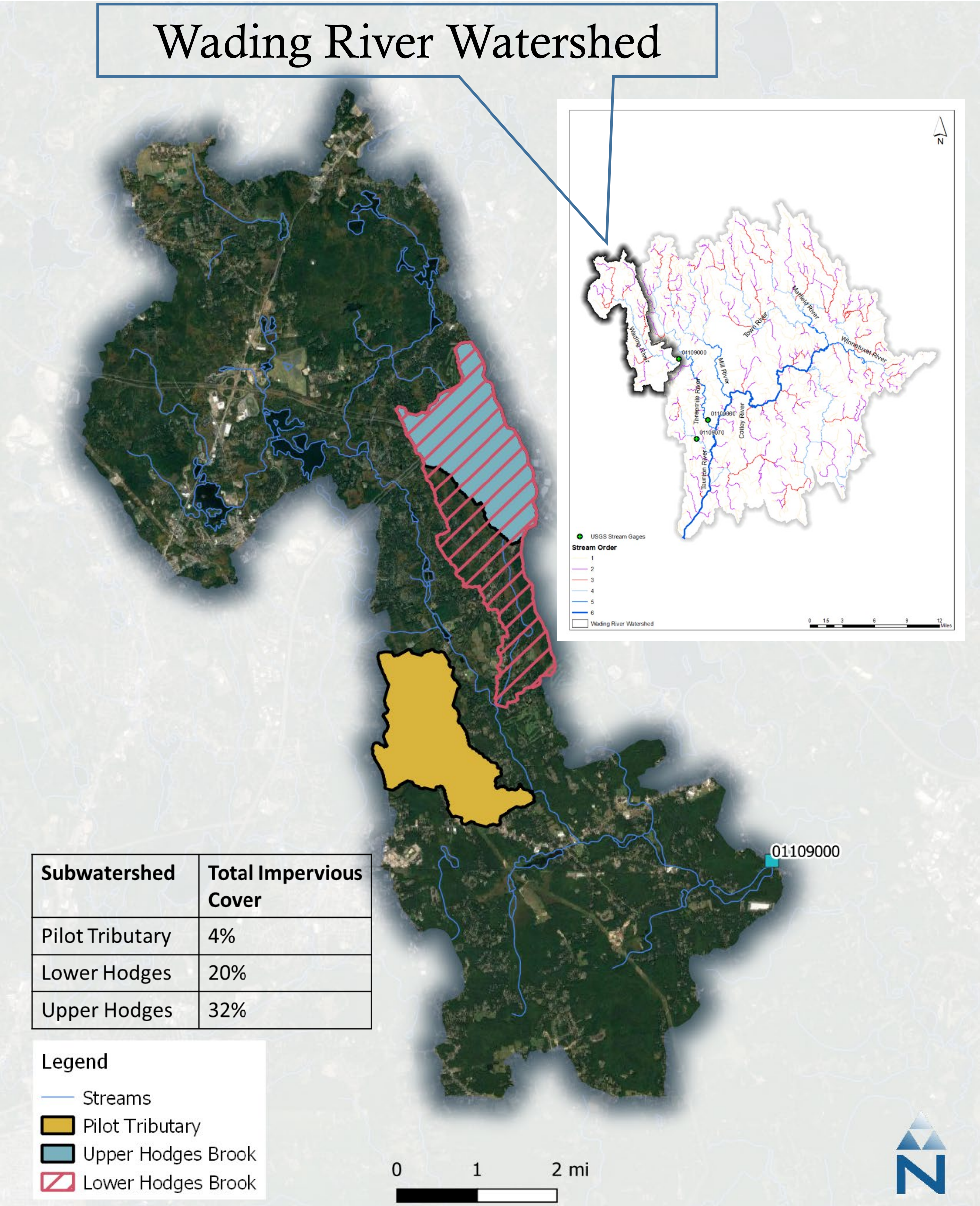
- Conversion of Natural Vegetated Areas to IC has **serious long-term implications** for future ecological health, economics, & community resilience
- Current land development management frameworks need thorough reevaluations to ensure sustainable water resource **protection & avoidance** of potential future cost burdens
- Application of EPA R1 Tools and information are shedding light on what are appropriate **Resilient Performance Standards at the site scale** to avoid impacts, minimize future cost burdens and increase community resiliency in the face of climate change

5 MINUTE BREAK

ATLANTA'S BELTLINE PARK IN HISTORIC 4TH WARD

Study Area: Taunton River Watershed

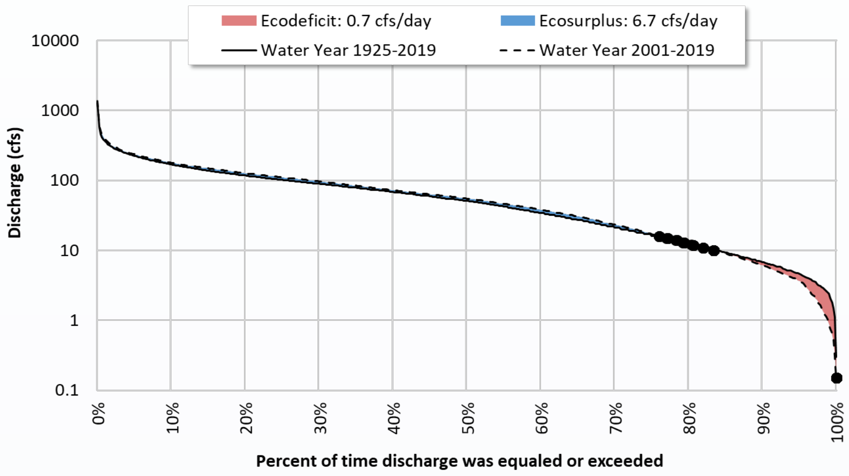


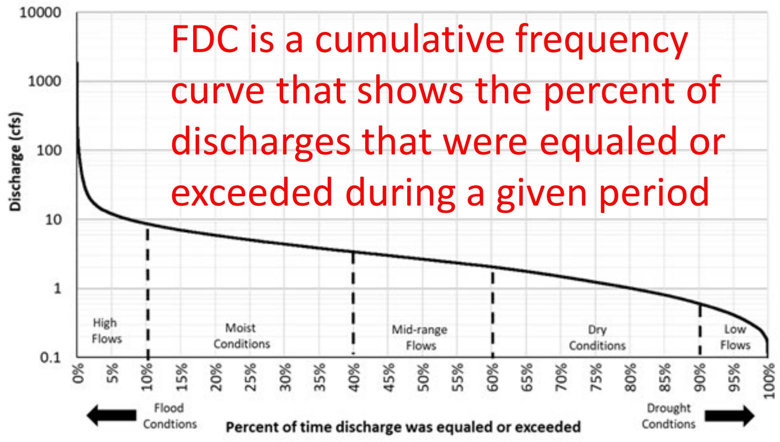


Subwatershed	Total Impervious Cover
Pilot Tributary	4%
Lower Hodges	20%
Upper Hodges	32%

Potential Metrics

Ecodeficit: 165 MG/yr Ecosurplus: 1,580 MG/yr

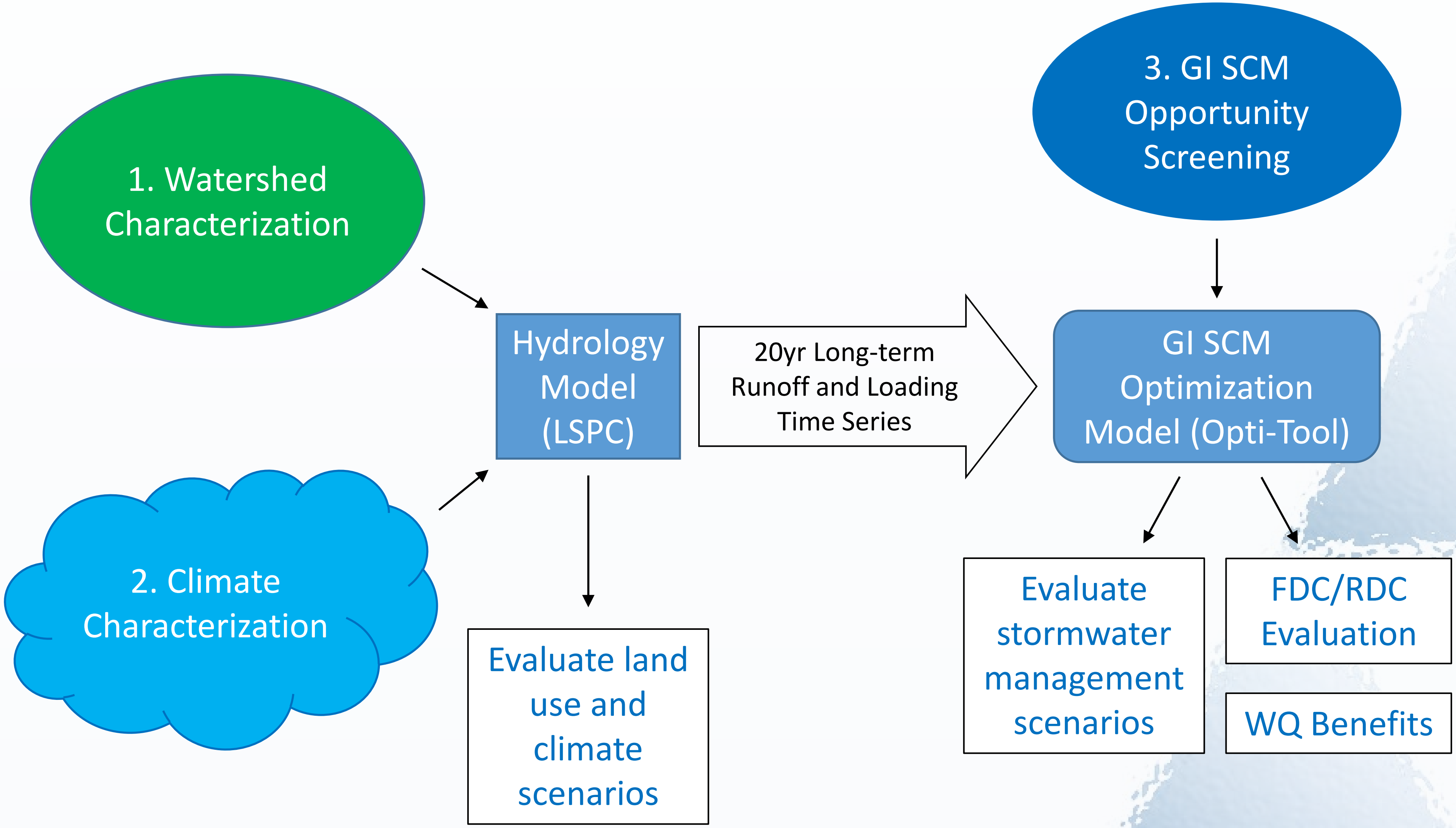




Evaluation Metric	Description
Trend Slope	Quantile-Kendall plot
Variability	Discharge variability over time
Annual Nutrient (P&N) load export (excluding channel processes)	Pollutant load Export rates
Annual surface runoff volume	Runoff yields
Annual Groundwater recharge	Infiltration
Ecodeficit/Ecosurplus	Flow Duration Curve
Composite IHA	Flow Duration Curve
$Q_{Bankfull}$	Flooding
Richard-Baker Flashiness index	Quicker routing of storm flows to streams and rivers relative to natural conditions
Critical Shear Stress (mobilization of particles)	Streambed Mobility/Stability
Evapotranspiration rate	Ecohydrology
Latent heat flux	Ecohydrology

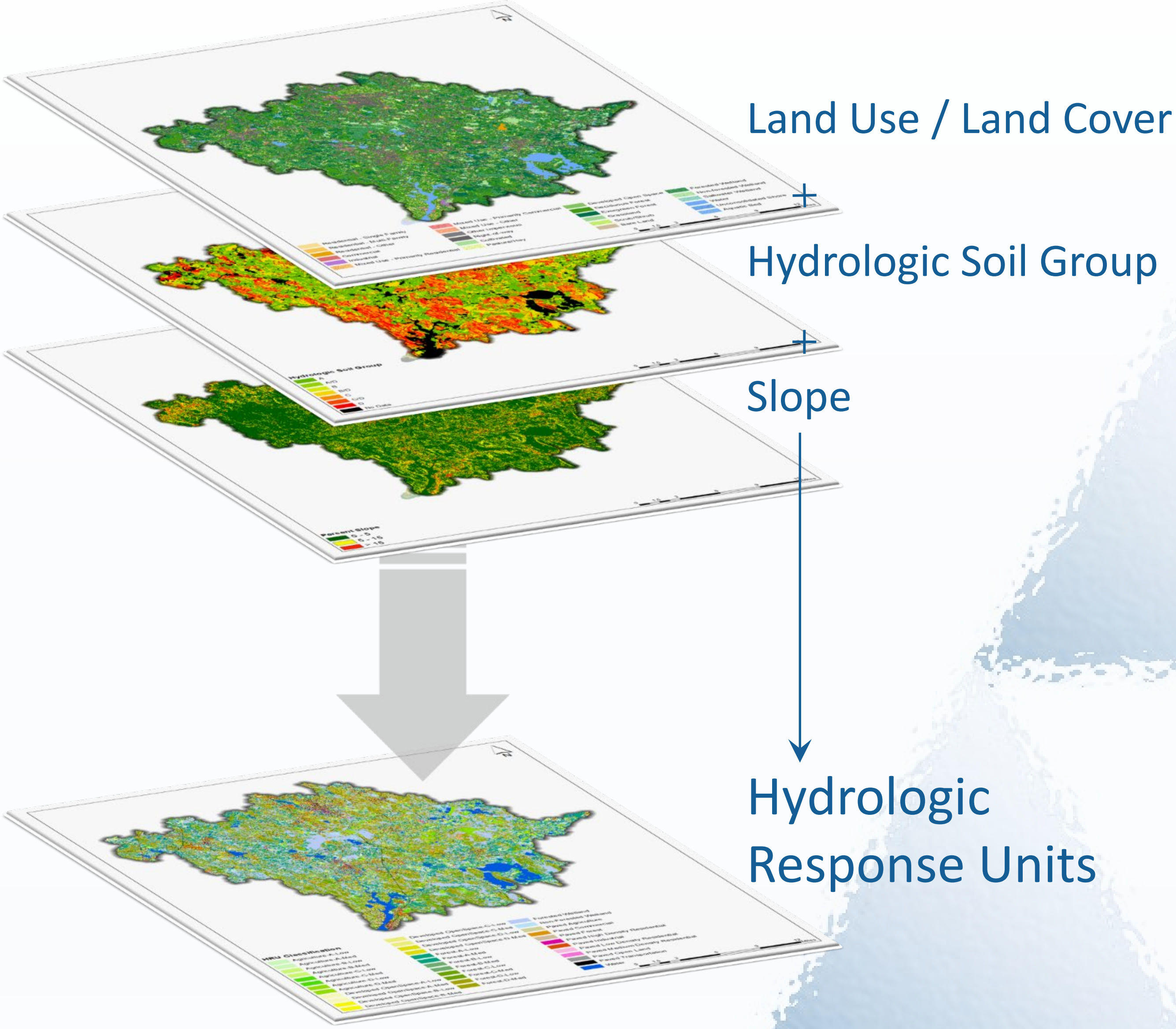
Group	IHA parameter
Group 1 Magnitude and timing (12 parameters)	Average monthly flow (1 value for each of the 12 months)
Group 2 Magnitude and duration (12 parameters)	Average annual 1-day minimum flow
	Average annual 3-day minimum flow
	Average annual 7-day minimum flow
	Average annual 30-day minimum flow
	Average annual 90-day minimum flow
	Average annual 1-day maximum flow
	Average annual 3-day maximum flow
	Average annual 7-day maximum flow
	Average annual 30-day maximum flow
	Average annual 90-day maximum flow
	Number of days per year with zero flow
	7-day minimum flow divided by mean flow in each year
Group 3 Timing (2 parameters)	Julian date of the minimum flow
	Julian date of the maximum flow
Group 4 Frequency and duration (4 parameters)	Number of low pulses
	Average duration of low pulse
	Number of high pulses
	Average duration of high pulses
Group 5 Rate of change and frequency (3 parameters)	Rise rate (mean of all positive differences)
	Fall rate (mean of all negative differences)
	Number of flow reversals

Modeling Framework

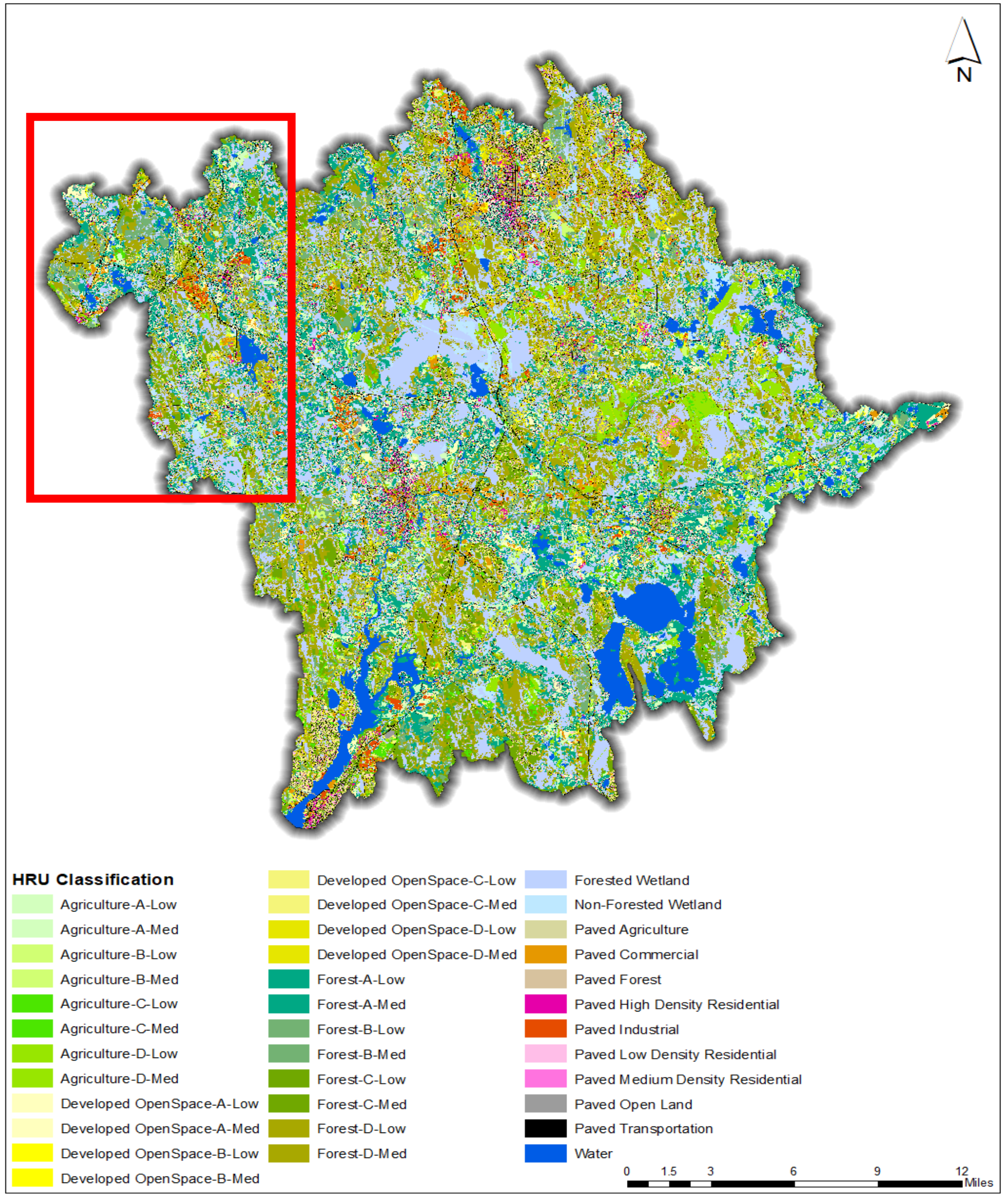


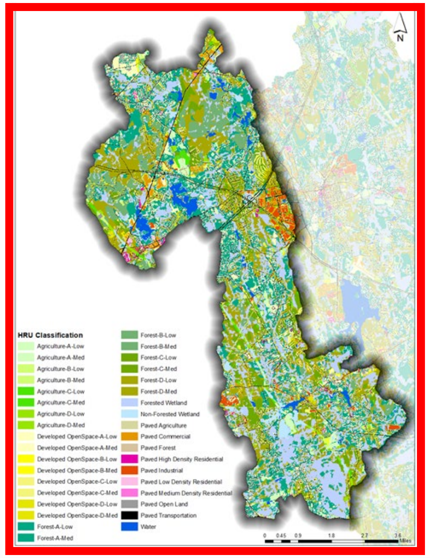
Watershed Characterization

- Evaluate and combine key spatial datasets that control runoff and pollutant generation
- Hydrologic Response Units (HRUs)

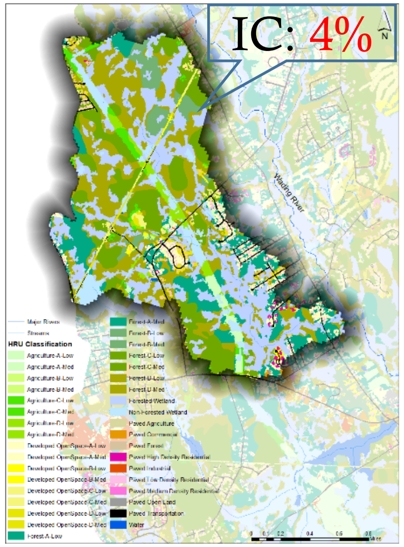


Taunton Watershed - HRUs

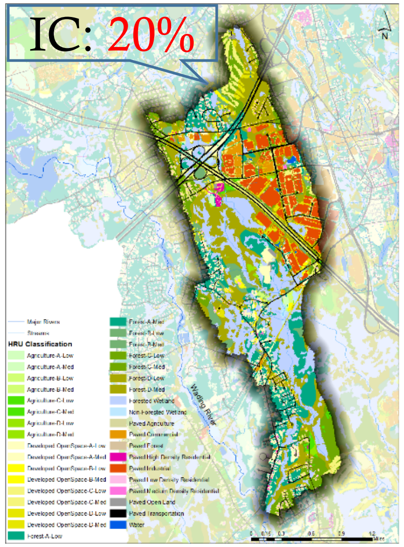




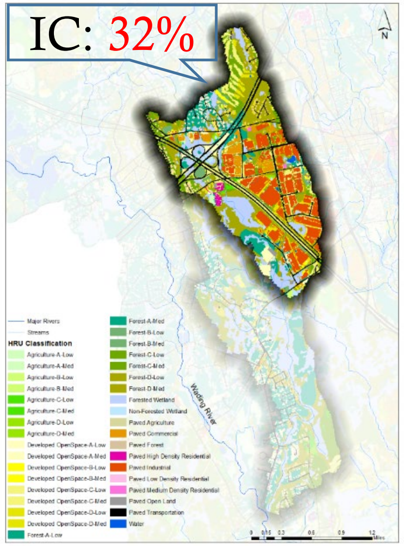
Wading River



Pilot Tributary



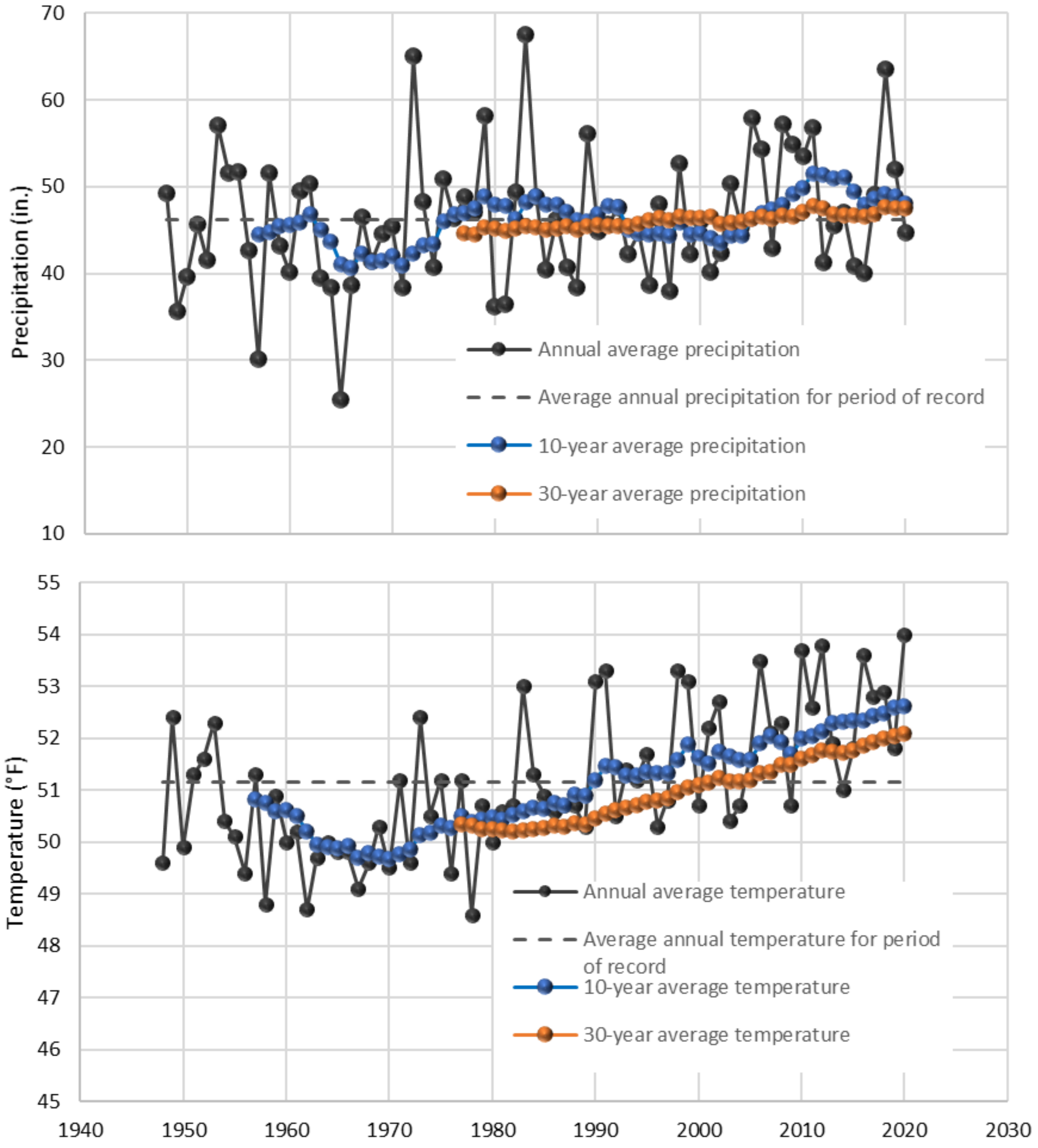
Lower Hodges Brook



Upper Hodges Brook

Climate Characterization

- Local climate data gathered from stations within the Taunton River Watershed and T.F. Green Airport in Providence RI
- Drives runoff and pollutant loads

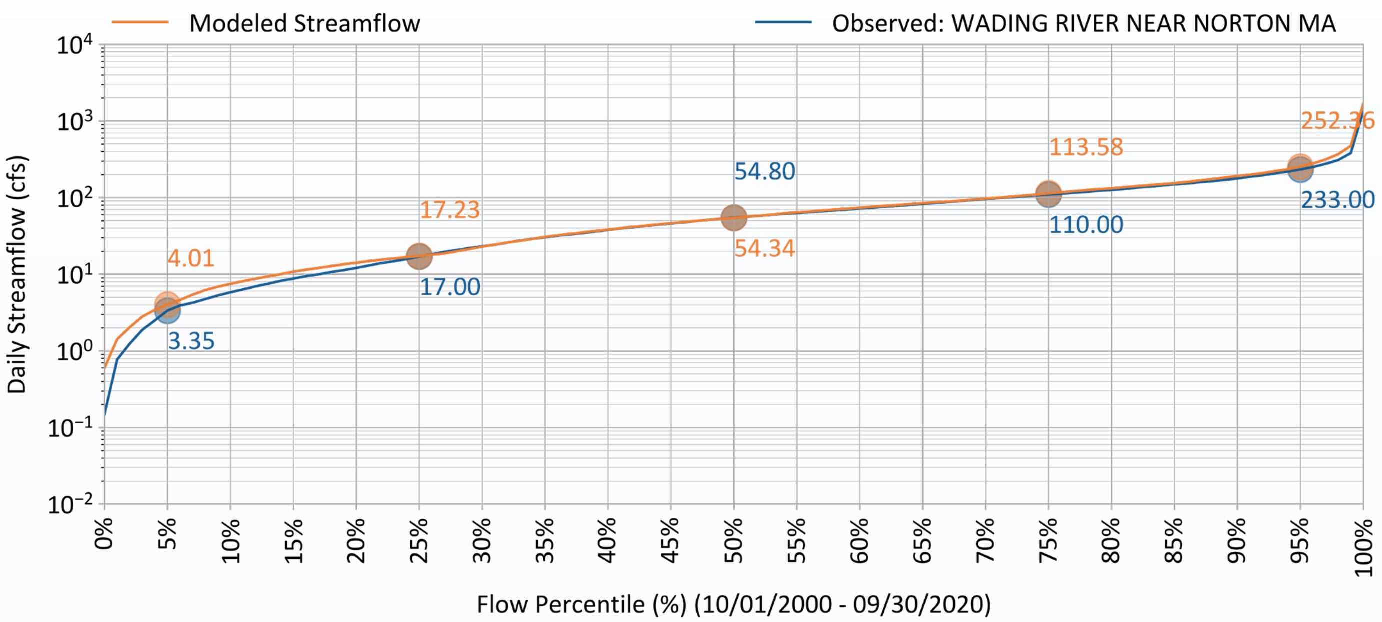


Calibration and Validation

- LSPC model based on HSPF model developed by USGS for Taunton River watershed
- 20 years of observed precipitation and streamflow
  - **10-year calibration and 10-year validation periods**
- Calibration: minimize the difference between model output and corresponding measured data by adjusting model parameter values
- Validation: Use calibration model parameters to predict a separate set of observed data
- Use both visual and statistical approaches to assess agreement between observed and simulated data

Model Calibration and Validation

Flow Duration Curves: Predicted vs Observed



Hydrology Monitoring Locations	Performance Metrics (Seasonal)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
WADING RIVER NEAR NORTON MA	Good -	Good -	Satisfactory +	Unsatisfactory -	Unsatisfactory -	Good	Very Good	Very Good	Unsatisfactory	Very Good	Satisfactory	Good	Very Good	Unsatisfactory	Good

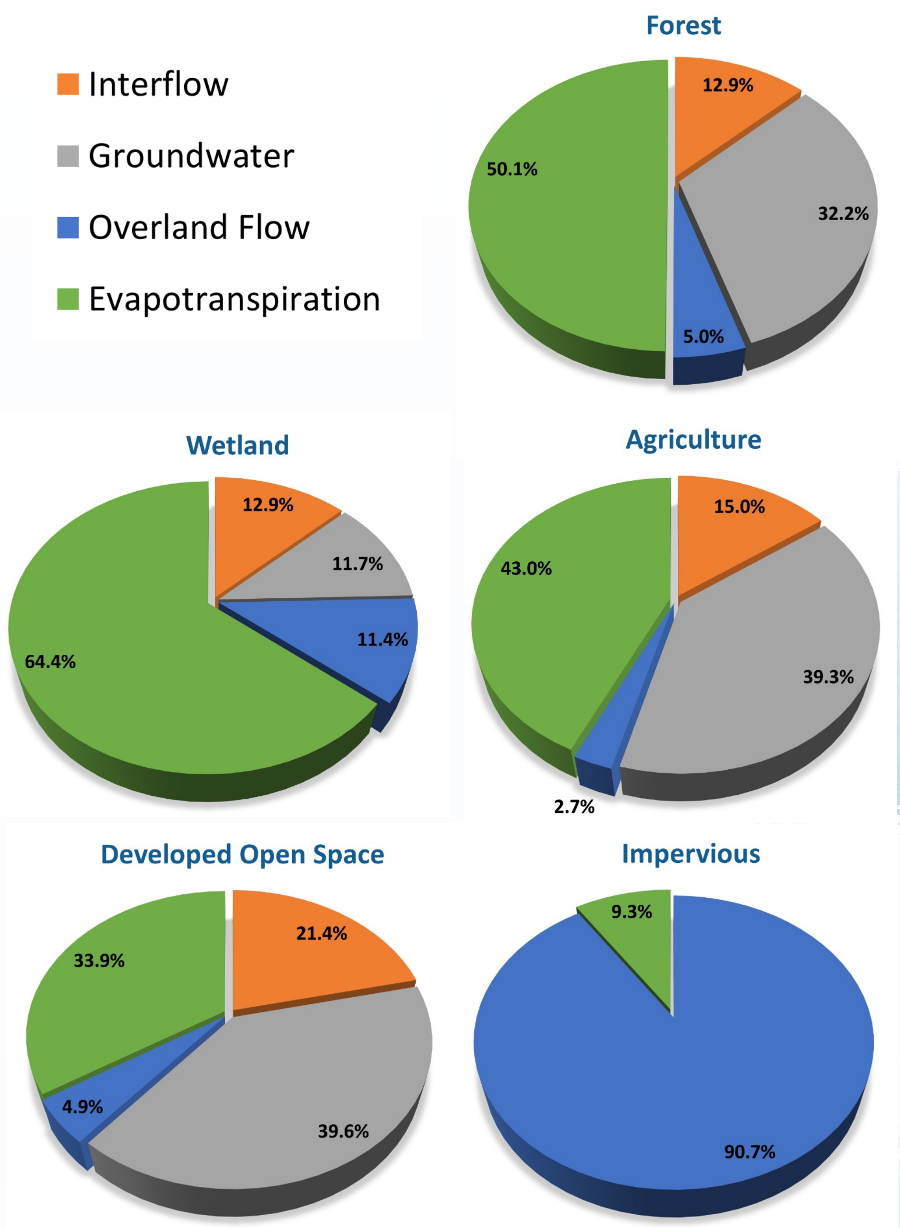
Hydrology Monitoring Locations	Performance Metrics (Flow Regime)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 10%	Storms	Low 50%	Baseflow	All	Top 10%	Storms	Low 50%	Baseflow	All	Top 10%	Storms	Low 50%	Baseflow
WADING RIVER NEAR NORTON MA	Good -	Very Good -	Good -	Unsatisfactory -	Very Good -	Good	Good	Very Good	Unsatisfactory	Very Good	Satisfactory	Unsatisfactory	Good	Unsatisfactory	Very Good

Very Good | Good | Satisfactory | Unsatisfactory

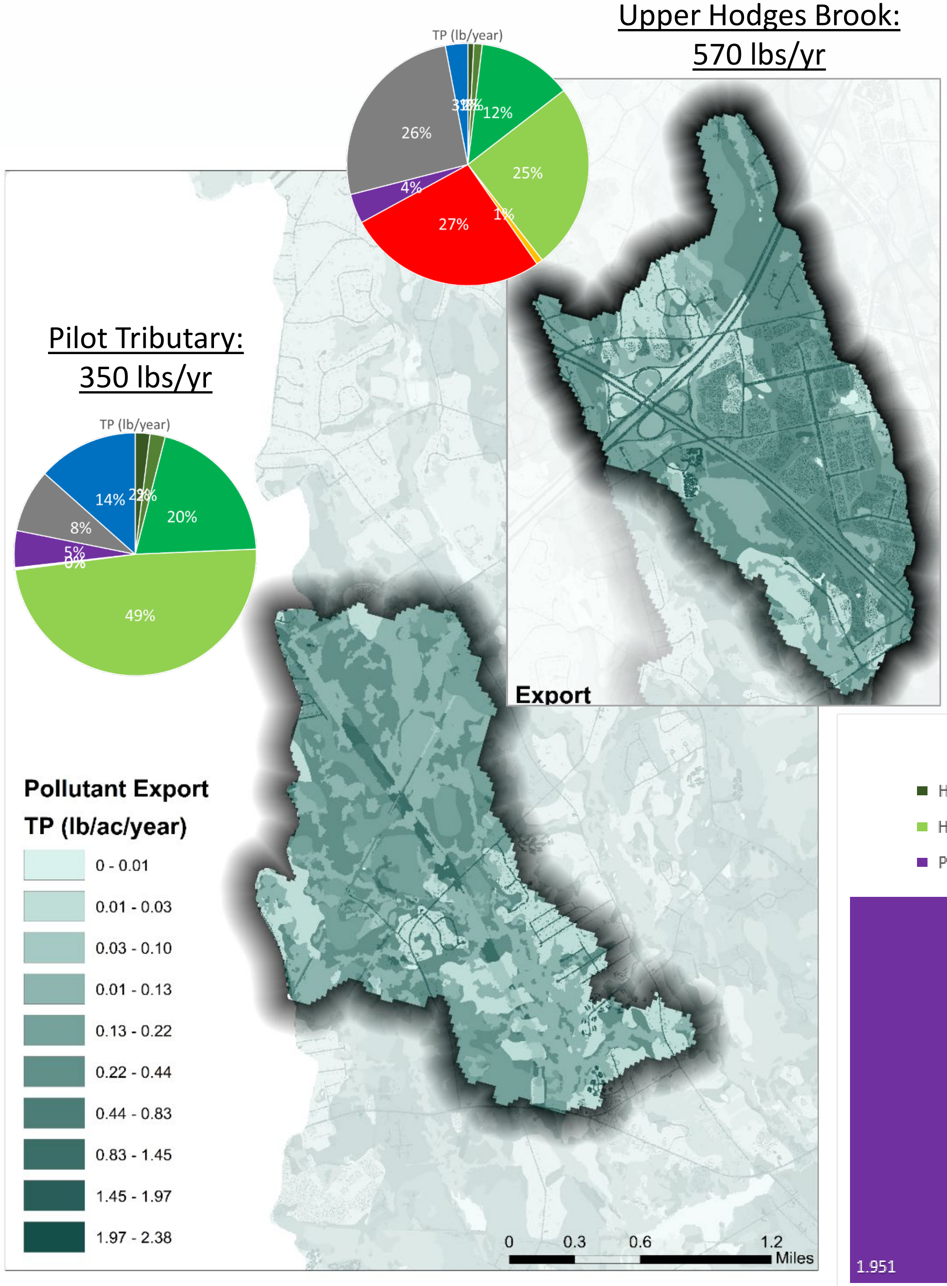
- Overpredicts | + Underpredicts

Impact of Land Cover on Water Balance

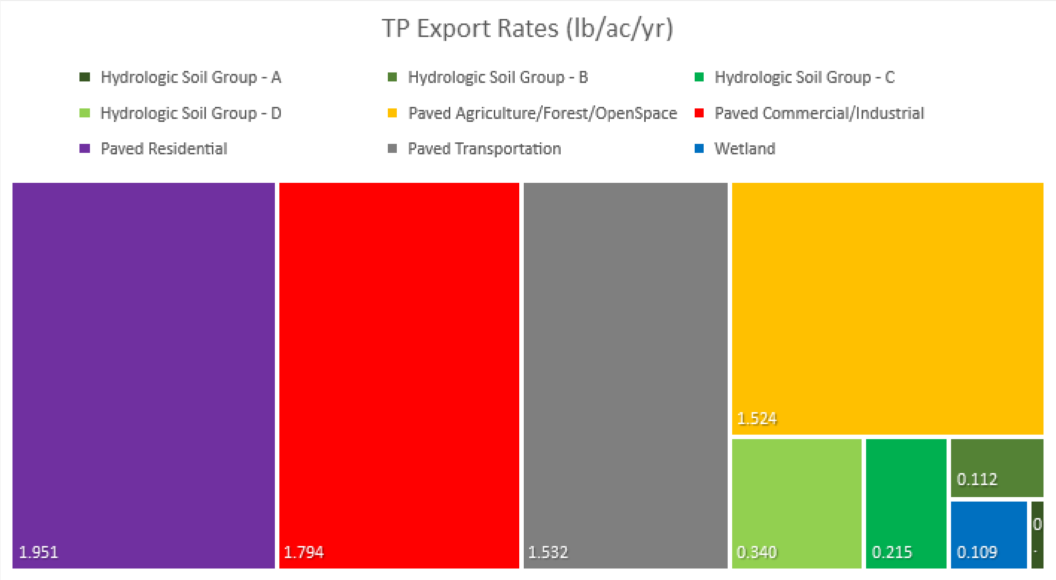
- Forests and wetlands return large amount of precipitation to atmosphere via evapotranspiration (ET)
  - **Small amount of runoff**
- ET greatly reduced from impervious surfaces, greatly increasing runoff
  - **Little to no transpiration**
- Pervious developed open space can have relatively low ET but increased interflow and groundwater recharge compared to other pervious land uses



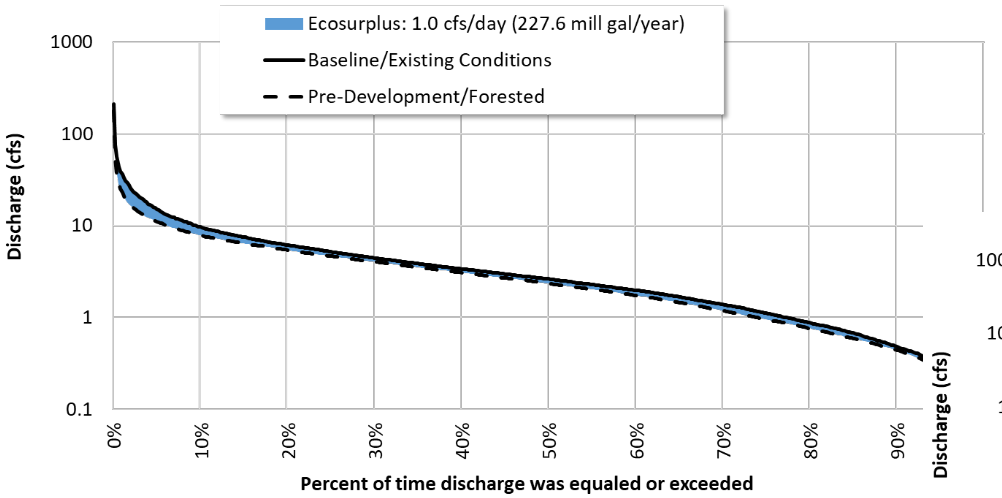
Impact of Land Cover on Water Quality

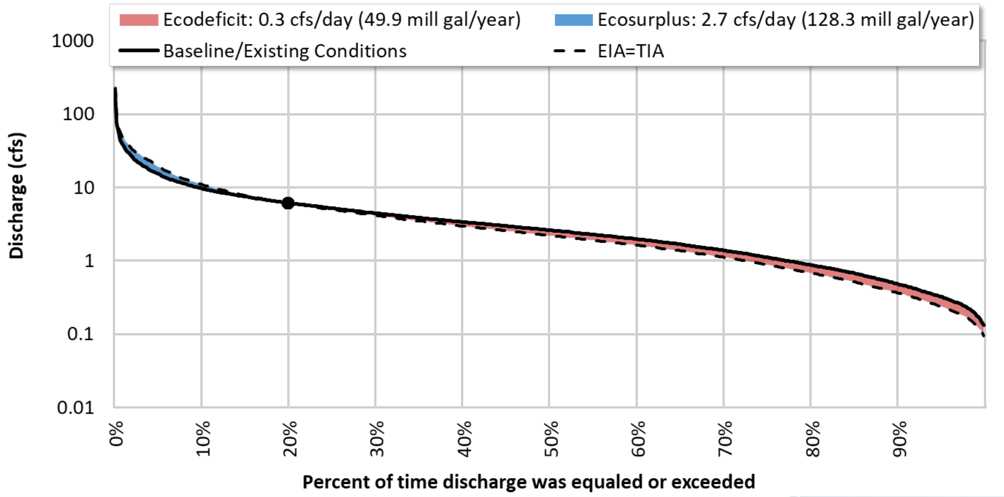


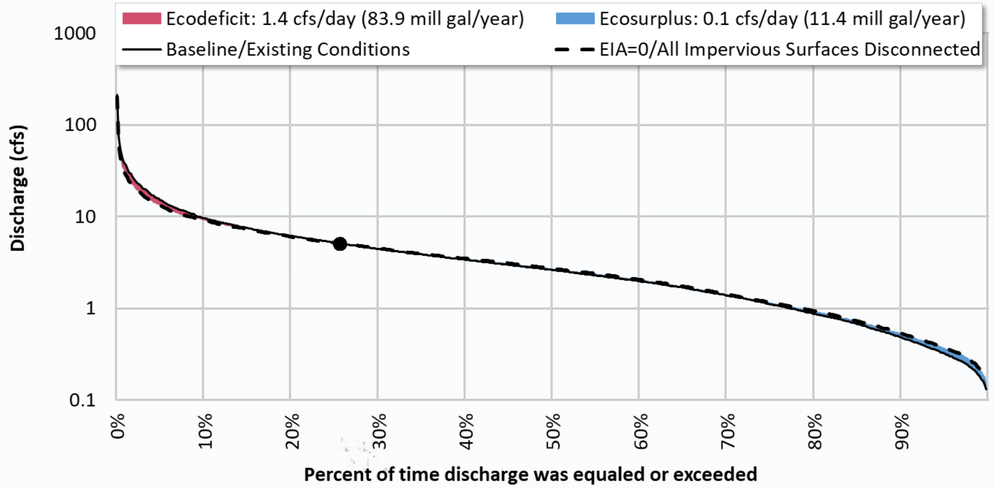
- Roads and urban areas have greater TP export
- Pervious areas can still contribute a large percentage of TP export in less developed watersheds
  - **Managing developed pervious can be important component of watershed reduction targets**



Impact of development on FDCs







HYDROLOGICAL PROCESSES
Hydrol. Process. **30**, 3156–3171 (2016)
Published online 26 April 2016 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10808

Urban base flow with low impact development

Aditi S. Bhaskar,[1]* Dianna M. Hogan[2] and Stacey A. Archfield[3]
[1] *National Science Foundation Postdoctoral Fellow hosted at U.S. Geological Survey, Eastern Geographic Science Center, 12201 Sunrise Valley Drive, MSN 521, Reston, VA, 20192, USA*
[2] *U.S. Geological Survey, Eastern Geographic Science Center, 12201 Sunrise Valley Drive, MSN 521, Reston, VA, 20192, USA*
[3] *U.S. Geological Survey, National Research Program, 12201 Sunrise Valley Drive, MSN 430, Reston, VA, 20192, USA*

URBAN STREAMS

Will it rise or will it fall? Managing the complex effects of urbanization on base flow

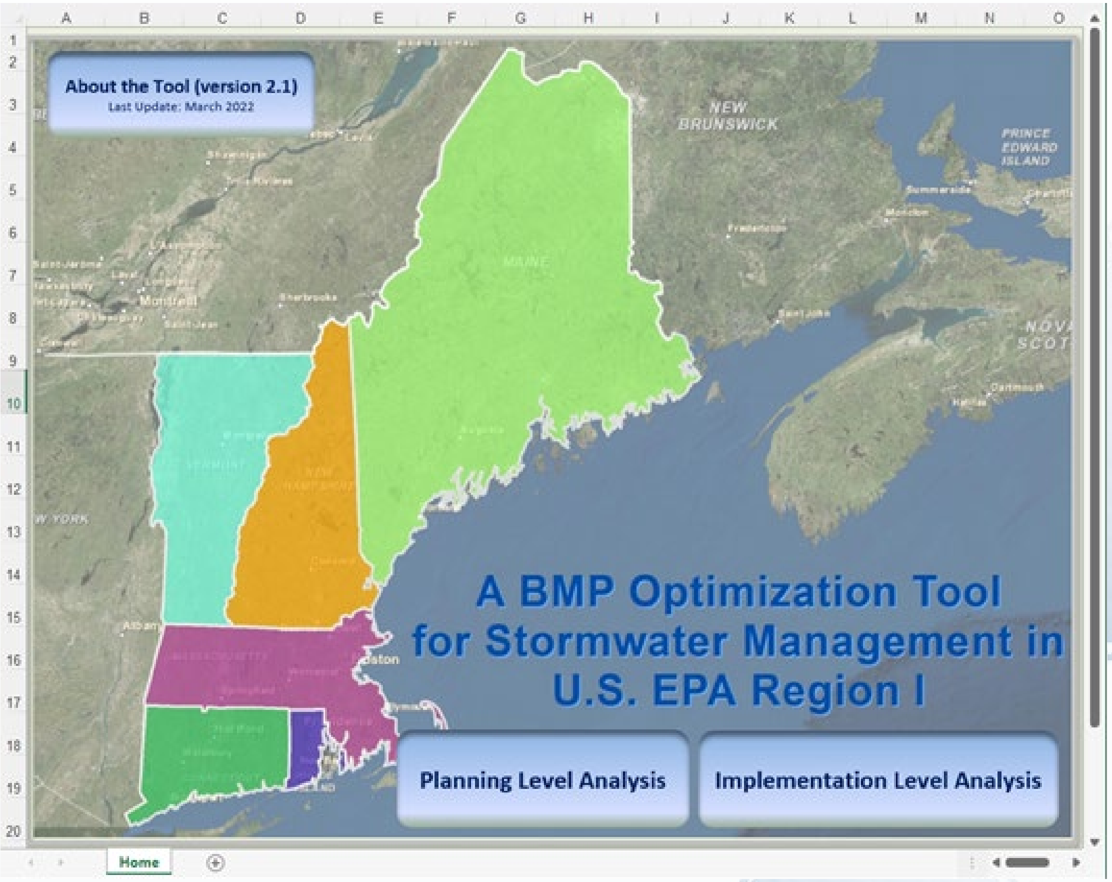
A. S. Bhaskar[1,7], L. Beesley[2,8], M. J. Burns[3,9], T. D. Fletcher[3,10], P. Hamel[4,11], C. E. Oldham[5,12], and A. H. Roy[6,13]

GIS Screening Criteria for SCM Opportunities

Land Use	Within 200 feet of impervious surface	Landscape Slope (%)	Within FEMA Hazard Areas	Within Wellhead Protection Zone	Within Active River Area	Within Wetland	Within 25 feet of Structure?	Soil Group	Management Category	SCM Type(s) in Opti-Tool
Pervious Area	Yes	<= 15	Yes	Yes	Yes	Yes	Yes	All	SCM with complicating characteristics	--
			No	No	No	No	No	A/B/C	Infiltration	Surface Infiltration Basin (e.g., Rain Garden)
								D	Biofiltration	Biofiltration (e.g., Enhanced Bioretention with ISR and underdrain option)
		> 15	--	--	--	--	--	--	SCM with complicating characteristics	--
	No	--	--	--	--	--	--	--	No SCM opportunity	--
Impervious Area		<= 5	Yes	Yes	Yes	Yes	Yes	All	SCM with complicating characteristics	--
			No	No	No	No	No	A/B/C	Infiltration	Infiltration Trench
								D	Shallow filtration	Porous Pavement
		> 5	--	--	--	--	--	--	SCM with complicating characteristics	--

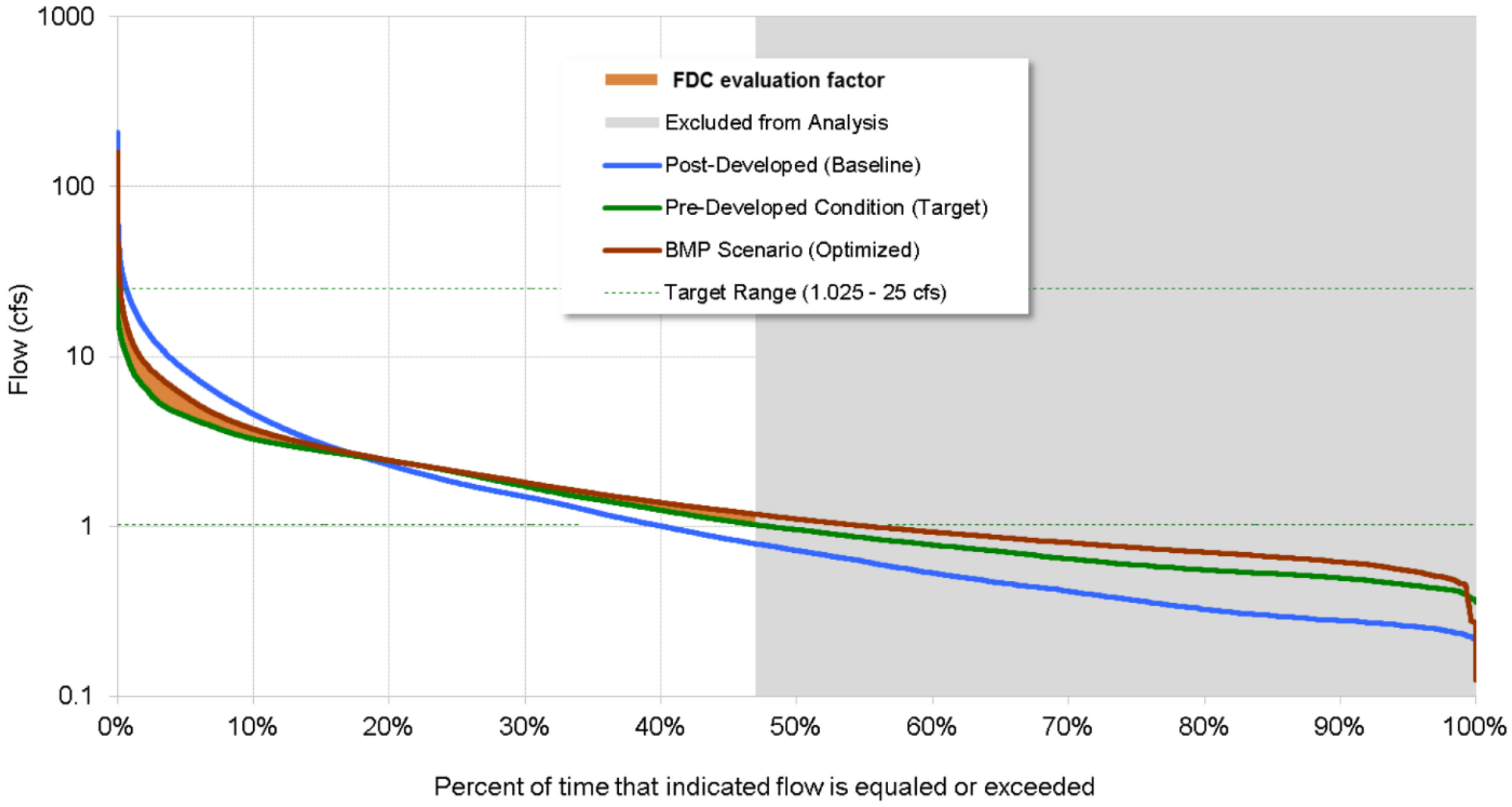
Opti-Tool

- Spreadsheet-based BMP optimization tool
  - **Updates to Opti-Tool**
    - Added FDC as an evaluation factor for optimization
    - Added Green Roof simulation option
    - Added IC Disconnection simulation with and without storage options



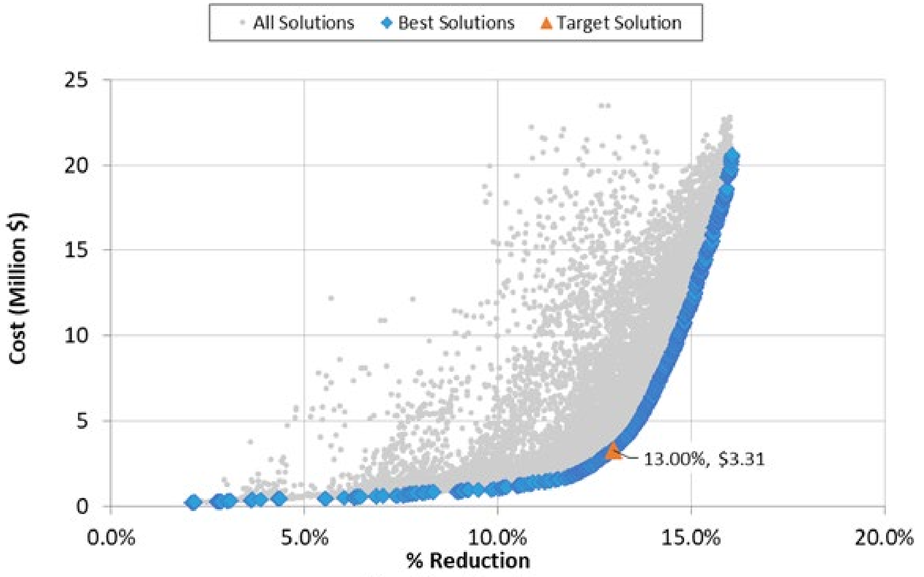
Flow Duration Curve Optimization

- Evaluation Factor: area between two FDCs

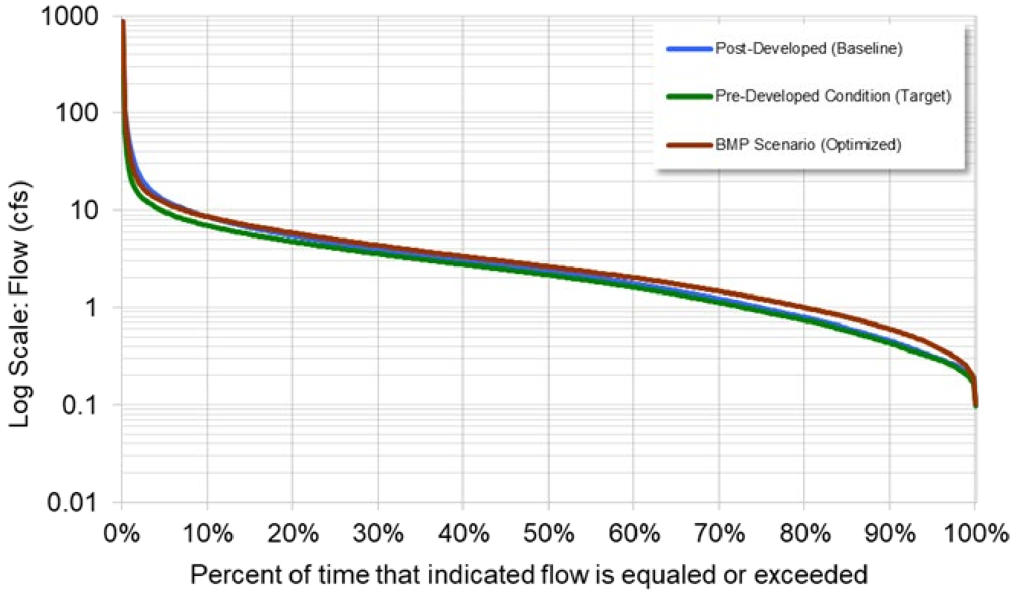


FDC Optimization Example: Upper Hodges Brook

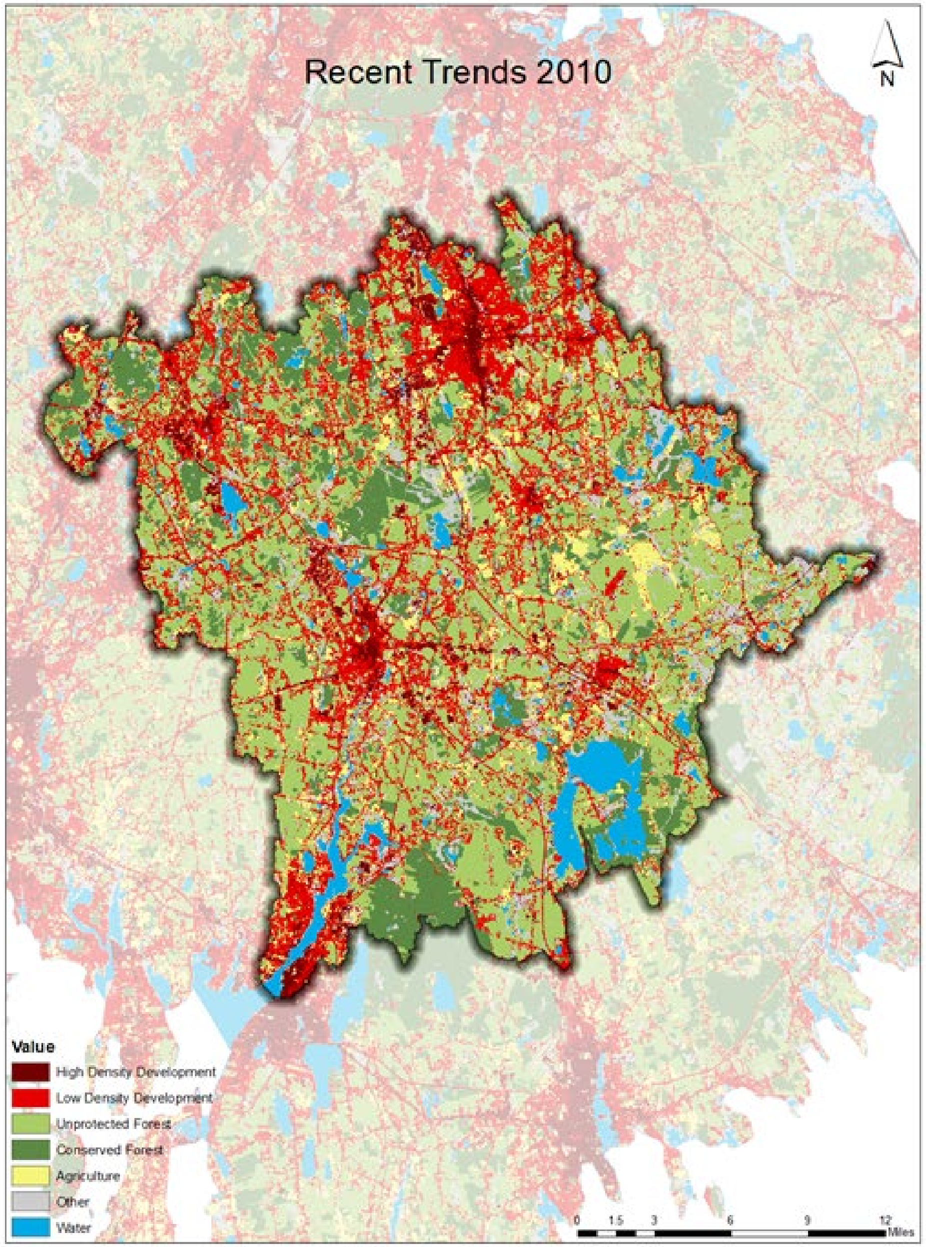
WQ Benefits and Costs of an Optimized Solution	Result
TSS Load Removed (tons/year)	63 (51% reduction from baseline)
TN Load Removed (pounds/year)	1,560 (36% reduction from baseline)
TP Load Removed (pounds/year)	211 (37% reduction from baseline)
Zn Load Removed (pounds/year)	196 (53% reduction from baseline)
Cost per Ton TSS Removed ($)	$52,487
Cost per Pound TN Removed ($)	$2,124
Cost per Pound TP Removed ($)	$15,682
Cost per Pound Zn Removed ($)	$16,893

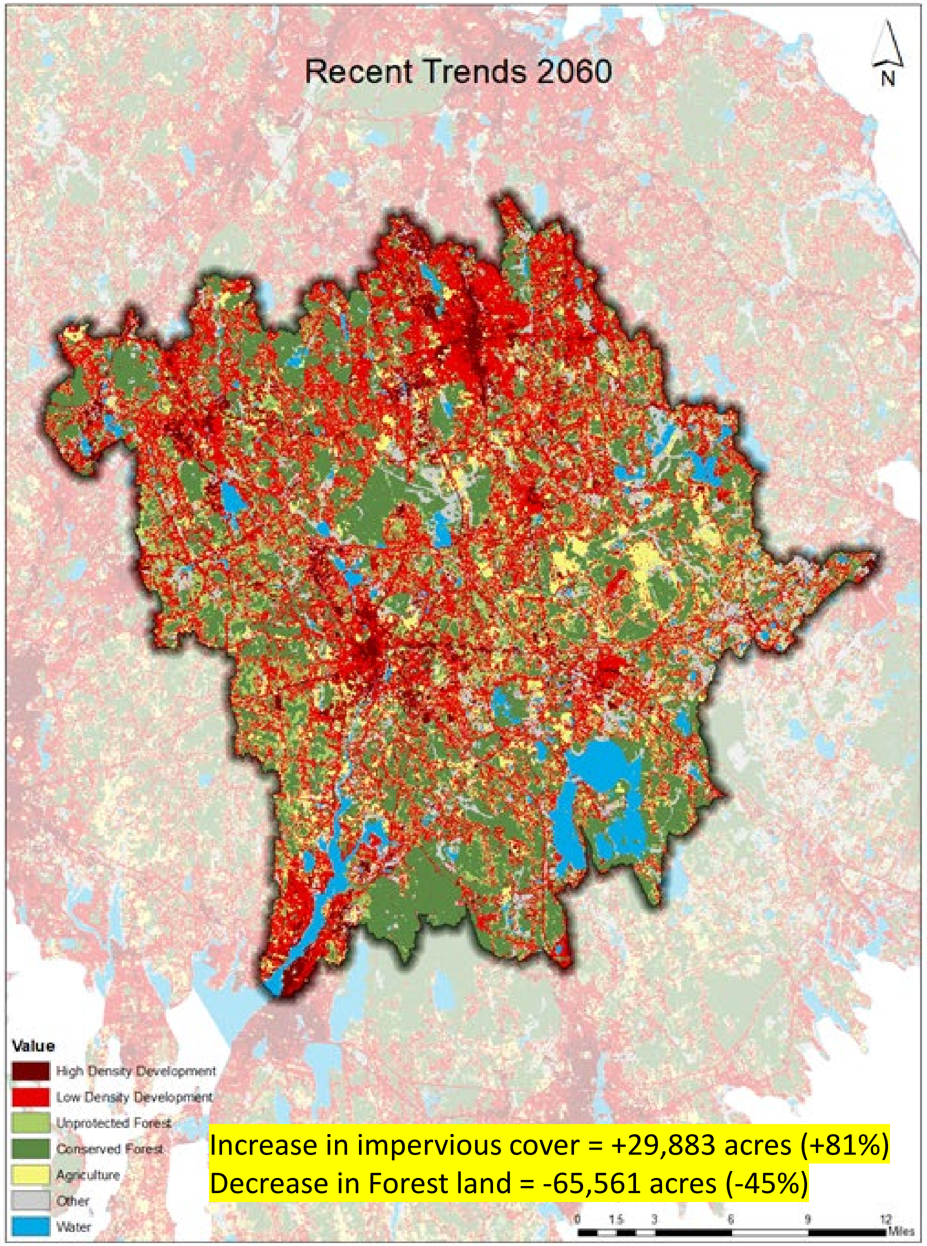


Flow Duration Curve



New England Landscape Futures (NELF) Dataset





Change in Hydrology and WQ for 2060 Future Development

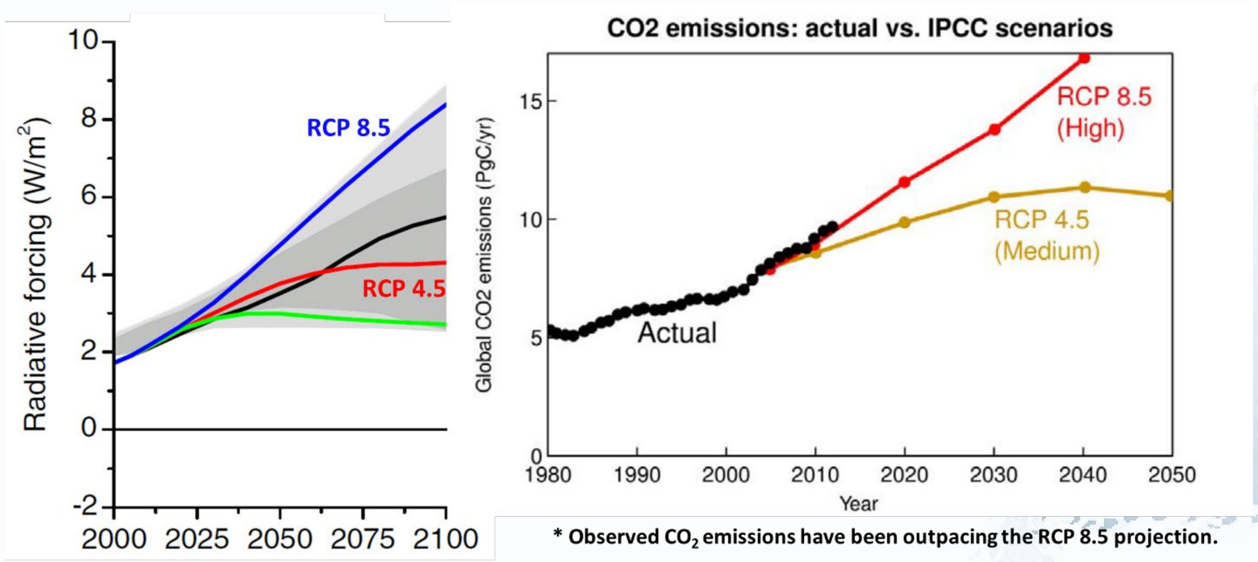
Major Land Use Classification	Annual Average Change				
	Runoff (MG/yr)	GW Recharge (MG/yr)	ET (MG/yr)	TN (lb/yr)	TP (lb/yr)
Paved Forest	0	0	0	0	0
Paved Agriculture	36	0	4	339	44
Paved Commercial	2,487	0	255	30,707	3,615
Paved Industrial	1,416	0	145	17,484	2,058
Paved Low Density Residential	13,290	0	1,361	153,634	16,182
Paved Medium Density Residential	795	0	81	9,192	1,269
Paved High Density Residential	1,463	0	150	16,905	2,823
Paved Transportation	12,168	0	1,246	101,133	15,101
Paved Open Land	5,232	0	536	48,661	6,646
Developed OpenSpace	14,095	17,376	16,307	59,202	5,516
Forested Wetland	0	0	0	0	0
Non-Forested Wetland	0	0	0	0	0
Forest	-15,485	-29,331	-44,628	-56,406	-11,193
Agriculture	174	220	303	2,916	485
TOTAL	**35,674**	**-11,734**	**-24,240**	**383,765**	**42,545**

Units: MG – million gallons, lb – pounds, yr – year

Note: A standard water tower can hold 1 million gallons of water and a typical large dump truck can carry about 28,000 pounds.

Representative Concentration Pathways (RCP) for Climate Change Analysis

- 64 future climate conditions were modeled
  - **32 General Circulation Models (GCMs)**
  - **2 Representative Concentration Pathways (RCPs)**
- Subset of future climate models selected based on ecosurplus and ecodeficit they produced

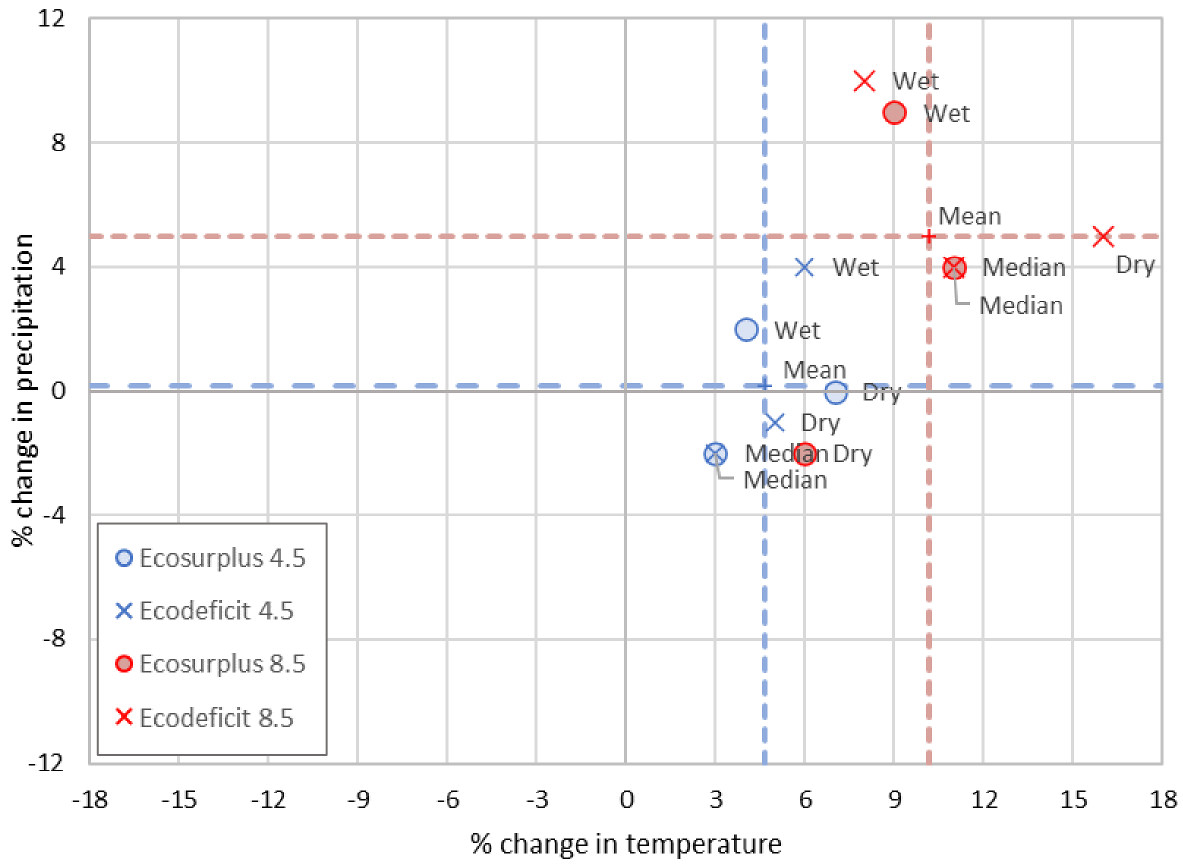


* Observed CO_2 emissions have been outpacing the RCP 8.5 projection.

Source: International Institute for Applied Systems Analysis, 2009

Future Precipitation and Temperature

- Annual precipitation projected to increase 5–8% by 2064.
  - **Massachusetts Climate Change Report[2]**
- Summer months are expected to become drier
- Winters are expected to become wetter[3].



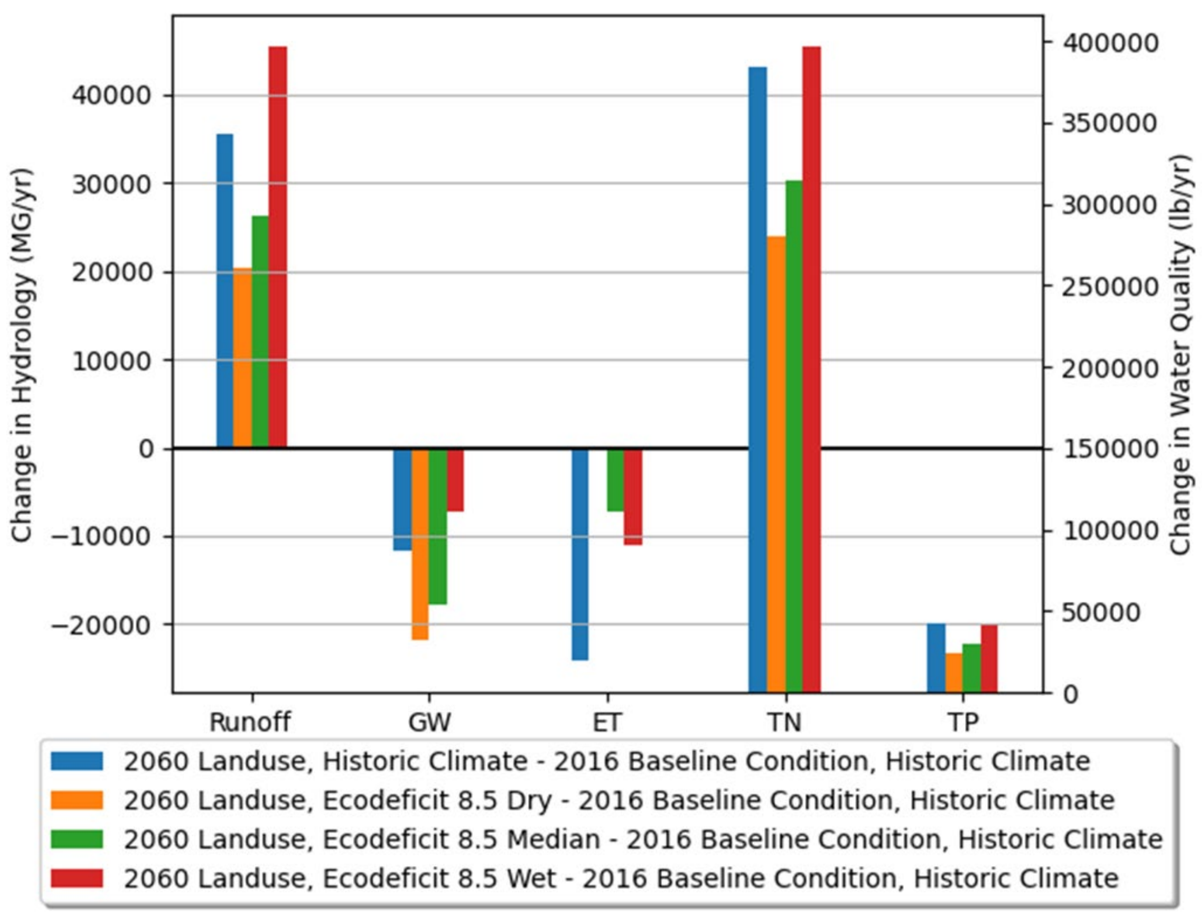
RCP	Scenario [1]	Ecosuplus Model	Ecodeficit Model
RCP 4.5	Dry	hadgem2-cc-1	mpi-esm-mr-1
	Median	bcc-csm1-1-m-1	bcc-csm1-1-m-1
	Wet	bcc-csm1-1-1	miroc-esm-chem-1
RCP 8.5	Dry	inmcm4-1	
	Median	cesm1-cam5-1	
	Wet	cesm1-bgc-1	

1: Dry, Median, and Wet correspond to the 20th, 50th, and 80th percentile hydrological responses. Models chosen for FDC Phase 2 are highlighted in yellow.

[2]MA EOEE, 2011. Climate Change Adaptation Report.
[3]Hayhoe, C.P., Wake, T.G., Huntington, L., Luo, M.D., Schrawtz, J., Sheffield, E., Wood, E., Anderson, B., Bradbury, A., Degaetano, T.J., Wolfe, D., 2006. Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast. Clim Dyn 28, 381–707. https://doi.org/10.1007

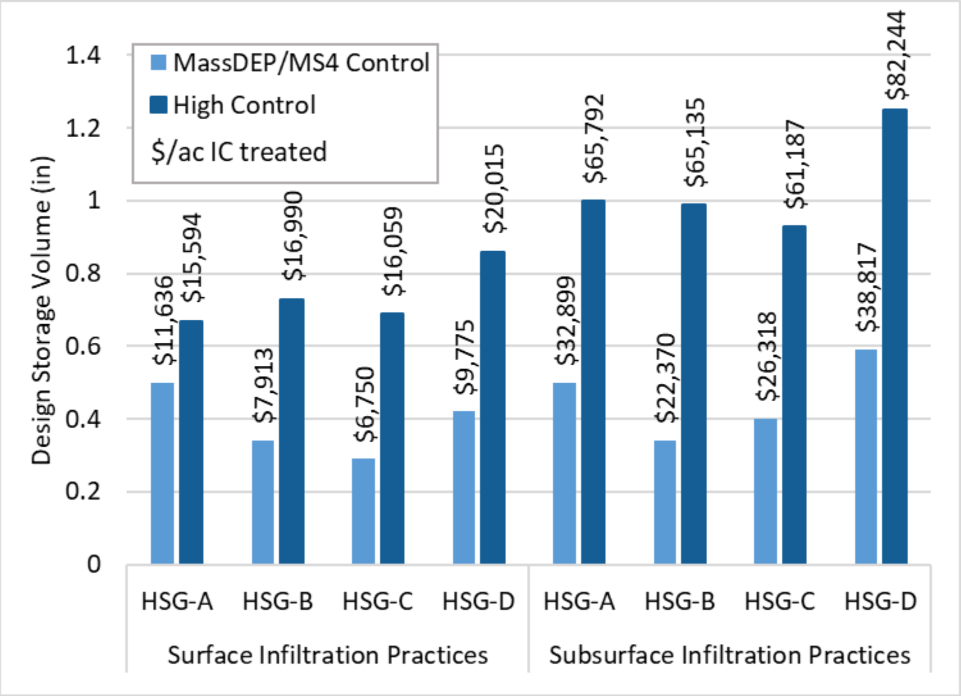
Changes to Hydrology and Water Quality Under Future Conditions

- Increased impervious cover:
  - Increases runoff volume and nutrient loads
  - Decreases groundwater recharge (GW) and evapotranspiration (ET)
- Future climate can amplify or dampen the change in hydrology and water quality
  - e.g., a wet future climate has more runoff than a dry one

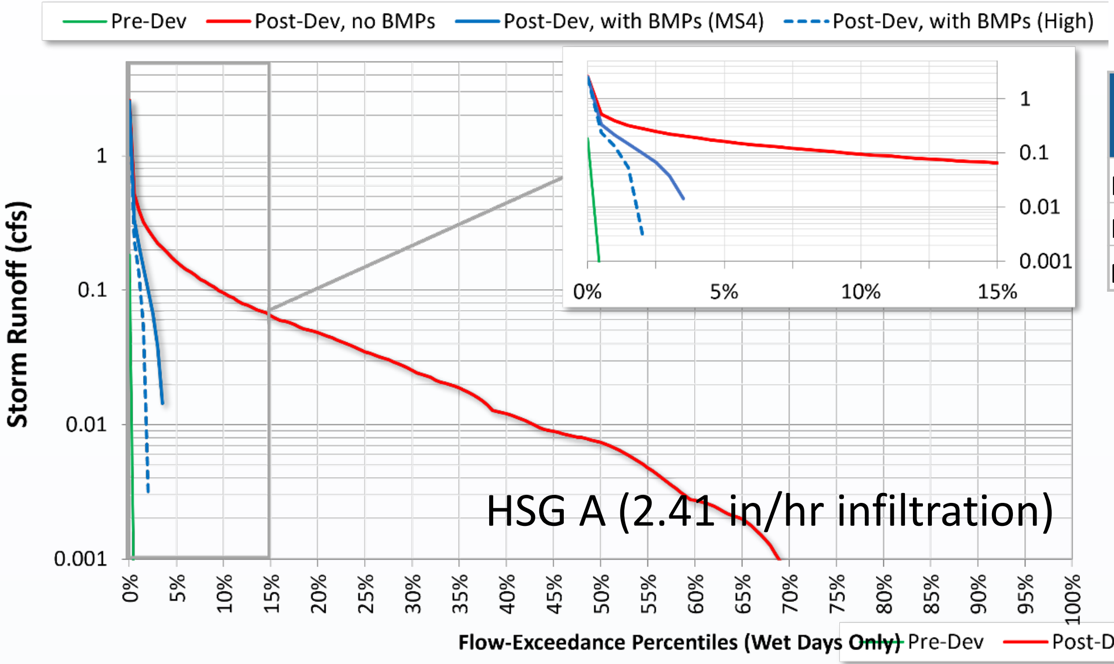


Current and Next-Generation SCMs Design

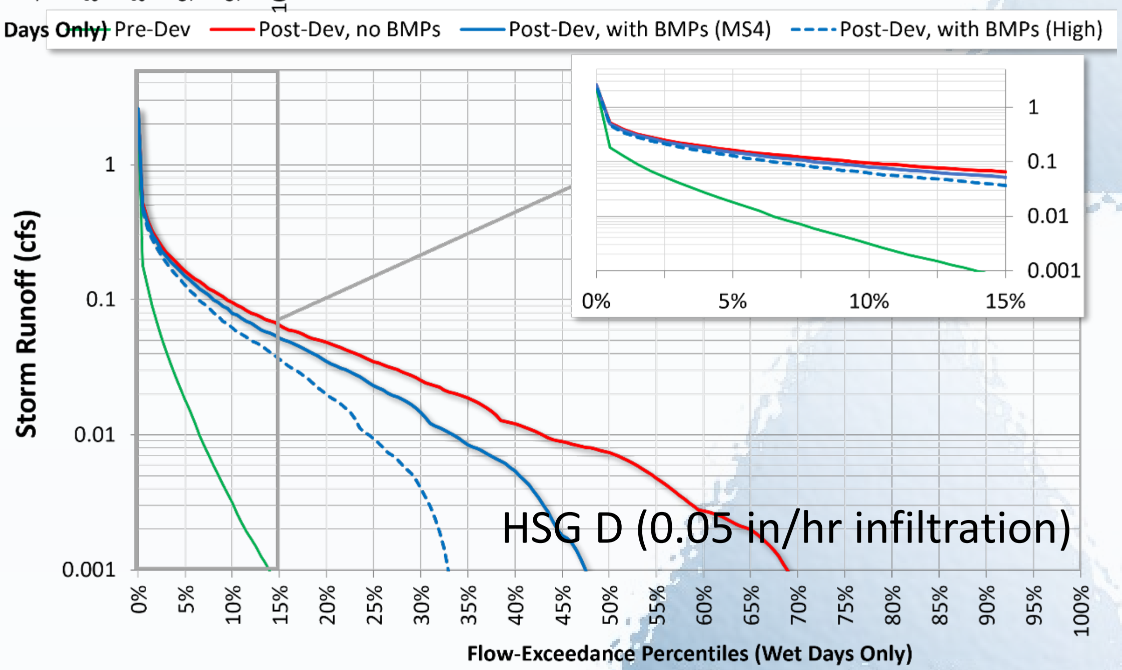
- Current MassDEP and MS4 control standards require reductions in TP by 60% and TSS by 90% and groundwater recharge based on hydrologic soil group
- Next-generation SCMs sized to meet predeveloped recharge conditions with no net increase in nutrient export
  - **Must be resilient to future climate conditions**
- Current standard and next-generation SCMs were tested using Opti-Tool with both historic and future land use and climate conditions



Comparison of Current to Next-Generation SCMs

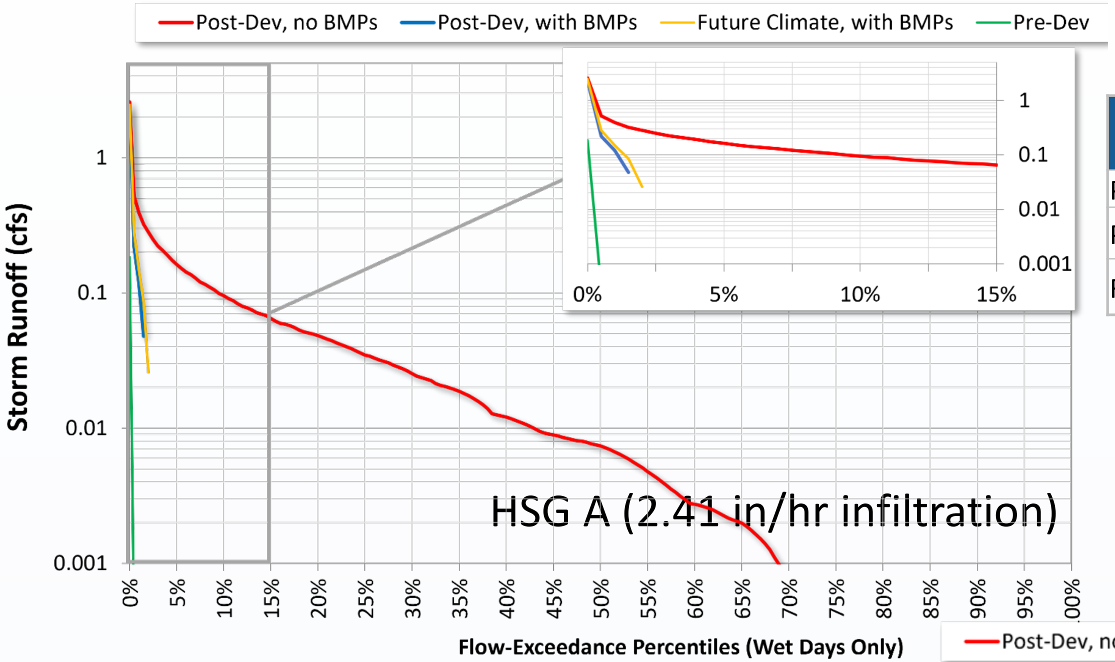


SCM Category	Compared to Predevelopment	
	MG/ac IC/yr	%
Post-Dev, no BMPs	+10.66	+4,839%
Post-Dev, with BMPs (MS4)	+3.86	+1,751%
Post-Dev, with BMPs (High)	**+3.19**	**+1,448%**

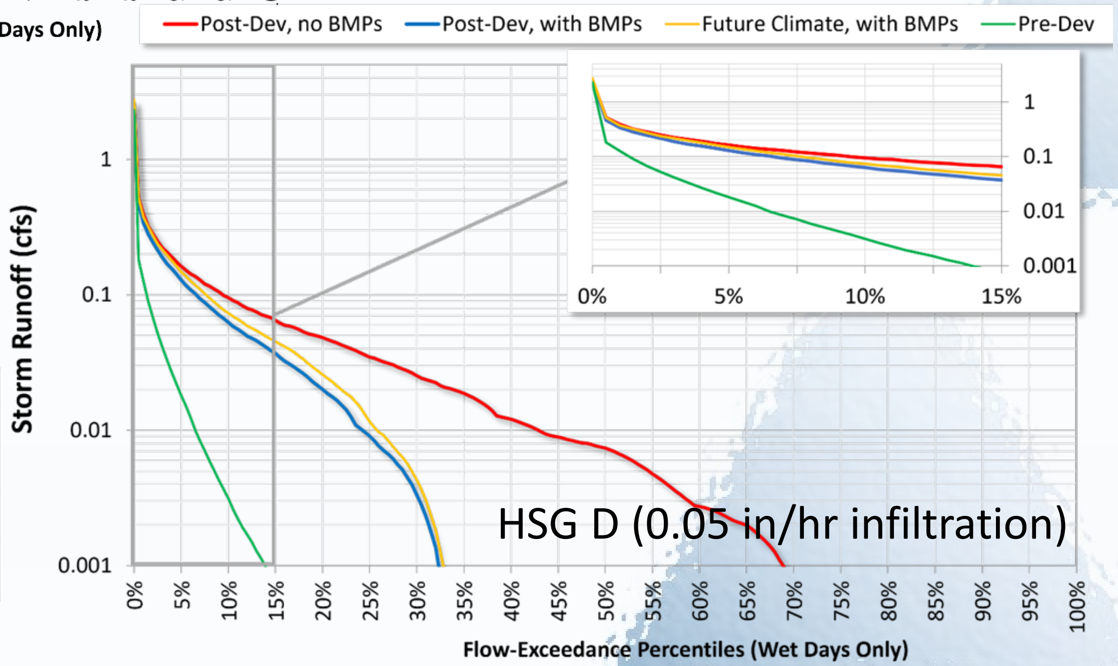


SCM Category	Compared to Predevelopment	
	MG/ac IC/yr	%
Post-Dev, no BMPs	+7.26	+201%
Post-Dev, with BMPs (MS4)	+5.76	+159%
Post-Dev, with BMPs (High)	**+4.31**	**+119%**

Resiliency of Next-Generation SCMs



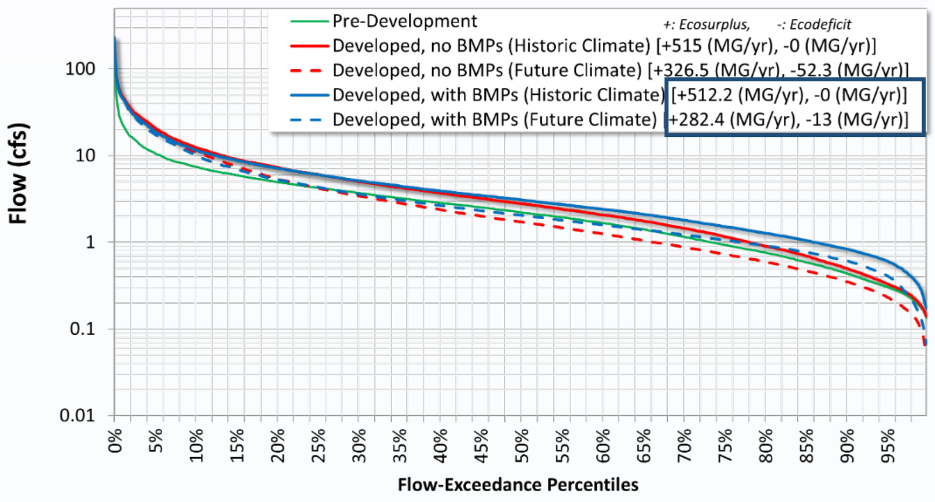
SCM Category	Compared to Predevelopment	
	MG/ac IC/yr	%
Post-Dev, no BMPs	+10.66	+4,839%
Post-Dev, with BMPs	+3.19	+1,448%
Future Climate, with BMPs	+3.57	+1,620%



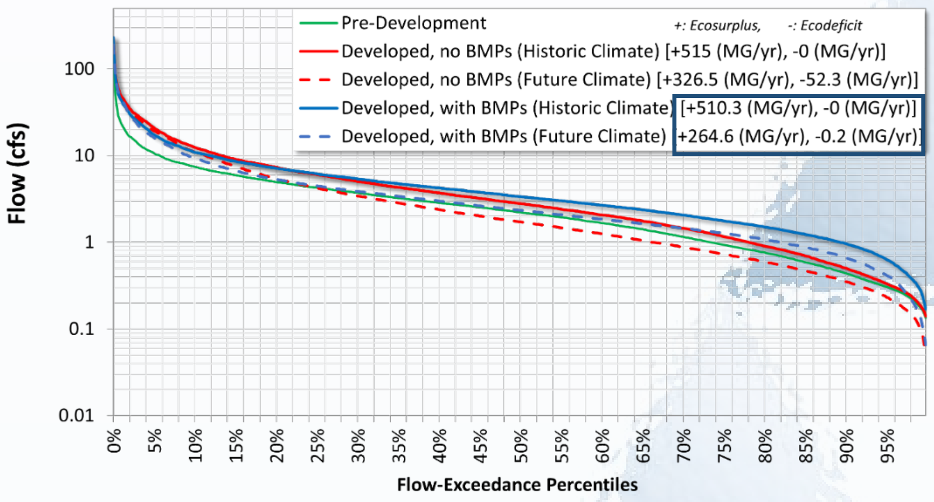
SCM Category	Compared to Predevelopment	
	MG/ac IC/yr	%
Post-Dev, no BMPs	+7.26	+201%
Post-Dev, with BMPs	+4.31	+119%
Future Climate, with BMPs	+5.34	+148%

FDCs for Current and Next-Gen SCMs: Upper Hodges Brook

- Next-generation SCMs provide benefits across the entire flow regime
  - **reduce ecodeficit and ecosurplus caused by future climate change**



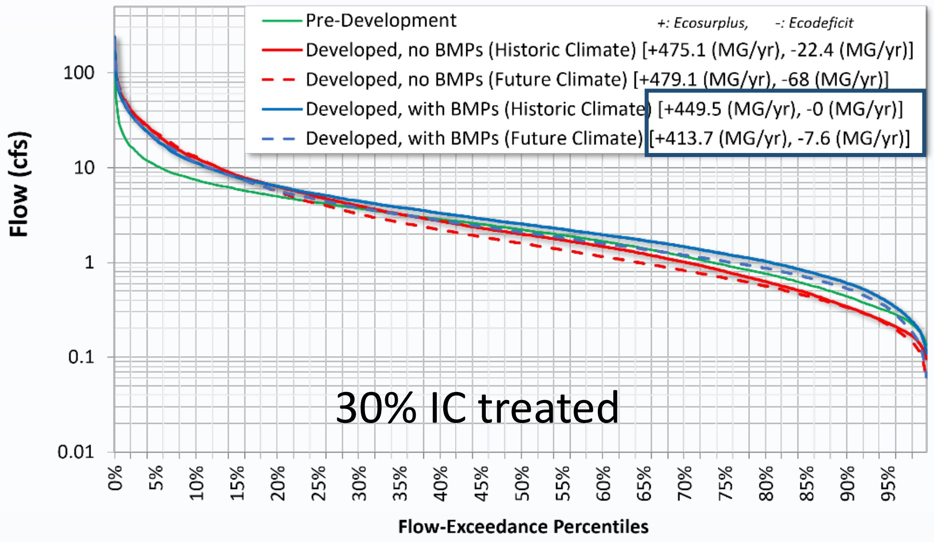
Flow duration curve with **MS4 control** SCMs treating 80% of the Upper Hodges Brook subwatershed's impervious cover under historic LULC with both historic and future climate conditions

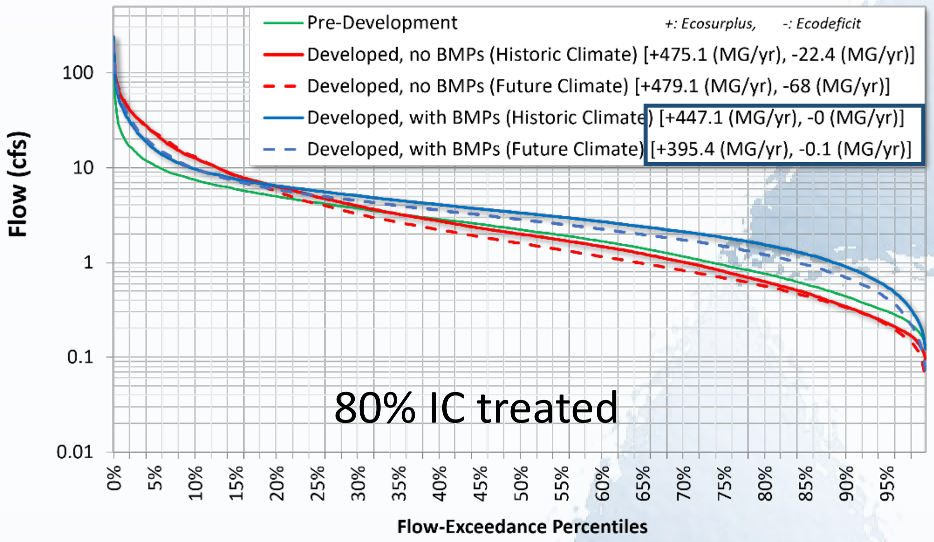


Flow duration curve with **High control** SCMs treating 80% of the Upper Hodges Brook subwatershed's impervious cover under historic LULC with both historic and future climate conditions

FDCs for 1-inch Retention SCMs: Upper Hodges Brook

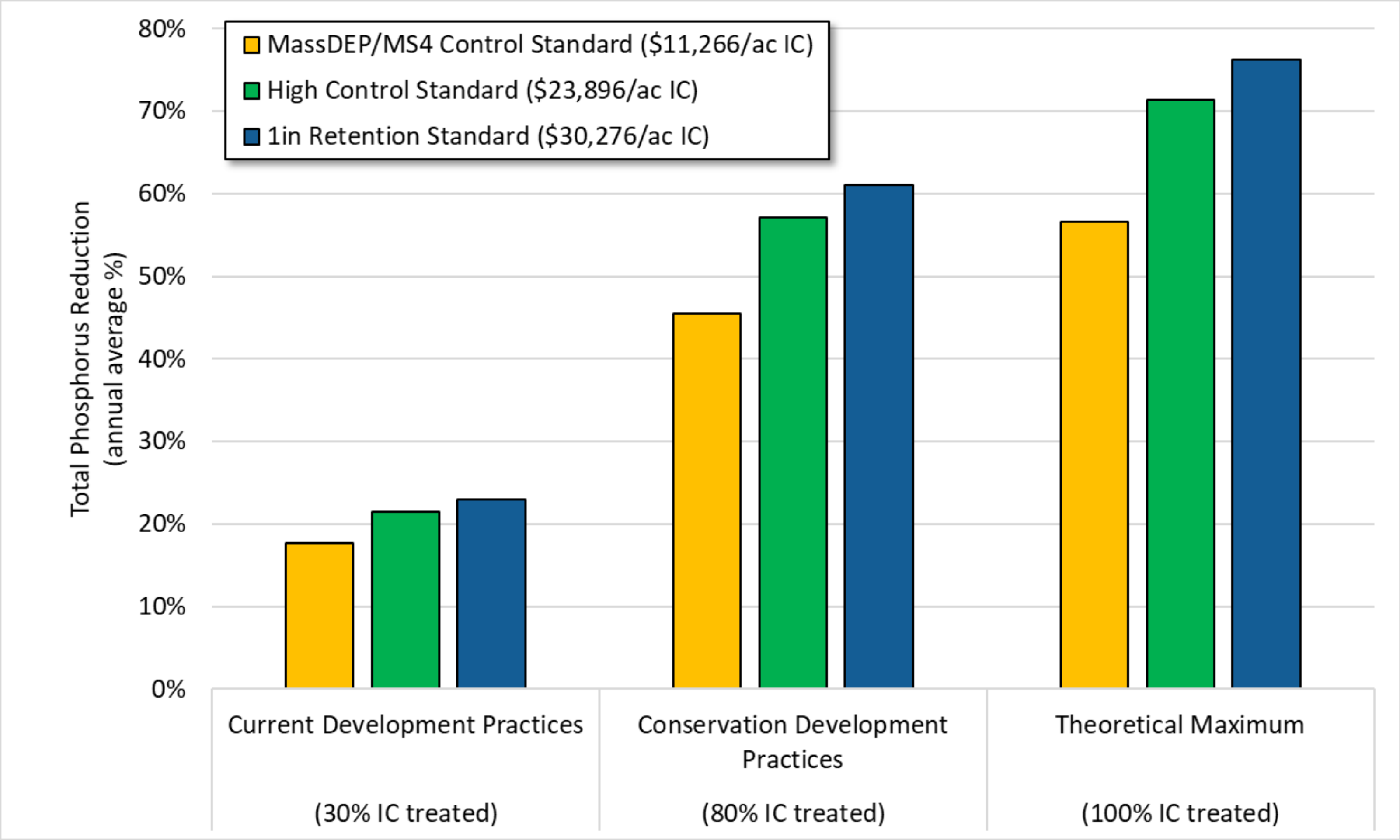
- Using a static 1-inch retention for sizing all SCMs also reduces ecosurplus and deficit with future land use and future climate
  - **Not varying SCM size by HSG increases cost**





Flow duration curve with **1-inch retention** SCMs treating **30% and 80%** of the Upper Hodges Brook subwatershed's impervious cover under future LULC with both historic and future climate conditions

SCMs TP Efficiency: Upper Hodges Brook



Conclusions

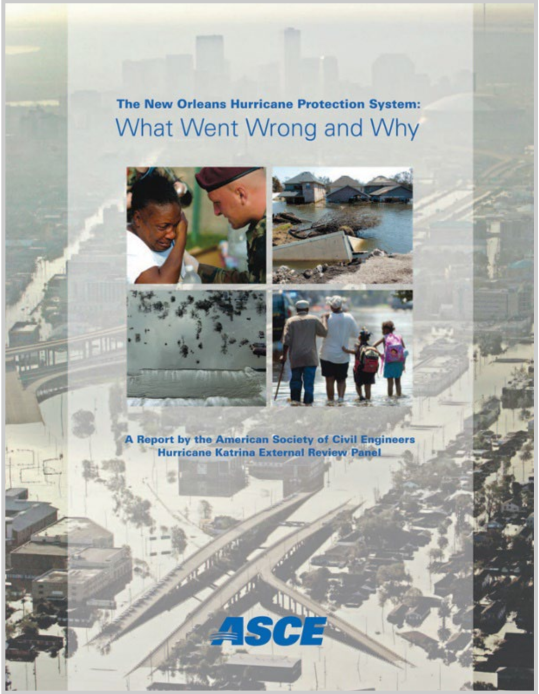
- The impact that development has on a FDC can vary depending on the intensity of development
- In the study watersheds, developed watersheds, including those that manage stormwater through impervious surface disconnection, tended to have higher flows across the FDC compared to pre-development conditions
- However, baseflows fell below pre-development conditions when the amount of connected impervious surfaces were substantially increased
  - **There appears to be a threshold somewhere between the forested and highly developed watershed conditions where baseflows may increase or decrease. Effect of infiltration and ET opportunities**
- The results improve our understanding of the extent to which SCMs restore predevelopment streamflows and improve watershed functions
- While SCM implementation can mitigate some of the impacts of impervious surfaces, it may be difficult to attain pre-development watershed functions without landscape-level changes that promote additional evapotranspiration
  - **There is also a need for source control on pervious surfaces to meet the WQ objective at the watershed-scale**
- SCM implementation can mitigate some of the impacts of climate change, especially projected lower baseflows, by promoting groundwater recharge

THE NEED FOR RESILIENT LANDSCAPES IS EVER INCREASING

- Current changes in rainfall depth
  - NRCC shows a 23-27% increase across New England for last 20+ years
- Future changes in rainfall depth
  - IPCC predicts a 15-25% increase by 2075
- Impacts of Sea Level Rise (SLR)
- Impacts of Sea Level Rise (SLR) and Storm Surge

10 Lessons Learned from Katrina by the ASCE Hurricane Katrina External Review Panel and the USACE Interagency Performance Evaluation Task Force

1. Failure to think globally and act locally-We must account for climate change
2. Failure to absorb new knowledge
3. Failure to understand, manage, and communicate risk-Need to take rigorous risk based approach,
4. Failure to build quality in
5. Failure to build in resilience
6. Failure to provide redundancy
7. Failure to see that the sum of many parts does not equal a system
8. The buck couldn't find a place to stop--Poor organization, lack of accountability
9. Beware of interfaces: materials and jurisdiction
10. Follow the money-People responsible for design and construction had no control of the monies.



The New Orleans Levees: The Worst Engineering Catastrophe in U.S. History – What Went Wrong and Why

Conceptual Design Plans

NEXT-GENERATION WATERSHED MANAGEMENT

CONSERVATION DEVELOPMENT - MAINTENANCE OF PREDEVELOPMENT HYDROLOGY, NUTRIENT LOAD, AND LANDSCAPE RESILIENCY

- Evaluate performance and cost based on real permitted projects
- Enables the examination of the real costs and benefits for actual viable projects
- Scenario analyses done at 4 levels:
  - Pre-development
  - No-controls
  - Minimum level LID per MassDEP
  - LID Infiltration for Water Quality and Peak Control

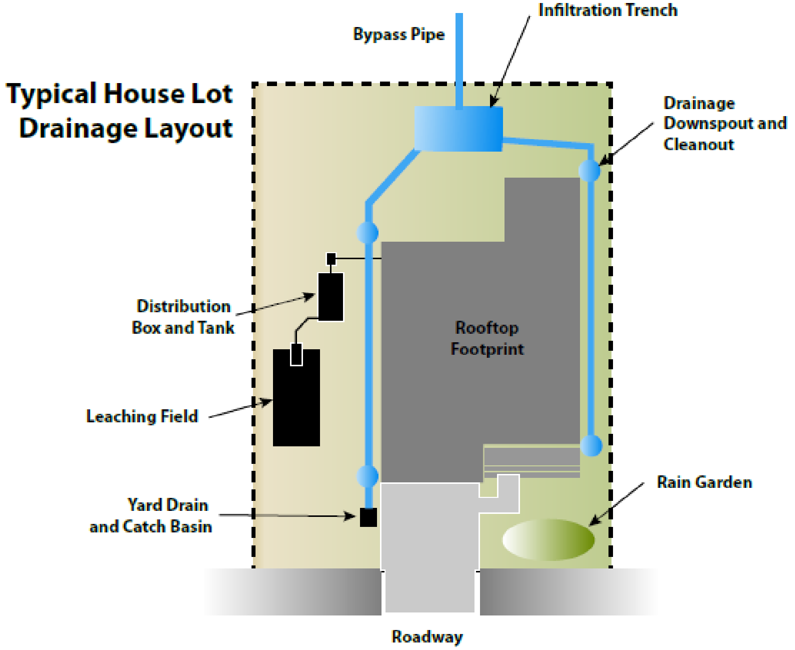
CONSERVATION DEVELOPMENT

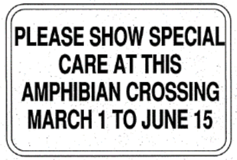
- 105-acre conservation development
- Designed to integrate homes with the landscape and provide protection for water quality and habitat.
- Sustainable development makes sense
- Exceptional and added value by Going Green
- Use of porous asphalt roadways enabled ~5 additional lot, a 12% increase
- Reduced time for environmental permitting and design
- Beautiful aesthetics with limited clearing, working around natural resources
- Over 55+ community managed by HOA and Maintenance vendor

LOT LAYOUT AND DRAINAGE

ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

- Lots designed to be nearly zero discharge
- Raingardens
- Rooftop infiltration
- Porous asphalt roadways and driveways
- Amended soils, limited lot clearing crossing
- **Conservation measures** to protect habitat for high value natural resources like Atlantic Cedar, vernal pools, frogs and other critters.
- ACOE Vernal Pool Recommendations[1]





CRITTER CROSSING ROAD SIGNAGE

ROLLINS HILL

STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

GREEN INFRASTRUCTURE

NEW HAMPSHIRE CERTIFIED
GREEN
SnowPro

INFILTRATION FOR ROOFTOP RUNOFF

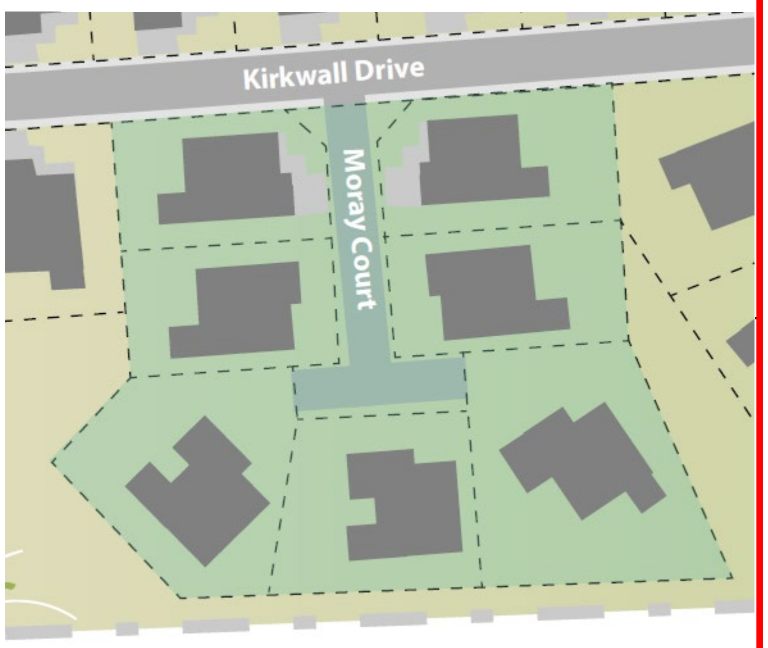
LOW CHLORIDE

POROUS ASPHALT ROADWAYS AND DRIVEWAYS

BIORETENTION AND BIOSWALE

ROADWAY SUBSURFACE INFILTRATION

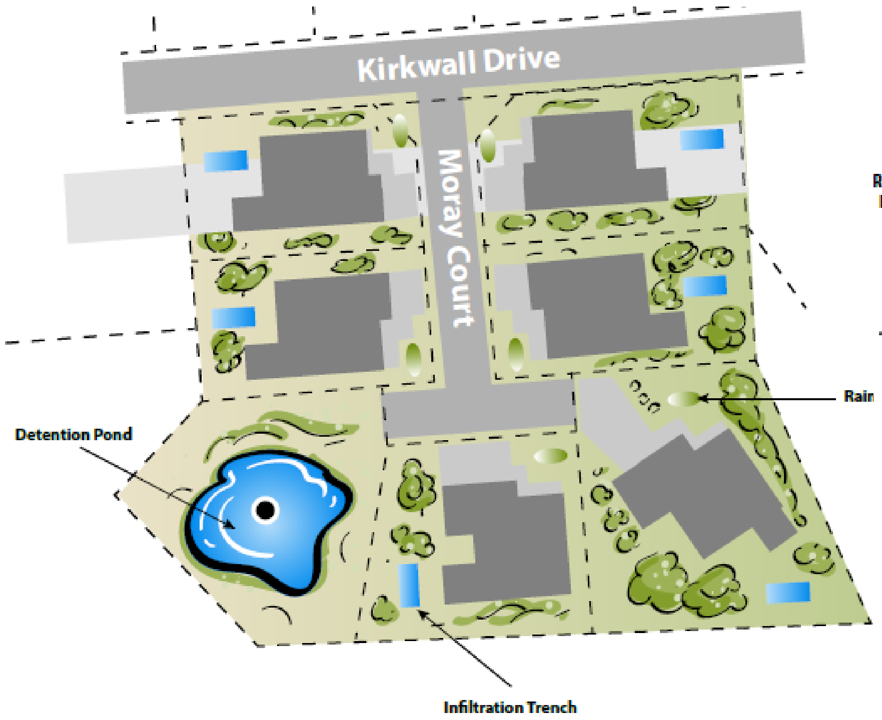
CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-B



CD1.2 No Controls High Density Residential

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY



CD1.3 LID MADEP High Density Residential

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.4 LID Peak High Density Residential

LID VOLUME

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-B

CD1.2 No Controls High Density Residential

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- NO BMPS
- COMMON FOR PROJECTS THAT DON'T TRIGGER STATE OR FEDERAL REQUIREMENTS
- AND MUNICIPALITIES WITH WEAK SWM REGULATIONS

CD1.3 LID MADEP High Density Residential

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- 3 BMP TYPES:
  - RAIN GARDEN (DRIVEWAYS), 0.5" WQV
  - SUBSURFACE INFILTRATION TRENCH (ROOFTOP), 0.5" WQV
  - DETENTION POND (ROADWAYS)
- RAINGARDEN AND ROOFTOP INFILTRATION TO SATISFY STDS 3 (GRV) AND STD 4 (NITROGEN AND PHOSPHOROUS)
- DETENTION POND TO SATISFY STD 2 (Q-PEAK)

CD1.4 LID Peak High Density Residential

LID VOLUME

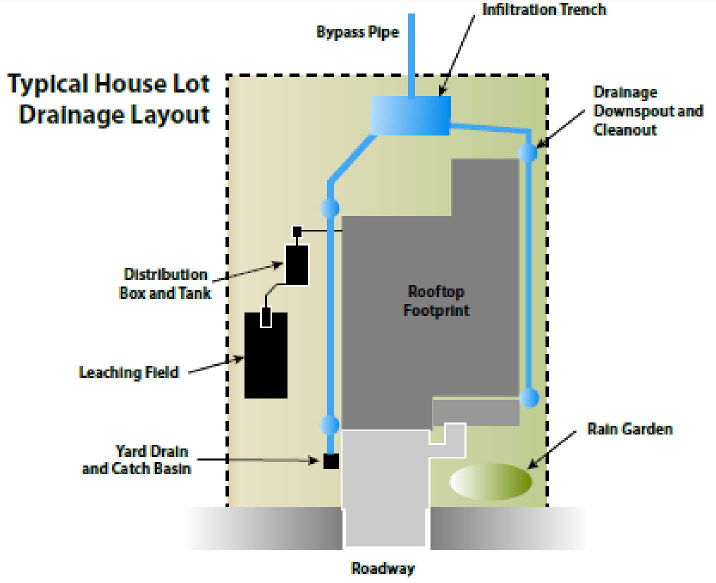
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

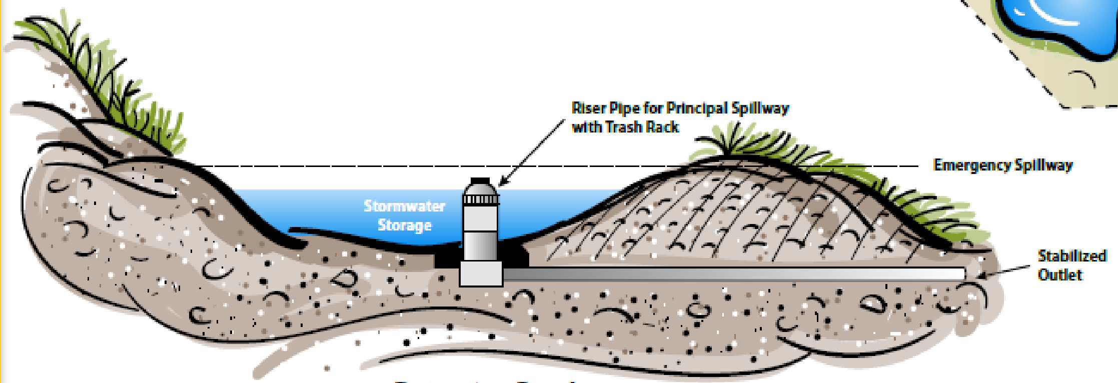
- 2 BMP TYPES:
- SUBSURFACE INFILTRATION FOR ROADWAYS AND DRIVEWAYS
- ROOFTOP INFILTRATION TO SATISFY STDS 3 (GRV) AND STD 4 (NITROGEN AND PHOSPHOROUS) , 1" WQV
- ROADWAY INFILTRATION TO SATISFY STD 2 (Q-PEAK), STRUCTURAL DESIGN

CD1.3 LID MADEP High Density Residential

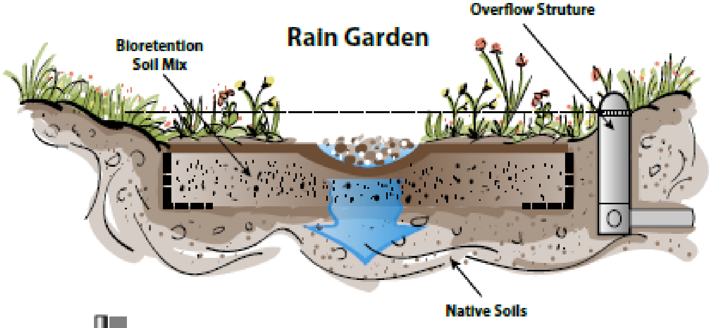
LID MADEP

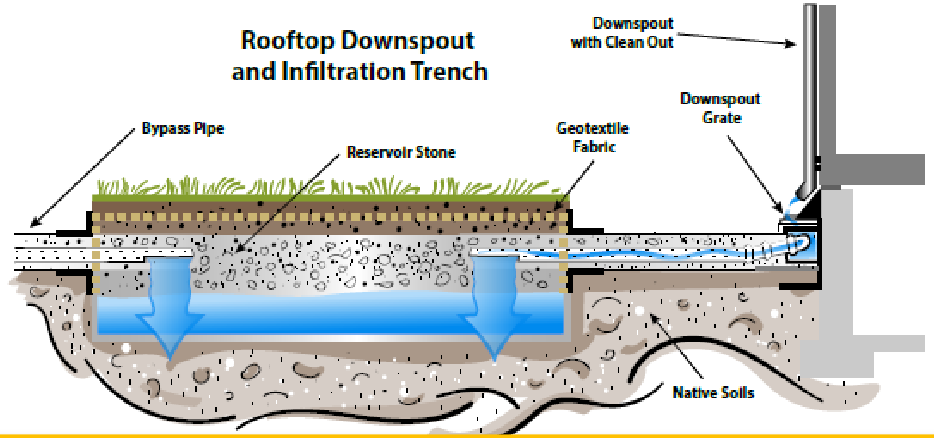
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY





Detention Pond



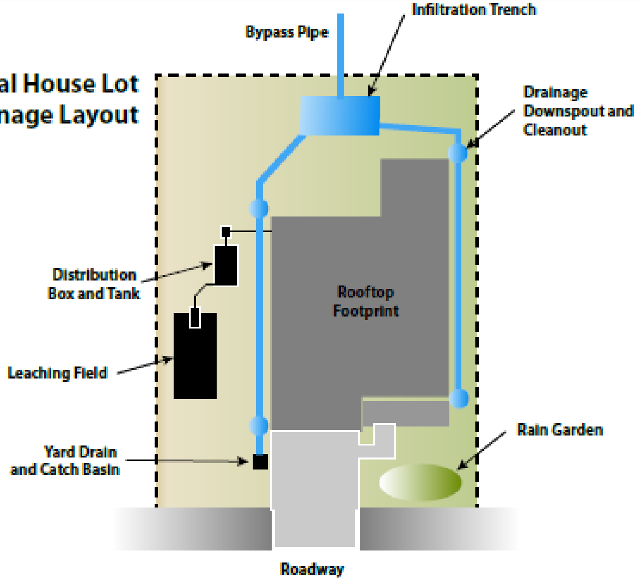


CD1.4 LID Peak High Density Residential

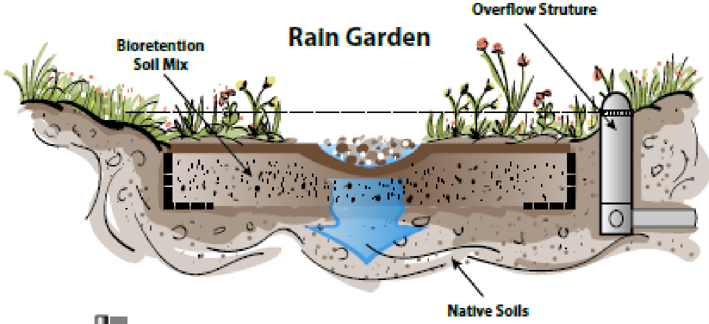
LID VOLUME

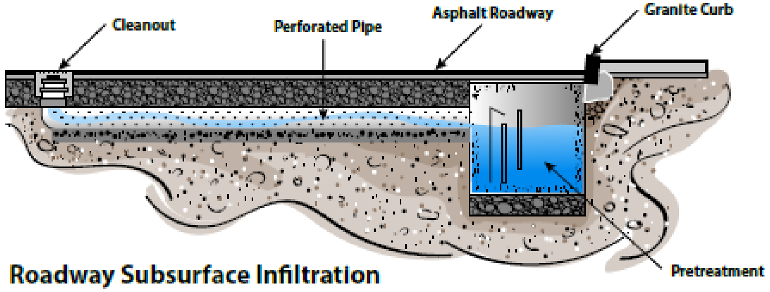
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

Typical House Lot Drainage Layout



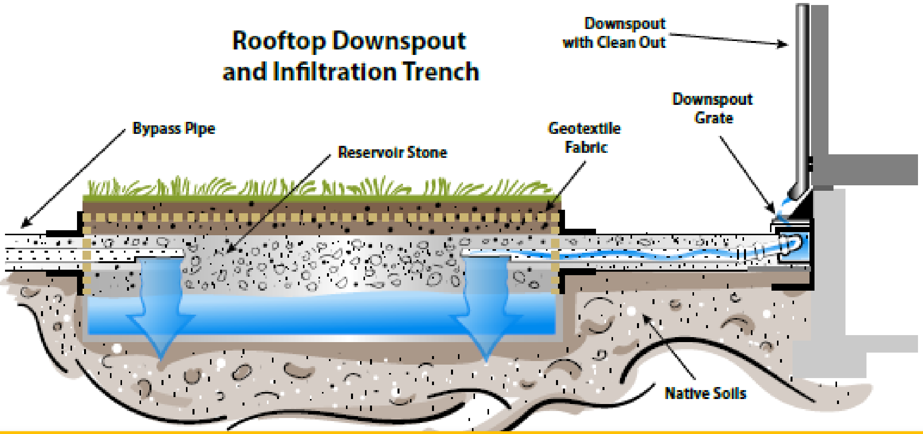
Rain Garden





Roadway Subsurface Infiltration and Pretreatment System

Rooftop Downspout and Infiltration Trench



CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.2 No Controls High Density Residential

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.3 LID MADEP High Density Residential

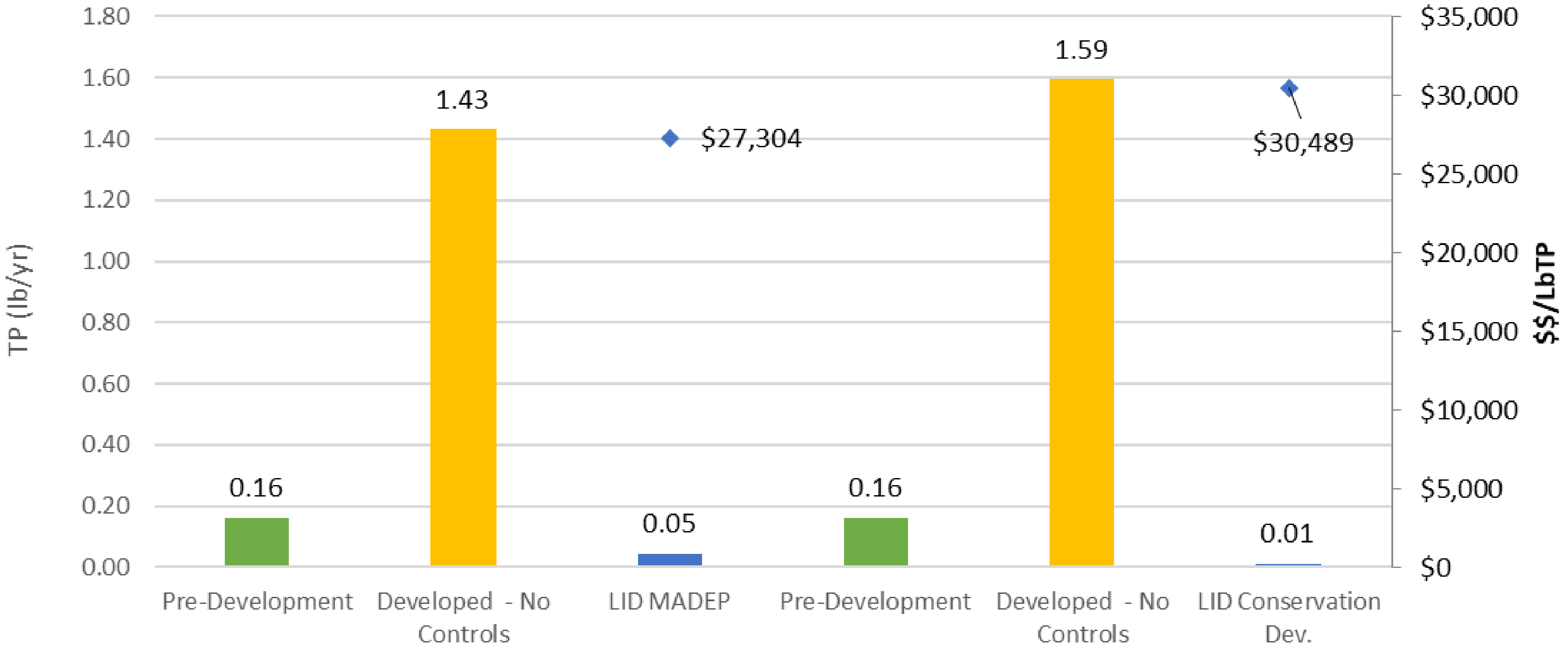
LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.4 LID Peak High Density Residential

LID VOLUME

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY



CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.3 LID MADEP High Density Residential

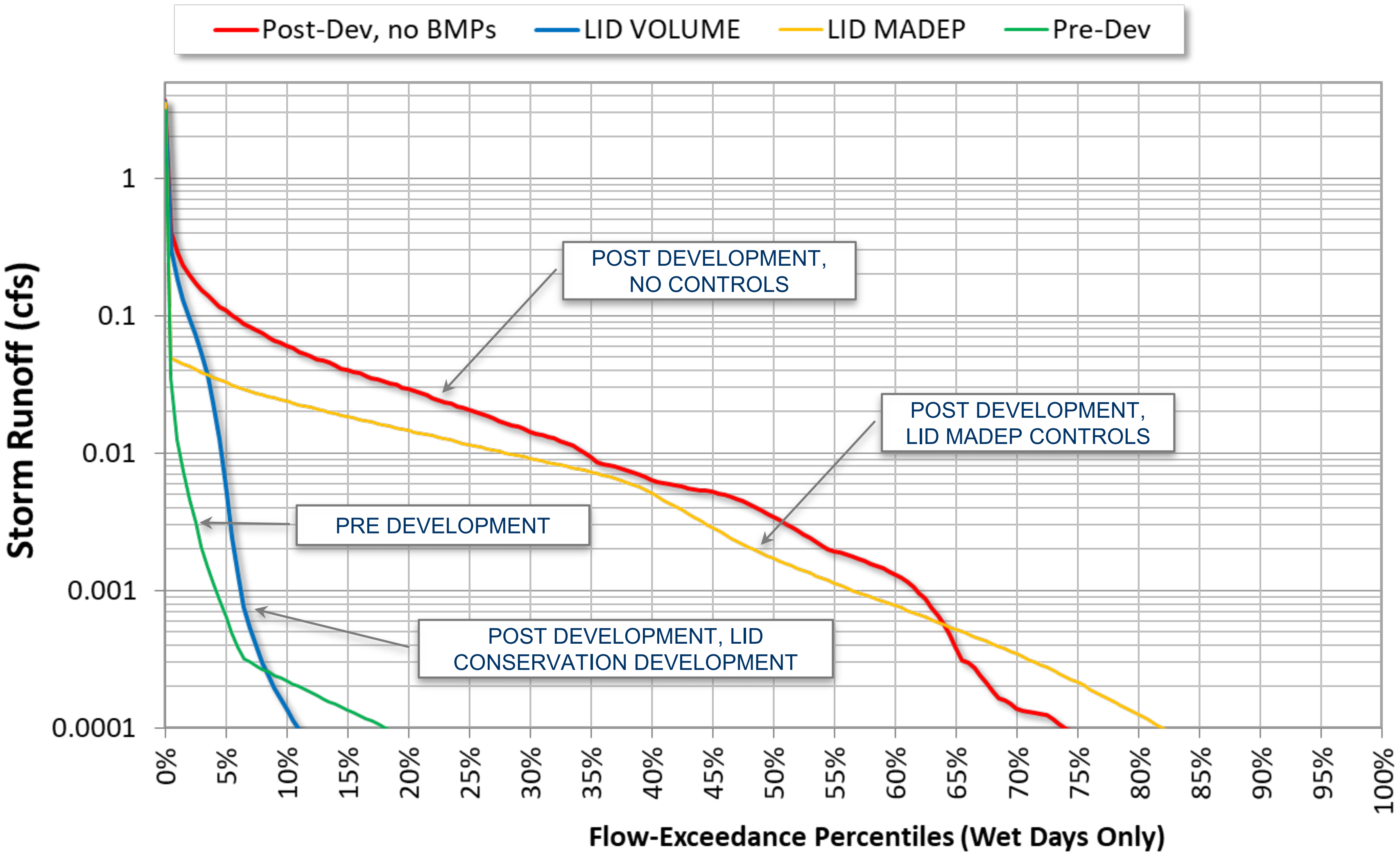
LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

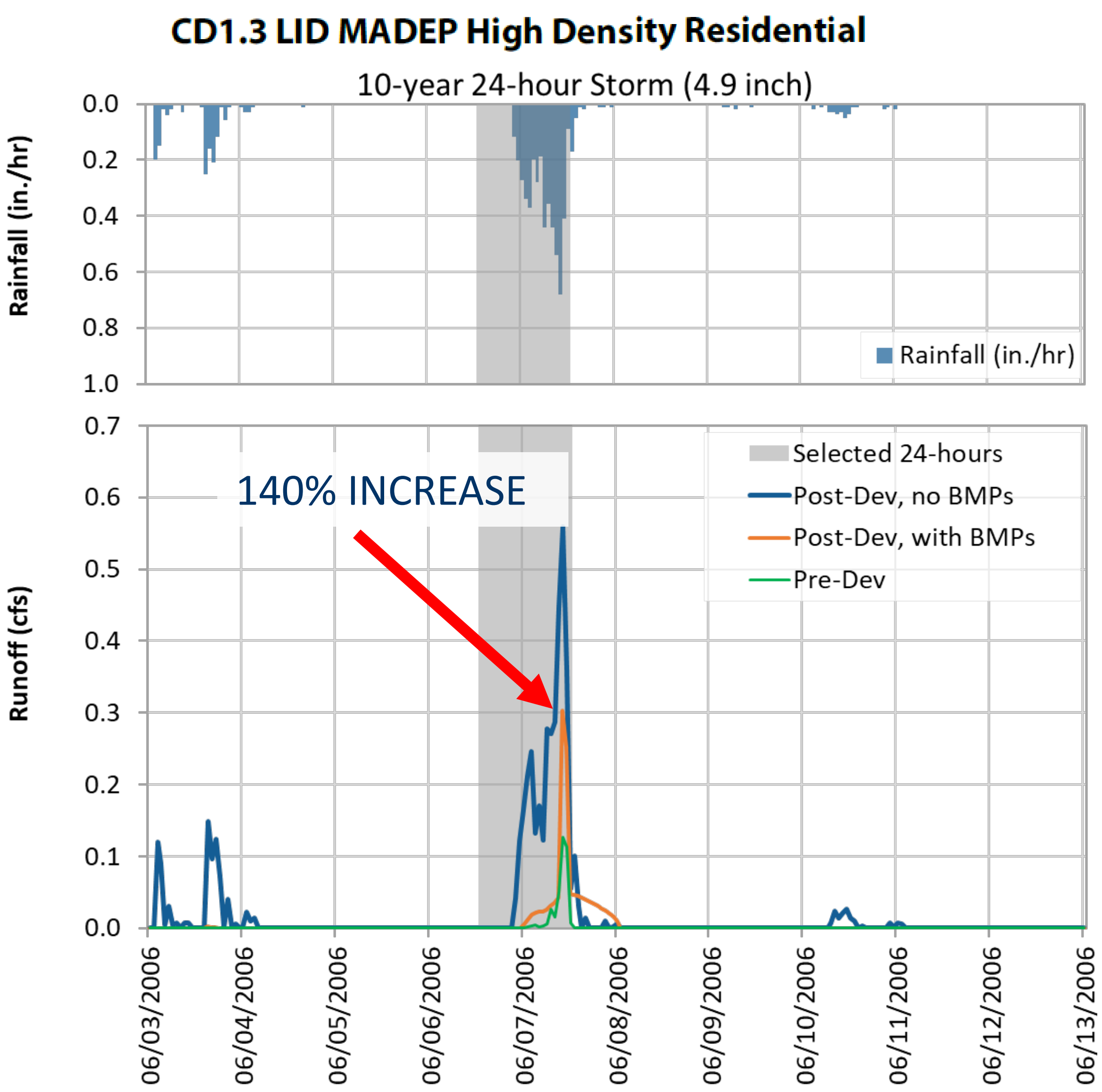
CD1.4 LID Peak High Density Residential

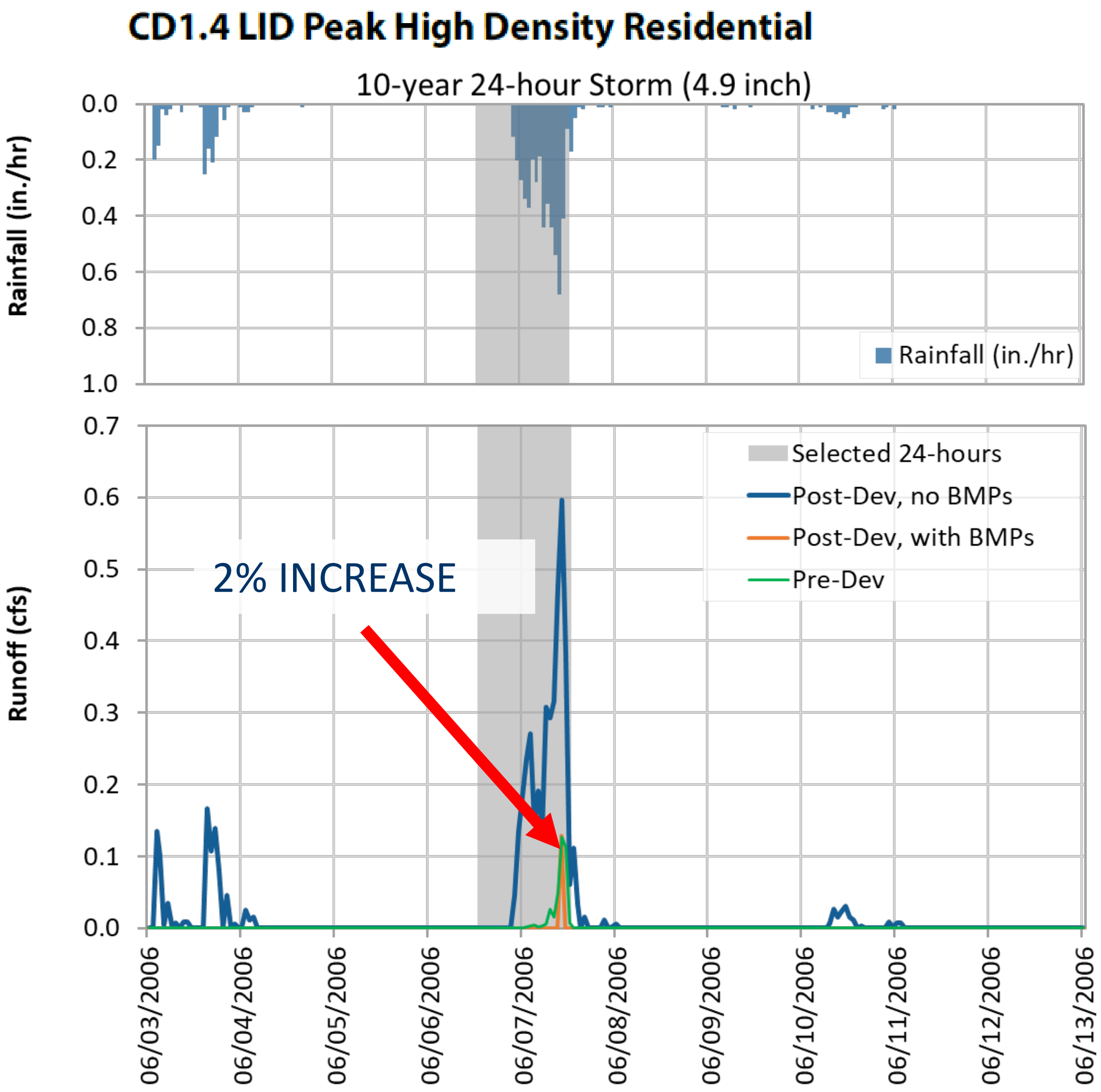
LID VOLUME

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY



CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C





CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A

CD2.2 No Controls Commercial Redevelopment

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- NO BMPS
- COMMON FOR PROJECTS THAT DON'T TRIGGER STATE OR FEDERAL REQUIREMENTS
- AND MUNICIPALITIES WITH WEAK SWM REGULATIONS

CD2.3 LID Basic Commercial Redevelopment

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- 3 BMP TYPES:
  - DRIP EDGE INFILTRATION (ROOFTOP), 0.5" WQV
  - PERMEABLE PATIO AND SUBSURFACE INFILTRATION (ROOFTOP), 0.5" WQV
  - SUBSURFACE DETENTION SYSTEM (PARKING LOT)
- DRIP EDGE AND SUBSURFACE INFILTRATION TO SATISFY STDS 3 (GRV) AND STD 4 (NITROGEN AND PHOSPHOROUS)
- SUBSURFACE DETENTION SYSTEM TO SATISFY STD 2 (Q-PEAK)

CD2.4 LID Volume Commercial Redevelopment

LID VOLUME

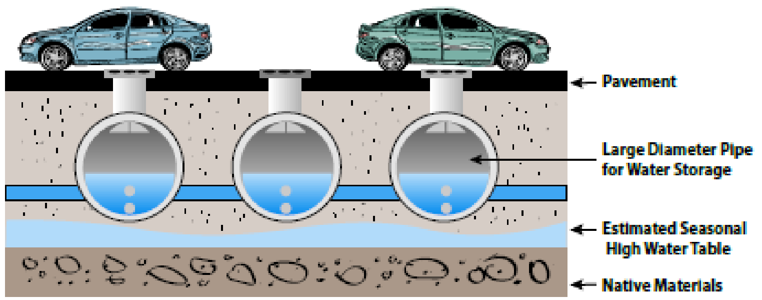
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

- 4 BMP TYPES:
  - DRIP EDGE INFILTRATION (ROOFTOP), 0.5" WQV
  - PERMEABLE PATIO AND SUBSURFACE INFILTRATION (ROOFTOP), 0.5" WQV
  - POROUS ASPHALT PAVEMENT (PARKING LOT)
  - DRY WELL (PERVIOUS SURFACE RUNOFF AND REDUNDANCY)
- DRIP EDGE AND SUBSURFACE INFILTRATION TO SATISFY STDS 3 (GRV) AND STD 4 (NITROGEN AND PHOSPHOROUS)
- POROUS PAVEMENT TO SATISFY STD 2 (Q-PEAK)

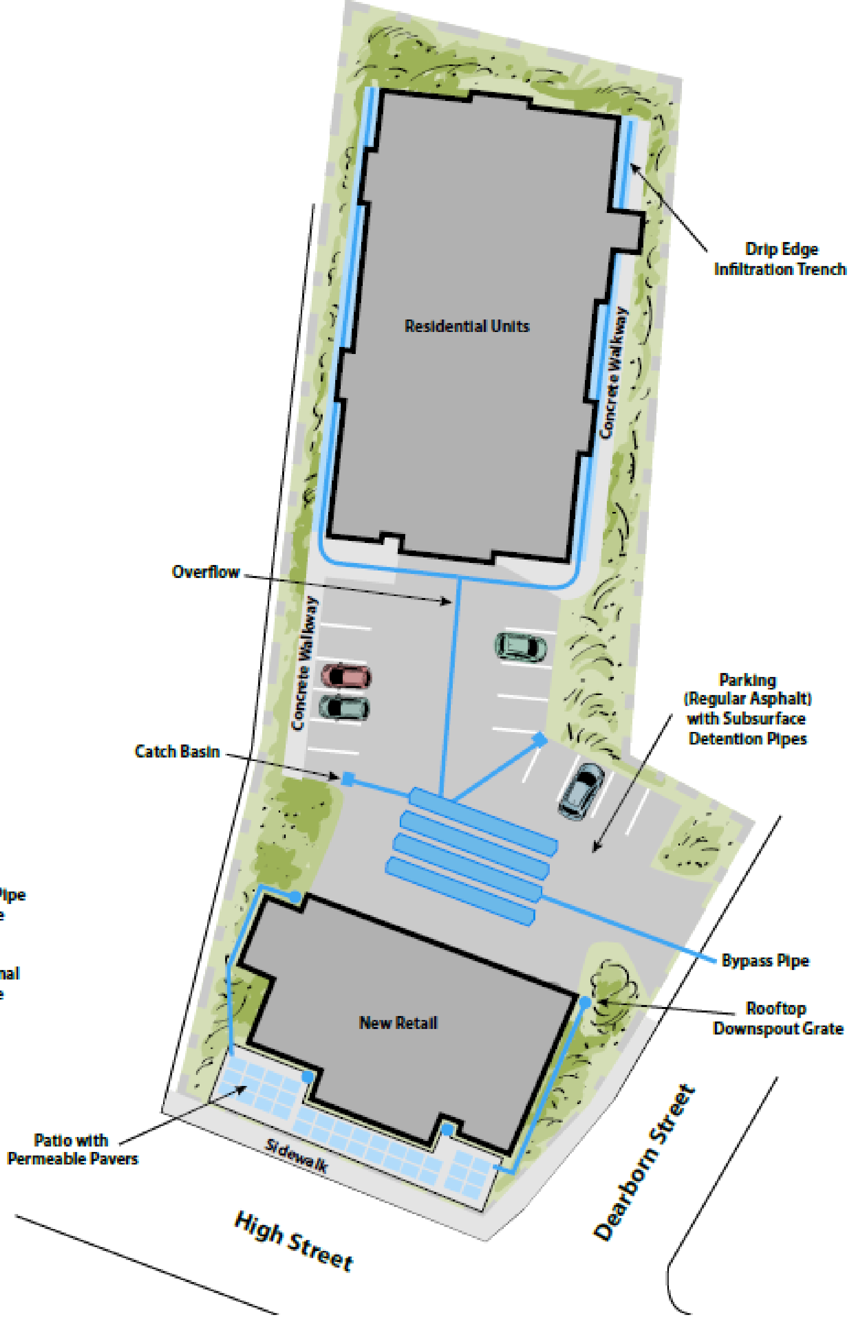
CD2.3 LID Basic Commercial Redevelopment

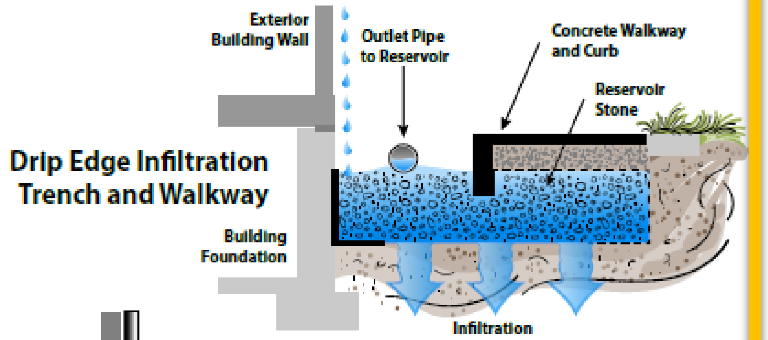
LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

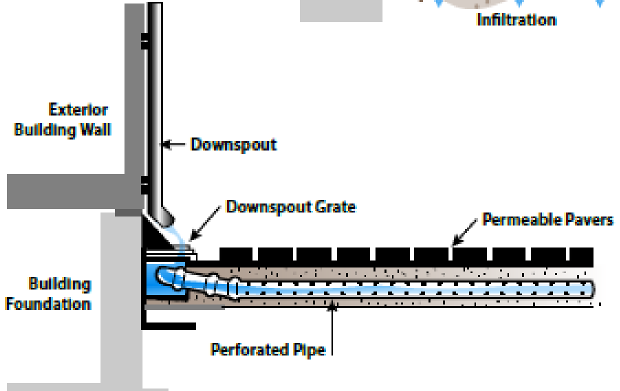


Subsurface Detention





Drip Edge Infiltration Trench and Walkway



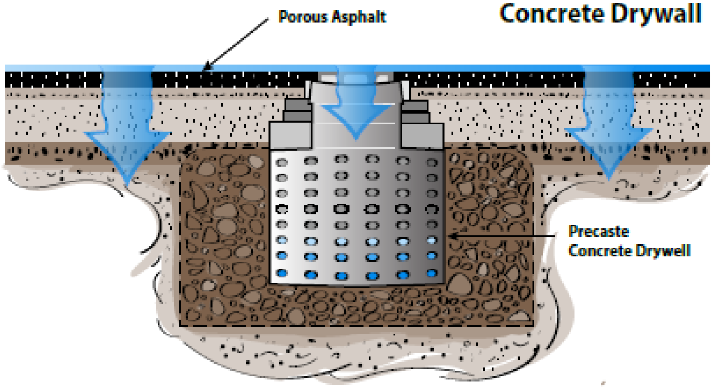
Rooftop Downspout and Permeable Pavers

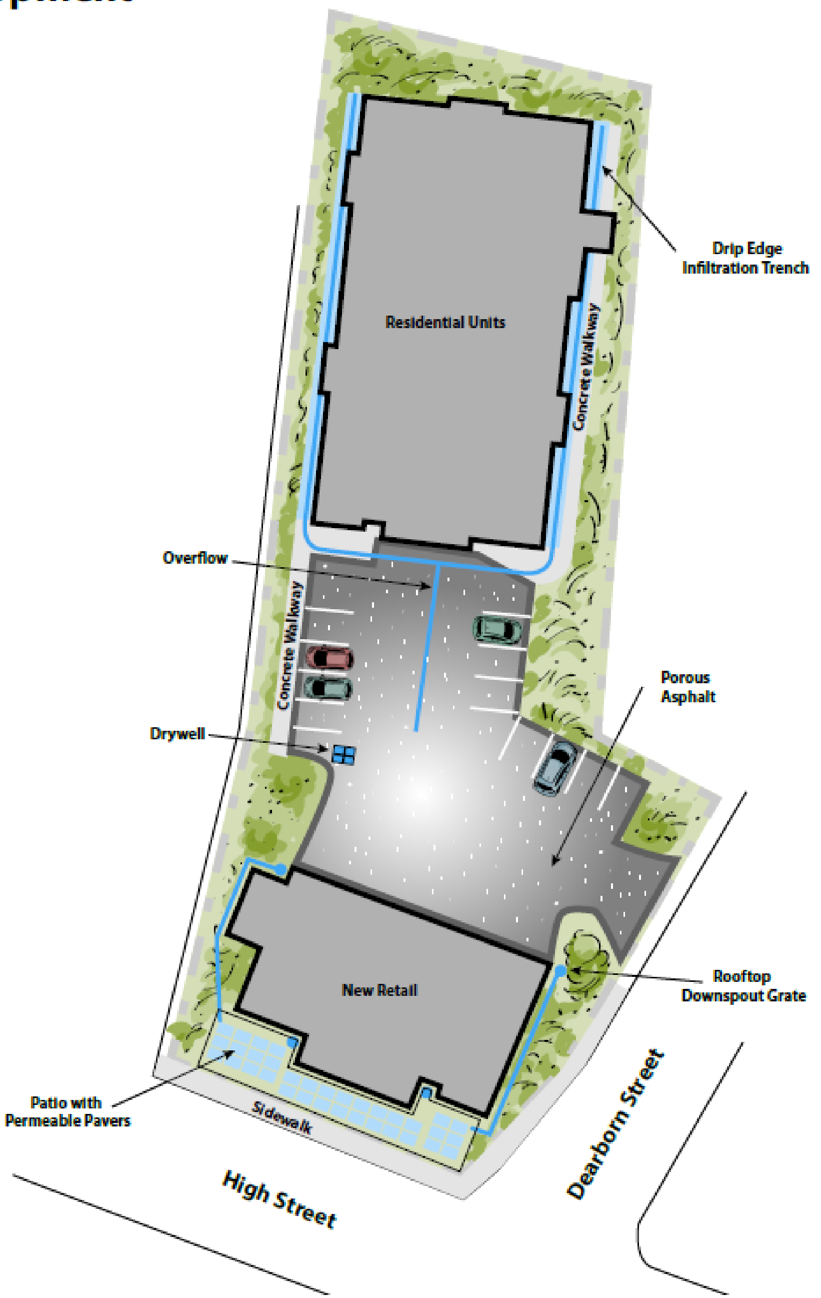
CD2.4 LID Volume Commercial Redevelopment

LID VOLUME

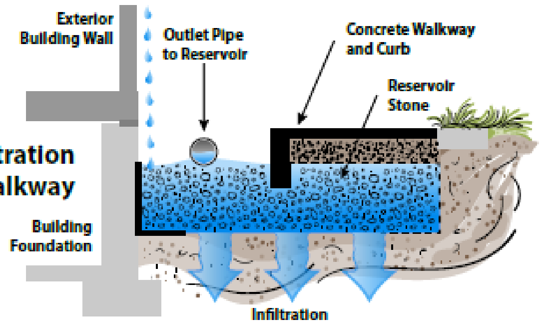
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

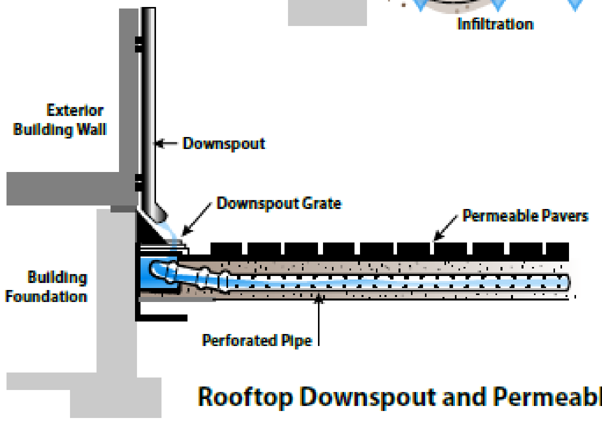
Standard Precast Concrete Drywall





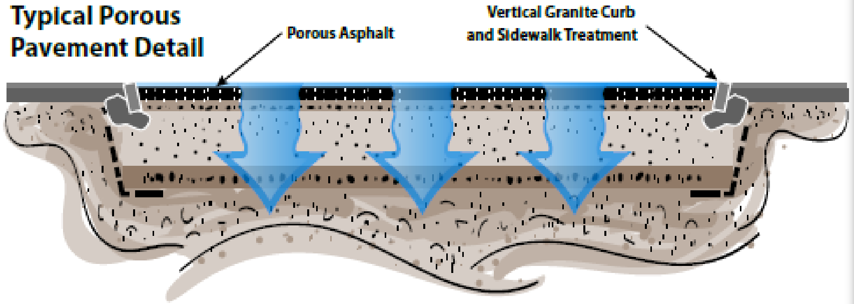
Drip Edge Infiltration Trench and Walkway





Rooftop Downspout and Permeable Pavers

Typical Porous Pavement Detail



CONCEPT PLAN 3: LOW DENSITY RESIDENTIAL HSG-B

CD3.2 No Controls
Low Density Residential

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- NO BMPS
- COMMON FOR PROJECTS THAT DON'T TRIGGER STATE OR FEDERAL REQUIREMENTS
- AND MUNICIPALITIES WITH WEAK SWM REGULATIONS

CD3.3 LID MADEP
Low Density Residential

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

3 BMP TYPES:

- FORESTED BUFFERS AS QUALIFYING PERVIOUS AREAS FOR LAKESHORE PROPERTIES (ESSD CREDIT#7)
- MEADOW BUFFERS AS QUALIFYING PERVIOUS AREAS FOR RESIDENTIAL HOUSELOTS (ESSD CREDIT#3)
- MEADOW BUFFERS AS QUALIFYING PERVIOUS AREAS FOR RESIDENTIAL ROADWAYS (ESSD CREDIT#4)
- ESSD ADDRESSES STD 2 (PEAK), STD 3 (GRV), AND STD 4 (TSS/TP)

CD3.4 LID Peak
Low Density Residential

LID VOLUME

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY

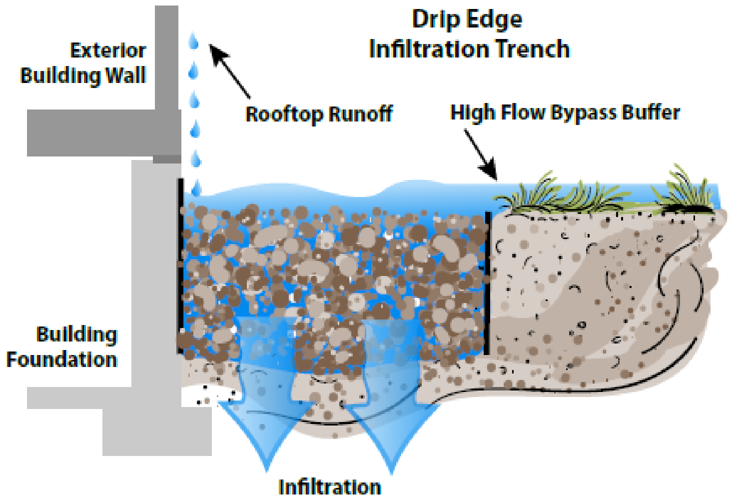
5 BMP TYPES:

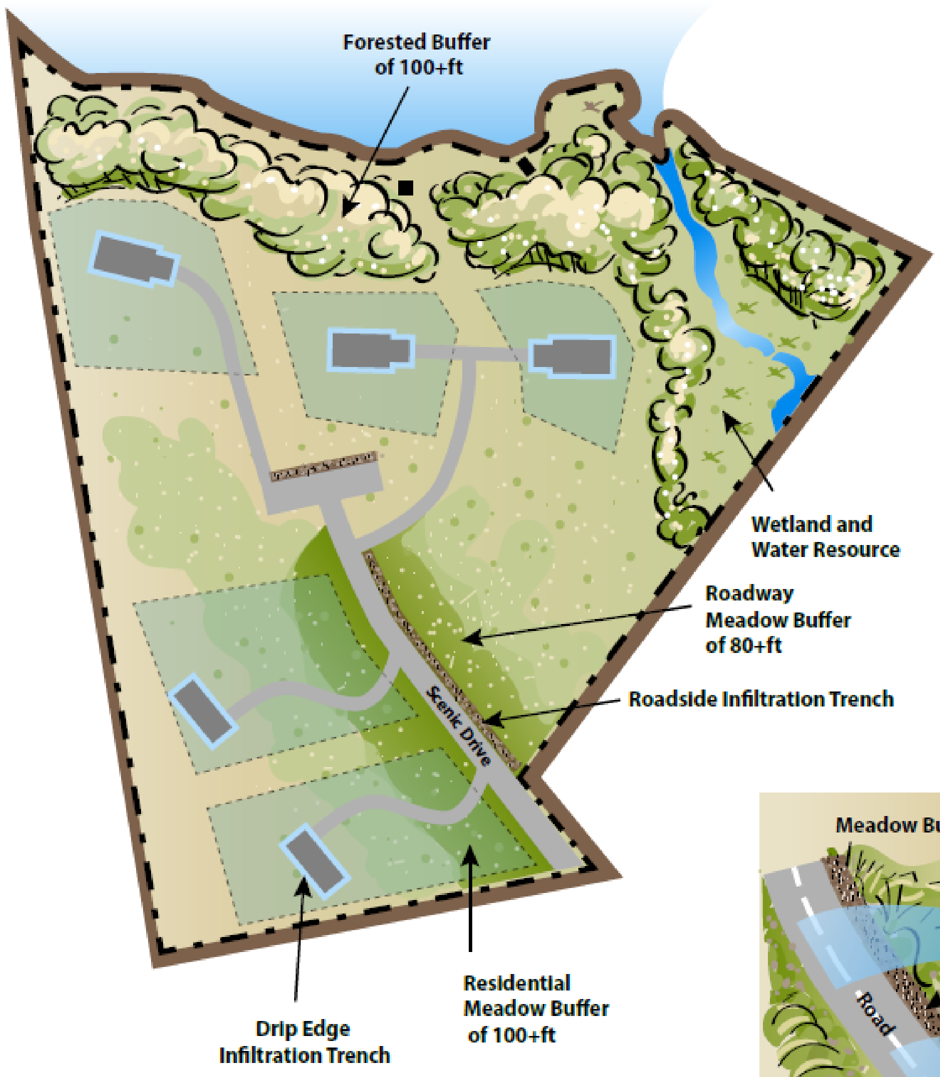
- FORESTED BUFFERS AS QUALIFYING PERVIOUS AREAS FOR LAKESHORE PROPERTIES (ESSD CREDIT#7)
- MEADOW BUFFERS AS QUALIFYING PERVIOUS AREAS FOR RESIDENTIAL HOUSELOTS (ESSD CREDIT#3)
- MEADOW BUFFERS AS QUALIFYING PERVIOUS AREAS FOR RESIDENTIAL ROADWAYS (ESSD CREDIT#4)
- DRIP EDGE INFILTRATION (ROOFTOP), 1" WQV
- ROADWAY INFILTRATION TRENCH, 1" WQV
- ESSD ADDRESSES STD 2 (PEAK), STD 3 (GRV), AND STD 4 (TSS/TP)

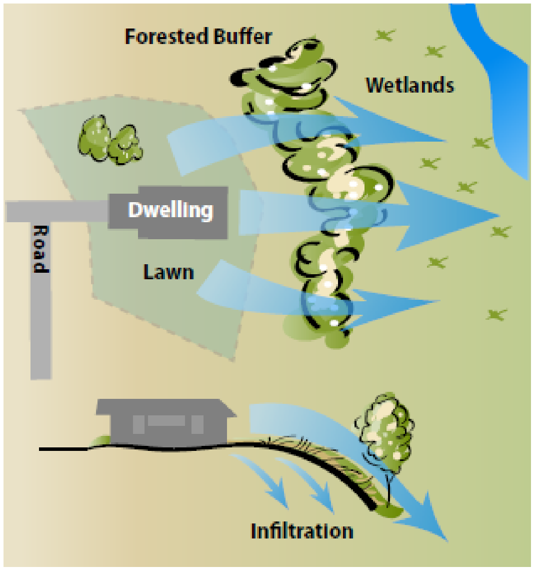
CD3.4 LID Peak
Low Density Residential

LID VOLUME

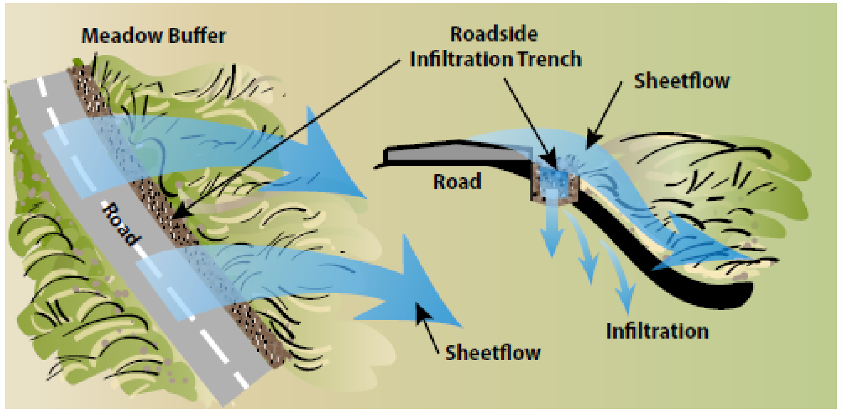
- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY







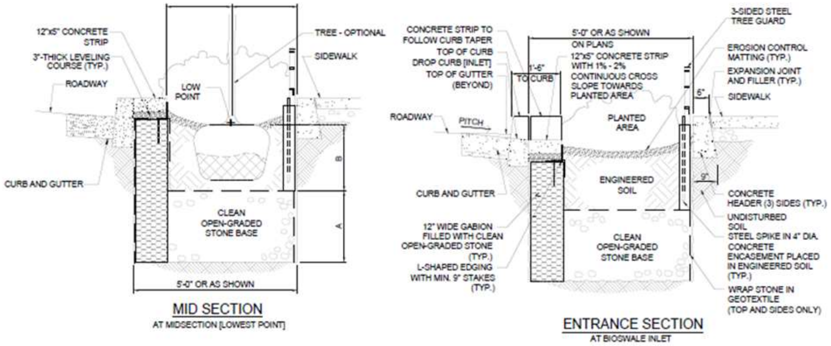
Residential Forested Meadow Buffer



Roadway Buffer and Infiltration

Compendium of Site-Development Stormwater Management Solutions for Water Resource Protection

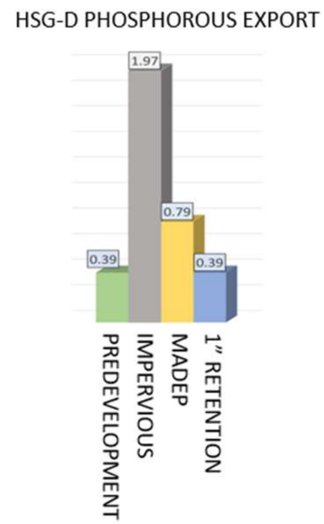
- The "Compendium" offers guidance on stormwater management strategies for site development
- Details a Watershed Protection Standard to ***Maintain Predevelopment Hydrology and Nutrient Load, and Resilient Landscapes***.
- Target audience is local government officials reviewing and approving site plans.
- Green Infrastructure (GI) and Low Impact Development (LID) techniques including emphasizing infiltration and minimizing disturbance
- Scalable GI/LID Stormwater Control Measures (SCMs)

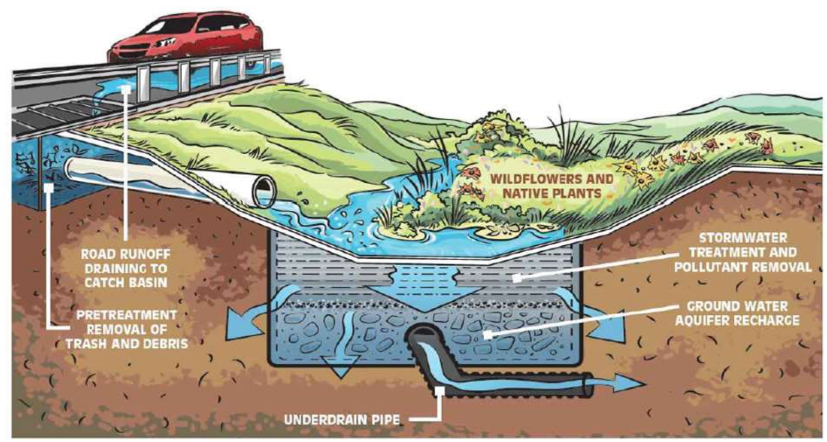


Compendium Overview

- Conceptual Site Designs illustrating sizing and location of dispersed GI techniques
- “Plug and Play” SCM options for many “wicked” site development situations
- Watershed protection standard approximately equal to a one (1) inch static retention standard
- Design summary table with sizing, performance, and costing for Hydrological Soil Groups
- A secondary design table for the MA MS4 and MADEP for TP and TSS reductions of 60% and 90%
- Sizing and costing based on EPA R1 Opti-Tool and SCM performance curves

WICKED PROBLEMS

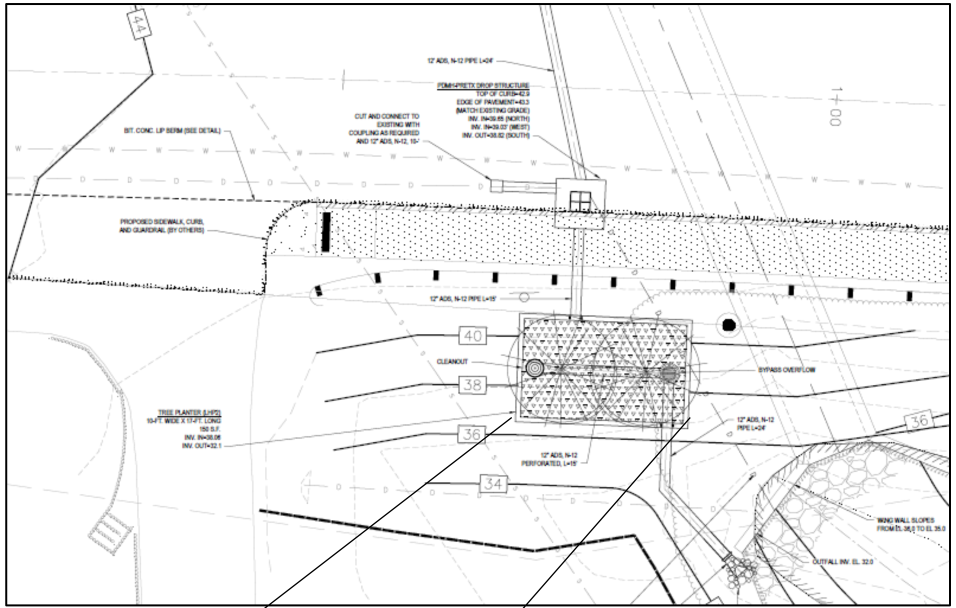


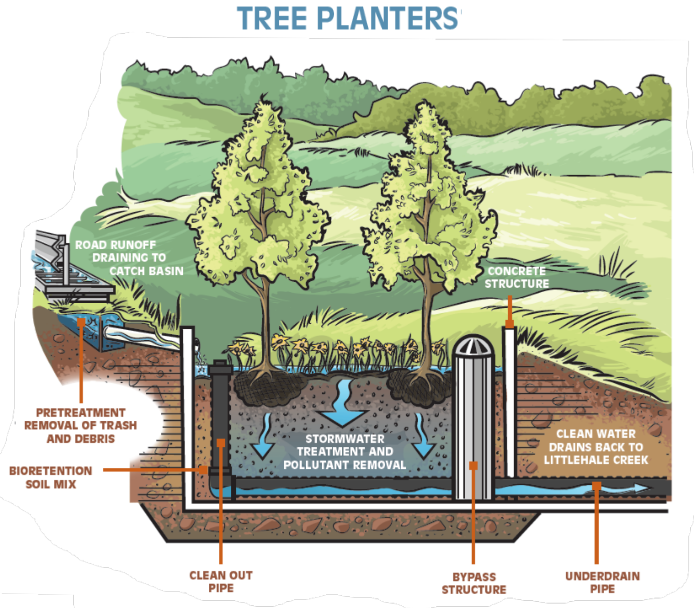


URBAN BIOSWALE/TREE PLANTER ONLINE/OFFLINE

Description: Brief Description of type of impervious cover to be managed, the type of SCM shown, its sizing and any site design constraints (e.g., none to very limited) that influences the selection of the SCM type and its design (footprint, depth etc.). The SCM shown has been sized to achieve the Water Resource Protection Standard for a unit area of one (1) acre of impervious cover (IC). The SCM design is scalable such that the dimensions can be reduced or increased depending on the IC area to be managed. For example, the same type of SCM needed to achieve average annual predevelopment conditions for 1/10th of acre IC would be 1/10th the size of the SCM shown in the plan view. Include a design table for varying IC drainage areas in 1/20th acre increments showing DSV and physical storage capacities in cubit feet.? Include the DSV equation for the practice.

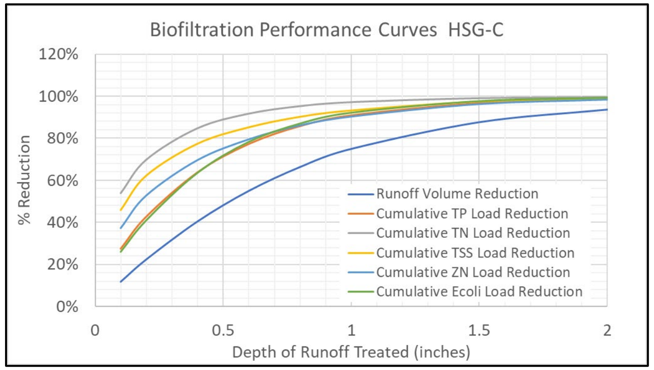
Water Resource Protection Standard: Approximates the 1" WQV static retention for IC that will: 1) Not exceed the long-term average annual predevelopment runoff nutrient load export; 2) Achieve average annual predevelopment groundwater recharge volumes; and 3) Maintain resilient landscape.

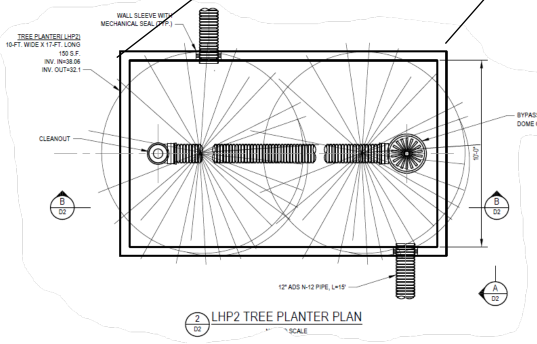


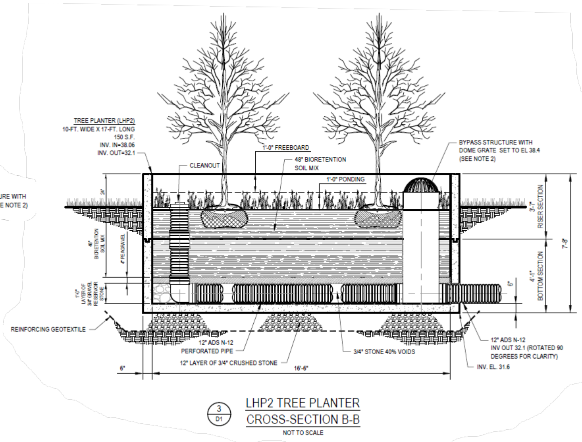


Surface Biofiltration Practice Design Details

IC Drainage area, acre	1.0	0.5	0.25	0.1	0.05
Infiltration Rate , in./hr.	8.27	8.27	8.27	8.27	8.27
Design Storage Volume, in.	0.39	0.39	0.39	0.39	0.39
Physical Storage Capacity, ft^3	1416	708	354	142	71
Depth of Pond Storage , ft	1.0	1.0	1.0	1.0	1.0
Length of Basin, ft	118	59	29	12	6
Top-Width of Basin, ft	15	15	15	15	15
side slope	3:1	3:1	3:1	3:1	3:1
Phosphorus Load Reduction, %	98%	98%	98%	98%	98%
Nitrogen Load Reduction, %	98%	98%	98%	98%	98%
Captiol Cost, $	$ 10,000	$ 5,000	$ 2,500	$ 1,000	$ 500







Water Resource Protection Standard for Impervious Cover Management: Surface Infiltration Practice[1] Design Storage Capacities

HSG	Infiltration Rate, in/hr	DSV[2], inches	Stormwater Control Measure Physical Storage Capacity based on Contributing IC Drainage area in acres , Cubic Feet																			
			Impervious Cover Drainage Area to SCM, acres																			
			0.05	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.9**	**0.95**	**1**
A	8.27	**0.39**	71	142	212	283	354	425	495	566	637	708	779	849	920	991	1062	1133	1203	1274	1345	1416
A	2.41	**0.67**	122	243	365	486	608	730	851	973	1094	1216	1338	1459	1581	1702	1824	1946	2067	2189	2310	2432
B	1.02	**0.59**	107	214	321	428	535	643	750	857	964	1071	1178	1285	1392	1499	1606	1713	1820	1928	2035	2142
B	0.52	**0.73**	132	265	397	530	662	795	927	1060	1192	1325	1457	1590	1722	1855	1987	2120	2252	2385	2517	2650
C	0.27	**0.60**	109	218	327	436	545	653	762	871	980	1089	1198	1307	1416	1525	1634	1742	1851	1960	2069	2178
C	0.17	**0.69**	125	250	376	501	626	751	877	1002	1127	1252	1378	1503	1628	1753	1879	2004	2129	2254	2379	2505
D	0.10	**0.60**	109	218	327	436	545	653	762	871	980	1089	1198	1307	1416	1525	1634	1742	1851	1960	2069	2178
D	0.05	**0.86**	156	312	468	624	780	937	1093	1249	1405	1561	1717	1873	2029	2185	2341	2497	2654	2810	2966	3122

1. Surface infiltration practices include basins, swales, raingardens/bioretention and permeable pavements.
2. DSV = Design Storage Volume. DSV equals the storage capacity of the SCM to hold water prior to overflow or bypass and is equal to the sum of free storage of surface ponding and of storage in pore space of filter media and washed stone/gravel backfill. See Table ?? For equations to calculate DSVs for various practices.

5 MINUTE BREAK

NANYANG TECHNOLOGICAL UNIVERSITY, SINGAPORE

MUNICPAL REGULATORY AUDIT AND MUNICIPAL RECOMMENDATIONS

MA Audubon Audit Tool

Audits to be completed for Middleborough, Mansfield and Easton

Provide recommendations for regulatory approaches

Provide sample regulatory language for a set of specific topics (some topics presented here today)

MA AUDUBON AUDIT TOOL FOR ZONING, SUBDIVISION, SITE PLAN REVIEW, AND STORMWATER OVERVIEW

Goal 1: Protect Natural Resources and Open Space : limit clearing and grading and encourage soil management, the use of native species, and revegetation of disturbed areas.

Goal 2: Promote Efficient Compact Development Patterns and Infill: Compact designs by making dimensional requirements such as setbacks, lot size, and frontage more flexible as well as allowing common drives to decrease the impervious surfaces and increase infiltration.

Goal 3: Smart Designs that Reduce Overall Imperviousness: **S**ite design elements such as street location, road width, cul-de-sac design, curbing, roadside swales, and sidewalk design and location to minimize impervious surfaces and allow for infiltration.

Goal 4: Adopt Green Infrastructure Stormwater Management Provisions: Low Impact Development structural controls are a preferred method, such as requiring roof runoff to be directed into vegetated areas, and a preference for infiltration wherever soils allow or can be amended.

Goal 5: Encourage Efficient Parking: Reduce impervious surfaces with standards for required parking - or even including parking maximums instead of minimums.

STORMWATER THRESHOLD FOR APPLICABILITY

Municipalities choose a threshold for applicability for enforcement of by-law stormwater management standards and/or standards under Subdivision Regulations and Site Plan Review Regulations

Choice of threshold applicability typically is based on an inventory of permitted projects over a period of 5-10 years [refer to the fact sheet Minimizing Environmental Impacts Through Stormwater Ordinances and Regulations]

Threshold for applicability often points to "area of disturbance" which includes soils, vegetation and other land cover or "addition of impervious cover"

Consideration of how many development projects might fall ***below*** the threshold and how many fall ***above*** the threshold

Consideration of impacts to sensitive natural resources as a result of uncontrolled and/or untreated stormwater discharges; an existing conditions plan with environmental and resource information may be warranted

Consideration of EPA MS4 Permit assets that may be affected by uncontrolled and/or untreated stormwater discharges especially to any impaired water body or jurisdictional outfall

Non-implementation of site inspection protocols, agreements such as O&M if SWM requirements are not implemented

Current climate change science reports project a 10-15% increase in precipitation by 2050

[for site specific past and current rainfall data, refer to Cornell Northeast Region Climate Center data for extreme precipitation http://precip.eas.cornell.edu/ and future projections in the NH Coastal Flood Risk Summary]

Designs of current development projects should incorporate projections of increased precipitation into their site designs

Redevelopment project standards should have clear metrics for retrofitting underperforming infrastructure and in some cases evaluating the absence of SWM controls on the site to address water quality issues

Creating resilient landscapes will rely on replacing outdated infrastructure as part of the redevelopment process; this will take time and may require enhanced education of property owners/developers

Creating resilient landscapes are dependent upon forward thinking paradigms for SWM that adopt the best available science and implement it

CLIMATE CHANGE PROJECTIONS FOR INCREASED PRECIPITATION AND RESILIENCE

ROUTINE INSPECTIONS AND RECORDING

- Every project approval should include an Operations & Maintenance (O&M) agreement that outlines the responsibilities of both the municipality and the developer/property owner
- O&M agreements should be recorded with the state's registry of deeds to ensure the document "follows with the property" in the event of its sale to another
- O&M agreements should include routine inspection schedules by municipal staff and/or a self reporting schedule by the property owner with verifications of inspection by a licensed engineer
- Reporting can be to municipality or by self-reporting initiated by the municipality with documentation kept for 5 years
- If municipal staff or a consulting engineer are tasked with site inspections, dedicated funding shall be established through an escrow account, bond or other funding mechanism

To reduce financial burdens and gain efficiency, municipalities may work together to fund a “regional site inspector” program

Such a regional program may likely require an intermunicipal agreement not unlike those for shared emergency services

For sites requiring annual site inspections (such as private SWM infrastructure) an annual fee may be charged to the property owner and can be detailed in the O&M agreement upon project approval

REGIONAL APPROACH TO FUNDING SITE INSPECTIONS

Some municipalities convene “technical advisory committees” that require review of development proposals before the application phase

TAC’s often include representatives from municipal departments and staff, and land use boards, committees and commissions

TAC comments are typically compiled and submitted to the potential applicant for consideration in site design and distributed among the participants

PRELIMINARY APPLICATION REVIEW BY TECHNICAL ADVISORY GROUP

APPROVAL PROCESS FOR BY-LAW AND REGULATION AMENDMENTS

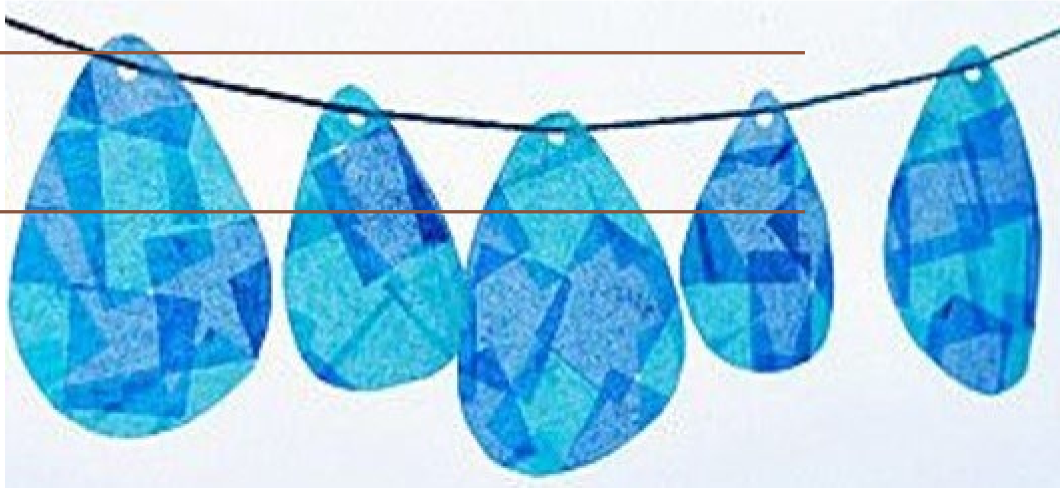
Bylaws amendments require a ballot vote by citizens of the municipality and so have a higher level of scrutiny and public comment

Site plan and subdivision regulations are typically approved at the municipal board or commission level and through a simpler public hearing approval process

Routine regulation updates to revise and improve, perhaps on a 1-2 year cycle or as needed to address emerging issues

ADDITIONAL REFERENCES

New Hampshire Southeast Watershed Alliance Model Standards



Information Sheets

Technical Project Summary

Town specific sheets for each Taunton community

Technical Project Summary

Target audience

- Stormwater professionals in the Taunton River Watershed
- Environmental groups
- Community scientists

Background information

- Study
- IC impacts
- Climate change

Project results

- Per acre IC impacts
- Watershed-wide projections
- SW Management Performance Standards and their impact
- Recommended standards for resiliency
- Cost burden and cost avoidance

References

Town Specific Sheets for Each Taunton Community

Target audience

- Municipal officials
- Anyone involved with town bylaws/ordinances
- Environmental community groups

Background information

- Simple, easy to read and understand
- References to the technical summary for more details

The problem: Town projections

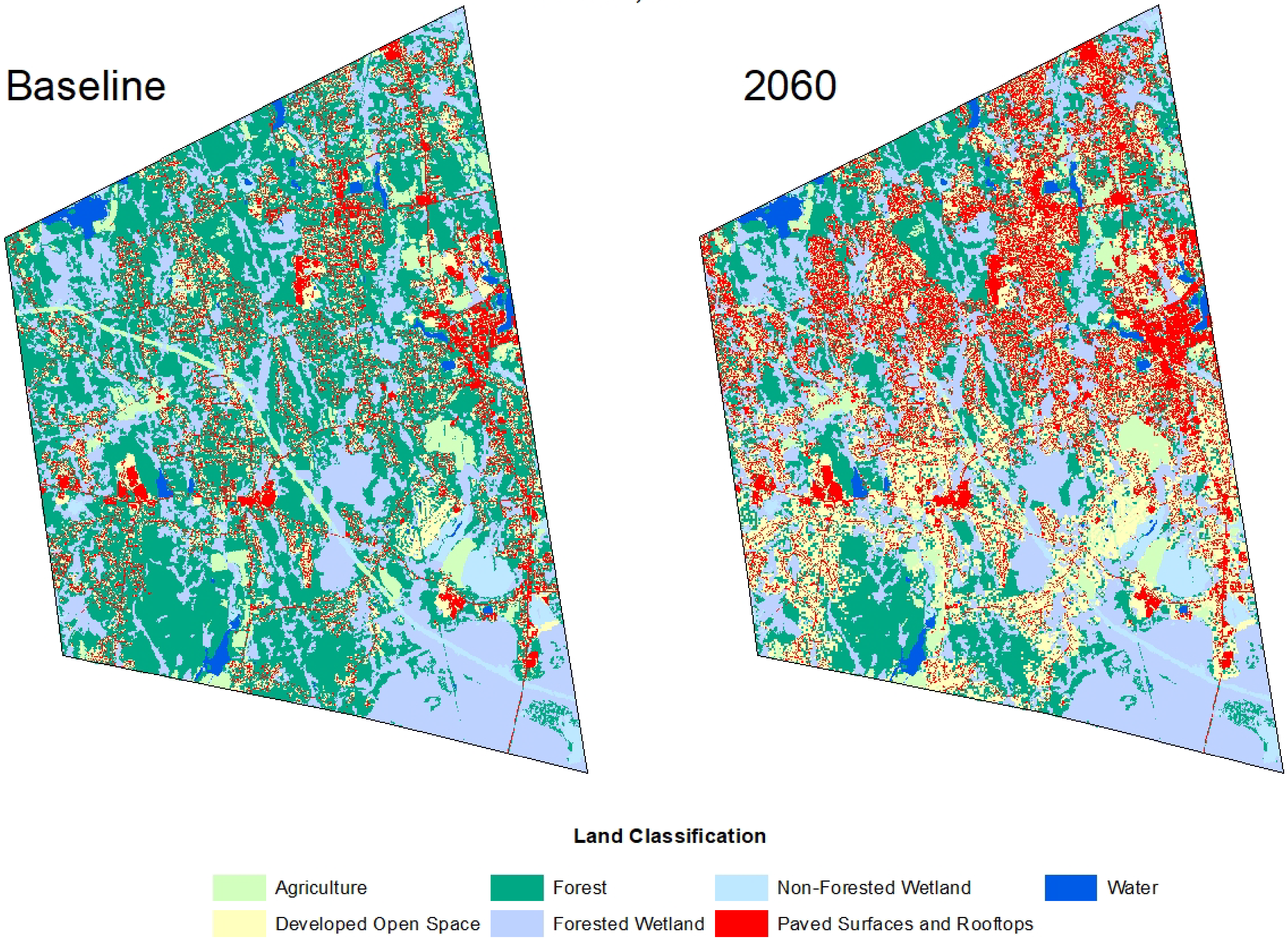
- Future development
- Nutrient loads
- Groundwater recharge impacts

Optimism: Resiliency

- How to prevent/mitigate impacts
- Cost avoidance

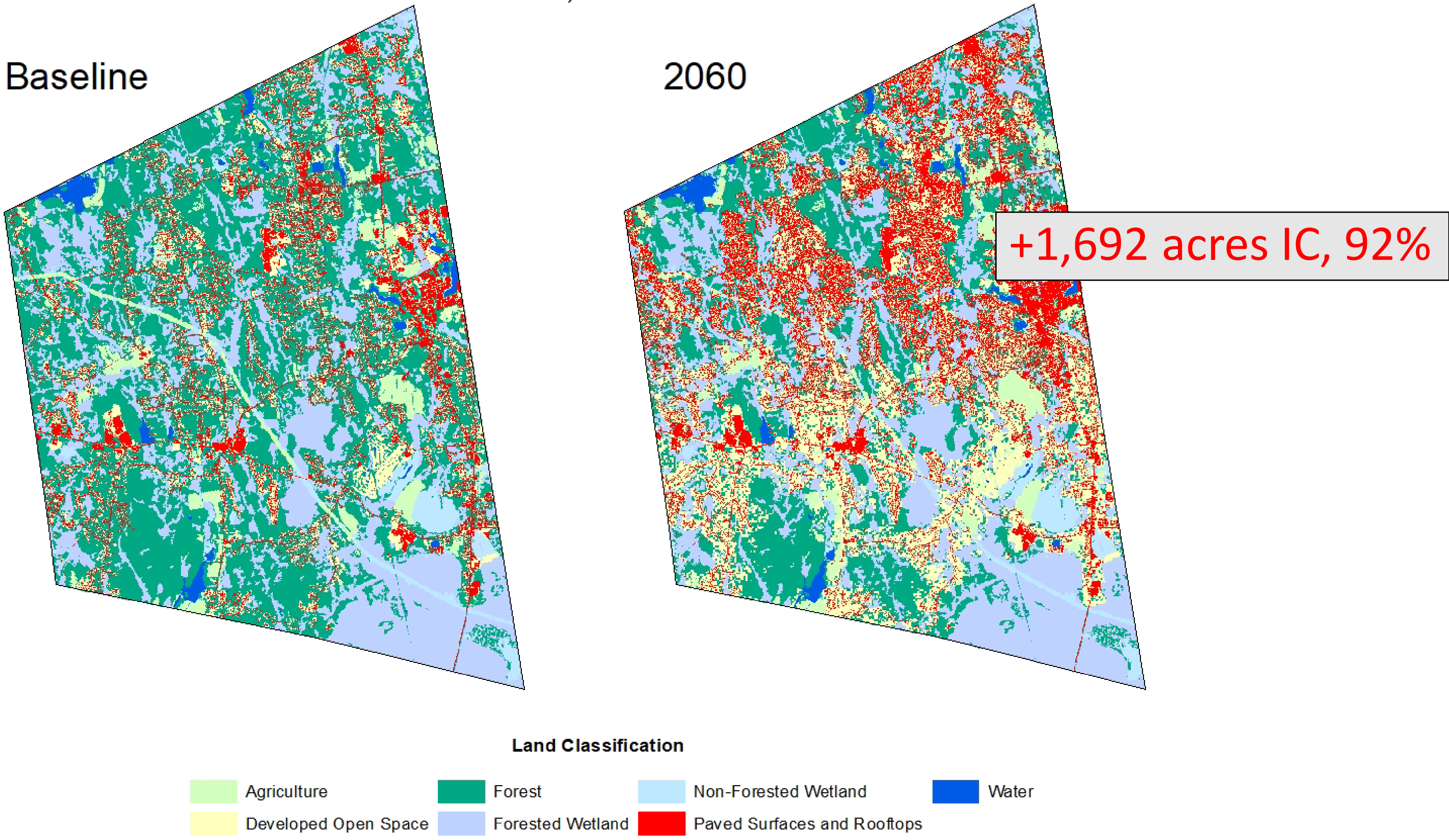
Projected Land Change

Easton, MA



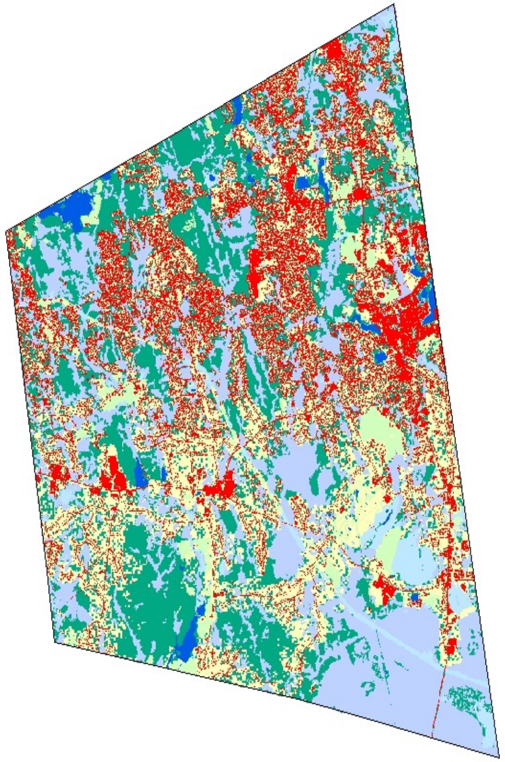
Projected Land Change

Easton, MA



Projected per Year Increases or Decreases

Runoff	+ 2,119 million gallons
Groundwater recharge	-665 million gallons
Evapotranspiration	-1,474 million gallons
Total Nitrogen	+ 21,848 pounds
Total Phosphorus	+ 2,309 pounds



PROJECT TEAM

- Ray Cody, Senior Policy Analyst, Stormwater Permits Section, Water Division, EPA Region 1
- Mark Voorhees, Environmental Engineer, Stormwater Permits Section, Water Division, EPA Region 1
- Michelle Vuto, Stormwater Permits Section, Water Division, EPA Region 1
- Khalid Alvi, Water Resources Engineer, Paradigm Environmental
- Robert Roseen, PHD., D.WRE, PE, Waterstone Engineering
- Julie LaBranche, JLB Planning
- Greg Smith, Great Lakes Environmental Center

THANK YOU FOR YOUR TIME

Phipps Center for Sustainable Landscapes