APPENDIX A. MUNICIPAL MEETING #1 – DECEMBER 18, 2021

AGENDA

Municipal Engagement Meeting #1

Next-Generation Watershed Management Practices for Conservation Development

12/8/2021 2-4PM

Microsoft Teams meeting

Click here to join the meeting

Learn More | Meeting options

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1. **Introductions and Project Team**

2. **Why We Are Here**
   a. Nutrients, water quality, MS4, resilience
   b. Discussion of Next Gen BMPs

3. **Project Overview**
   a. FDC1 - *Holistic Watershed Management for Existing and Future Land Use Development Activities: Opportunities for Action for Local Decision Makers*
   b. FDC2 - The *Next-Generation Watershed Management Practices for Conservation Development*

4. **Project Partner Involvement**
   a. Draft Schedule of Municipal Engagement Working Meetings – **Project Partner feedback**

5. **Project Deliverables - Municipal Engagement 'Toolbox'** of next-generation SW management and CD practices
   a. Conceptual Site-Development Plans – **Project Partner feedback from examples**
   b. Next-Generation Model Ordinance and Bylaw Recommendations
   c. Compendium of Advanced SW Management and Conservation Design Practices
   d. Communications Materials

1. **Next Steps**
   a. Feedback on site development plans and/or examples of "great" projects
   b. Feedback on communications materials

Meeting Materials

1. Project Overview FDC2B
2. Factsheets FDC2A
3. Sample Conceptual Site Development Plans

Meeting Participants

Confirmed

1. Katelyn Gonyer, Mansfield
2. Jenn Carlino, Easton
3. Tricia Cassidy, Middleboro

Pending

1. Plympton, Linda Leddy
2. Foxborough, Bill Guenther, Michael Johns, Jane Peirce, Paige Duncan, Gaby Jordan, Thomas Buckley, Bob Worthley

Project Team

1. Sara Burns, Ducks Unlimited
2. Danica Belknap, SRPEDD
3. Kimberly Groff, SNEP
4. Ray Cody, Mark Voorhees, Michelle Vuto, EPA
5. Laura Shifman, MADEP
6. Robert Roseen, Waterstone Engineering
7. Khalid Alvi, Paradigm

APPENDIX B. MUNICIPAL MEETING #2 – JUNE 30, 2022

AGENDA

Municipal Engagement Meeting #2

Next-Generation Watershed Management Practices for Conservation Development

June 30, 2022 1-3:00 PM

Town of Mansfield, Public Safety Building, Community Meeting Room

500 East Street, Mansfield, Massachusetts 02048

Remote Option - Microsoft Teams meeting Click here to join the meeting

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1. **Introductions and Project Team (All, 5 min)**

2. **EPA Intro - How / Why We Got Here (Ray, 5 min)**
    a. Applied Research under the Clean Water Act
    b. The Problem of Impervious Cover
    c. Developing Practicable Approaches for a Sustainable and Resilient Future

3. **Project Context (Mark, 10 min)**
    a. Vision
    b. MS4 Overview
    c. Impacts of IC
    d. Cost burdens of Reduced Management

4. **Modeling Overview (Alvi, 20 min)**
    a. FDC Phase 1 and Phase 2
    b. Watershed Scale Modeling Results
    c. Discussion (10 min)

5. **Site Development Approach Goals (Rob, 30 min)**
    a. Example – Rollins Hill medium and high density
    b. Review Conceptual Site-Development Plans
        i. High Density Residential
        ii. Commercial Mixed-Use Redevelopment
        iii. Modeling Results (Alvi)
    c. Benefits of Increased Level of Controls
    d. Discussion (15 min)

6. **Next Steps (Mark, 10 min)**
    a. Information sheets
    b. Compendium
    c. Recharge Calculations
    d. Discussion (10 min)

Meeting Materials

1. Information Sheets
2. Sample Conceptual Site Development Graphics
3. Modeling Results
4. Compendium Framework

Meeting Participants

Confirmed

1. Tricia Cassidy, Middleboro
2. Katelyn Gonyer, Mansfield
3. Jenn Carlino, Easton
4. Stefanie Covino, Blackstone Watershed Collaborative
5. Scott Horsley, Consultant, Tufts University

Pending

1. Gretchen Rabinkin, BSLA
2. Anne Herbst, MAPC

Project Team

1. Sara Burns, Ducks Unlimited (Remote)
2. Danica Belknap, SRPEDD
3. Kimberly Groff, SNEP
4. Ray Cody, Mark Voorhees, Michelle Vuto, Newt Tedder, Matt Stamas, EPA
5. Laura Shifman, MADEP
6. Robert Roseen, Waterstone Engineering
7. Khalid Alvi, Paradigm

Municipal Engagement Meeting #2 Next-Generation Watershed Management Practices for Conservation Development

June 30, 2022
Public Safety Building, Mansfield, MA

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"We have disrupted the natural water cycle for centuries in an effort to control water for our own prosperity. Yet every year, recovery from droughts and floods costs billions of dollars, and we spend billions more on dams, diversions, levees, and other feats of engineering. These massive projects not only are risky financially and environmentally, they often threaten social and political stability. ***What if the answer was not further control of the water cycle, but repair and replenishment?***"

-Sandra Postel, the Replenish, The Virtuous Cycle of Water and Prosperity

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Agenda

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    a. Applied Research under the Clean Water Act
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6. **Next Steps (Mark, 10 min)**
    a. Information sheets
    b. Compendium
    c. Recharge Calculations
    d. Discussion (10 min)

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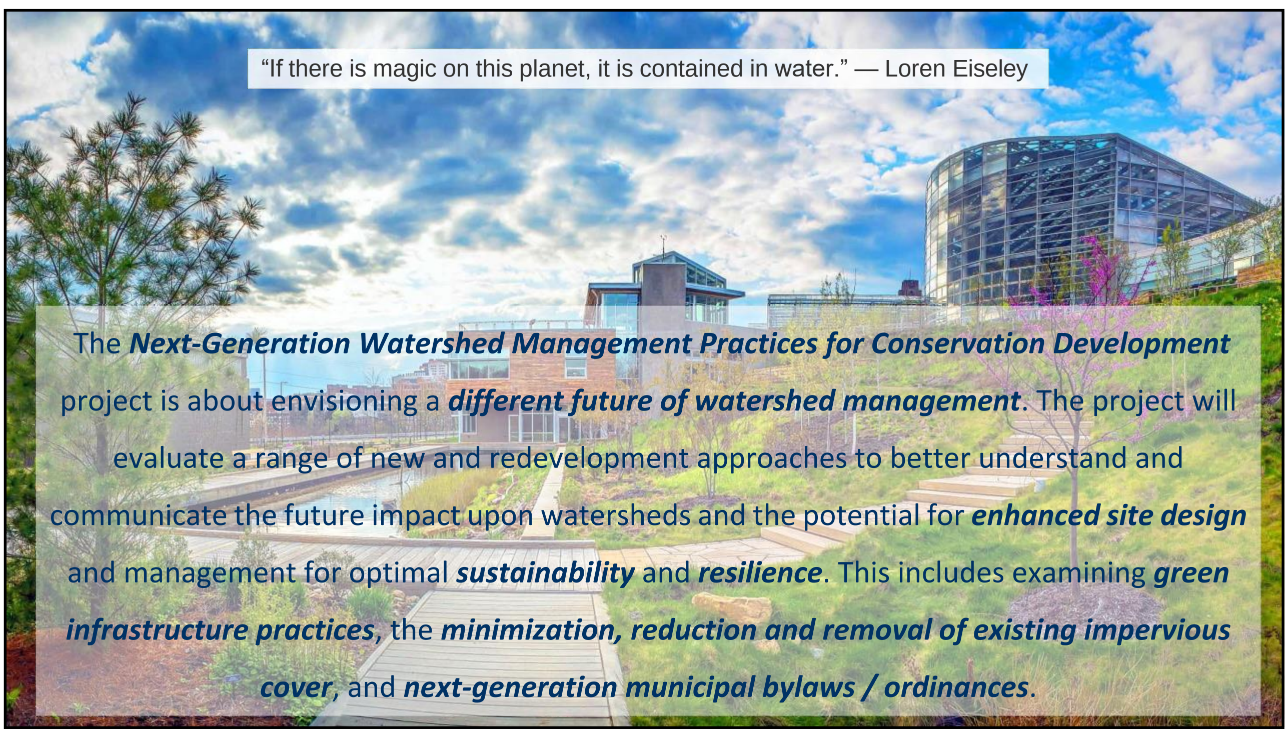

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Sound Future Land Development & Stormwater Management

Are we on the path for Resiliency?

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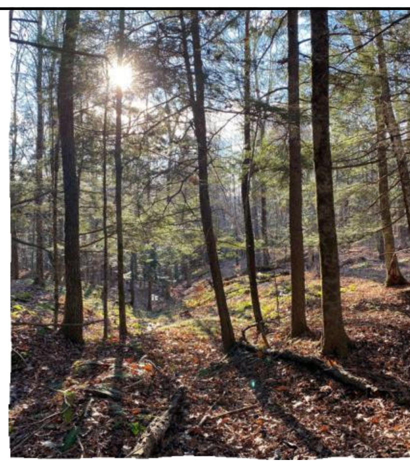

Applying Advances in EPA Region 1 Analytical Tools to Quantify

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

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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
  - ~0.3 to 0.5 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
  - ~+500% to +13,000% increase (11 to 13 pounds/acre/year)

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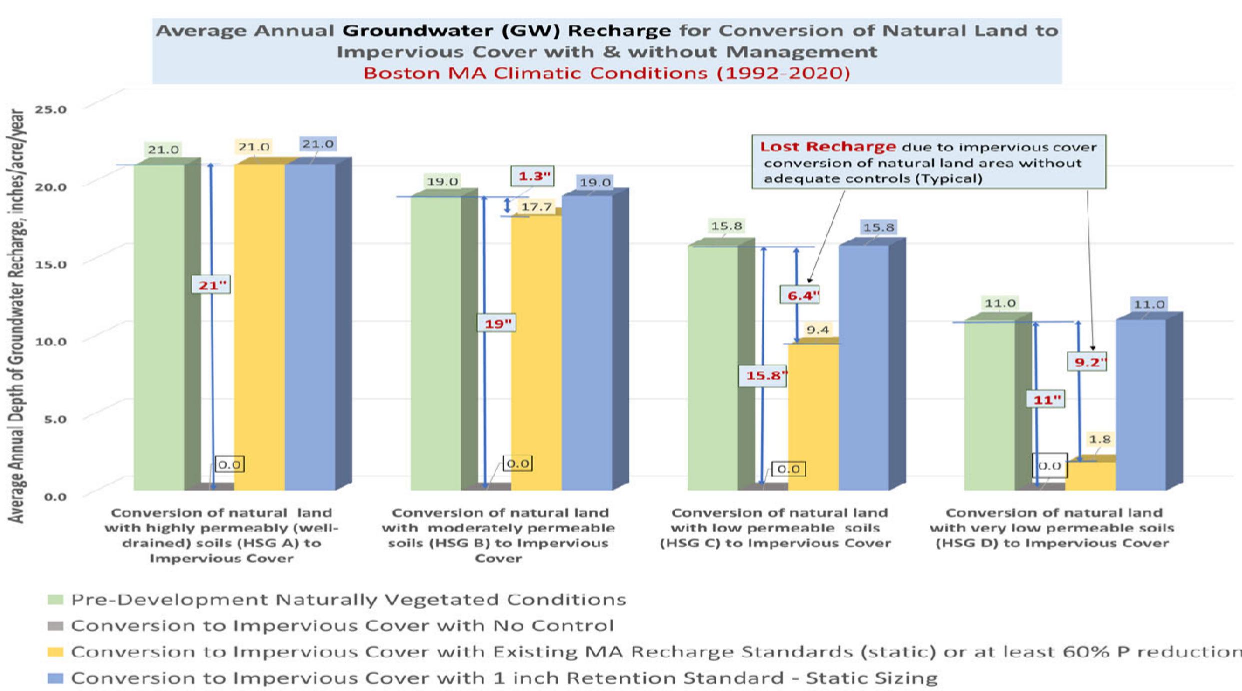

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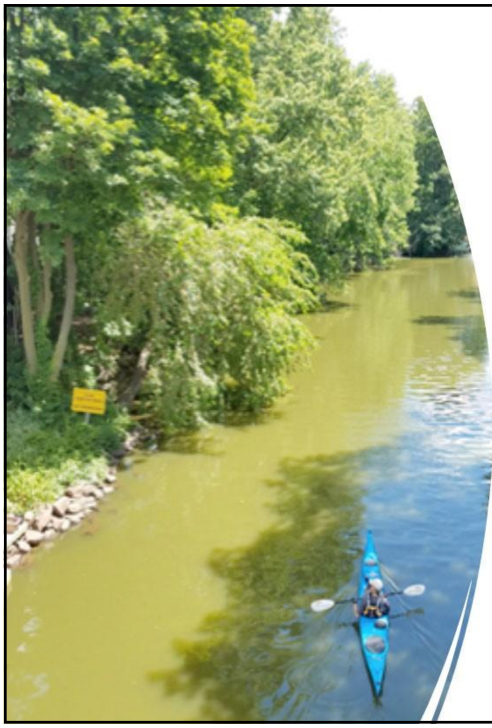

The Nutrient Challenge & SW Permitting

- **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**

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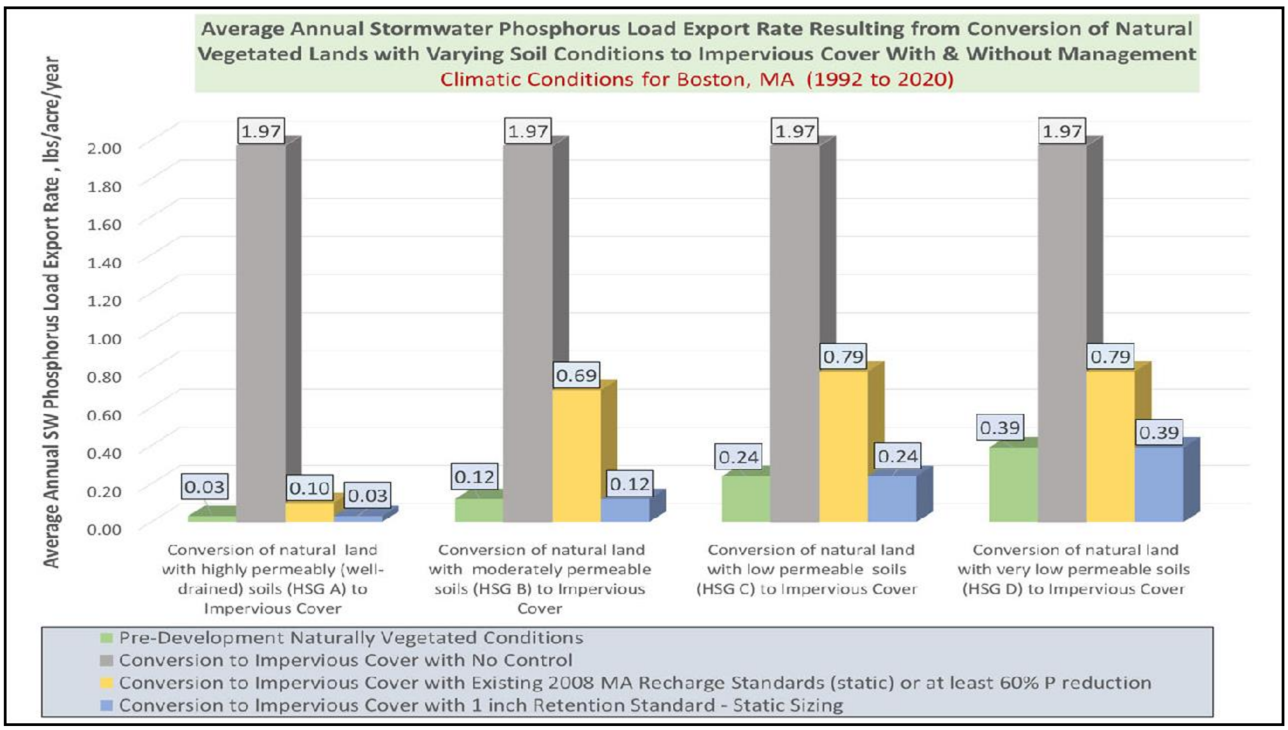

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Minimizing Future Retrofit Needs

- 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

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Potential Cost Burden & Opportunity for Cost Avoidance – SW Nutrient Loading Management

Potential Future Stormwater Management Cost Burdens Associated with Converting Natural Vegetated Areas to Impervious Cover (IC Conversion)				
Nutrient	**Management Scenario**	**Range of Increase in Average Annual Nutrient Load Export Rate from IC Conversion**	**Range in Stormwater Retrofit costs (yr 2020)****	**Range in Potential Future SW Retrofit Cost Burden to offset increased nutrient loading from IC conversion ($/acre IC)**
Phosphorus	**No controls*****	1.5 to 2.0 lbs/acre/yr	$25,000 to $60,000 per lb Phosphorus Captured	$62,000 to $79,000 per IC acre
	60% P Load reduction at time of development	0.6 to 0.8 lbs/acre/yr		$15,000 to $48,000 per IC acre
	1 Inch Retention standard with Recharge Targets	**0 lbs/acre/yr**	**$0**	**$0**
Nitrogen	**No controls*****	10.9 to 13.1 lbs/acre/yr	$2,200 to $7,500 per lb Nitrogen Captured	$48,000 to $58,000 per IC acre
	65% N Load reduction at time of development	3.8 to 4.6 lbs/acre/yr		$8,400 to $35,000 per IC acre
	1 Inch Retention Standard with Recharge Targets	**0 lbs/acre/yr**	**$0**	**$0**

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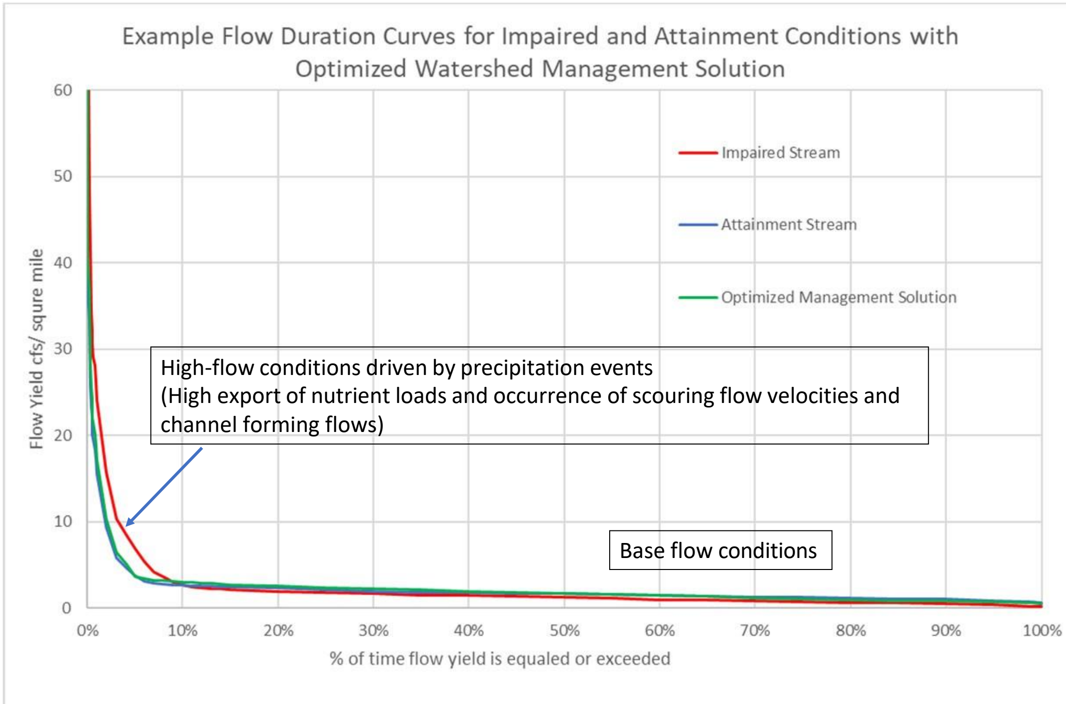

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Summary & Take Away Information

- 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

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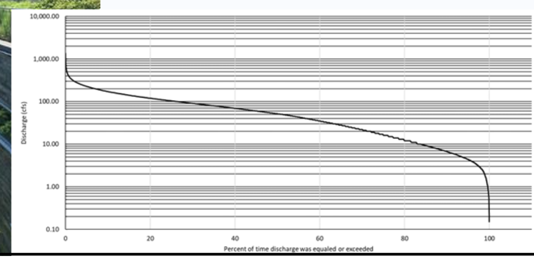
EPA Region 1's Flow Duration Curve work is a two-phase project

Investigate the impacts of Conservation Development (CD) practices on watershed hydrology and stream health. Improving the way we design, develop, and re-develop our communities

Understand the sustainability and resilience of alternative approaches to development



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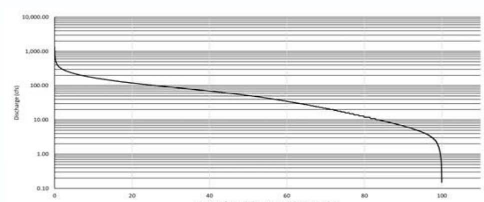
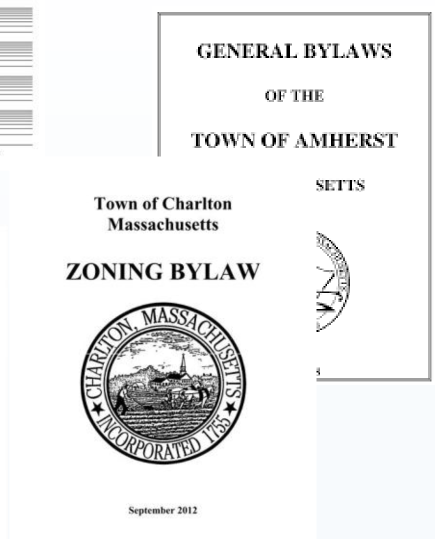
Sustainability

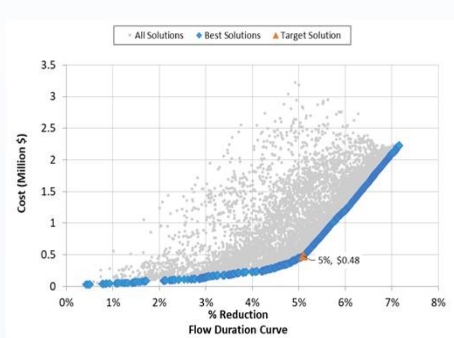
- Environmental



- Social



- Economic



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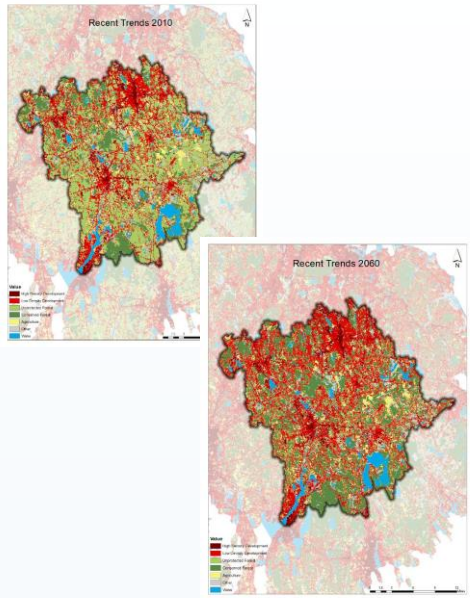
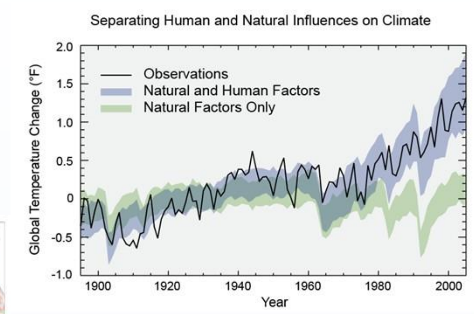
Resilience

- Future land use



- Future Climate



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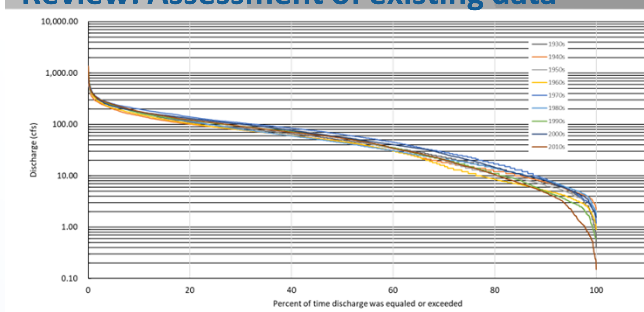
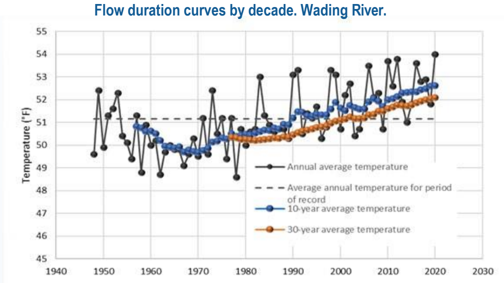
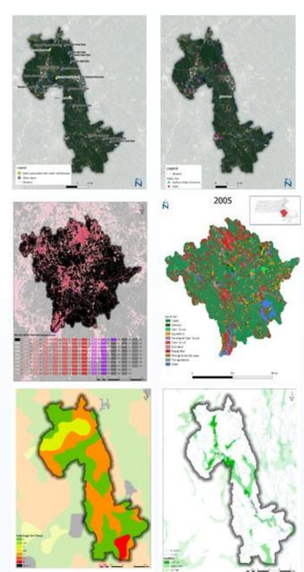
Review: Assessment of existing data



Flow duration curves by decade. Wading River.



Annual average temperature trends (T.F. Green Airport).



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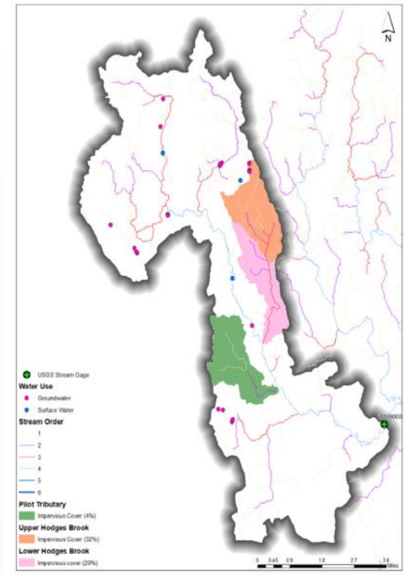
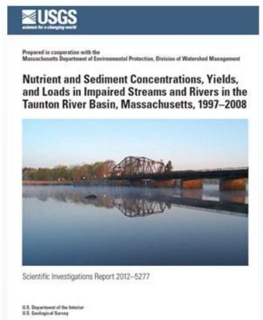
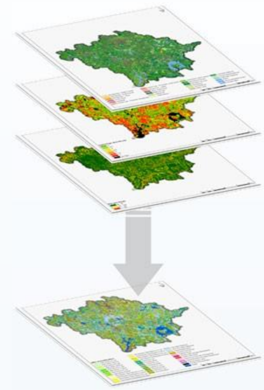
Review: Model Configuration







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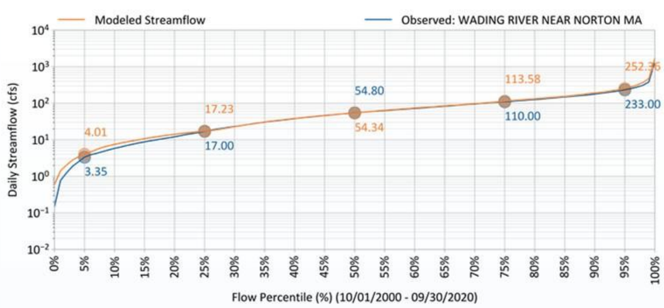
Review: Model Calibration and Validation



Flow Duration Curves: Predicted vs Observed

Hydrology Monitoring Locations	Performance Metrics (Seasonal)															Performance Metrics (Flow Regime)														
	PBIAS					R-squared					Nash-Sutcliffe E					PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	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	-	-	+	-	-											-	-	-	-	-										

Very Good | Good | Satisfactory | Unsatisfactory
- Overpredicts | + Underpredicts

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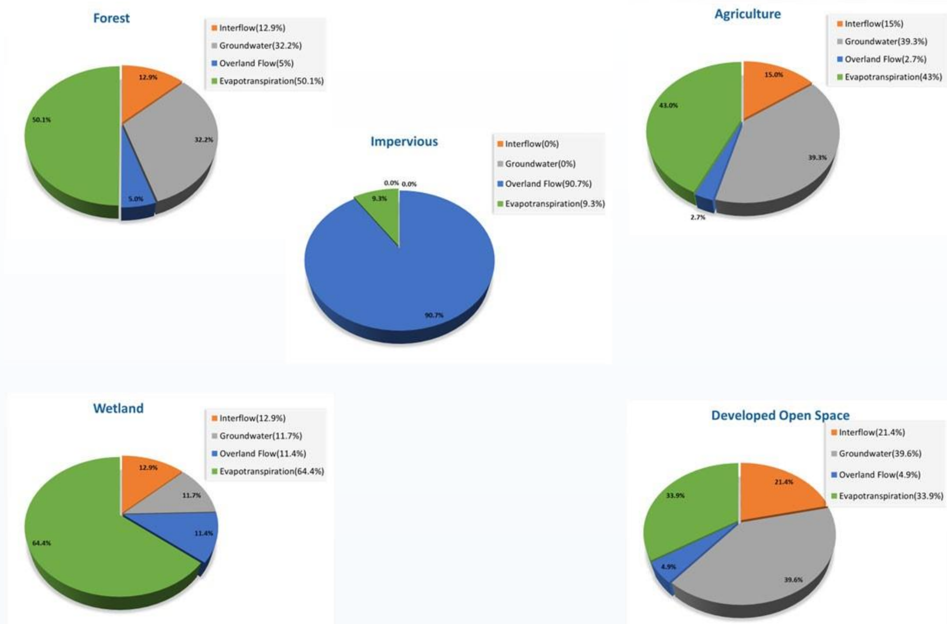
Review: Water Balance



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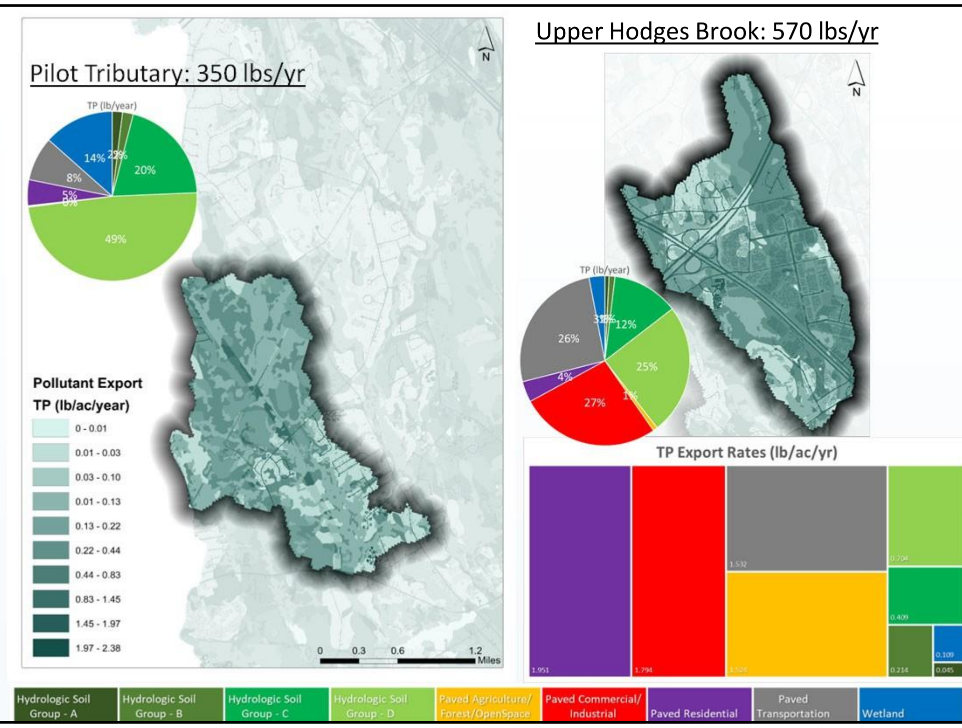

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Optimization: Opportunity Screening

Land Use	Within 200 feet of impervious surface	Landscape Slope (%)	Within FEMA Hazard Areas	Within Surface Water Protection Zone	Within 100 feet of Stream/ Coastline	Within Wetland	Within 25 feet of Structure?	Hydrologic 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	Surface Infiltration	Surface Infiltration Basin (e.g., Rain Garden)
								D	Biofiltration	Biofiltration with 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	Subsurface Infiltration	Infiltration Trench
								D	Shallow filtration	Porous Pavement
		> 5	–	–	–	–	–	–	SCM with complicating characteristics	–

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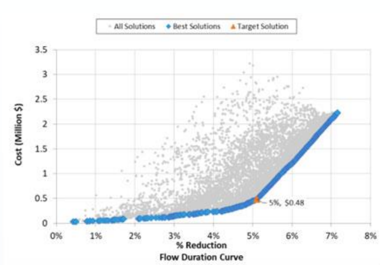
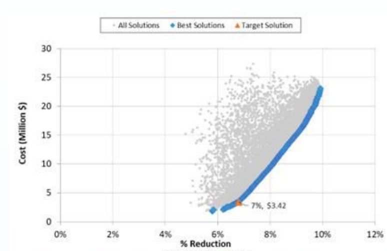
Optimization: Cost Effectiveness Curves

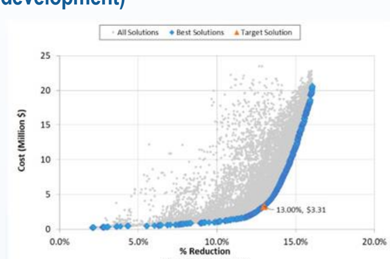


Pilot Tributary (low development)



Lower Hodges (medium development)

CECs: used average year



Upper Hodges (high development)

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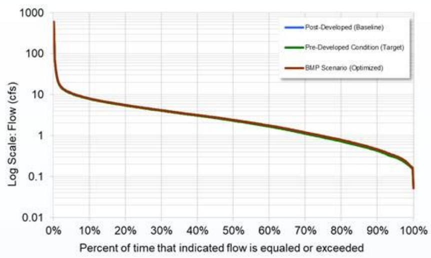
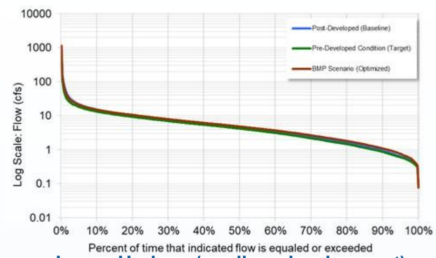
Optimization: Opti–Tool FDCs

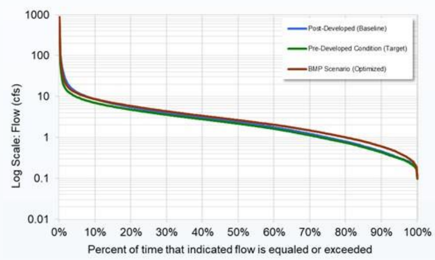


Pilot Tributary (low development)



Lower Hodges (medium development)

FDCs: used 20 years of data

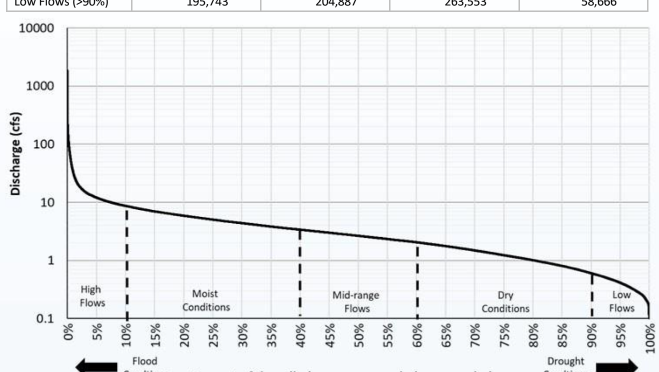


Upper Hodges (high development)

Optimization: Opti–Tool Results By Flow Regime

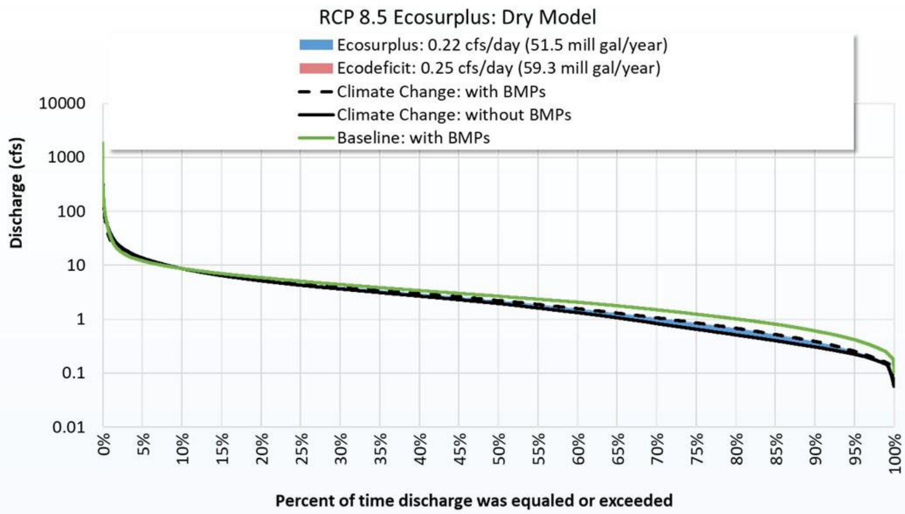
Average daily flow by flow regime (gallons per day) for Upper Hodges sub-watershed.

FDC Flow Regime	Pre-development	Existing Conditions	SCM Implementation	Difference between Existing Conditions and SCM Implementation
High Flows (<10%)	10,328,678	15,542,489	14,047,584	-1,494,905
Moist Conditions (10% - 40%)	2,821,690	3,249,150	3,452,334	203,184
Mid-range Flows (40% - 60%)	1,418,780	1,545,519	1,730,688	185,169
Dry Conditions (60% - 90%)	625,365	676,662	821,837	145,174
Low Flows (>90%)	195,743	204,887	263,553	58,666



Adapted from U.S. EPA, 2007.

Optimization: Resiliency to Climate Change



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Change in Land Use – Land Cover for 2060 Future Condition in Taunton River Watershed

Opti-Tool Land Use Classification	Baseline 2016 (acre)	Future 2060 (acre)	Change (acre)	% Change
Paved Forest	9	9	0	0%
Paved Agriculture	128	158	30	23%
Paved Commercial	4,858	6,873	2,015	41%
Paved Industrial	2,745	3,892	1,147	42%
Paved Low Density Residential	9,951	20,717	10,766	108%
Paved Medium Density Residential	489	1,133	644	132%
Paved High Density Residential	2,856	4,041	1,186	42%
Paved Transportation	11,852	21,709	9,857	83%
Paved Open Land	4,138	8,377	4,239	102%
Developed OpenSpace	40,955	76,120	35,165	86%
Forested Wetland	66,463	66,463	0	0%
Non-Forested Wetland	9,734	9,734	0	0%
Forest	144,393	78,832	-65,561	-45%
Agriculture	25,255	25,768	513	2%
Water	17,628	17,628	0	0%

Increase in impervious cover = +29,883 acres (+81%)
Decrease in Forest land = -65,561 acres (-45%)

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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.

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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 was 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 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.

SCM Implementation can mitigate some of the impacts of climate change, especially projected lower baseflows, by promoting groundwater recharge.

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

CONSERVATION DEVELOPMENT

- 105-acre conservation development
- Designed to integrate homes with the landscape and provide protection for water quality and habitat.
- Permeable pavements, raingardens, and rooftop infiltration are used to recharge groundwater.
- Homes near to vernal pools include porous driveways to reduce the need snow and ice management, and 12" of rich loam for all landscaping so plantings and lawns will thrive and reduce the need for fertilizer and pesticides.

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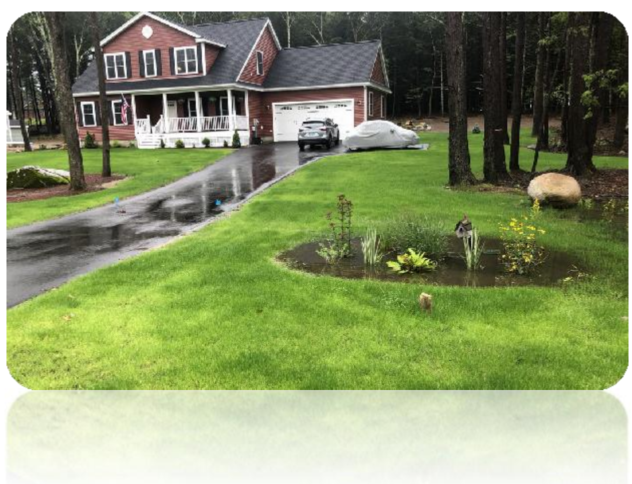
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

MARKET VALUE

- 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 (wetlands, cedar swamps)
- Simplified permitting, porous asphalt made the project possible.
- Over 55+ community managed by HOA and Maintenance vendor



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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

CONSERVATION LANDS AND VERNAL POOL PROTECTION

- 105-acre development
- 55 acres in conservation
- ACOE Vernal Pool Recommendations[1]
  - Directional buffer
  - Critical terrestrial habitat
  - 100' - No disturbance
  - 175'- Limited clearing
  - 250'- Land use restrictions

AMPHIBIAN TUNNEL

LIMITED LOT CLEARING

CRITTER CROSSING ROAD SIGNAGE

[1]US Army Corps of Engineers, New England District. 2015. Vernal Pool Best Management Practices.

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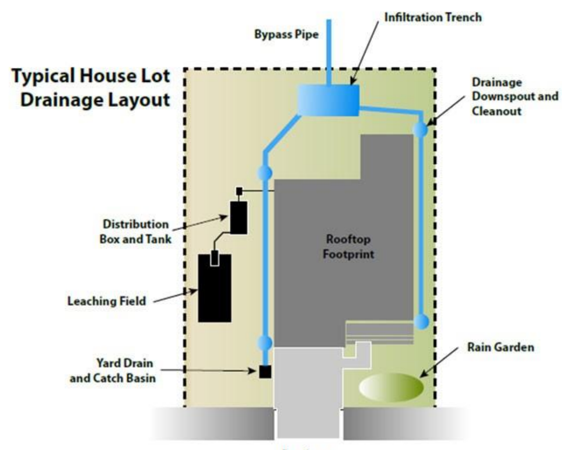
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

LOT LAYOUT AND DRAINAGE

- Lots designed to be nearly zero discharge
- Raingardens
- Drip edge infiltration and infiltration trench
- Porous asphalt roadways
- **Conservation measures** to protect habitat for high value natural resourc like Atlantic Cedar, vernal pools, frogs and other critters.



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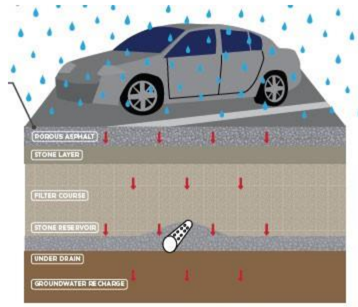
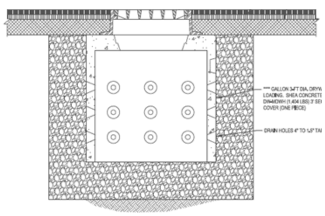
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

POROUS PAVEMENTS



POROUS ASPHALT DIAGRAM



REDUNDANT DRAINAGE - DRY WELLS

- 3,864 LF, 2.1 acres of porous asphalt roadways
- 9 porous asphalt driveways (Phase II)
- ATPB (asphalt treated permeable base)
  PG76-28, 23% voids, binder course
- Porous asphalt – PG76-28 18% voids, wearing course

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

INFILTRATION

ROADWAY INFILTRATION TRENCH CONNECTED TO PRETX

ROADWAY INFILTRATION POST- CONSTRUCTION

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

BIOFILTRATION

BIORETENTION CUL-DE-SAC

BIOSWALE AND PRETX POST-CONSTRUCTION

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

HOUSE LOT INFILTRATION

DOWNSPOUT SELF CLEANING GRATES

INFILTRATION TRENCH FOR ROOFTOP RUNOFF

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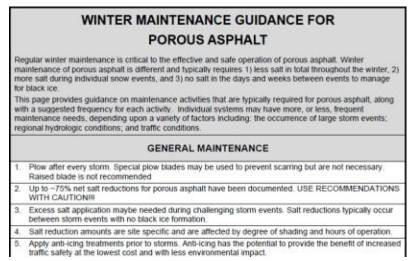
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

LOW /NO CHLORIDE

- **<u>POROUS ROADWAY AND DRIVEWAY RESTRICTIONS on the Use of Chloride/Deicing Chemicals</u>:** Roadway snow removal will be conducted by a NHDES certified Green SnowPro Salt Applicator Certification with environmentally friendly winter maintenance practices with a goal of low chloride and deicing chemical usage

NEW HAMPSHIRE CERTIFIED GREEN SnowPro


WINTER MAINTENANCE GUIDANCE FOR POROUS ASPHALT

Regular winter maintenance is critical to the effective and safe operation of porous asphalt. Winter maintenance of porous asphalt is different and typically requires 1) less salt in total throughout the winter, 2) more salt during individual snow events, and 3) no salt in the days and weeks between events to manage for black ice.

This page provides guidance on maintenance activities that are typically required for porous asphalt, along with a suggested frequency for each activity. Individual systems may have more, or less, frequent maintenance needs, depending upon a variety of factors including: the occurrence of large storm events; regional hydrologic conditions; and traffic conditions.

GENERAL MAINTENANCE

1. Plow after every storm. Special plow blades may be used to prevent scarring but are not necessary. Raised blade is not recommended
2. Up to ~75% net salt reductions for porous asphalt have been documented. USE RECOMMENDATIONS WITH CAUTION!!!
3. Excess salt application maybe needed during challenging storm events. Salt reductions typically occur between storm events with no black ice formation.
4. Salt reduction amounts are site specific and are affected by degree of shading and hours of operation.
5. Apply anti-icing treatments prior to storms. Anti-icing has the potential to provide the benefit of increased traffic safety at the lowest cost and with less environmental impact.

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

LOW /NO CHLORIDE


STANDARD ASPHALT DRIVEWAY AND POROUS ASPHALT ROADWAY 2/9/2022


POROUS ASPHALT DRIVEWAY AND POROUS ASPHALT ROADWAY 2/9/2022

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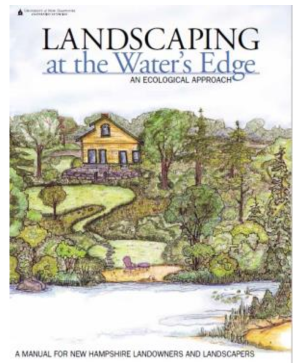
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

FERTILIZER AND PESTICIDE RESTRICTIONS AND LOAM AUGMENTATION

- Fertilizer and pesticide limited, except for establishing initial landscaping within the first season of growth.
- Long-term landscaping will follow practices for water quality protection in *Landscaping at the Water's Edge, an Ecological Approach (2007)*.
- A list of professional landscapers for homeowners for the evaluation of soils, fertilizing and pest management.
- Fertilizers used on the property must contain no phosphorus unless a soil test indicates that additional phosphorus is needed for growth.
- Loam augmentation, placement of 12" of high quality soils comprised of topsoil, compost, and fertilizer if necessary, tested by Soils lab for N, P, pH, organic matter



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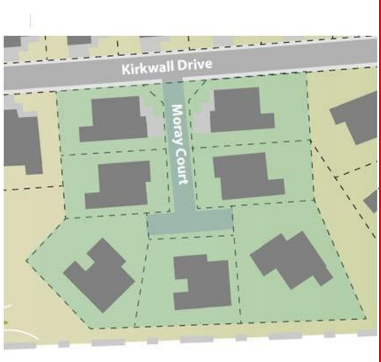
CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C



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
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  - TP 60% REMOVAL
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- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.4 LID Peak High Density Residential

LID VOLUME

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

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.2 No Controls High Density Residential

NO CONTROL
- ✗ STD 2 - PEAK FLOW CONTROL
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- ✗ 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

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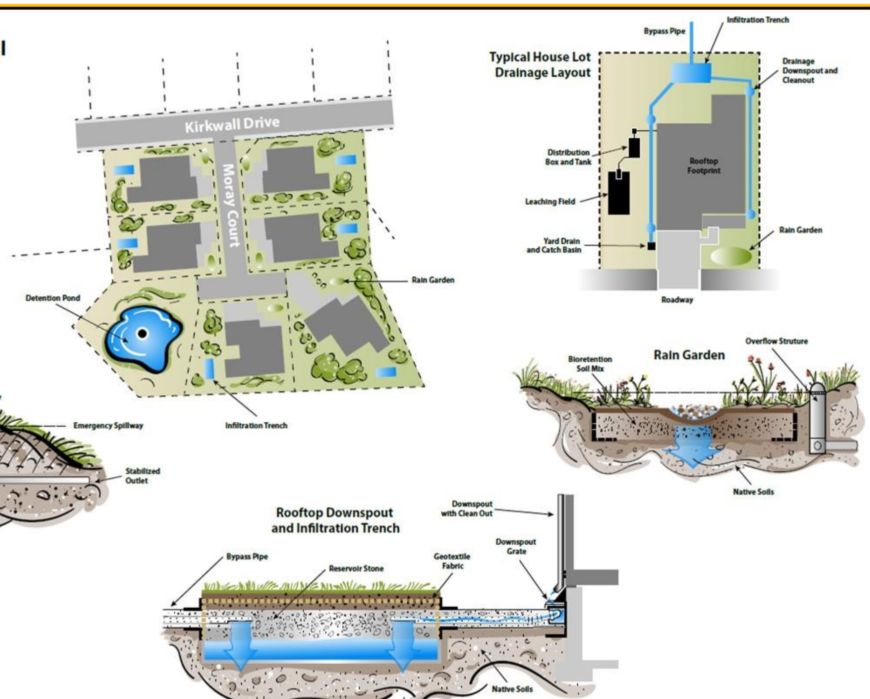
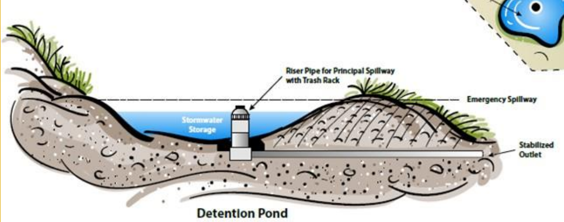
CD1.3 LID MADEP High Density Residential

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





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CD1.4 LID Peak High Density Residential

LID VOLUME

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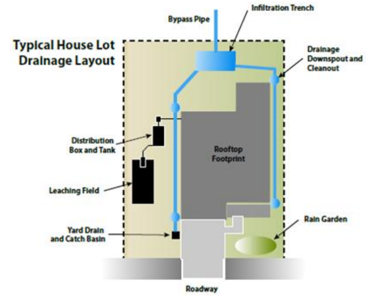
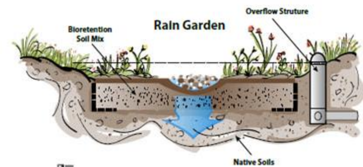
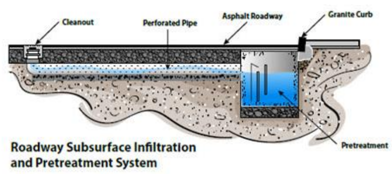
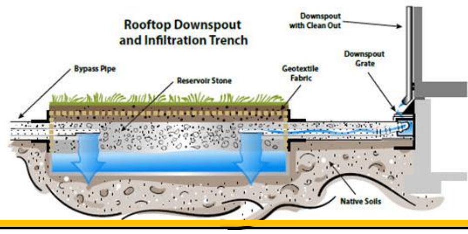
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY









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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
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  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.3 LID MADEP High Density Residential

LID MADEP

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- ✓ 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
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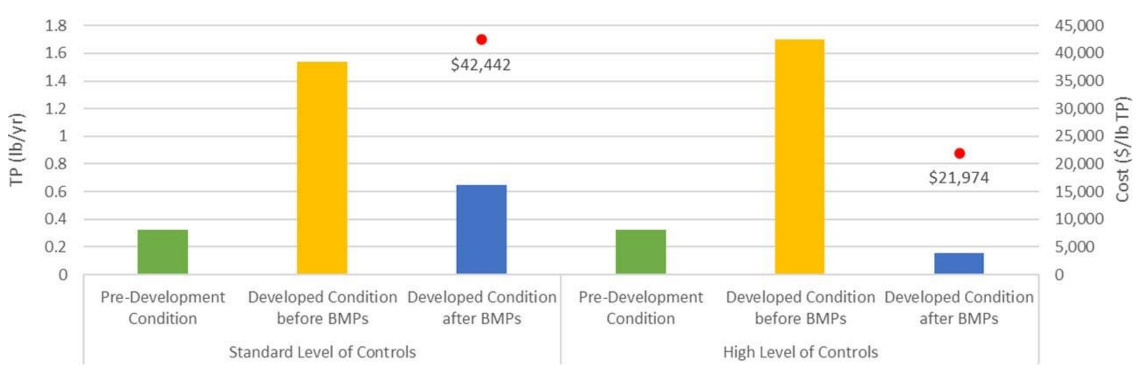
- ✓ RESILIENT HYDROLOGY



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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.3 LID MADEP High Density Residential

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
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- ✗ RESILIENT HYDROLOGY

CD1.4 LID Peak High Density Residential

LID VOLUME

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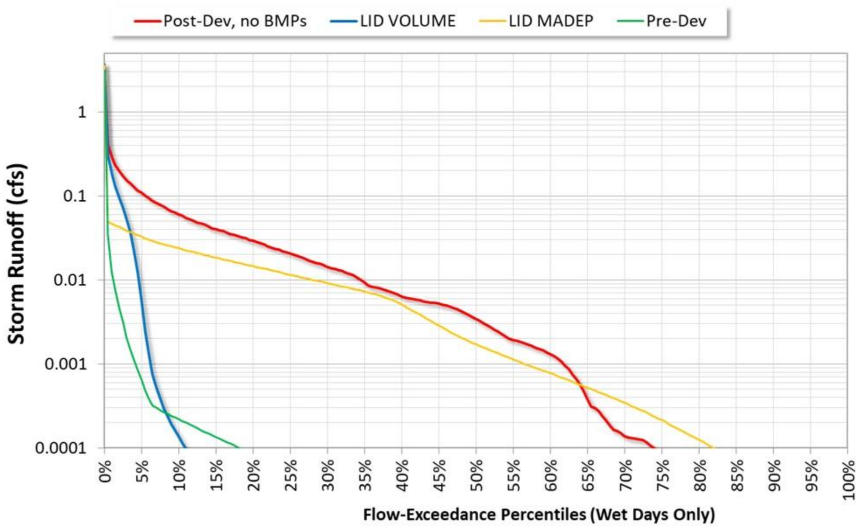

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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A

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

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

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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A

CD2.2 No Controls Commercial Redevelopment

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
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- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

- NO BMPS
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- AND MUNICIPALITIES WITH WEAK SWM REGULATIONS

CD2.3 LID Basic Commercial Redevelopment

LID MADEP

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- ✓ 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

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- ✓ 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)

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CD2.3 LID Basic Commercial Redevelopment

LID MADEP

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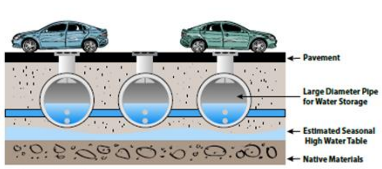
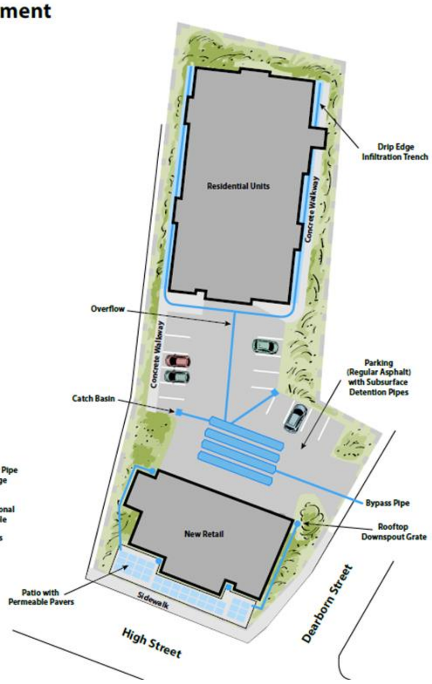
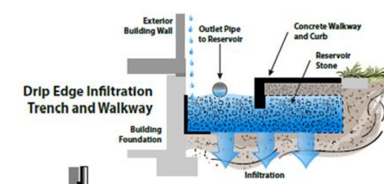
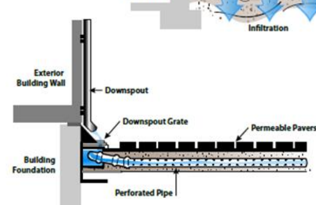


Subsurface Detention







Rooftop Downspout and Permeable Pavers

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CD2.4 LID Volume Commercial Redevelopment

LID VOLUME

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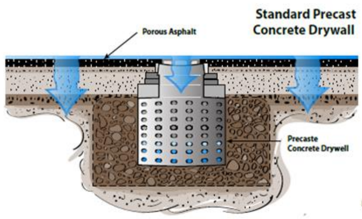

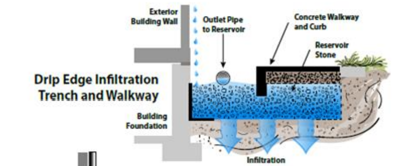

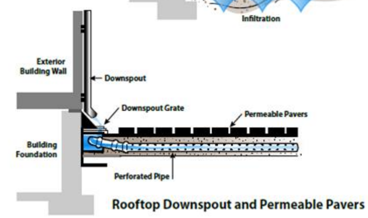

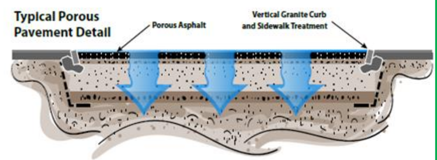

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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A

CD2.2 No Controls Commercial Redevelopment

NO CONTROL

- ✗ STD 2 - PEAK FLOW CONTROL
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- ✗ RESILIENT HYDROLOGY

CD2.3 LID Basic Commercial Redevelopment

LID MADEP

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CD2.4 LID Volume Commercial Redevelopment

LID VOLUME

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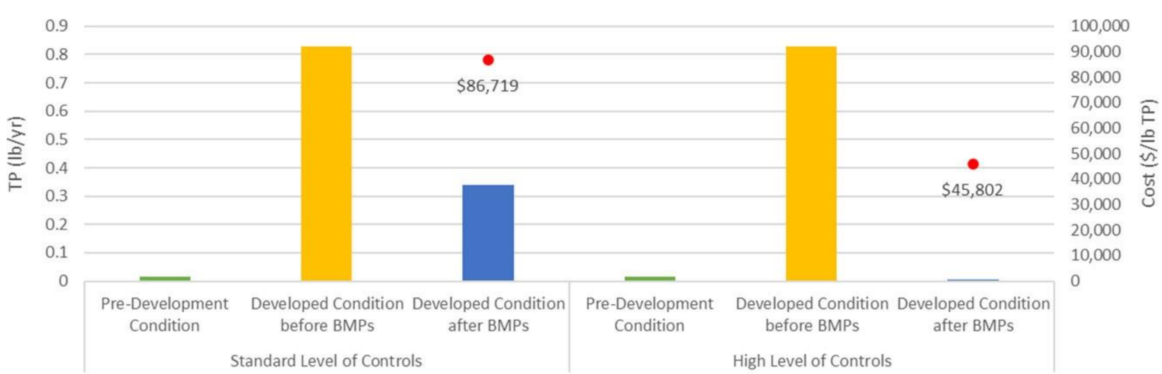

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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL – RUNOFF VOLUME

CD2.3 LID Basic Commercial Redevelopment

LID MADEP

- ✓ STD 2 - PEAK FLOW CONTROL
- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
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  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD2.4 LID Volume Commercial Redevelopment

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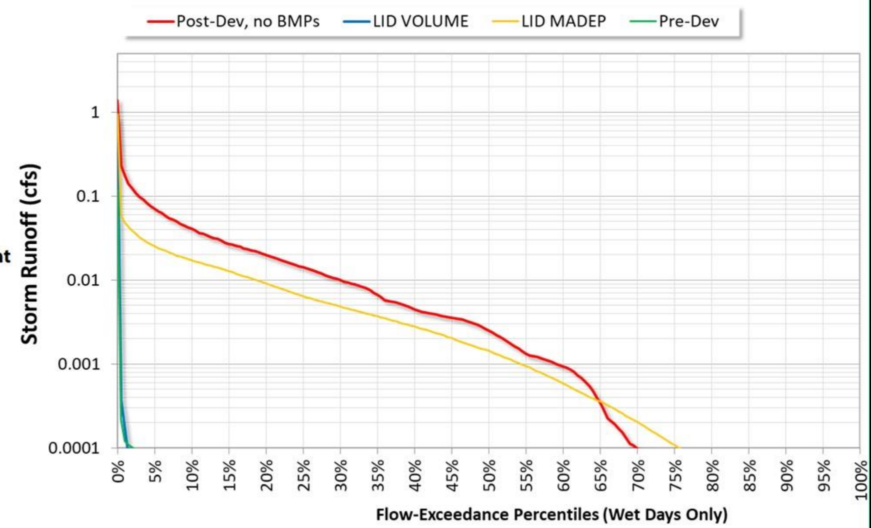
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY



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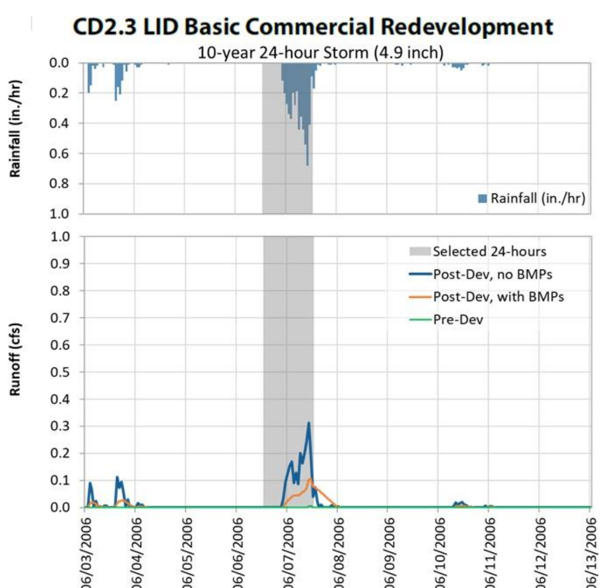
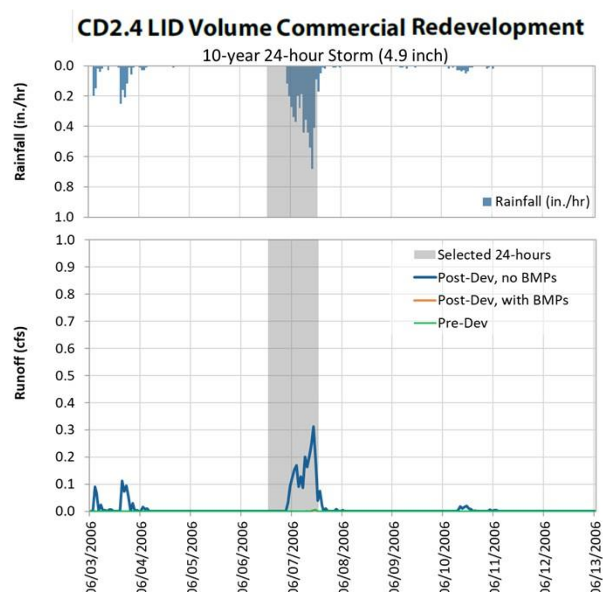
CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL - RESILIENCY





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NEXT STEPS

- Meeting/Webinar in September
- Information sheets
- Compendium
- Recharge Calculations
- Discussion (10 min)

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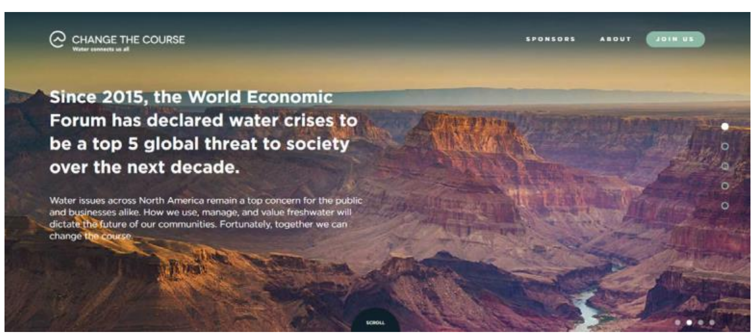
THANK YOU FOR YOUR TIME



Envisioning A Different Future Of Watershed Management

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APPENDIX C. MUNICIPAL MEETING #3 – SEPTEMBER 13, 2022

AGENDA

Municipal Engagement Meeting #3

Next-Generation Watershed Management Practices for Conservation Development

September 19, 2022 10-11:30 AM

Town of Mansfield, Public Safety Building, Community Meeting Room

500 East Street, Mansfield, Massachusetts 02048

Remote Option - Microsoft Teams meeting Click here to join the meeting

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1. **Why We Are Here (Ray, 5 min)**
2. **Project Overview and Recap (Mark, 10 min)**
3. **Costing and Performance of Conceptual Development Plans (Rob, 15 min)**
4. **Introduce Compendium (Rob, 5 min)**
5. **Overview of Local Regulations Review and Recommendations (Julie, 10 min)**
6. **Information Sheets (Michelle, 5 min)**
7. **Discussion (All, 35 min)**
8. **Next Steps (Mark and Rob, 5 min)**

Meeting Participants

Confirmed

1. Tricia Cassidy, Middleboro
2. Katelyn Gonyer, Mansfield
3. Jenn Carlino, Easton
4. John Thomas, Norton
5. Scott Horsley, Consultant, Tufts University

Pending

1. Gretchen Rabinkin, BSLA
2. Margherita Pryor, EPA
3. Stefanie Covino, Blackstone Watershed Collaborative

Project Team

1. Sara Burns, Ducks Unlimited (Remote)
2. Danica Belknap, SRPEDD
3. Kimberly Groff, SNEP
4. Ray Cody, Mark Voorhees, Michelle Vuto, Newt Tedder, Matt Stamas, EPA
5. Laura Shifman, MADEP
6. Robert Roseen, Waterstone Engineering
7. Khalid Alvi, Paradigm
8. Julie Labranche, JLB Planning

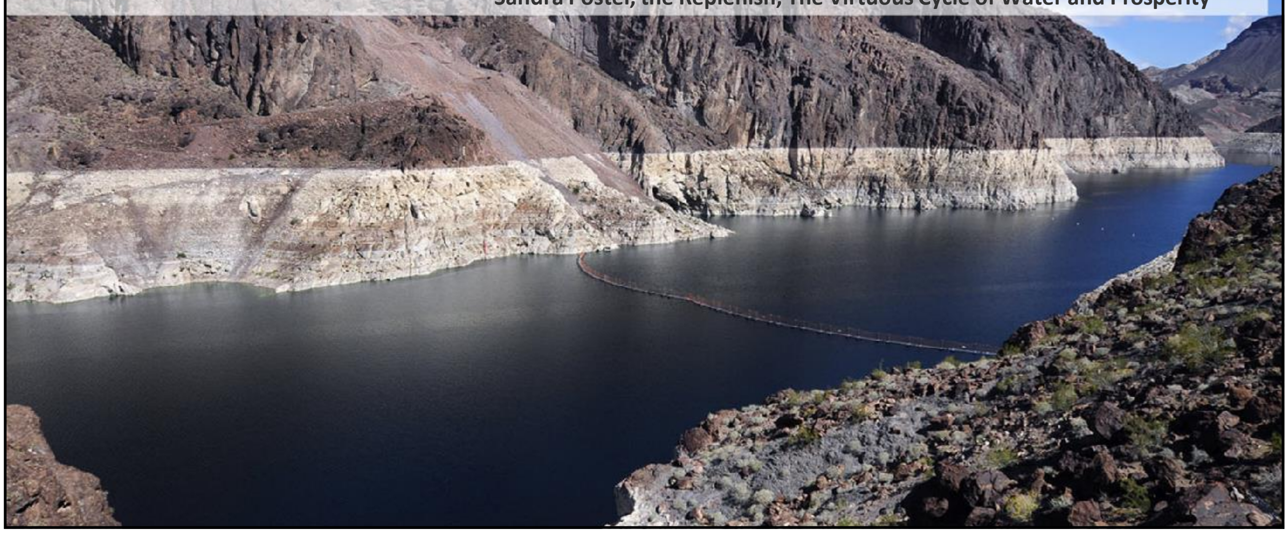
MUNICIPAL ENGAGEMENT MEETING #3 NEXT-GENERATION WATERSHED MANAGEMENT PRACTICES FOR CONSERVATION DEVELOPMENT

September 19, 2022
Public Safety Building, Mansfield, MA

1

"We have disrupted the natural water cycle for centuries in an effort to control water for our own prosperity. Yet every year, recovery from droughts and floods costs billions of dollars, and we spend billions more on dams, diversions, levees, and other feats of engineering. These massive projects not only are risky financially and environmentally, they often threaten social and political stability. *What if the answer was not further control of the water cycle, but repair and replenishment?*"

-Sandra Postel, the Replenish, The Virtuous Cycle of Water and Prosperity



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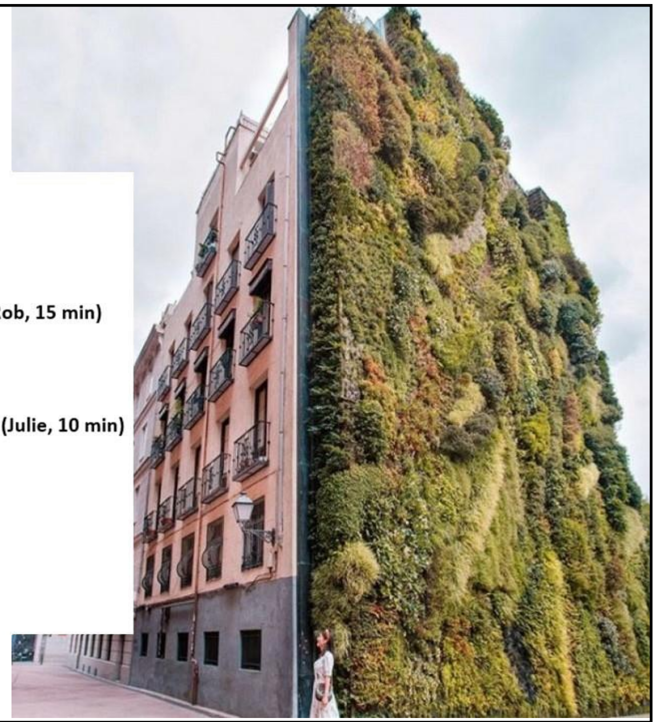
Agenda 10-11:30

1. Why We Are Here (Ray, 5 min)
2. Project Overview and Recap (Mark, 10 min)
3. Costing and Performance of Conceptual Development Plans (Rob, 15 min)
4. Introduce Compendium (Rob, 5 min)
5. Overview of Local Regulations Review and Recommendations (Julie, 10 min)
6. Information Sheets (Michelle, 5 min)
7. Discussion (All, 35 min)
8. Next Steps (Mark and Rob, 5 min)



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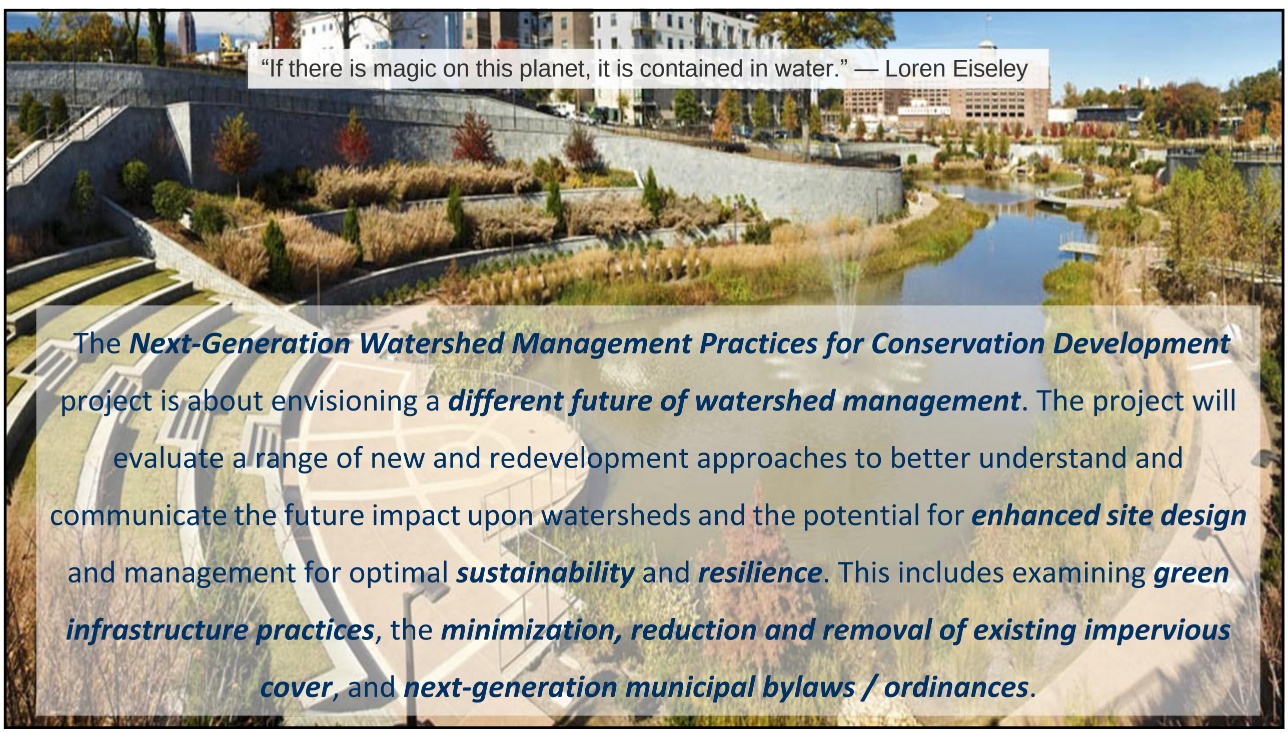

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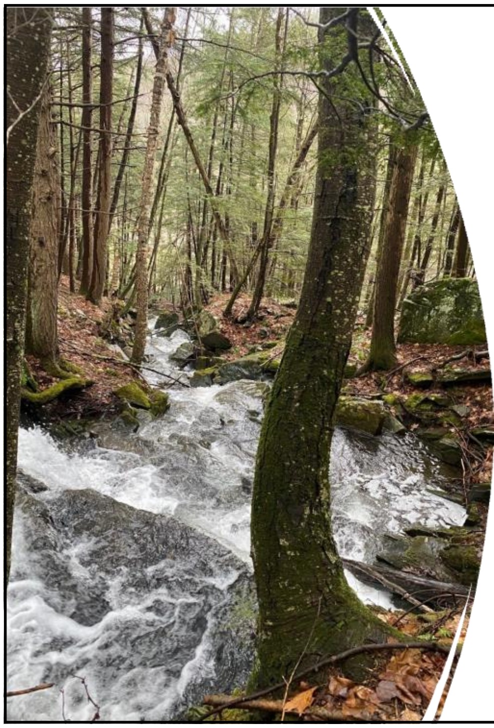

Sound Future Land Development & Stormwater Management

- Development of a ***Watershed Protection 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.

5

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

6

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
  - ~0.3 to 0.5 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
  - ~+500% to +13,000% increase (11 to 13 pounds/acre/year)

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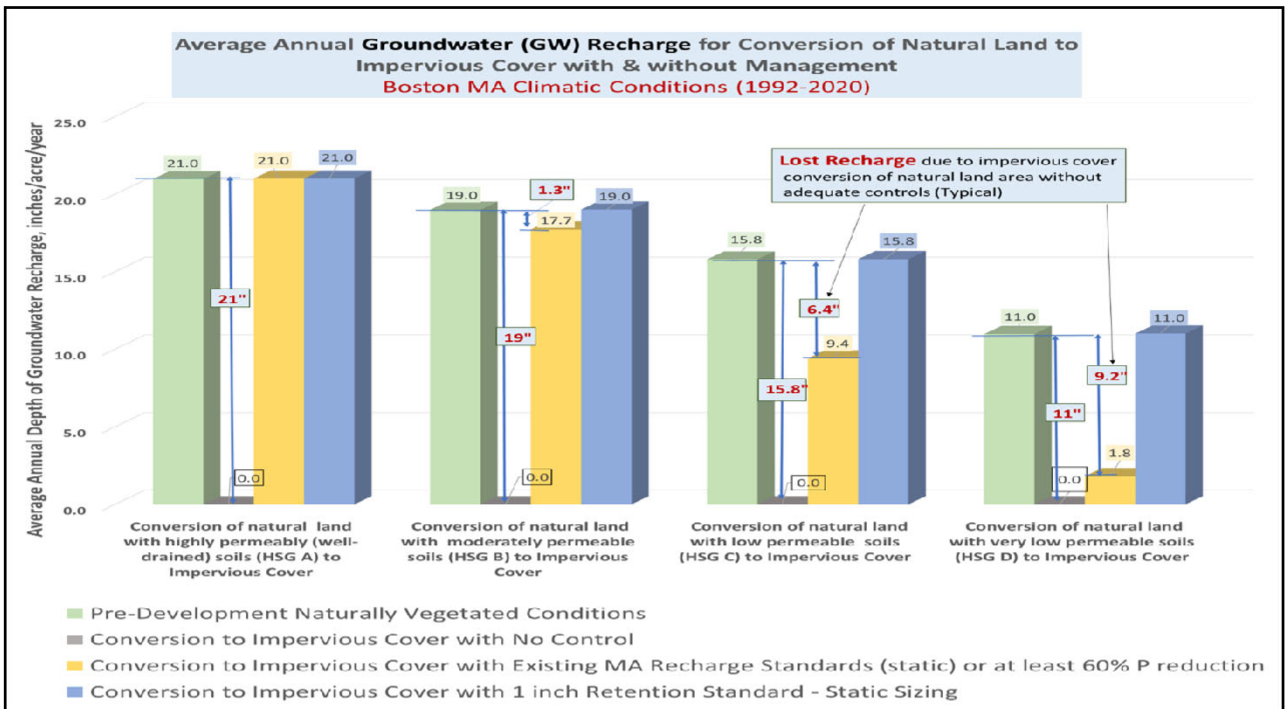

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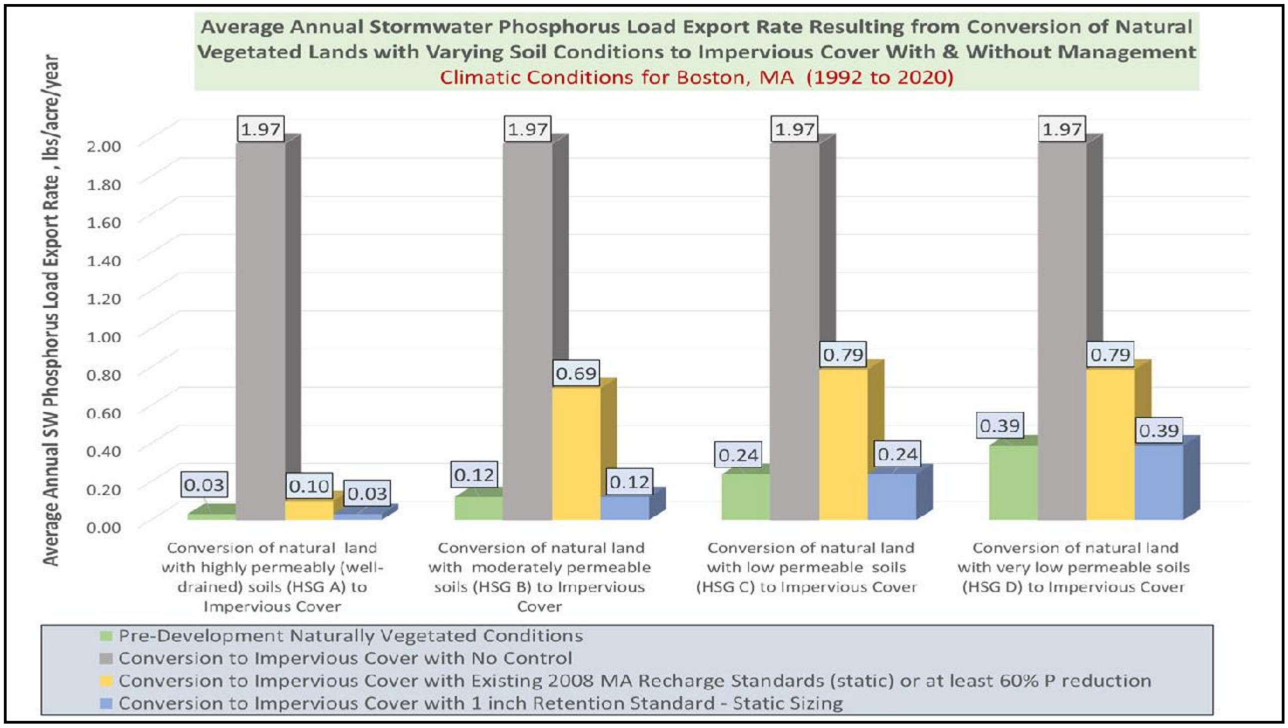

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Minimizing Future Retrofit Needs

- 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

10

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

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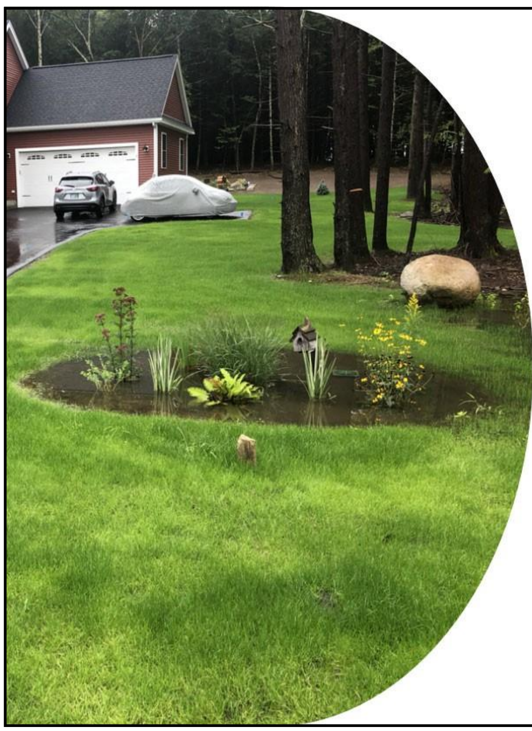

Conceptual Design Plans

NEXT-GENERATION WATERSHED MANAGEMENT

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

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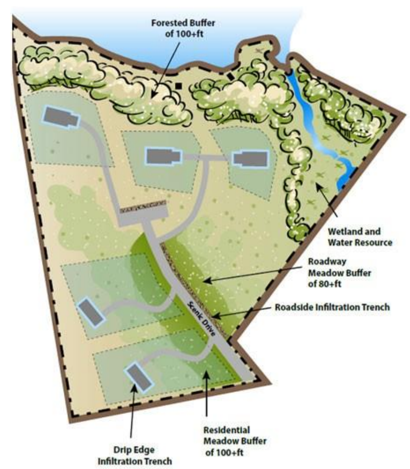
CONCEPT DEVELOPMENT PLANS

CD-1 HIGH DENSITY RESIDENTIAL
INFILTRATION AND RAINGARDENS

CD-2 COMMERCIAL REDEVELOPMENT
POROUS PAVEMENTS AND INFILTRATION

CD3- LOW DENSITY RESIDENTIAL
BUFFERS AND INFILTRATION



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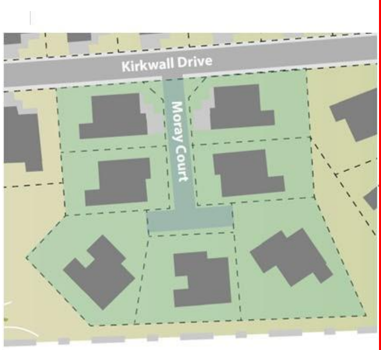
CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-B



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
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- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
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- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD1.4 LID Peak High Density Residential

LID VOLUME

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

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-B

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- ✗ 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

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  - 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

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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)
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- ✗ NO INCREASE IN NUTRIENT LOAD
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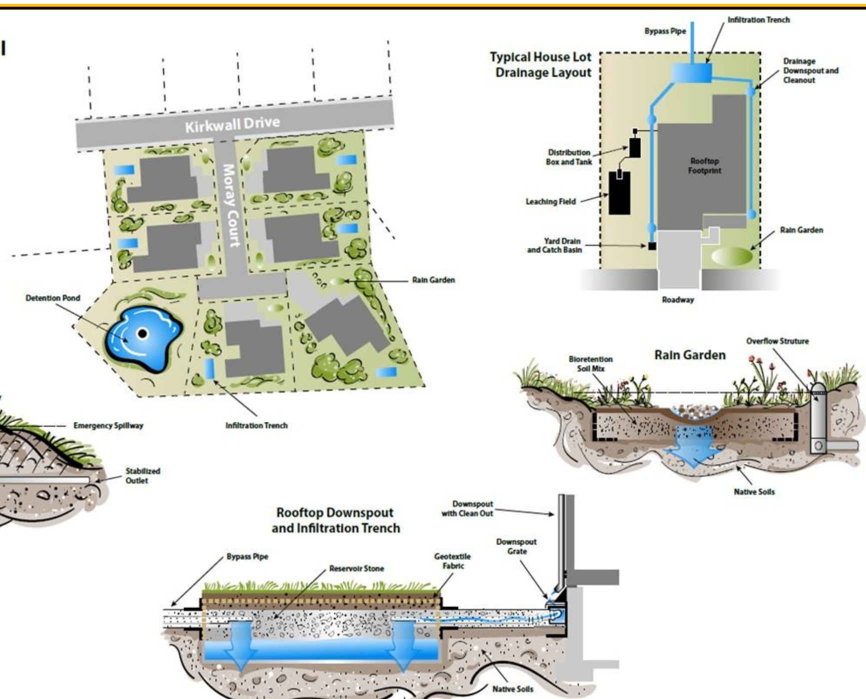
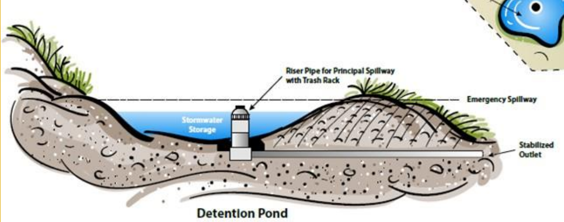
- ✗ RESILIENT HYDROLOGY





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CD1.4 LID Peak High Density Residential

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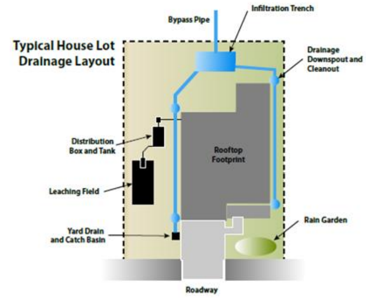

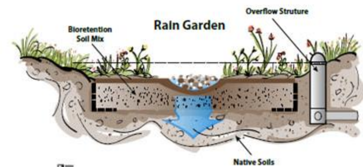

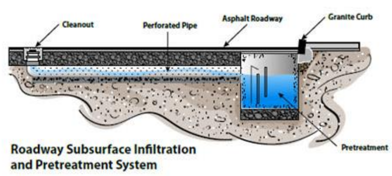

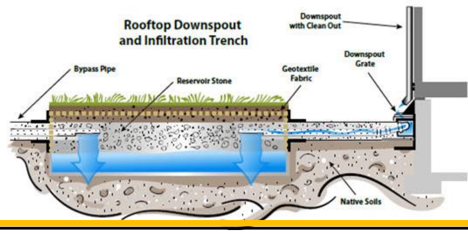

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.2 No Controls High Density Residential

NO CONTROL

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- ✗ RESILIENT HYDROLOGY

CD1.3 LID MADEP High Density Residential

LID MADEP

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- ✗ PREDEVELOPMENT HYDROLOGY
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CD1.4 LID Peak High Density Residential

LID VOLUME

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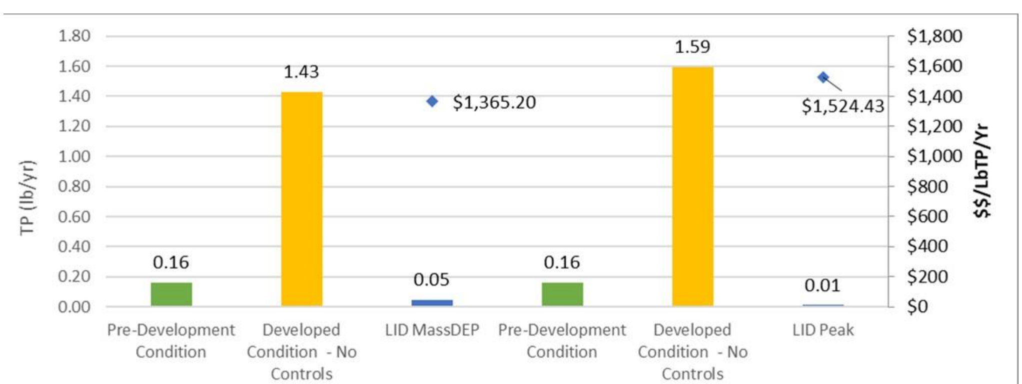

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.3 LID MADEP High Density Residential

LID MADEP

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CD1.4 LID Peak High Density Residential

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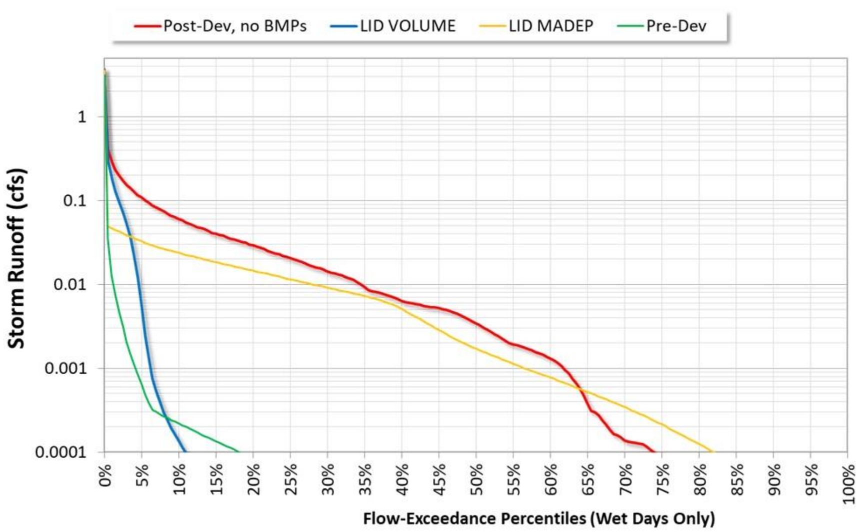

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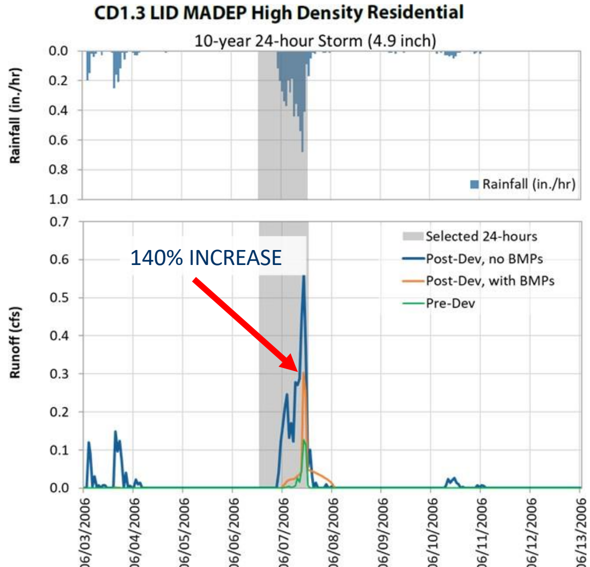
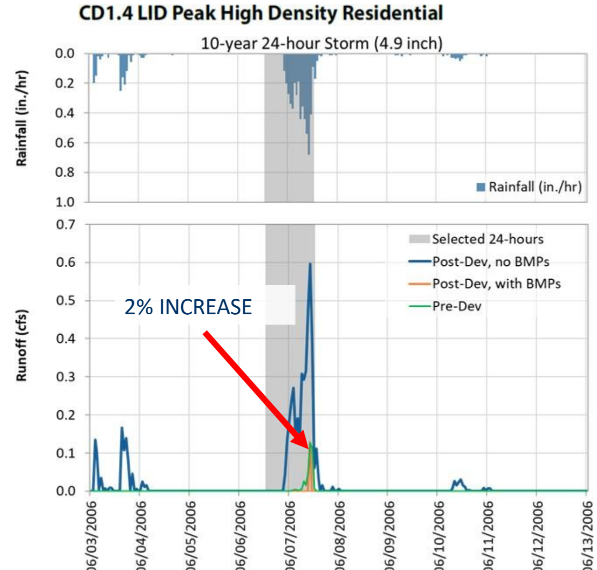
CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.3 LID MADEP High Density Residential



CD1.4 LID Peak High Density Residential



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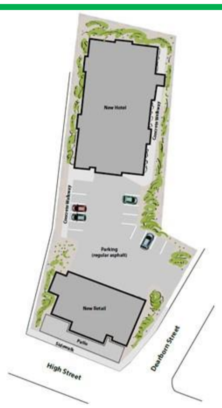
CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A



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

CD2.3 LID Basic Commercial Redevelopment

LID MADEP
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- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
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- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY

CD2.4 LID Volume Commercial Redevelopment

LID VOLUME
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- ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
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- ✓ RESILIENT HYDROLOGY

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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL HSG-A

CD2.2 No Controls Commercial Redevelopment

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- ✗ RESILIENT HYDROLOGY

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- AND MUNICIPALITIES WITH WEAK SWM REGULATIONS

CD2.3 LID Basic Commercial Redevelopment

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  - TP 60% REMOVAL
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- ✗ 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)

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CD2.3 LID Basic Commercial Redevelopment

LID MADEP

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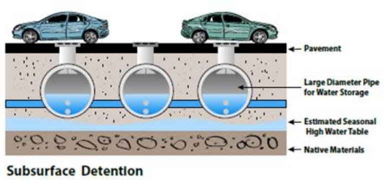

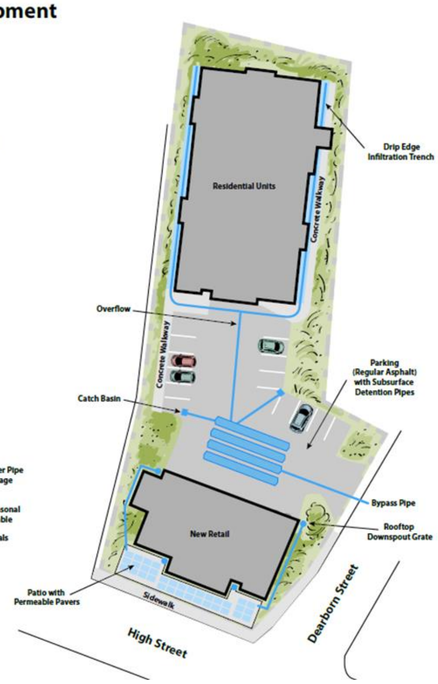

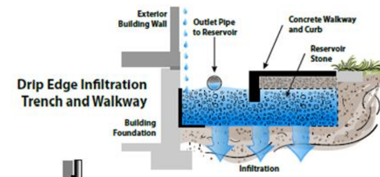

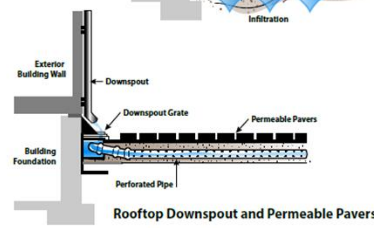

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CD2.4 LID Volume Commercial Redevelopment

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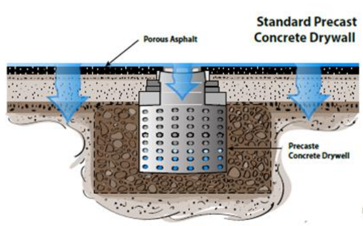
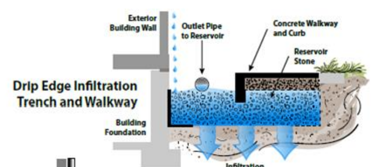
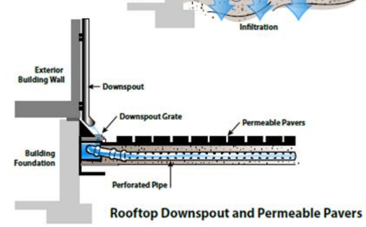
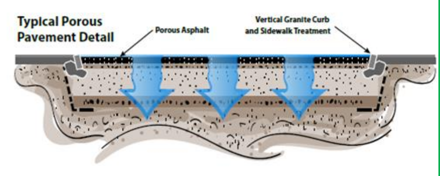
- ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✓ NO INCREASE IN NUTRIENT LOAD
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY









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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

CD2.3 LID Basic Commercial Redevelopment

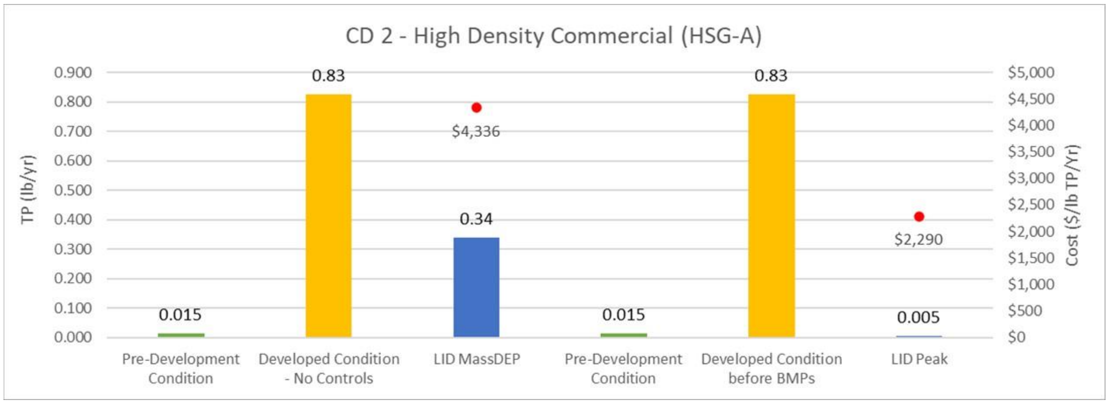
LID MADEP

- ✓ 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



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25

CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL – RUNOFF VOLUME

CD2.3 LID Basic Commercial Redevelopment

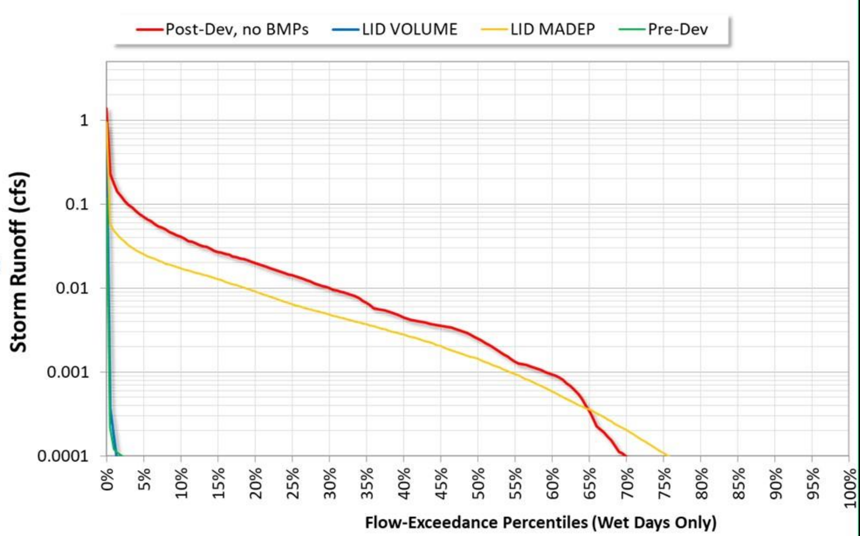
LID MADEP

- ✓ 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



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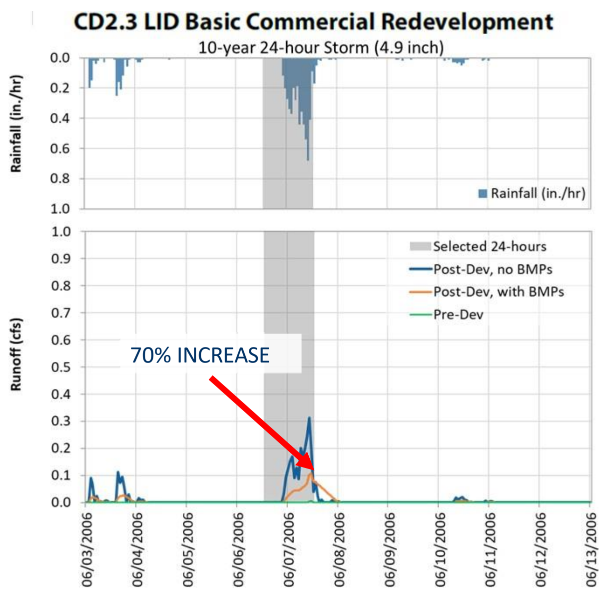
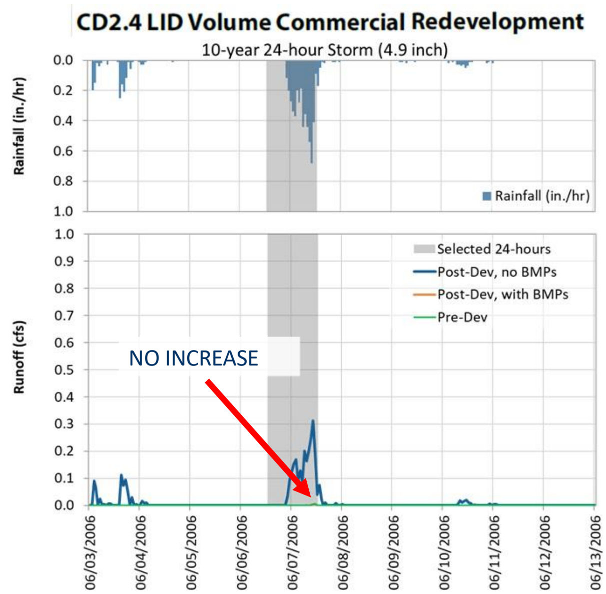
CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL - RESILIENCY





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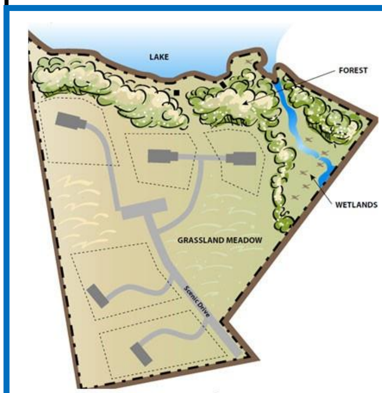
CONCEPT PLAN 3: LOW DENSITY RESIDENTIAL HSG-B



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

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

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

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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)

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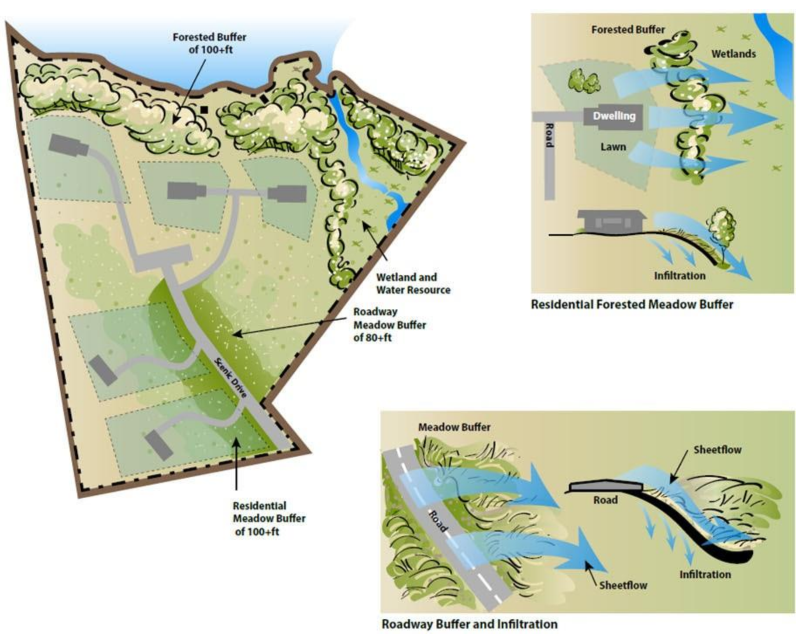
CD3.3 LID MADEP
Low Density Residential

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



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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)
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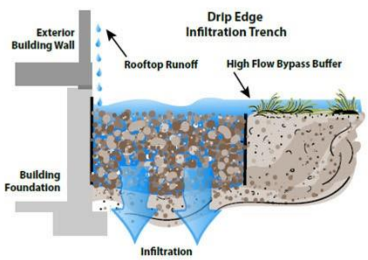

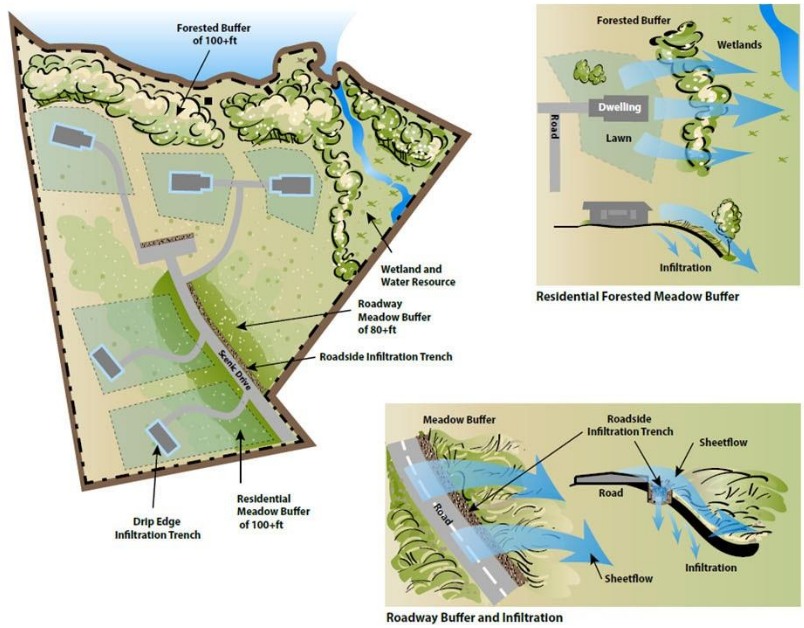

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CONCEPT PLAN 3: LOW DENSITY RESIDENTIAL HSG-B

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

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)
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CD3.4 LID Peak
Low Density Residential

LID VOLUME

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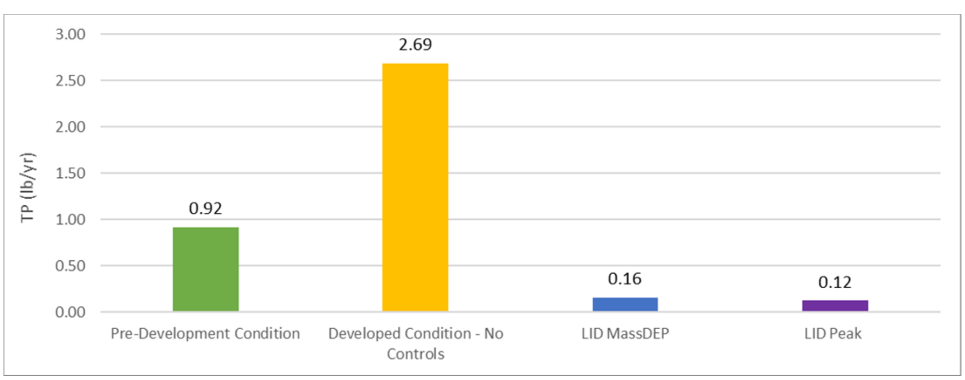

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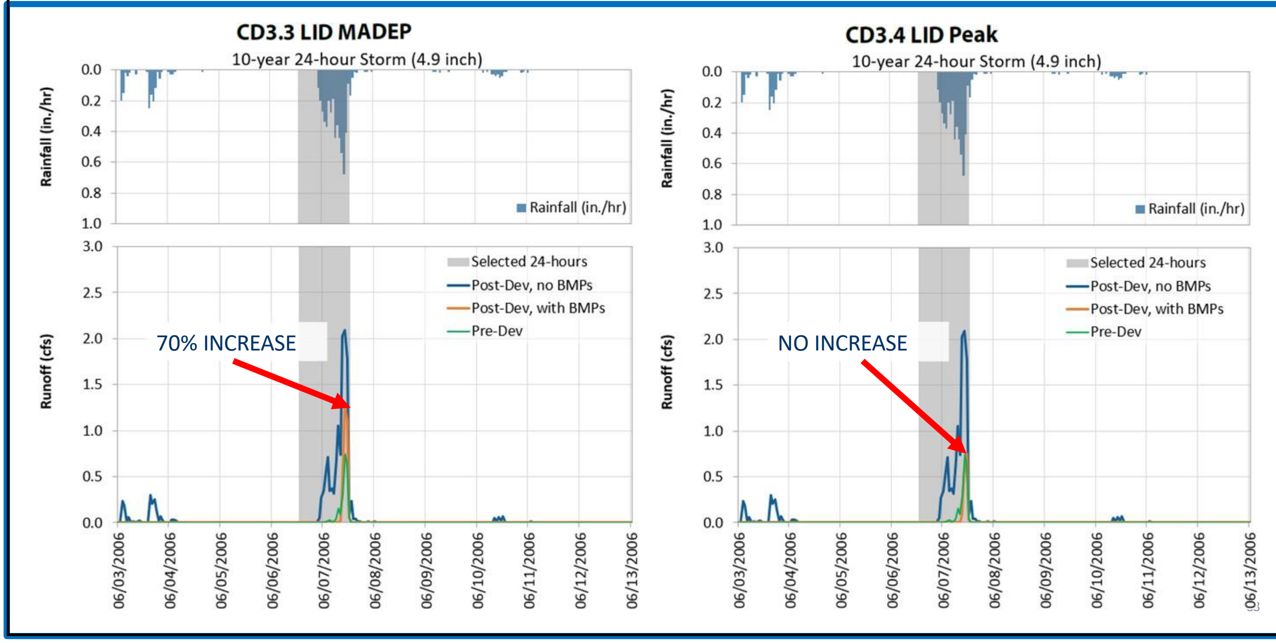
CONCEPT PLAN 3: LOW DENSITY RESIDENTIAL HSG-B



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COMMUNITY AUDIT GOAL SUMMARY

- Achieve municipal capacity building around planning for long-term **stormwater based climate change adaptation and resilience planning**.
- Encourage a comprehensive and coordinated approach to local permitting, review and infrastructure management.
- Advance implementation of **stormwater management and other means of adaptation for water quality protection,** flood damage avoidance, resource protection, maintenance cost reductions and avoidance of system disruptions.

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CLIMATE ADAPTATION AND RESILIENCE PLANNING GUIDING PRINCIPCLES

Ensure the community is better prepared to protect the security, health and safety of its citizens.

Protect natural resources from the impacts of flooding and stormwater hazards.

Provide for a stable and viable economic future.

Minimize the future costs of infrastructure replacement and maintenance.

Support installations of green infrastructure, low impact development and sound regulatory and planning approaches and processes.

IMPLEMENTATION ACTIONS AND FOCUS AREAS

- Municipal Policy and Actions
- Management and Investment
- Environment-Natural Resources
- Regulatory, Land Use and Comprehensive Planning
- Community-Based Support

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Maintain pre-development hydrology and nutrient load to create resilient landscapes

Anticipated Outcomes

- Groundwater recharge (resources and drinking water)
- Flood control with a focus on peak flow in waterways and SW discharge low-lying upland areas subject to flooding
- Wetland protection (hydrology and habitats)
- Water quality protection
- Reduced infrastructure impacts
- Coordinated infrastructure management and inspection
- Improved local coordination of permitting processes

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Elements of a regulatory audit for a comprehensive approach to resilient landscapes

[From Metropolitan Area Planning Council]

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Operations & Maintenance Agreements and Site Inspections

Close attention to municipal process and management of stormwater assets is key! The following elements should be managed closely at the local level in coordination with state and federal permits.

Operations & Maintenance Plans and Agreements

O&M Plans and Agreements should be finalized as part of an application by the approval board or commission.

Municipal Tracking of Inspections

Development and redevelopment site inspections should be part of the application approval process and conducted on an agreed upon schedule and frequency. Site inspection reports are required to be filed annually as part of the EPA MS4 Permit.

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OVERVIEW OF REGULATORY AND PLANNING AUDIT

- Review of current zoning by-law, land development and other regulations
- Identify ***strengths, weaknesses, opportunities and threats*** (SWOT)
  - Identify conflicting requirements and development/design standards
  - Evaluate process for application review including application requirements and follow-up actions (bonding, site inspections, O&M plans)
  - Examine coordination with local and state approval mechanisms
  - Coordination with EPA MS4 Permit requirements and activities
- Develop recommendations based on SWOT results
- **Final summary report of findings**

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COMMUNITY OUTCOMES AND BENEFITS

- Proactive strategies are identified and implemented that address the impacts of climate change hazards to create a more sustainable and resilient community.
- Enhanced focus on stormwater management and water quality protection and improvement.
- Prepare the community for a predictable, stable and viable economic future.
- Protect natural resources and ecosystem services the community relies upon.
- Establish a sound basis for decision making, municipal investments and a solid rationale for grant and other funding opportunities.

40

Information Sheets

- Technical Project Summary
- Town specific sheets for each Taunton community

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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

42

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

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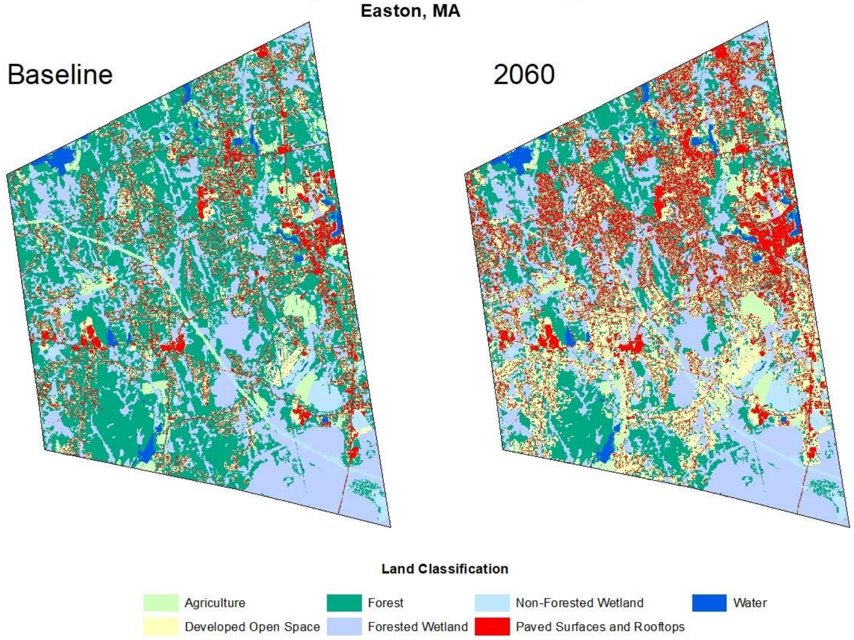
Projected Land Change

Easton, MA



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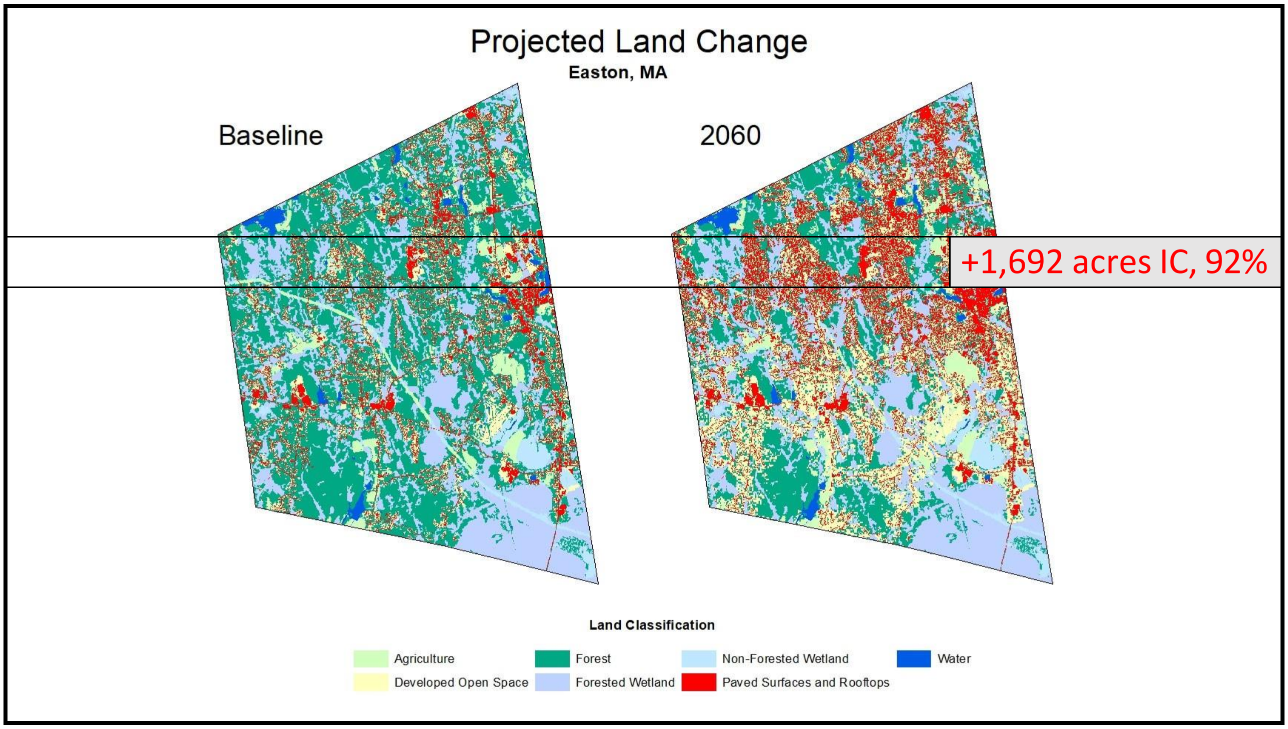

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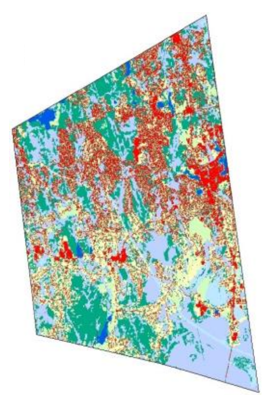
Projected per Year Increases or Decreases

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



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NEXT STEPS

- Webinar September 29
- Information Sheets
- Compendium
- Recharge Calculations

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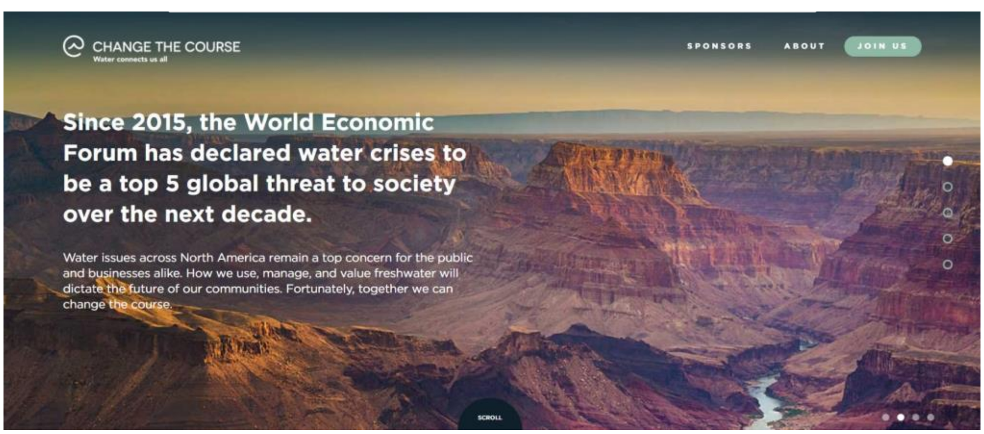
THANK YOU FOR YOUR TIME



Envisioning A Different Future Of Watershed Management

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APPENDIX D. SOUTHERN NEW ENGLAND PROGRAM (SNEP) WEBINAR – SEPTEMBER 29, 2022

AGENDA

SNEP Protective Stormwater Standards Workshop Webinar

September 29, 2022, 10:00 AM-2:00 PM

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

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)

1

WISHING THE BEST FOR PEOPLE IMPACTED BY HURRICANE IAN

2

"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

3

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
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Michelle Vuto, EPA Region 1, Boston
1:15-1:50 | Discussion / Q&A
1:50–2:00 | Wrap up and closing / Next Steps

Sept. 29, 2022

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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.

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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.).

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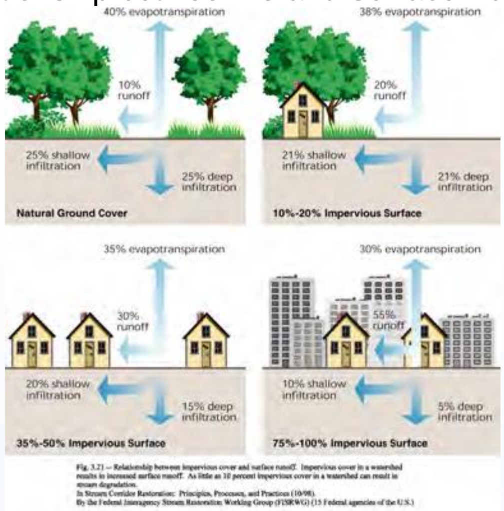
The Problem with Impervious Cover (IC) - Relationship between IC and Surface Runoff



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

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Flooding




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

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Drought


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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

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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.

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Water Quality

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

10

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.

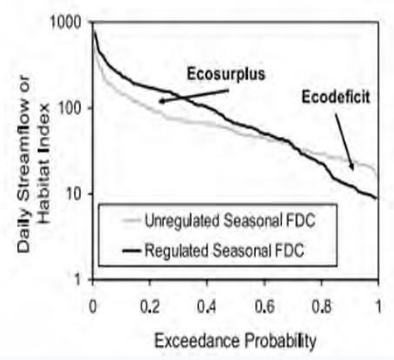
Because each of these HRU combinations describe an existing discrete land use type, they become the hydrologic 'building blocks' for evaluating stormwater runoff for a given community.

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.

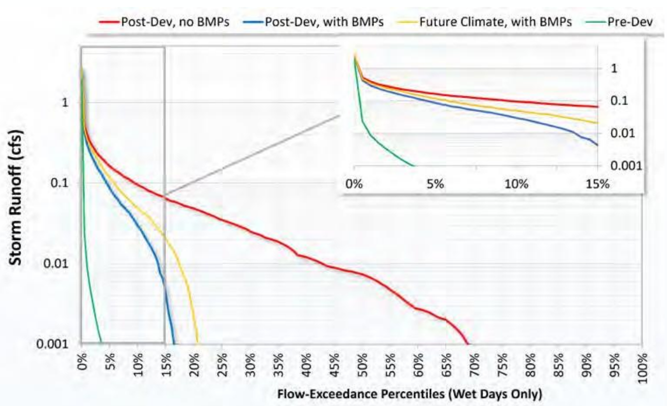
As development occurs, the high flows become higher (ecosurplus = flooding) and the low flows become lower (ecodeficit = drought)



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

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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. ..

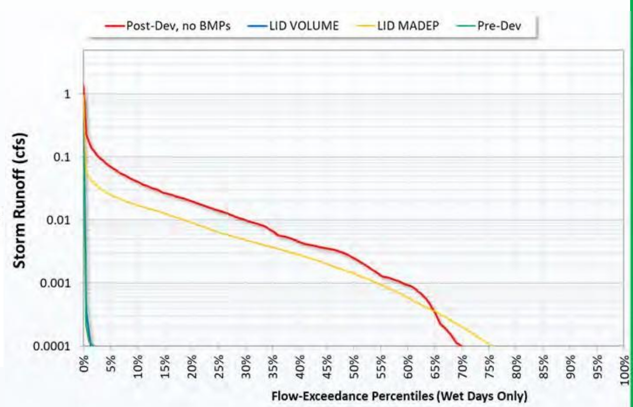
CDCD Plan showing Runoff Volume for a High-density Commercial Development

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



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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

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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

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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

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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.

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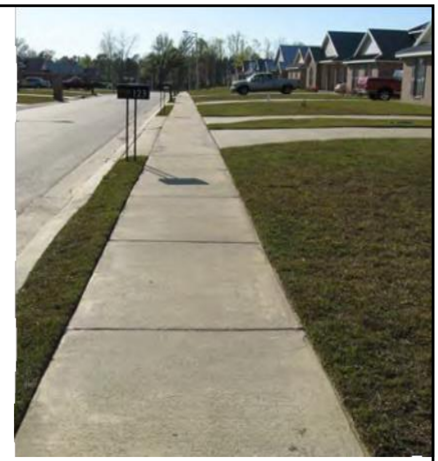

Applying Advances in EPA Region 1 Analytical Tools to Quantify

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

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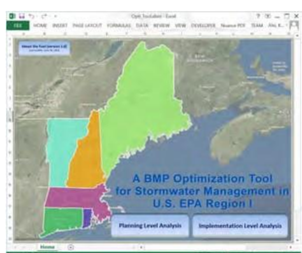
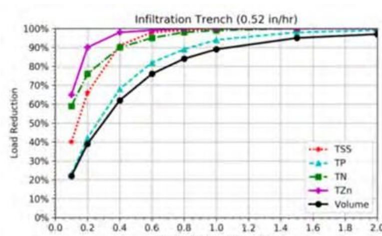
EPA R1 Applied Research and Development of SW Tools, (2007 to 2022)

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.unh.edu/unhsc/sites/default/files/media/ms4_permit_nomographs_sheet_final_2020.pdf

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

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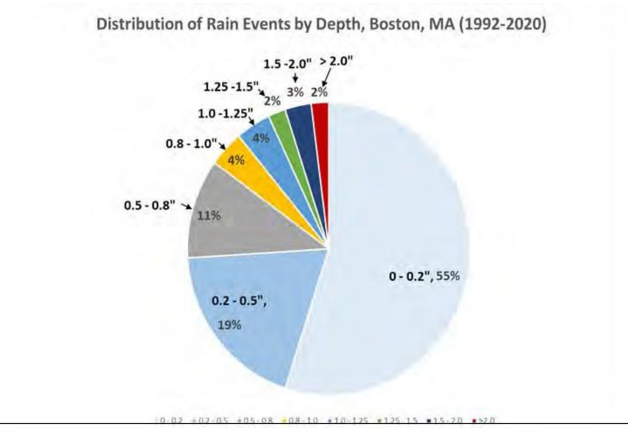
New England Region Rainfall Patterns Important Points

- 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

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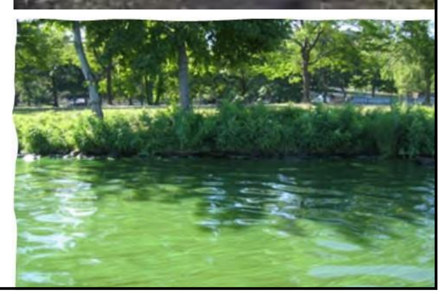
Converting Natural Land to Impervious Cover: Site Scale

- **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)



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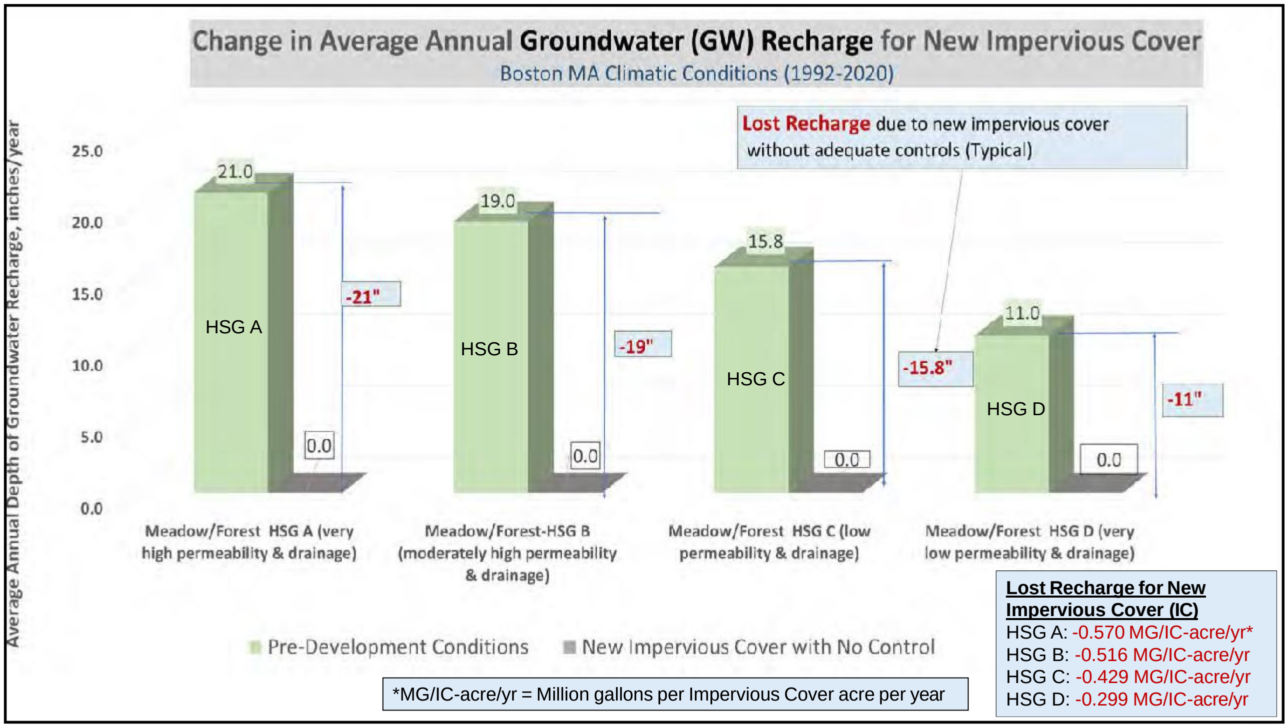

Change in Average Annual Groundwater (GW) Recharge for New Impervious Cover
Boston MA Climatic Conditions (1992-2020)
Lost Recharge due to new impervious cover without adequate controls (Typical)
Average Annual Depth of Groundwater Recharge, inches/year
25.0
20.0
15.0
10.0
5.0
0.0
21.0
HSG A
-21"
0.0
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

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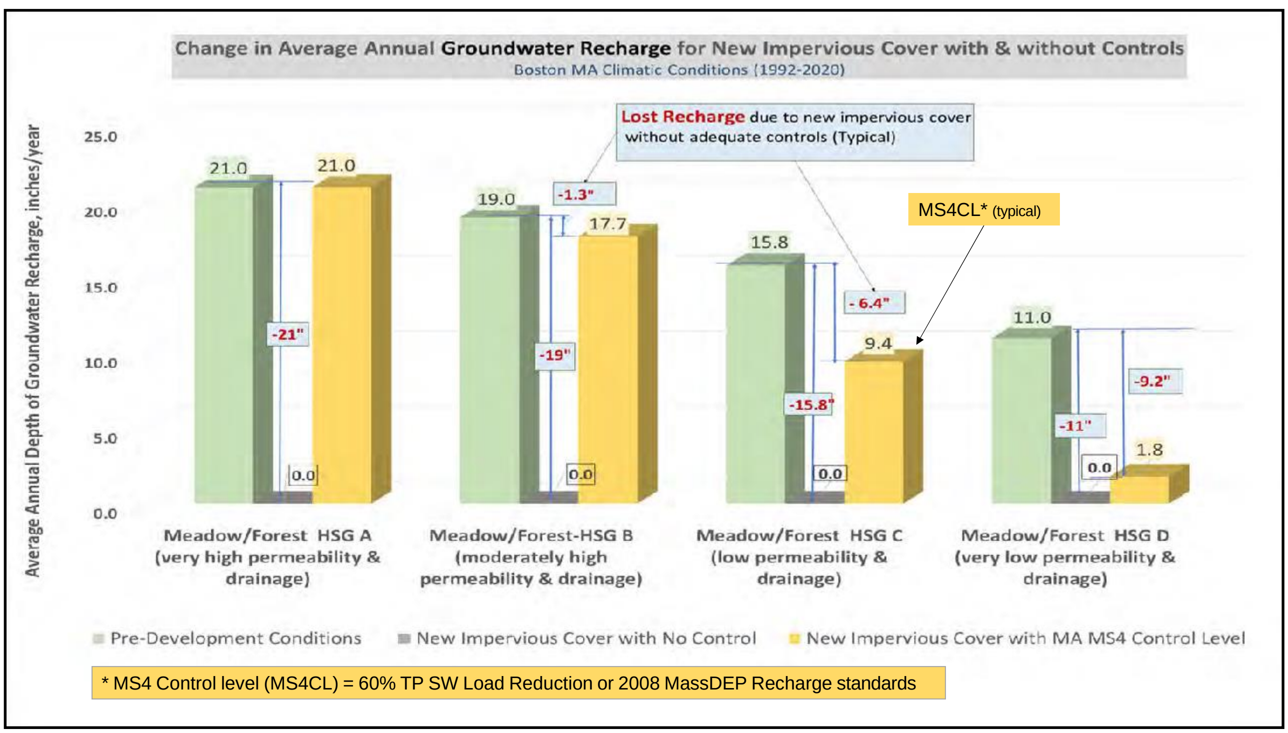

Change in Average Annual Groundwater Recharge for New Impervious Cover with & without Controls
Boston MA Climatic Conditions (1992-2020)
Lost Recharge due to new impervious cover without adequate controls (Typical)
MS4CL* (typical)
Average Annual Depth of Groundwater Recharge, inches/year
25.0
20.0
15.0
10.0
5.0
0.0
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"
0.0
1.8
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

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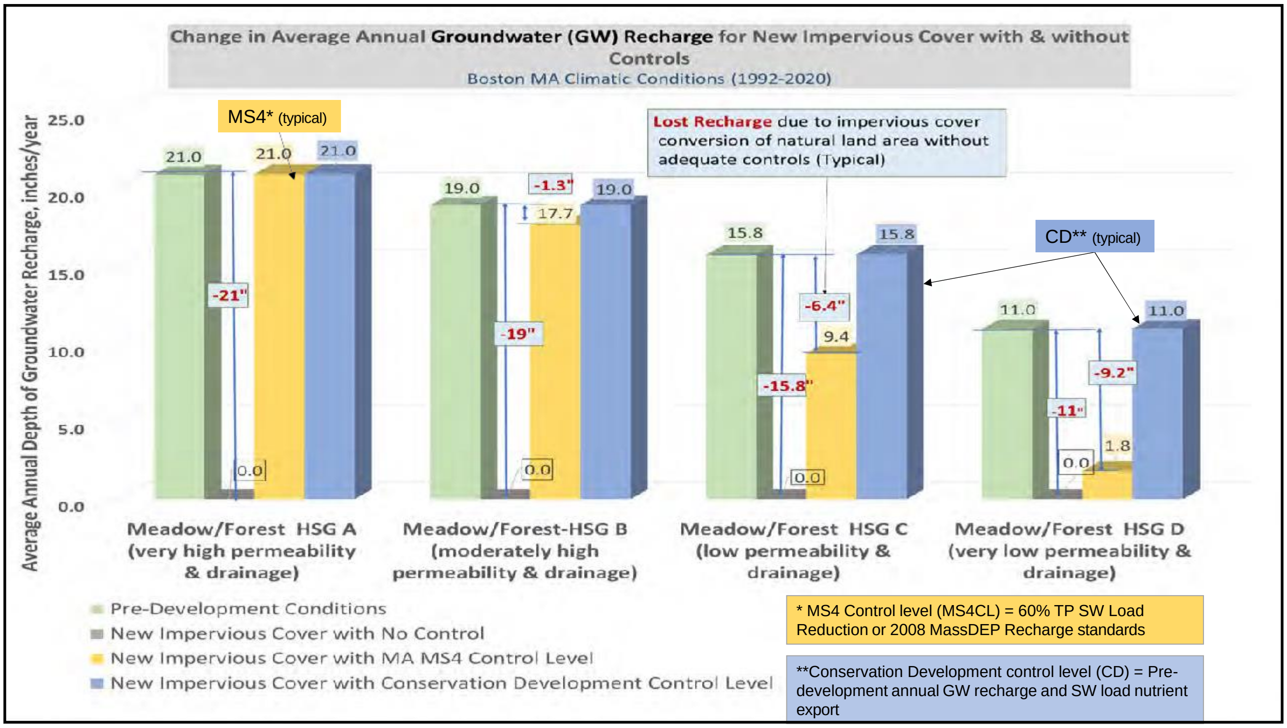

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The Nutrient Challenge & SW Permitting

- **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**

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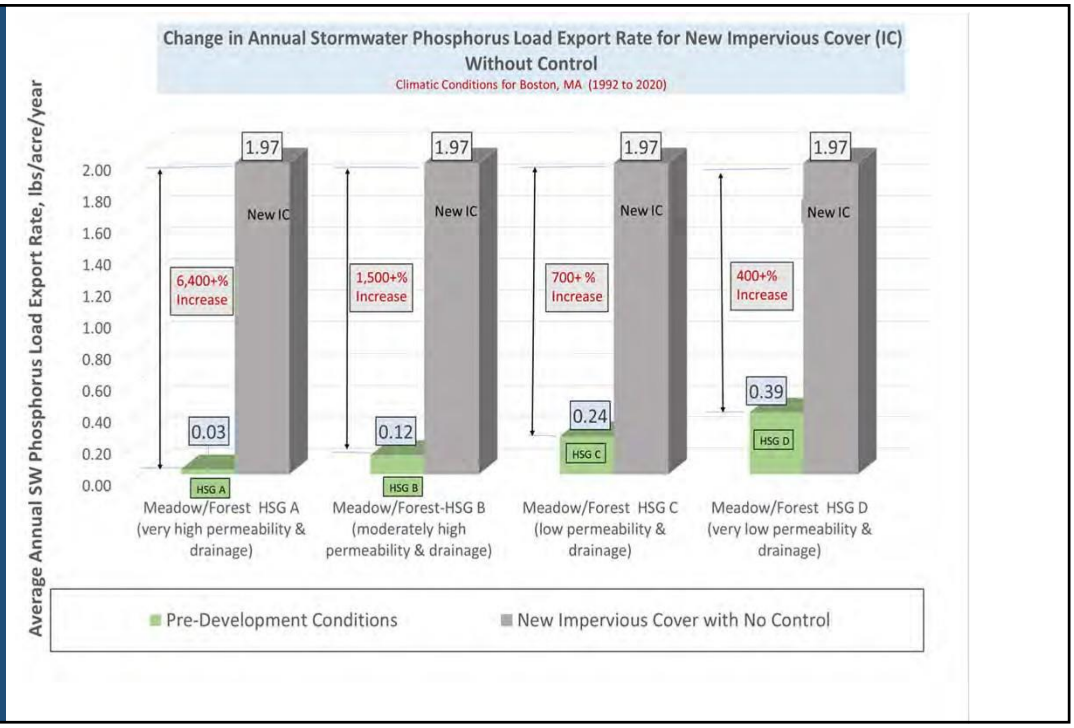
Change in SW Nutrient Export Due to Impervious Cover



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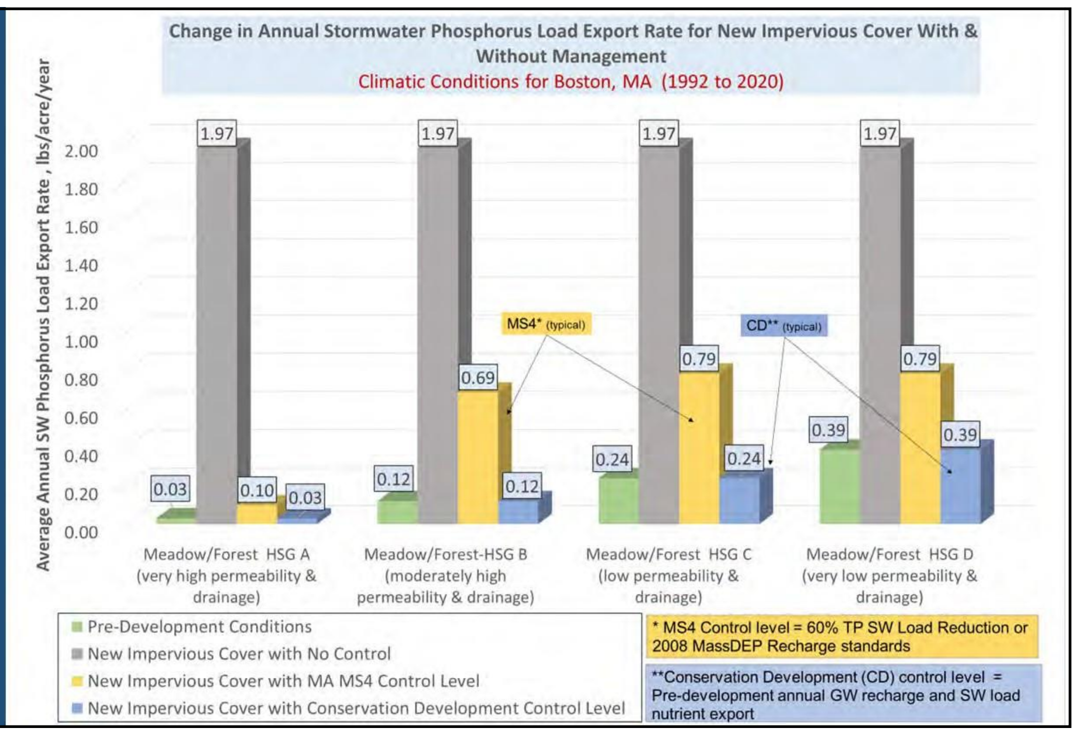
SW Nutrient Control for New Impervious Cover



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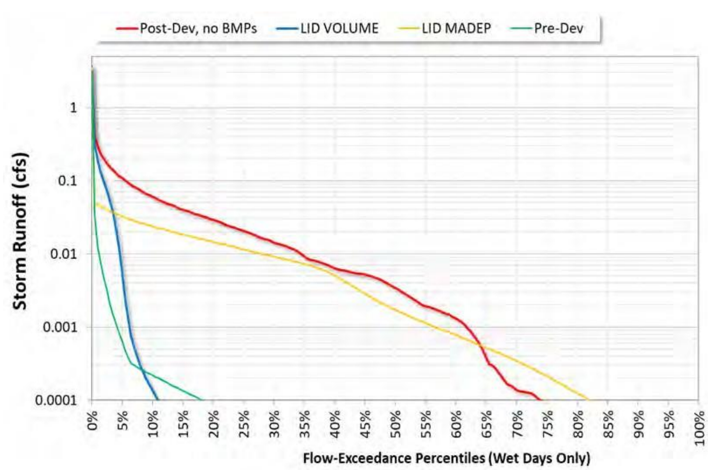
The Power of Continuous Simulation, Flow Duration and Runoff Duration Curves

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

Runoff Duration Curve for Project Site Scale



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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

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$ 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.

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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

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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

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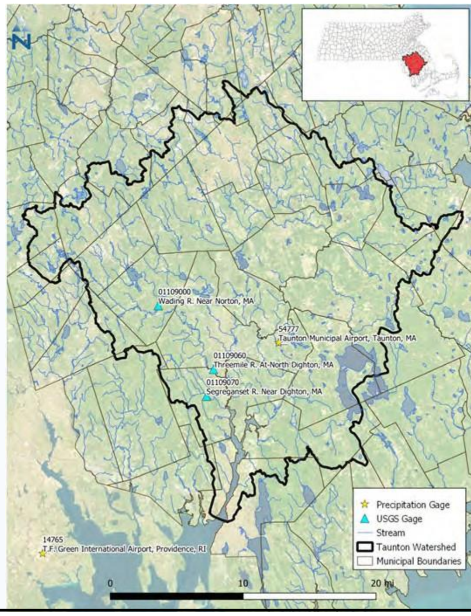
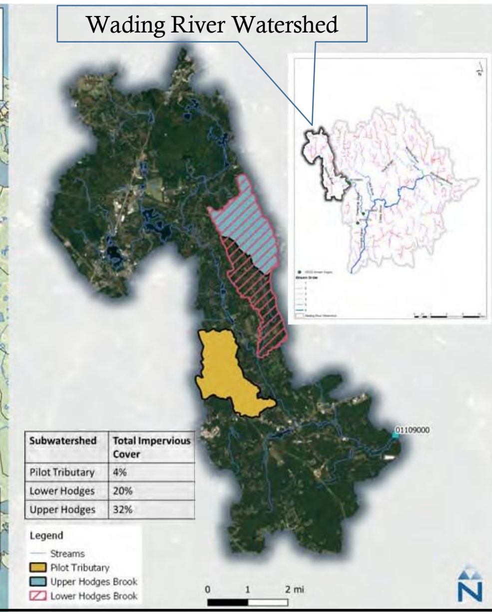
Study Area: Taunton River Watershed





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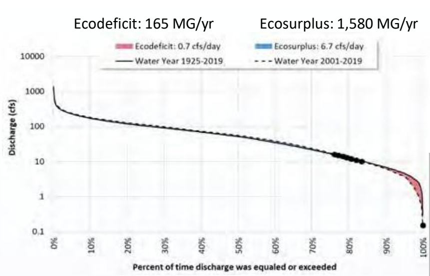
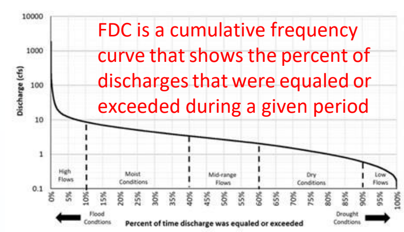
Potential Metrics





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

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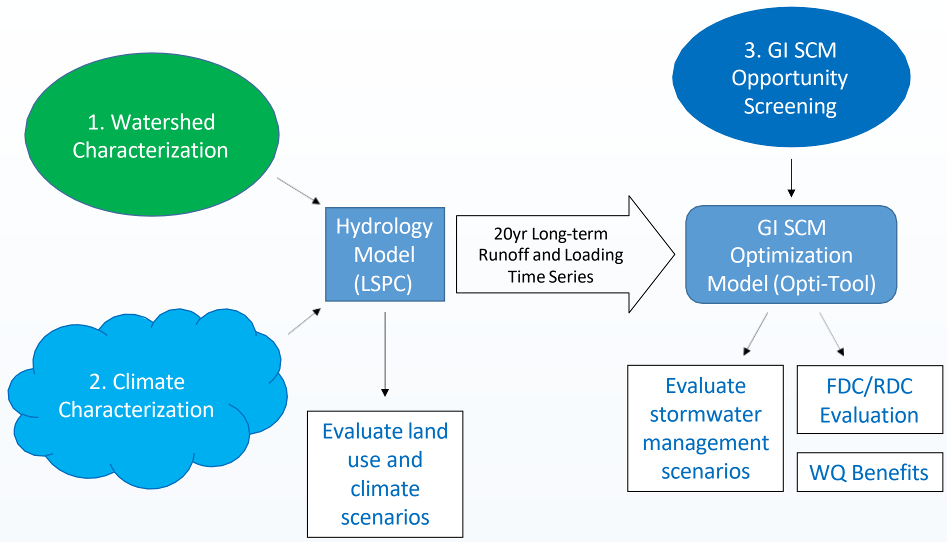
Modeling Framework



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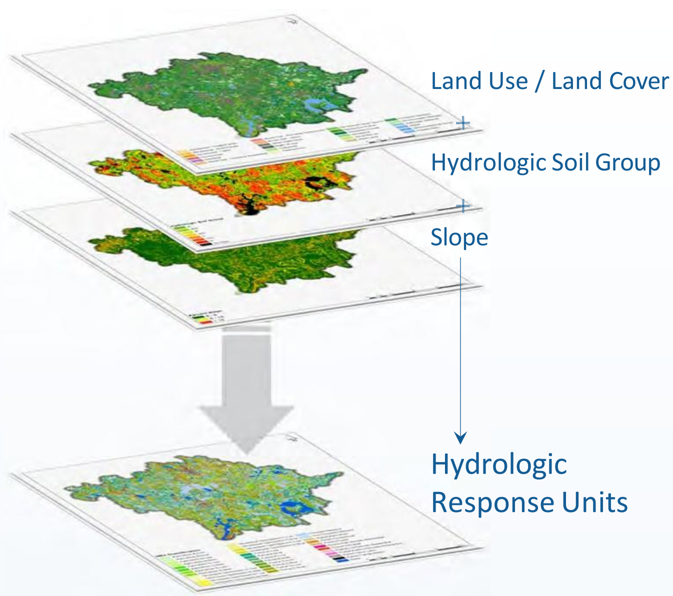
Watershed Characterization

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



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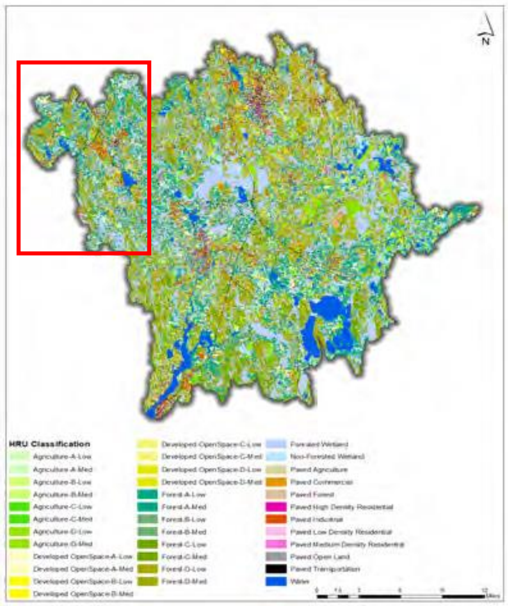
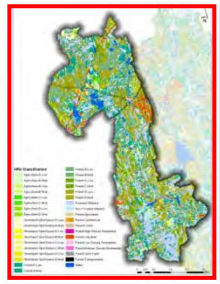
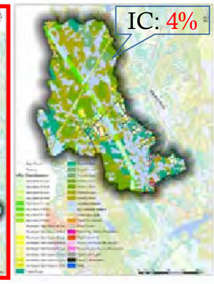
Taunton Watershed - HRUs





Wading River



Pilot Tributary

Lower Hodges Brook

Upper Hodges Brook

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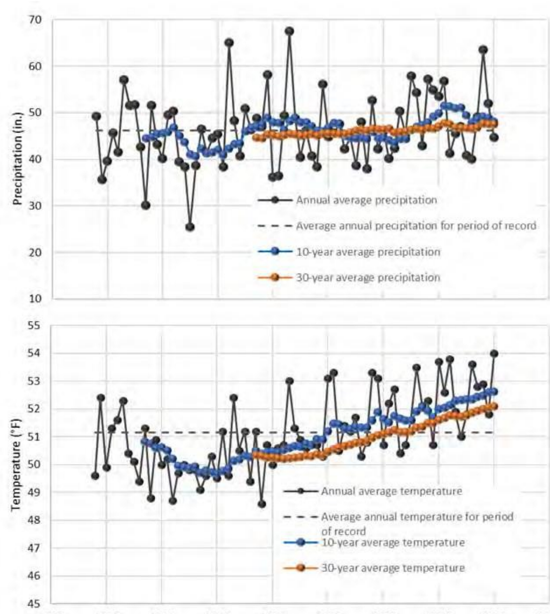
Climate Characterization

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



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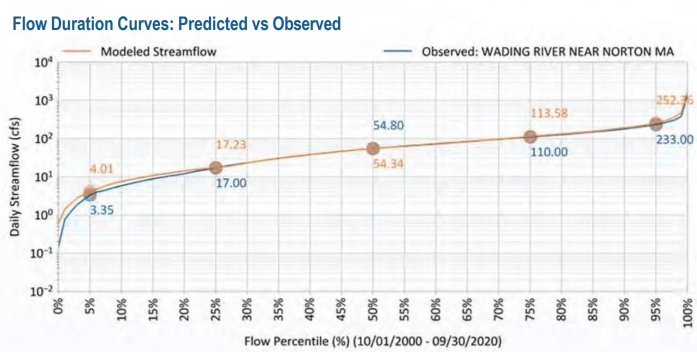
Calibration and Validation

- 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

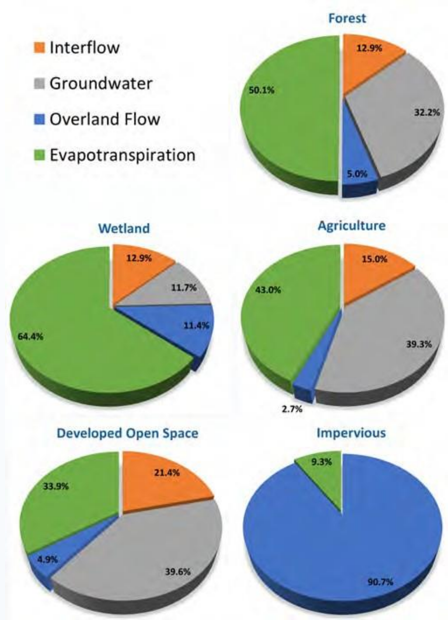


Hydrology Monitoring Locations	Performance Metrics (Seasonal)															Performance Metrics (Flow Regime)														
	PBIAS					R-squared					Nash-Sutcliffe E					PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Top 10%	Storms	Low 50%	Baseflow	All	Top 10%	Storms	Low 50%	Baseflow	All	Top 10%	Storms	Low 50%	
WADING RIVER NEAR NORTON MA	-	-	+	-	-											-	-	-	-	-										

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



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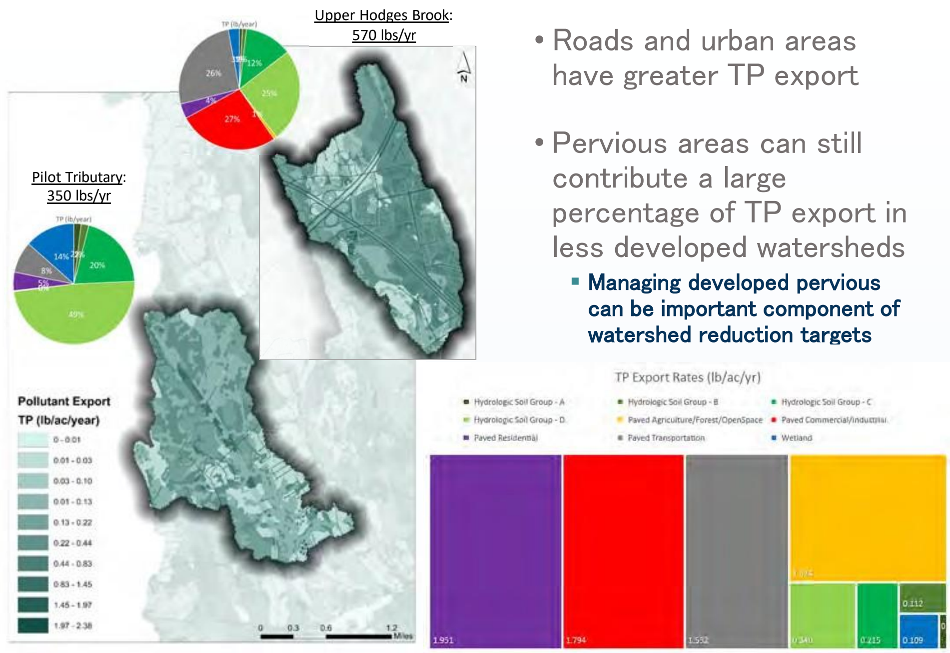
Impact of Land Cover on Water Quality



- 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**

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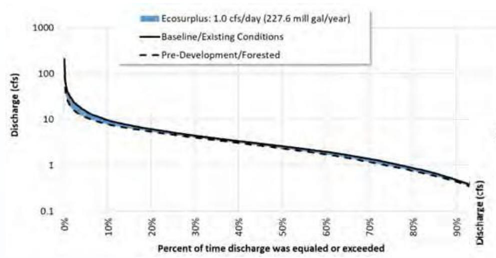
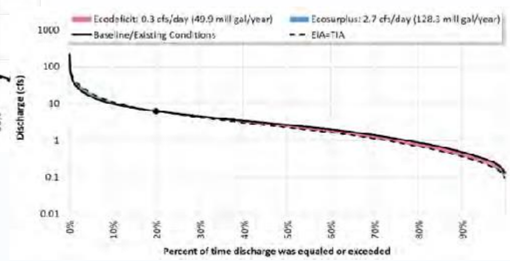
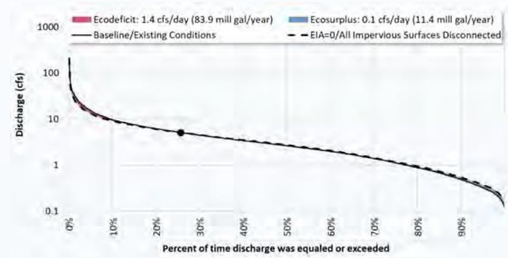
Impact of development on FDCs








HYDROLOGICAL PROCESSES

Urban base flow with low impact development

Aditi S. Bhaskar, Dianna M. Hogan and Stacey A. Archfield

URBAN STREAMS

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

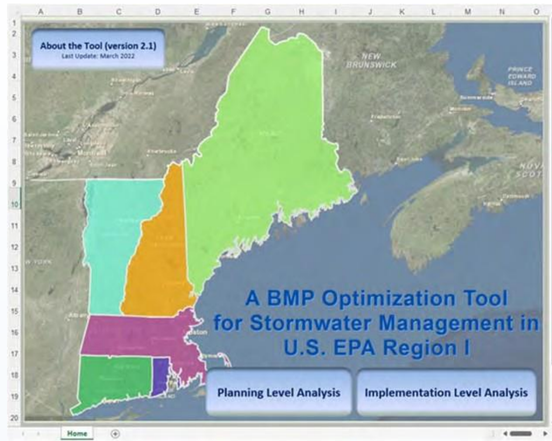
A. S. Bhaskar, L. Beesley, M. J. Burns, T. D. Fletcher, P. Hamel, C. E. Oldham, and A. H. Roy

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



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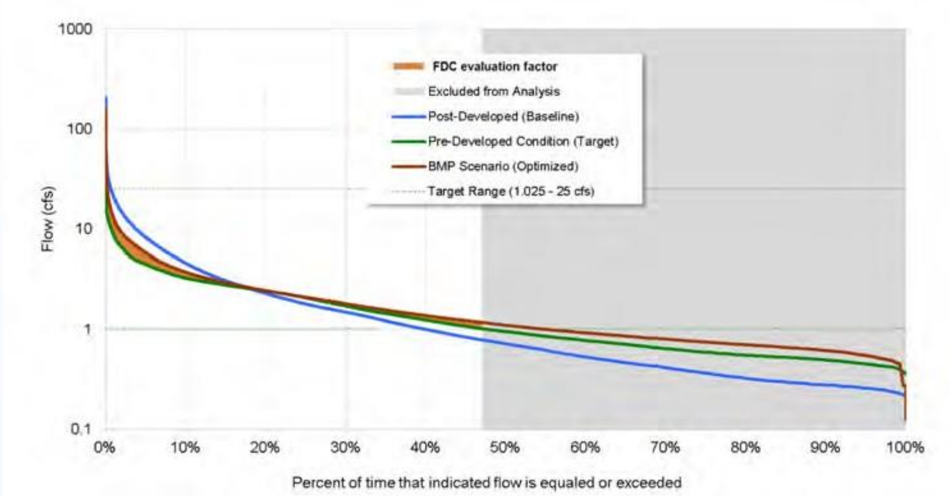
Flow Duration Curve Optimization

- Evaluation Factor: area between two FDCs



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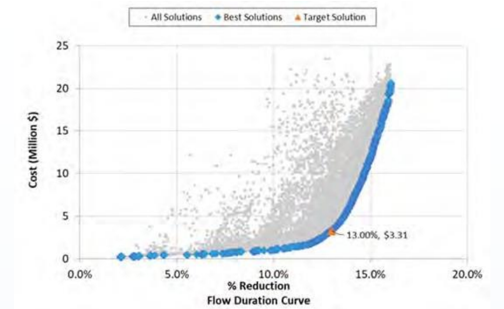
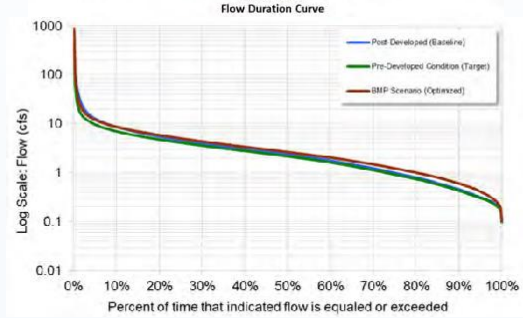
FDC Optimization Example: Upper Hodges Brook

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





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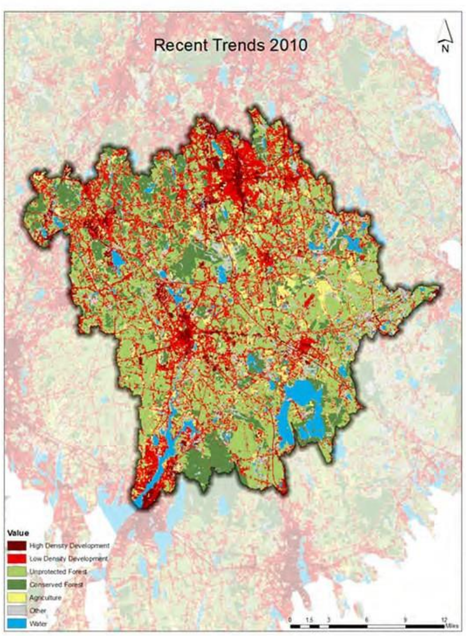
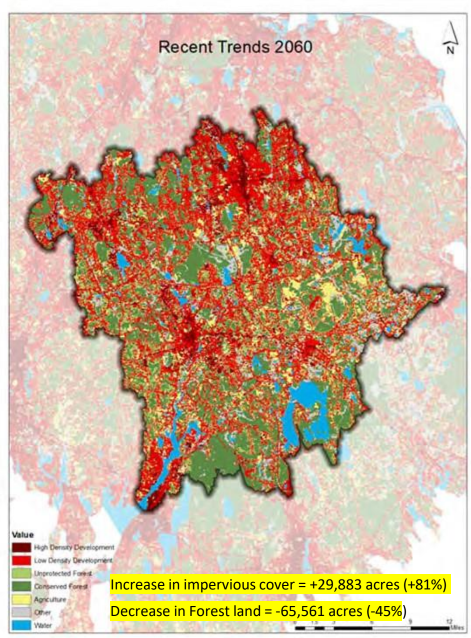
New England Landscape Futures (NELF) Dataset





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.

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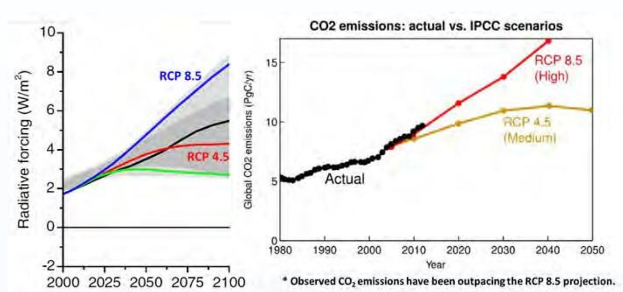
Representative Concentration Pathways (RCP) for Climate Change Analysis

- 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



Source: International Institute for Applied Systems Analysis, 2009

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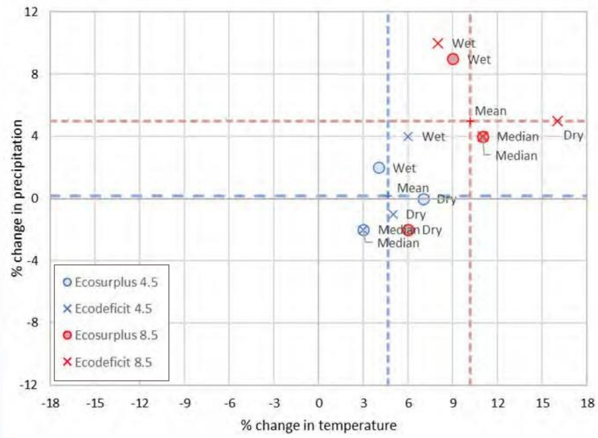
Future Precipitation and Temperature

- 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	miroc-esm-1
	Median	cesm1-cam5-1	cesm1-cam5-1
	Wet	cesm1-bgc-1	mri-cgcm3-1

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

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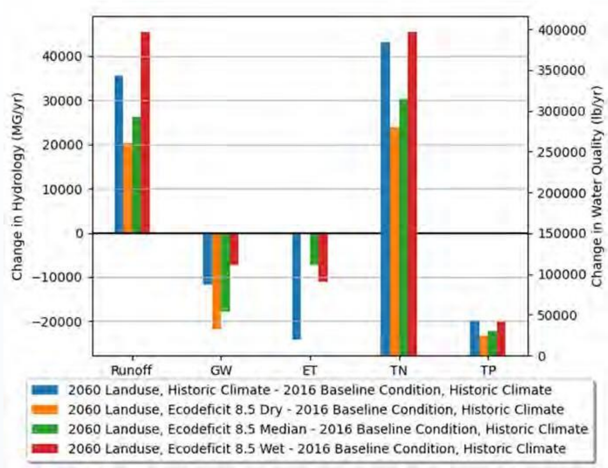
Changes to Hydrology and Water Quality Under Future Conditions

- 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



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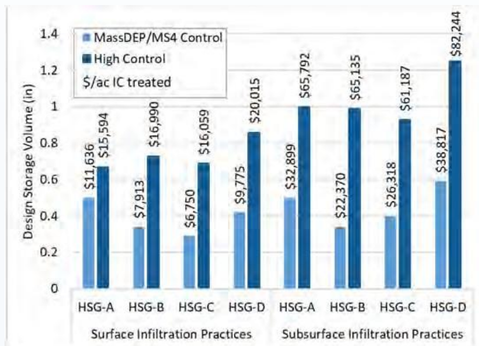
Current and Next-Generation SCMs Design

- 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



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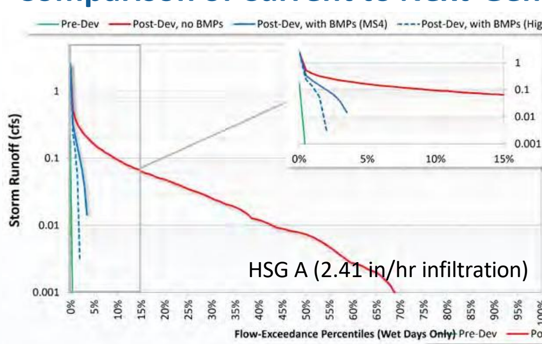
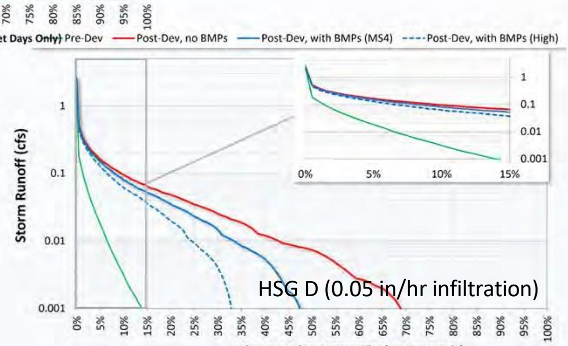
Comparison of Current to Next-Generation SCMs



SCM Category	Compared to Pr edevelopment	
	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 Pr edevelopment	
	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%**

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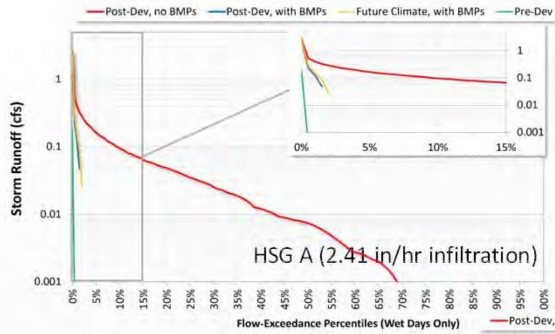
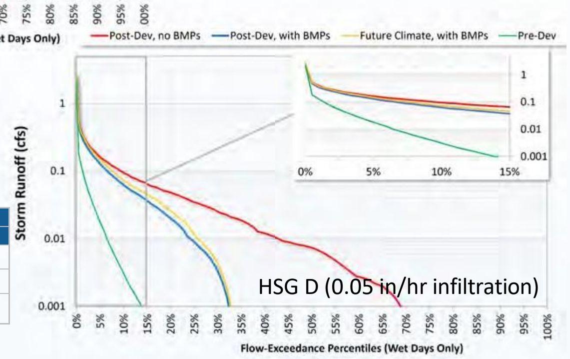
Resiliency of Next-Generation SCMs



SCM Category	Compared to Prec evelopment	
	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 Prec evelopment	
	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%

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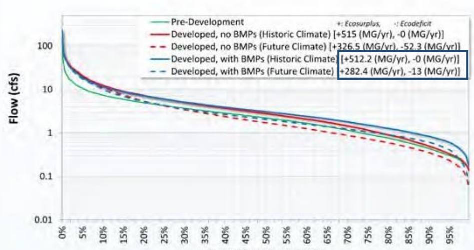
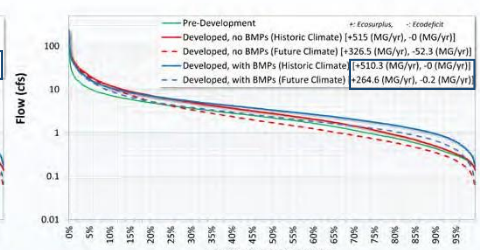
FDCs for Current and Next-Gen SCMs: Upper Hodges Brook

- 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

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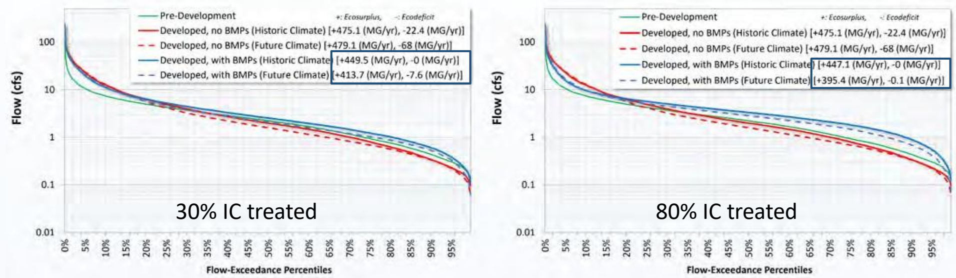
FDCs for 1-inch Retention SCMs: Upper Hodges Brook

- 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

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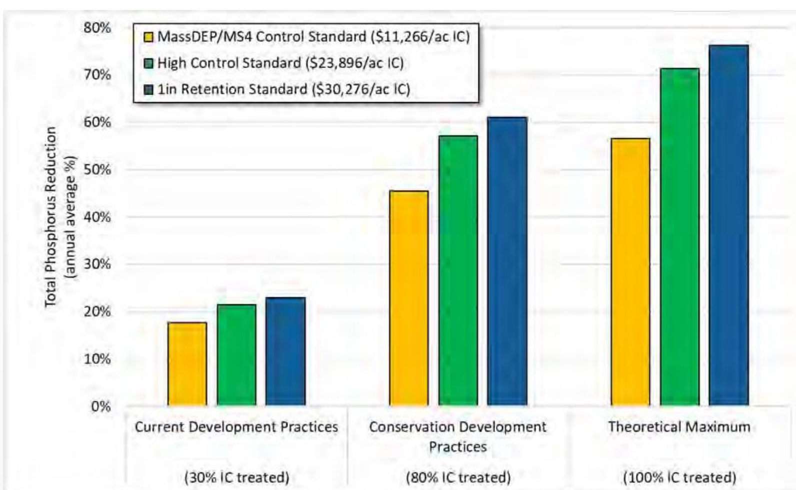
SCMs TP Efficiency: Upper Hodges Brook



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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

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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

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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

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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

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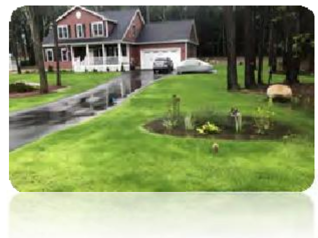
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

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



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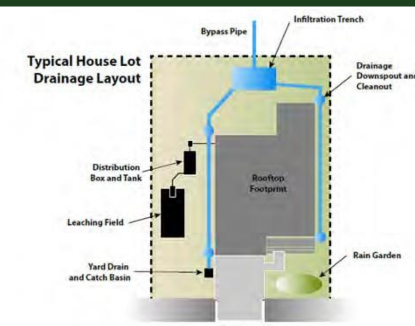
ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

LOT LAYOUT AND DRAINAGE

- 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

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ROLLINS HILL
STRATHAM'S FIRST ECO FRIENDLY COMMUNITY

GREEN INFRASTRUCTURE

INFILTRATION FOR ROOFTOP RUNOFF LOW CHLORIDE POROUS ASPHALT ROADWAYS AND DRIVEWAYS

BIORETENTION AND BIOSWALE ROADWAY SUBSURFACE INFILTRATION

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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

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CD1.4 LID Conservation Development

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- ✗ 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

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- ✗ 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 Conservation Development

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  - TP 60% REMOVAL
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- ✓ 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

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CD1.3 LID MADEP High Density Residential

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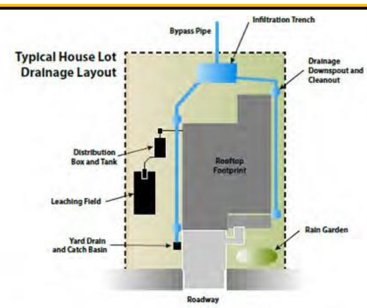

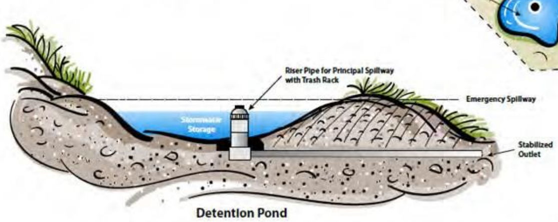

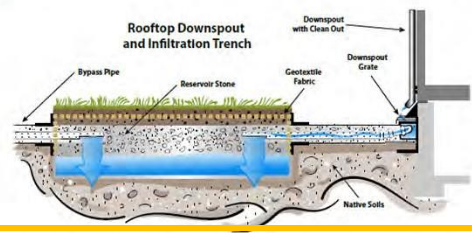

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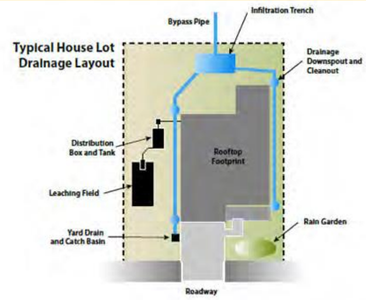

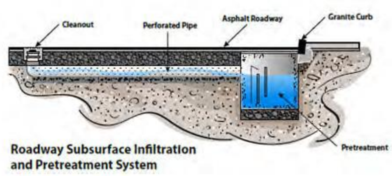

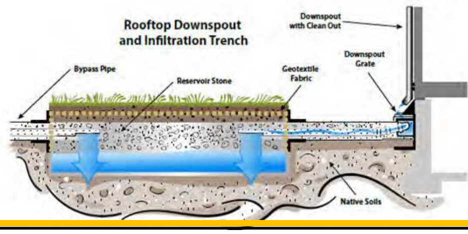

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

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CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

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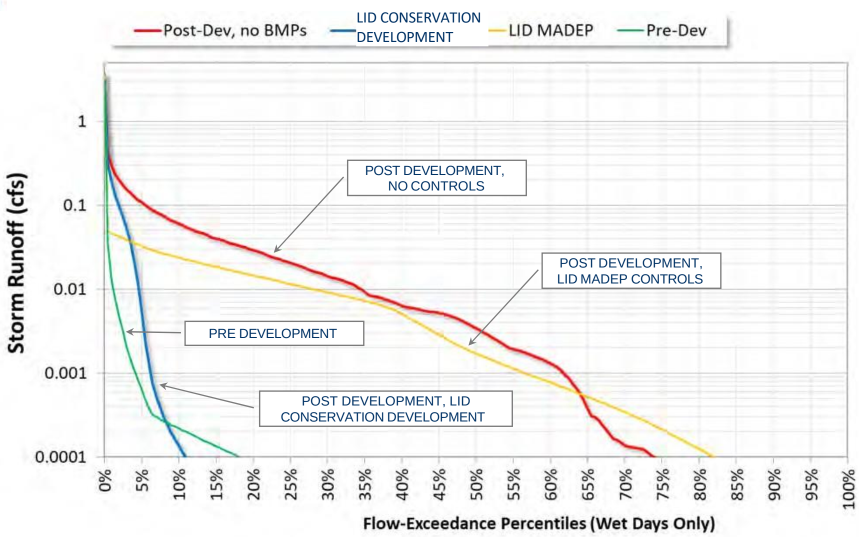
- ✓ PREDEVELOPMENT HYDROLOGY
- ✓ RESILIENT HYDROLOGY



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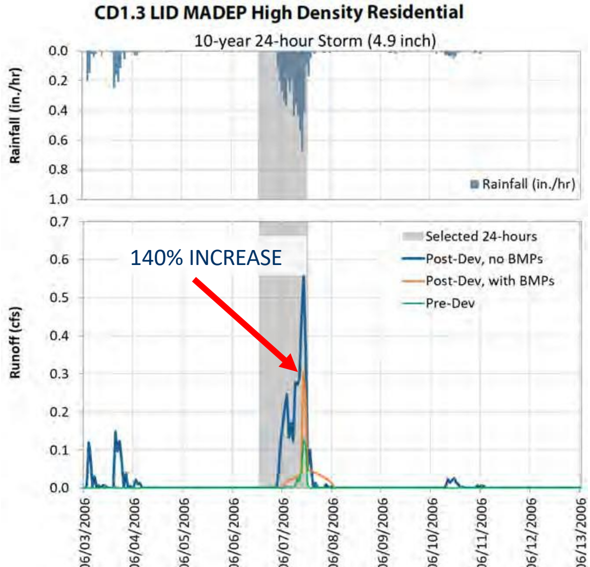
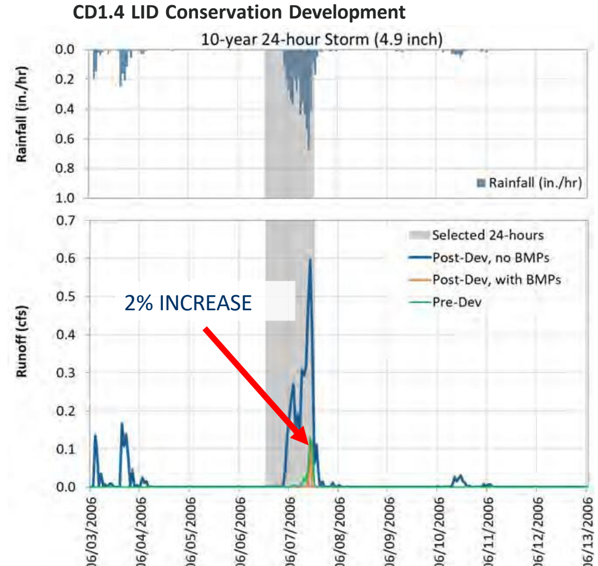
CONCEPT PLAN 1: HIGH DENSITY RESIDENTIAL HSG-C

CD1.3 LID MADEP High Density Residential



CD1.4 LID Conservation Development



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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 Conservation Development

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)

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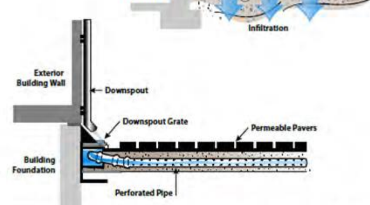
CD2.3 LID Basic Commercial Redevelopment

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

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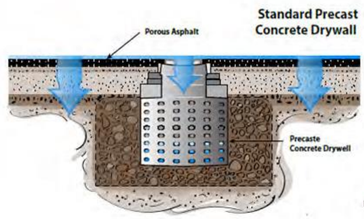
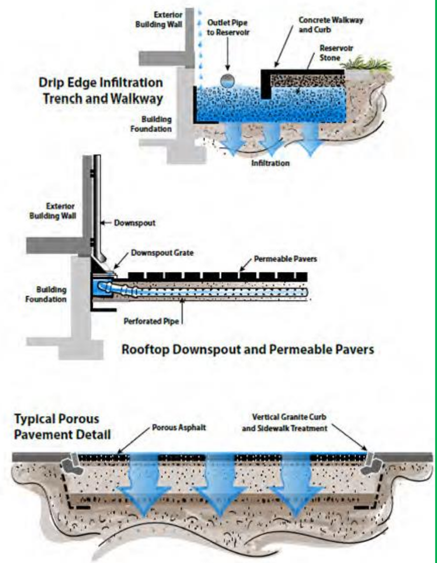
CD2.4 LID Conservation Commercial Redevelopment

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





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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

CD2.3 LID Basic Commercial Redevelopment

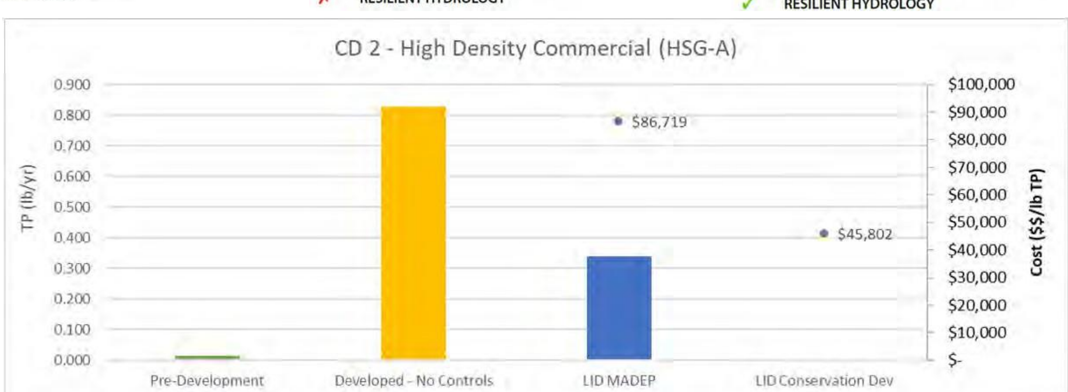
LID MADEP

- ✓ 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 CD 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



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CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL – RUNOFF VOLUME

CD2.3 LID Basic Commercial Redevelopment

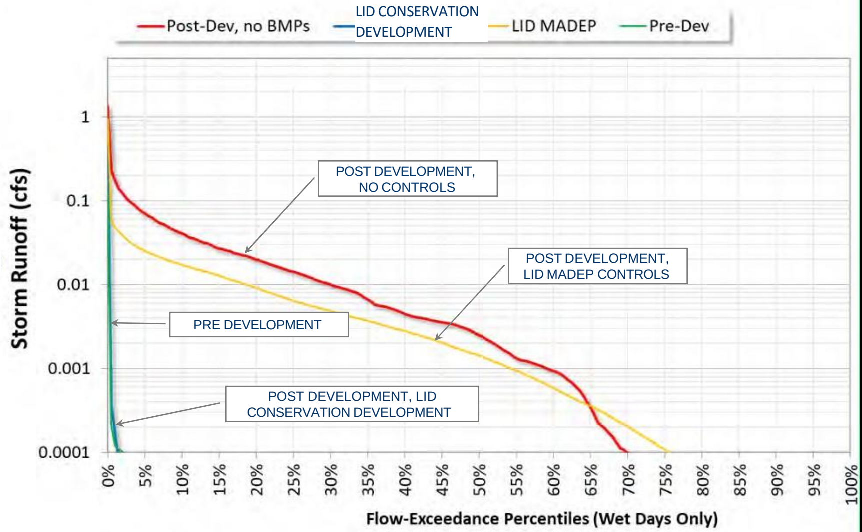
LID MADEP

- ✓ 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 CD 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



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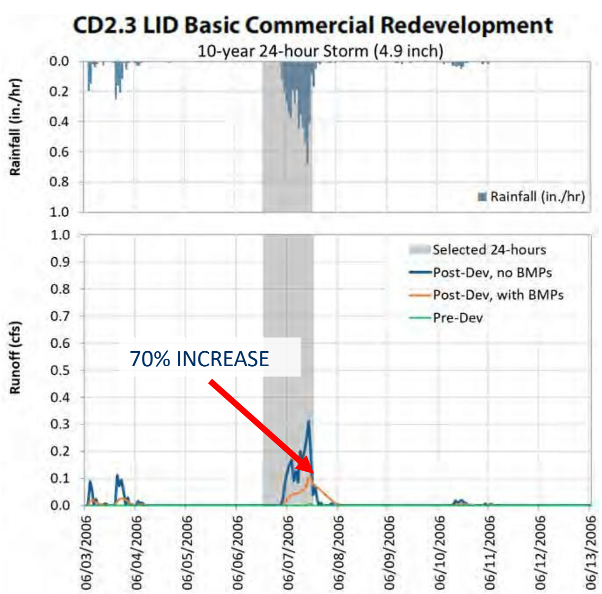
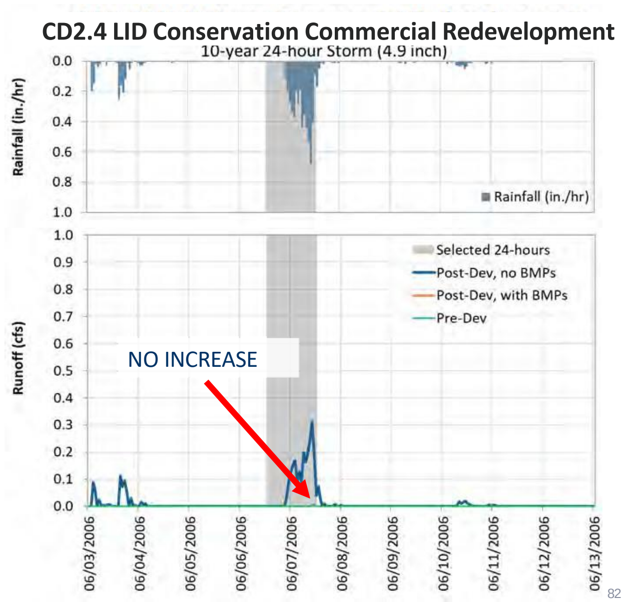
CONCEPT PLAN 2: HIGH DENSITY COMMERCIAL - RESILIENCY





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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 Conservation Development 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)

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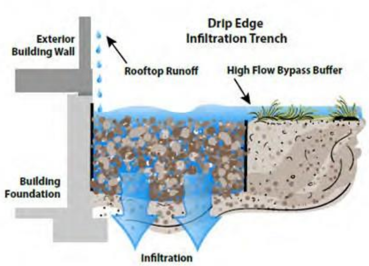
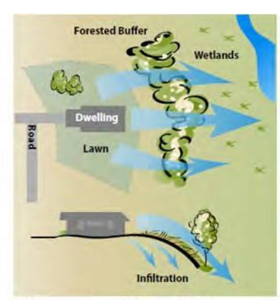
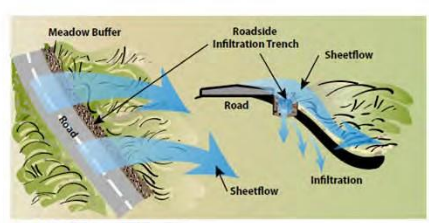
CD3.4 LID Conservation Development Low Density Residential

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

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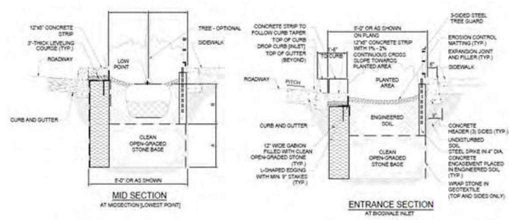
Compendium of Site-Development Stormwater Management Solutions for Water Resource Protection

- 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)



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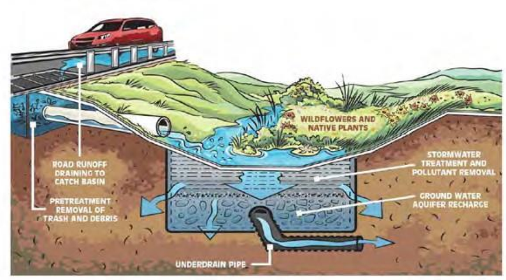
Compendium Overview

- 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



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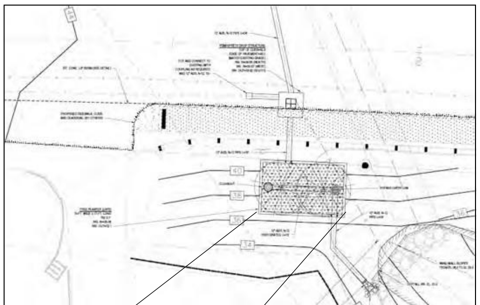
URBAN BIOSWALE/TREE PLANTER ONLINE/OFFLINE

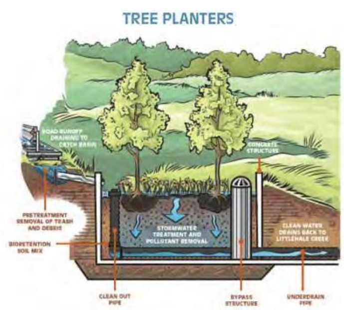
Description: Brief Description of type of impervious cover to be managed, the type of SCM shown, its sizing and any site design constraints (e.g., none to very limited) that influences the selection of the SCM type and its design (footprint, depth etc.). The SCM shown has been sized to achieve the Water 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.

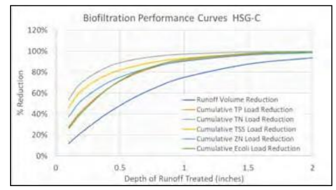
Water Resource Protection Standard: Approximates the 1" WQV static retention for IC that will: 1) Not exceed the long-term average annual predevelopment runoff nutrient load export; 2) Achieve average annual predevelopment groundwater recharge volumes; and 3) Maintain resilient landscape.

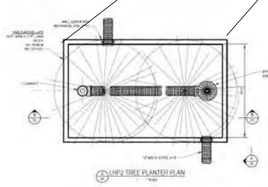
Surface Biofiltration Practice Design Details

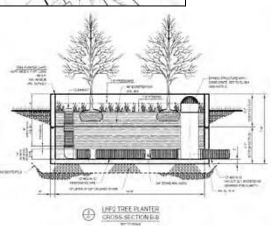
IC Drainage area, acre	1.0	0.5	0.25	0.1	0.05
Infiltration Rate , in./hr.	8.27	8.27	8.27	8.27	8.27
Design Storage Volume, in.	0.39	0.39	0.39	0.39	0.39
Physical Storage Capacity, ft^3	1416	708	354	142	71
Depth of Pond Storage , ft	1.0	1.0	1.0	1.0	1.0
Length of Basin, ft	118	59	29	12	6
Top-Width of Basin, 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.

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5 MINUTE BREAK

NANYANG TECHNOLOGICAL UNIVERSITY, SINGAPORE

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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)

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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.

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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

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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

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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

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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

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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

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APPROVAL PROCESS FOR BY-LAW AND REGULATION AMENDMENTS

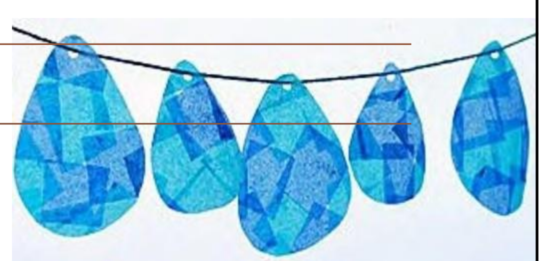
Bylaws amendments require a ballot vote by citizens of the municipality and so have a higher level of scrutiny and public comment

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



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Information Sheets

Technical Project Summary

Town specific sheets for each Taunton community

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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

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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

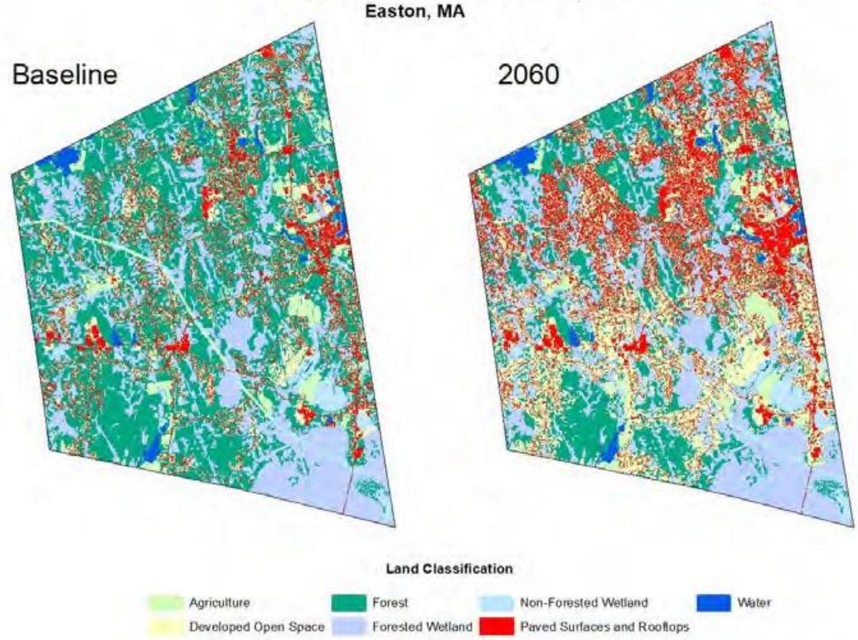
Optimism: Resiliency

- How to prevent/mitigate impacts
- Cost avoidance

99

Projected Land Change

Easton, MA



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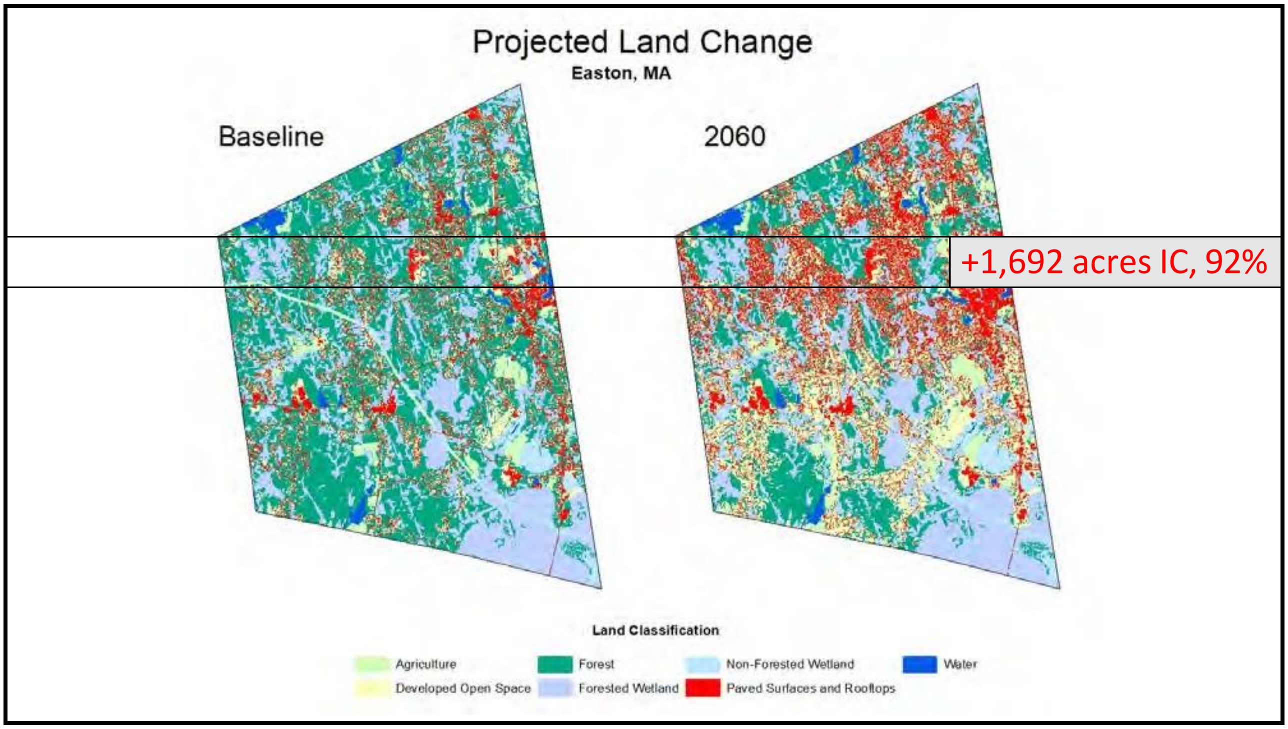
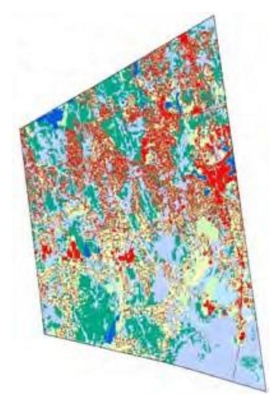


101

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



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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

Sept. 29, 2022

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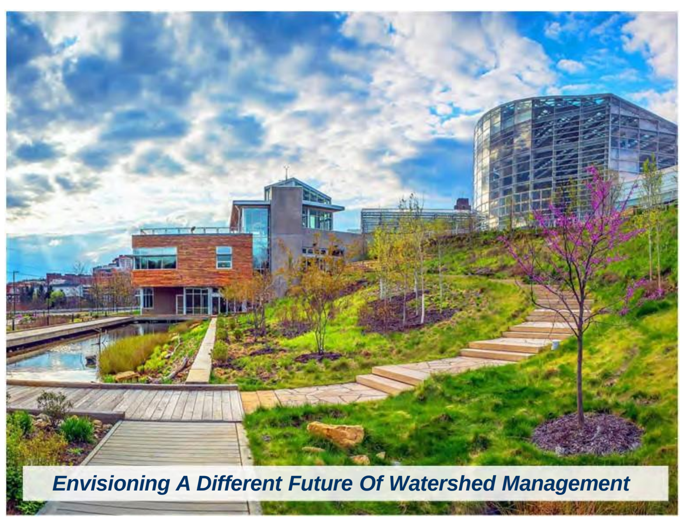
THANK YOU FOR YOUR TIME



Phipps Center for Sustainable Landscapes

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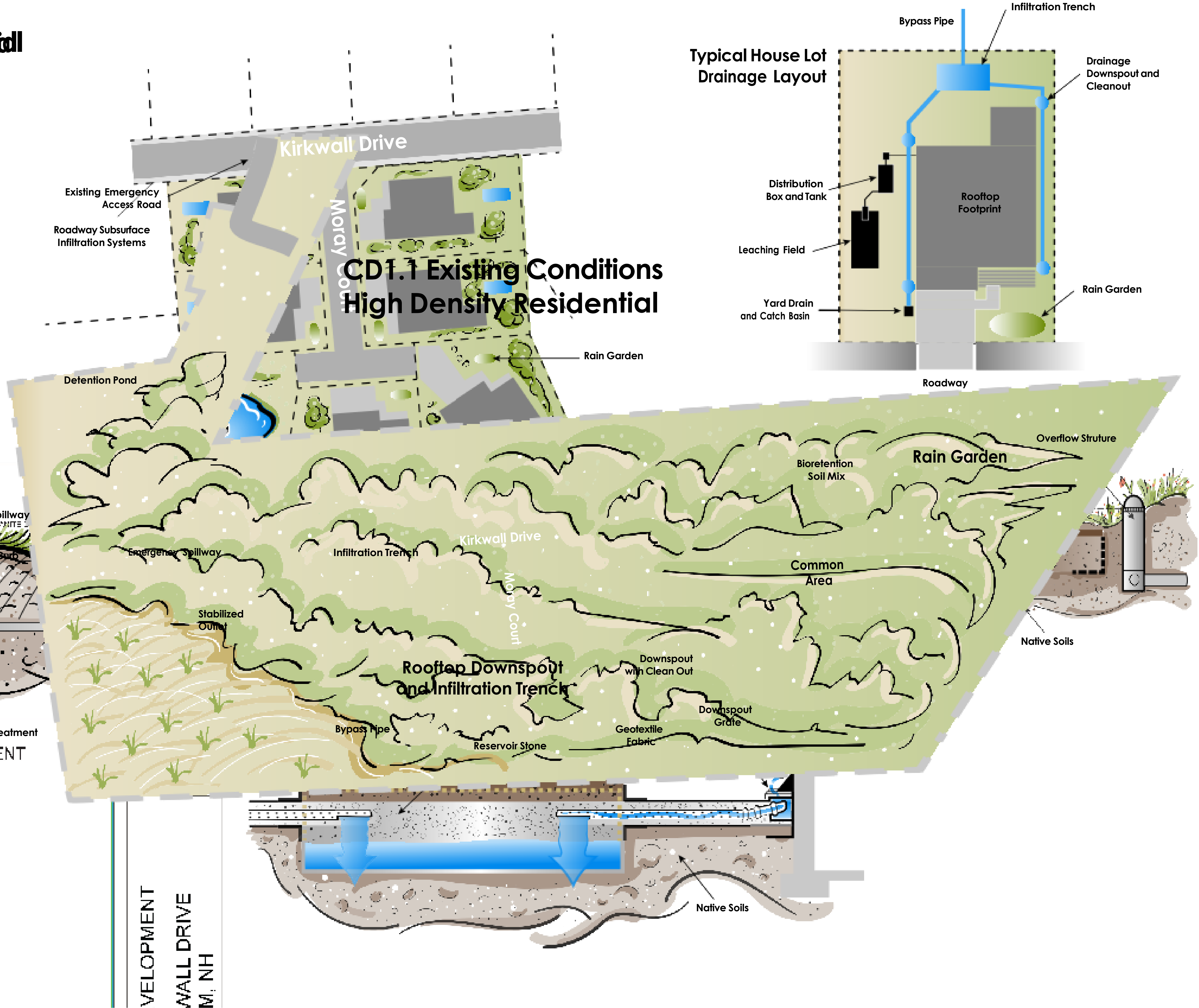
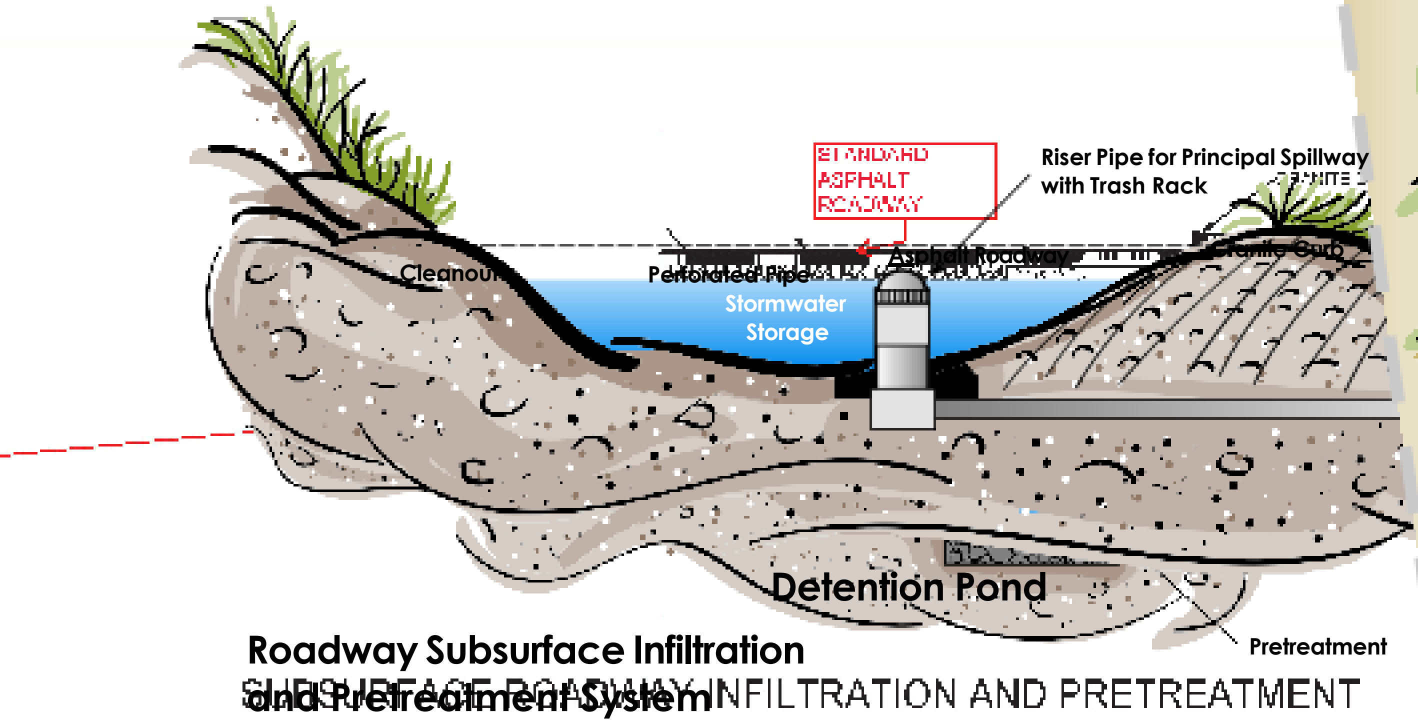
APPENDIX E. CONCEPT DEVELOPMENT PLANS FOR HIGH DENSITY RESIDENTIAL, COMMERCIAL REDEVELOPMENT, AND LOW DENSITY

CD1.4 High Density Residential

NO WATERFEL

- ✗ 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

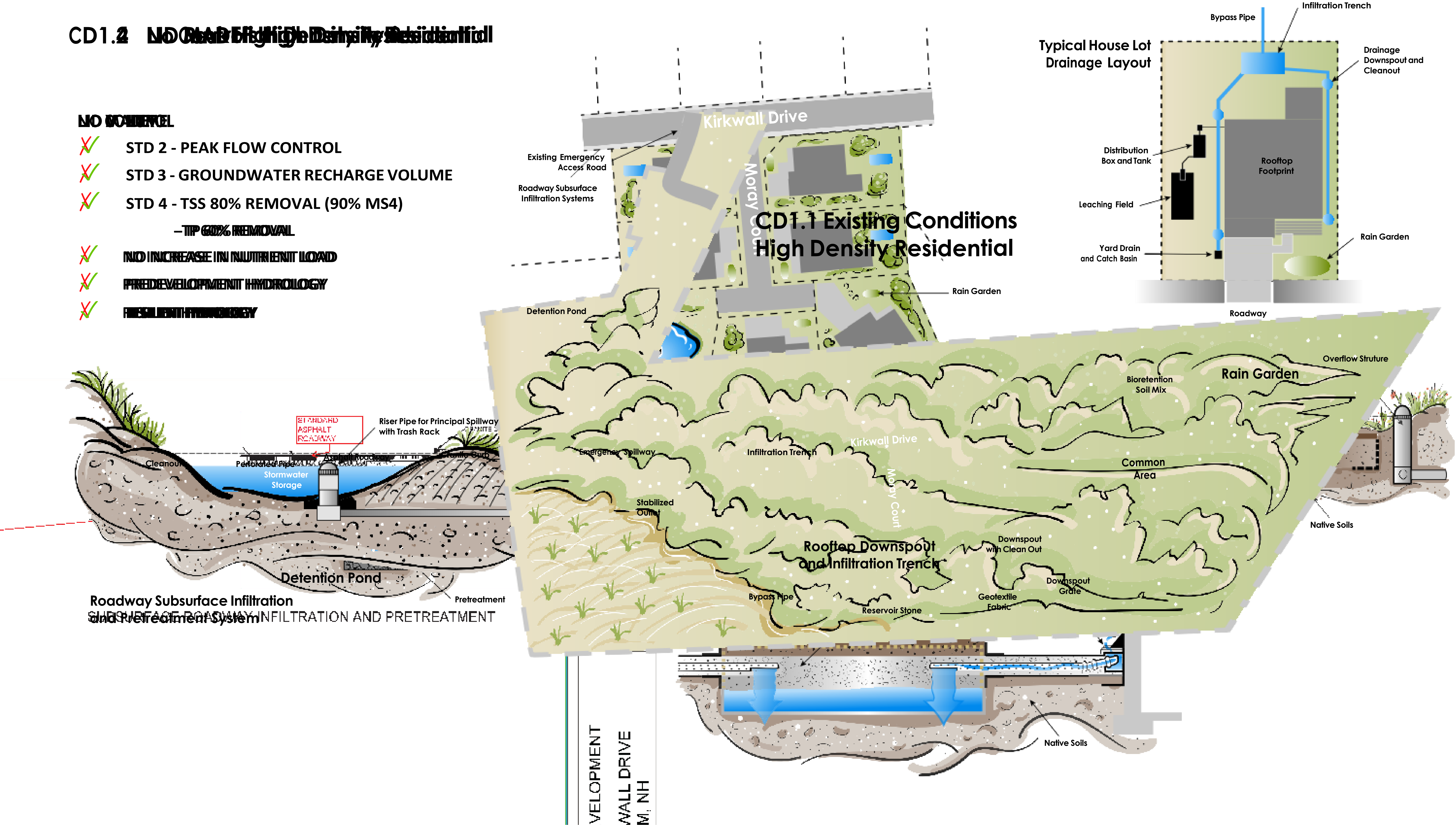




CD1.4 [illegible] High Density Residential

[illegible]

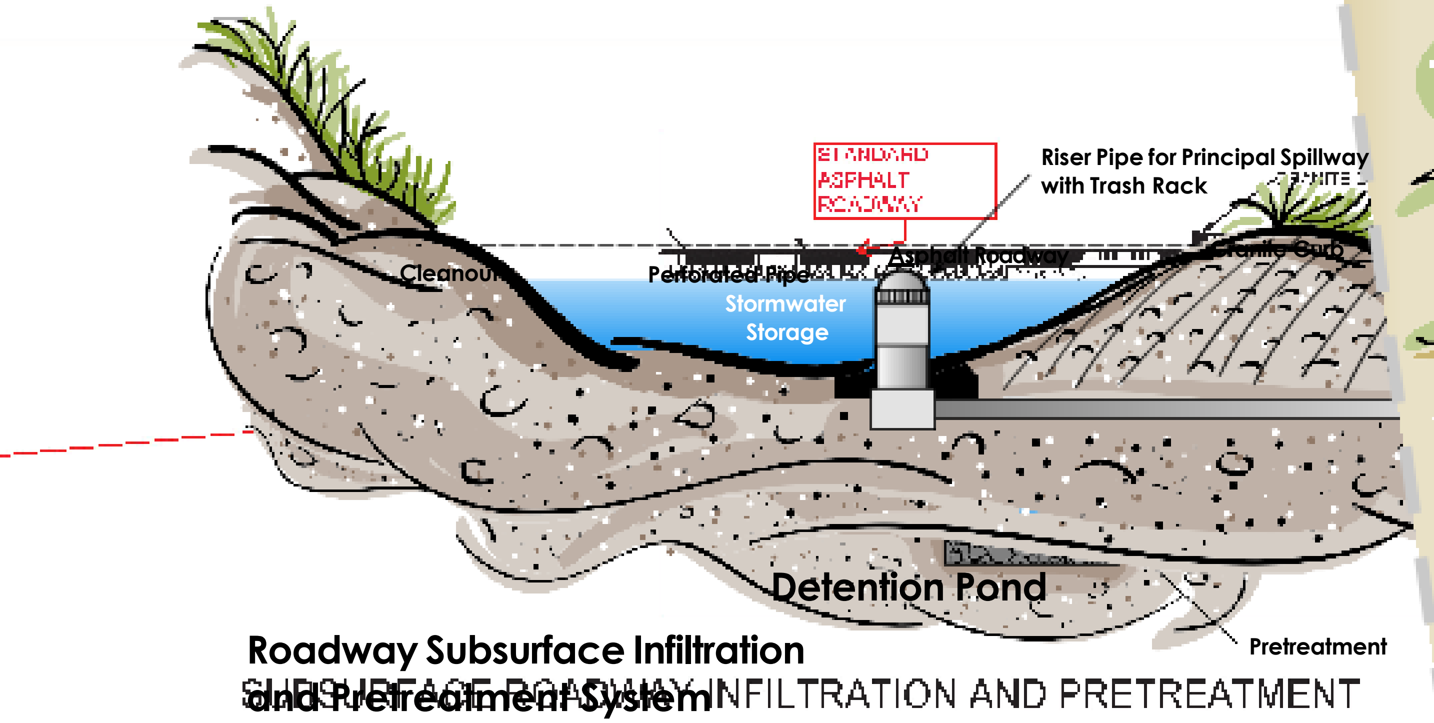
- STD 2 - PEAK FLOW CONTROL
- STD 3 - GROUNDWATER RECHARGE VOLUME
- STD 4 - TSS 80% REMOVAL (90% MS4)
  - –TP 60% REMOVAL
- NO INCREASE IN NUTRIENT LOAD
- PREDEVELOPMENT HYDROLOGY
- [illegible]

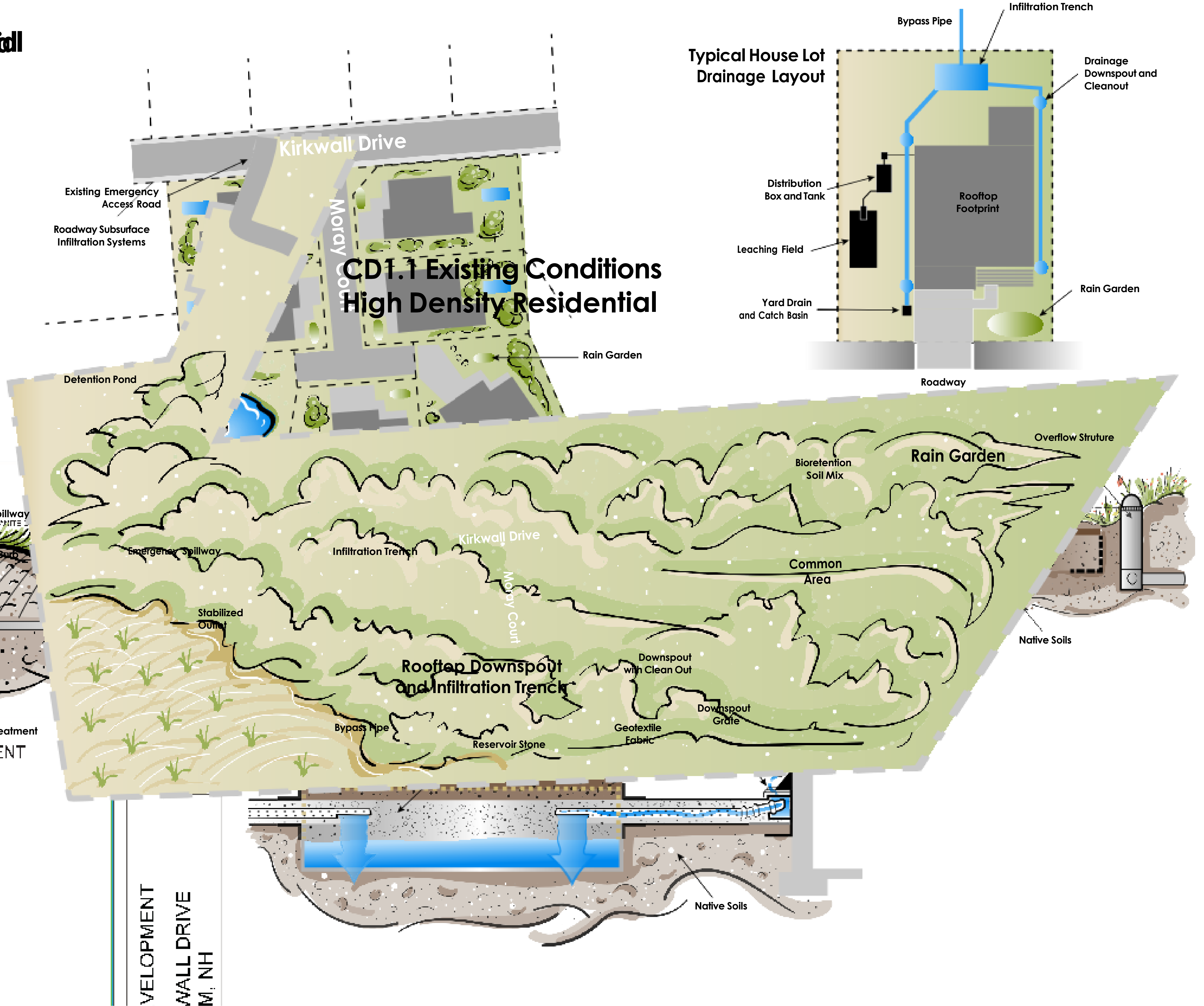


CD1.2 [illegible] High Density Residential

[illegible]

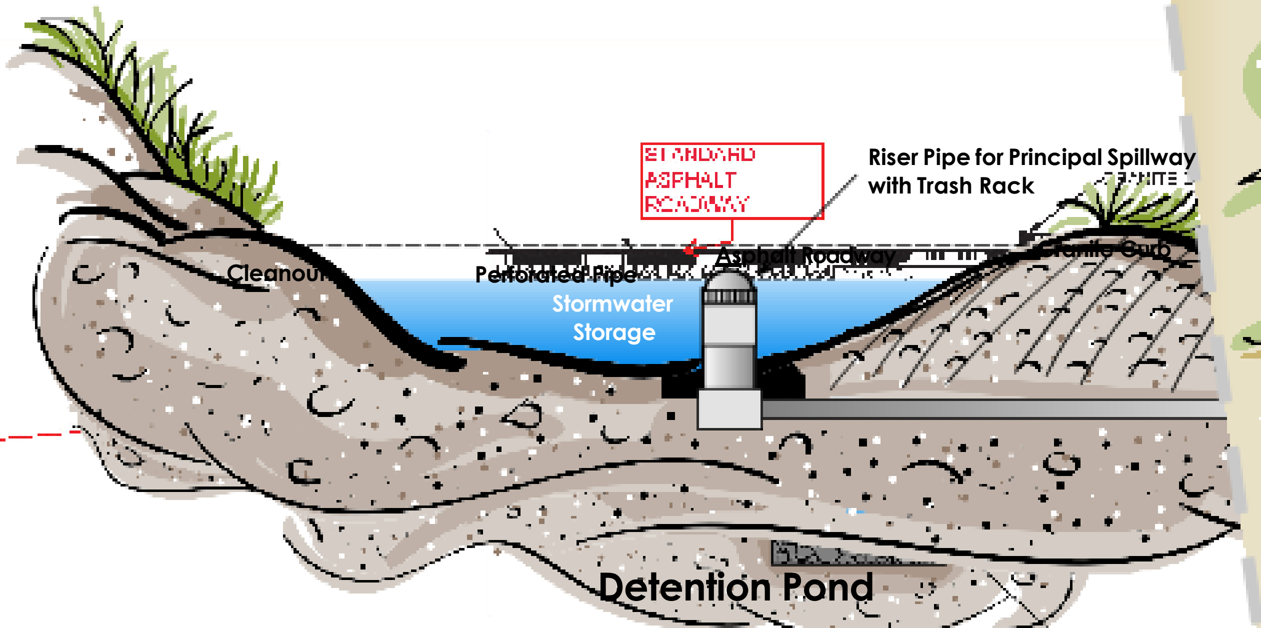
- STD 2 - PEAK FLOW CONTROL
- STD 3 - GROUNDWATER RECHARGE VOLUME
- STD 4 - TSS 80% REMOVAL (90% MS4)
  - – TP 60% REMOVAL
- NO INCREASE IN NUTRIENT LOAD
- PREDEVELOPMENT HYDROLOGY
- RESILIENT HYDROLOGY



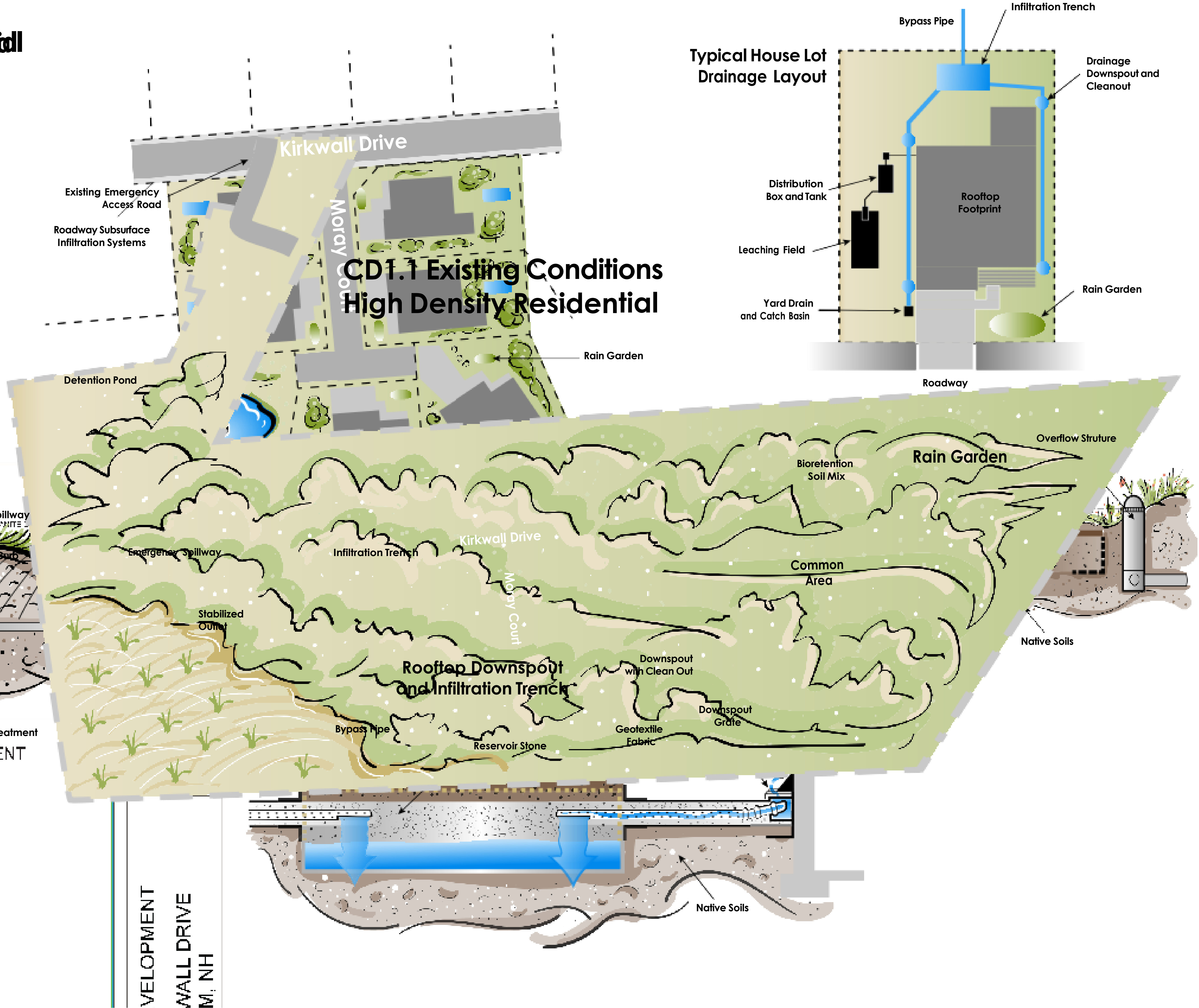


CD1.3 ... High Density Residential

- ✗✓ 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



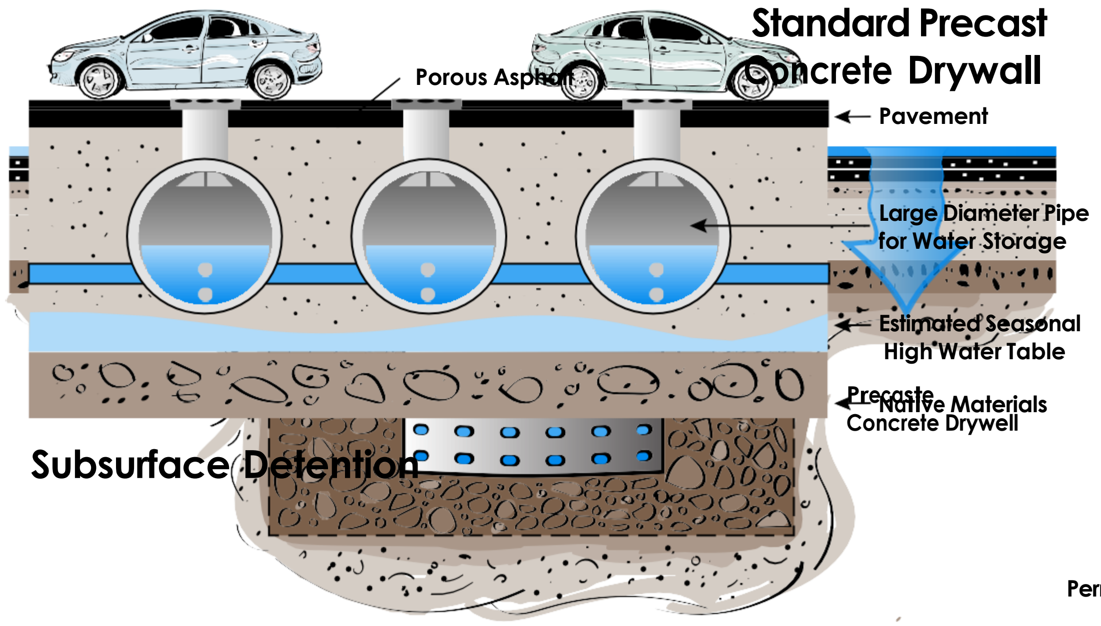
Roadway Subsurface Infiltration
and Pretreatment System
SUBSURFACE ROADWAY INFILTRATION AND PRETREATMENT

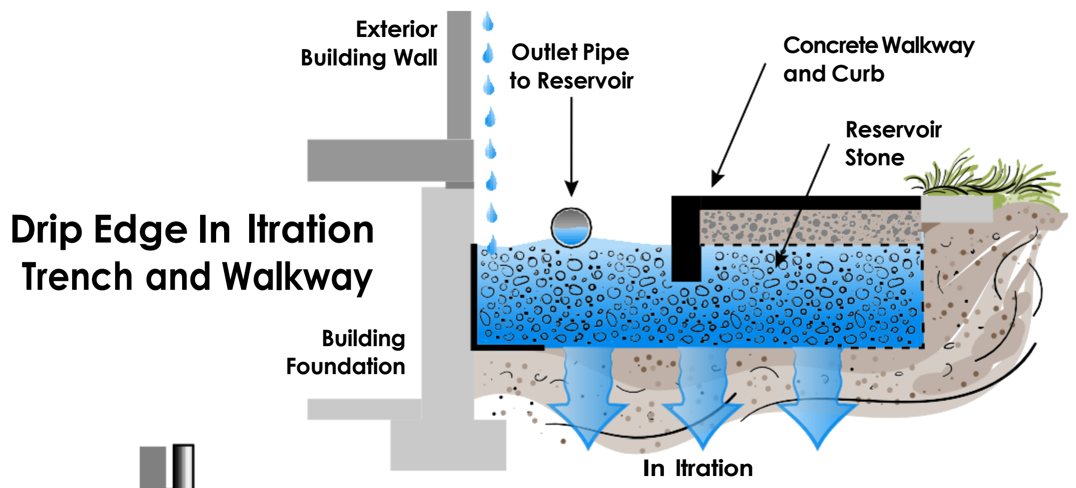


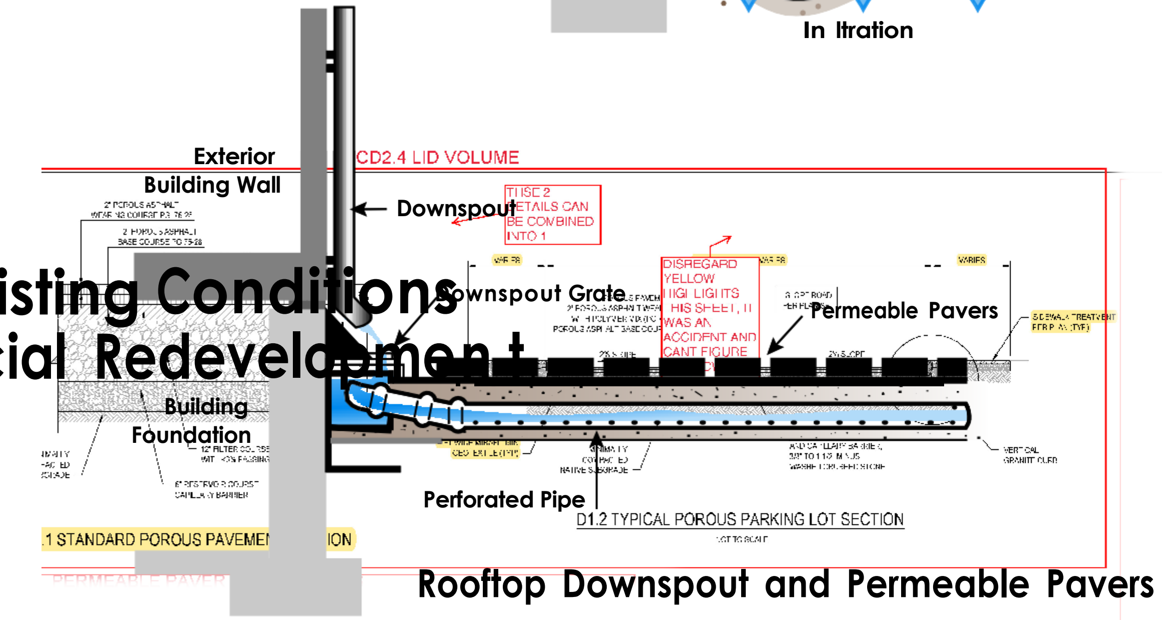
CD2.4 LID Controls Commercial Redevelopment

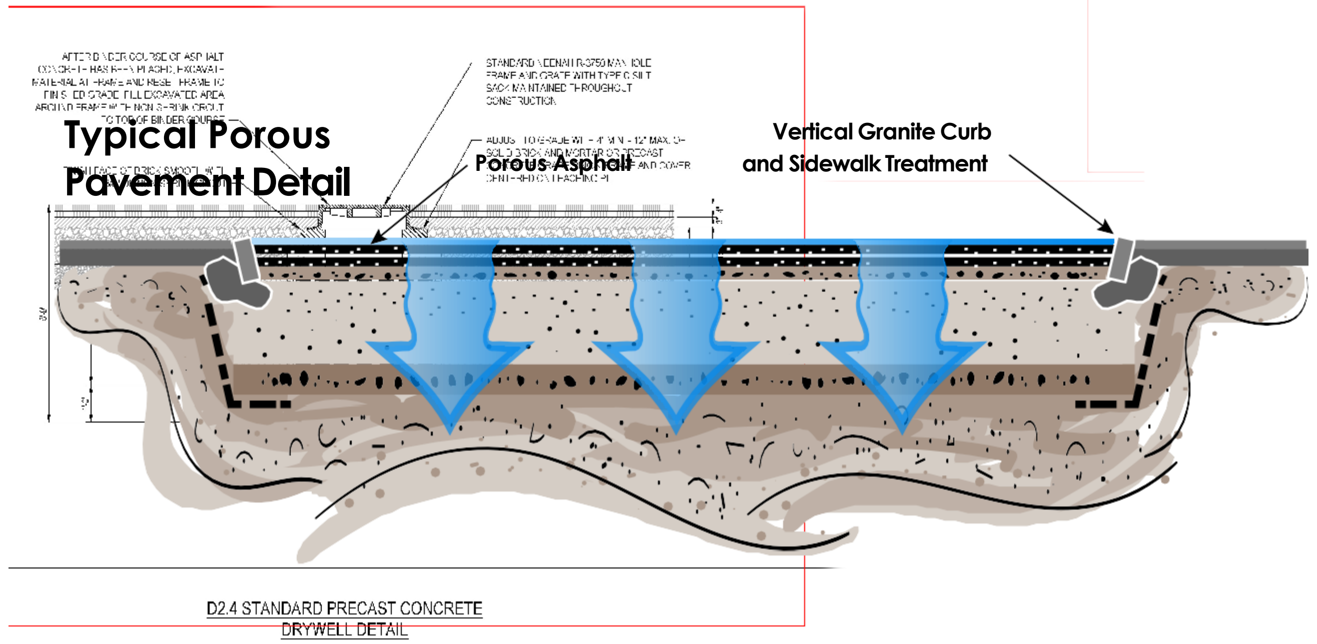
NO VOLUME

- ✗✓ 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





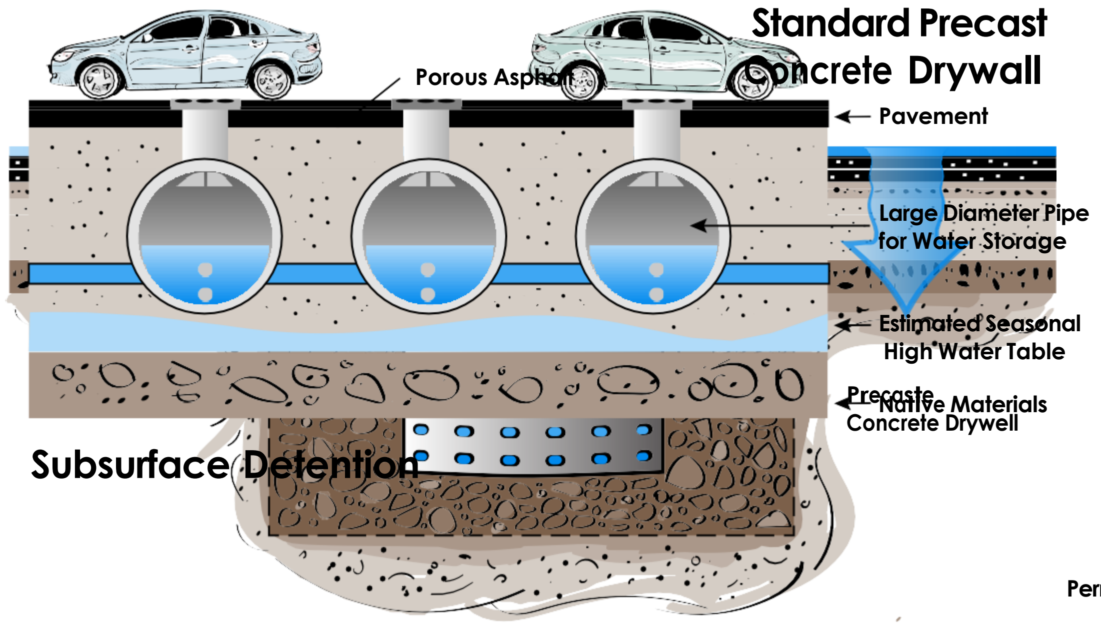


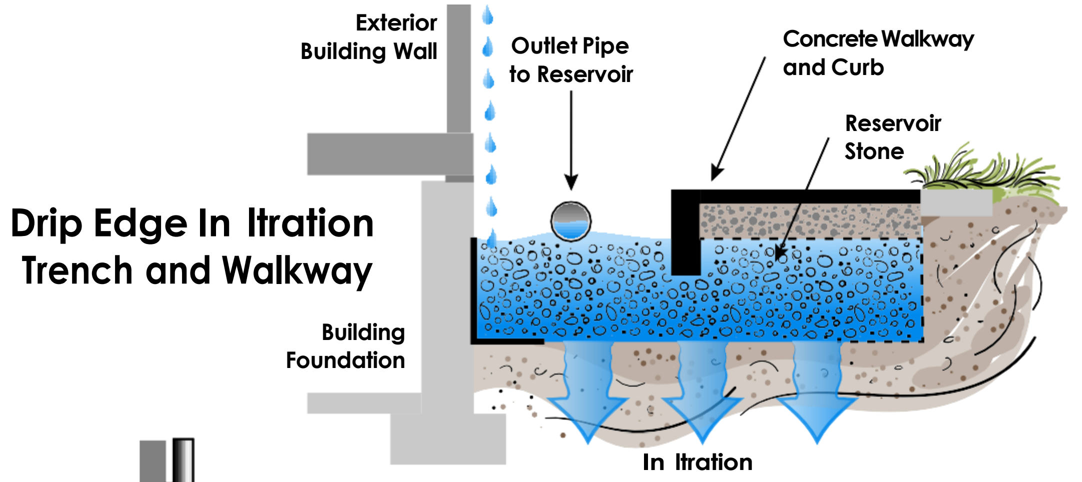


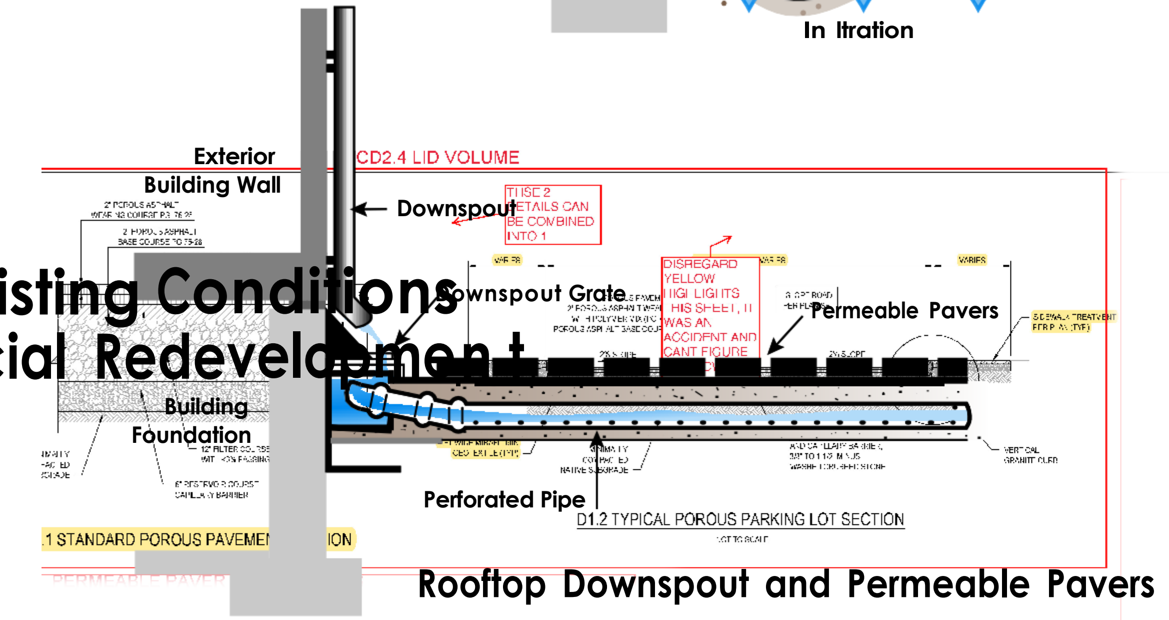
CD2.4 LID Controls Commercial Redevelopment

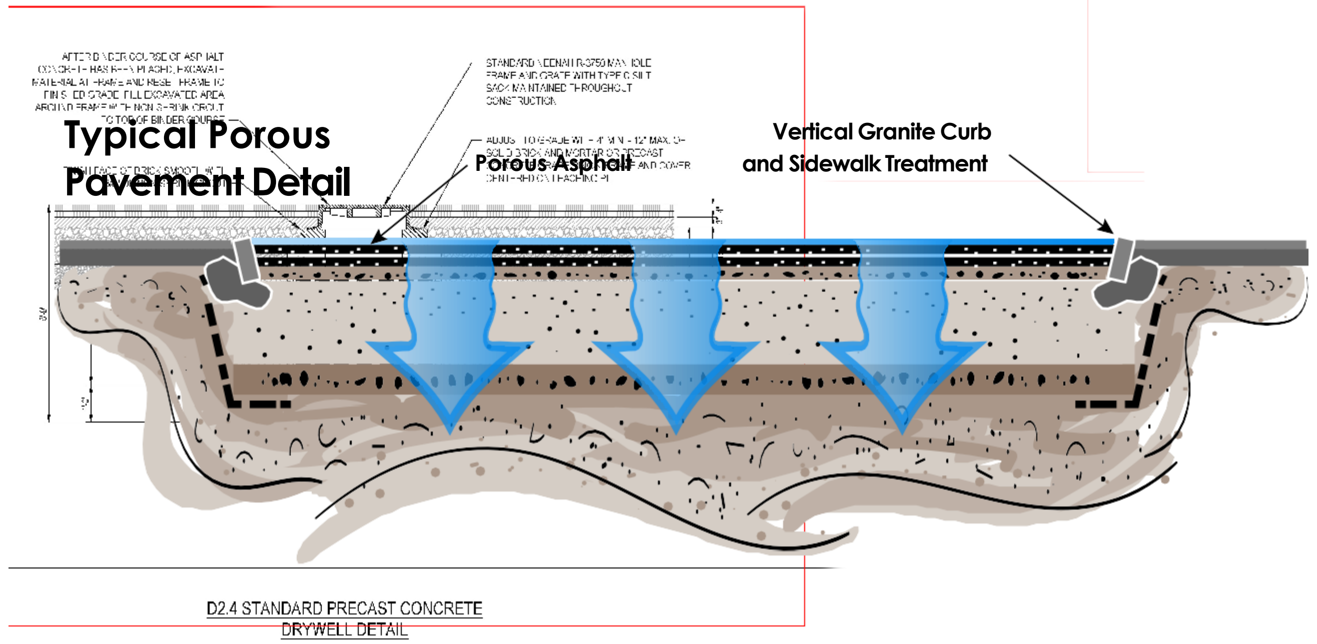
LID VOLUME

- ✗✓ 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





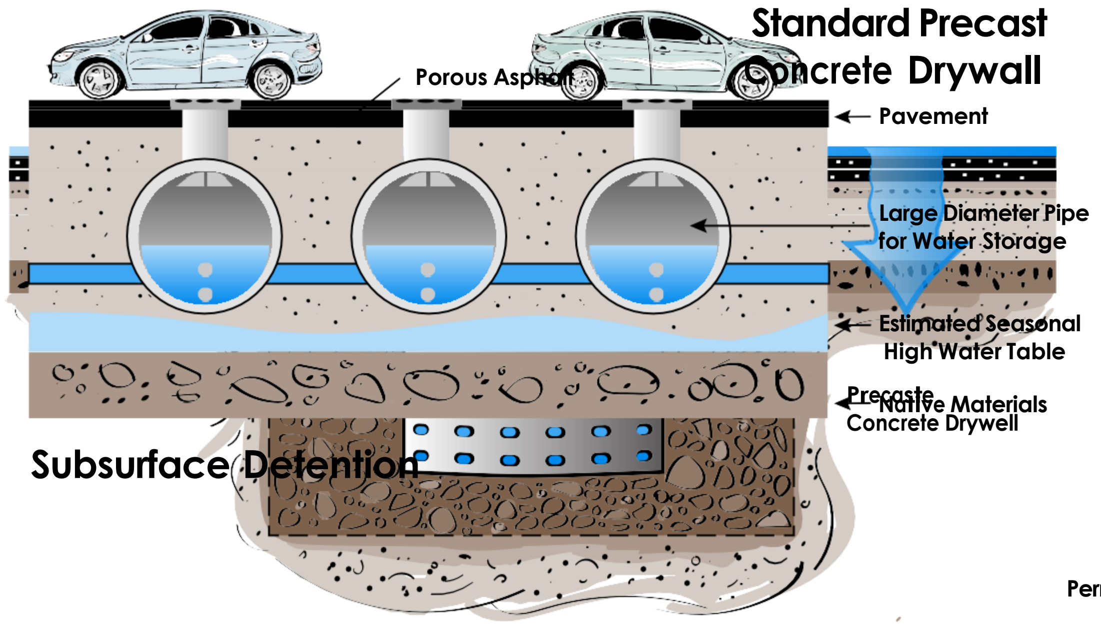


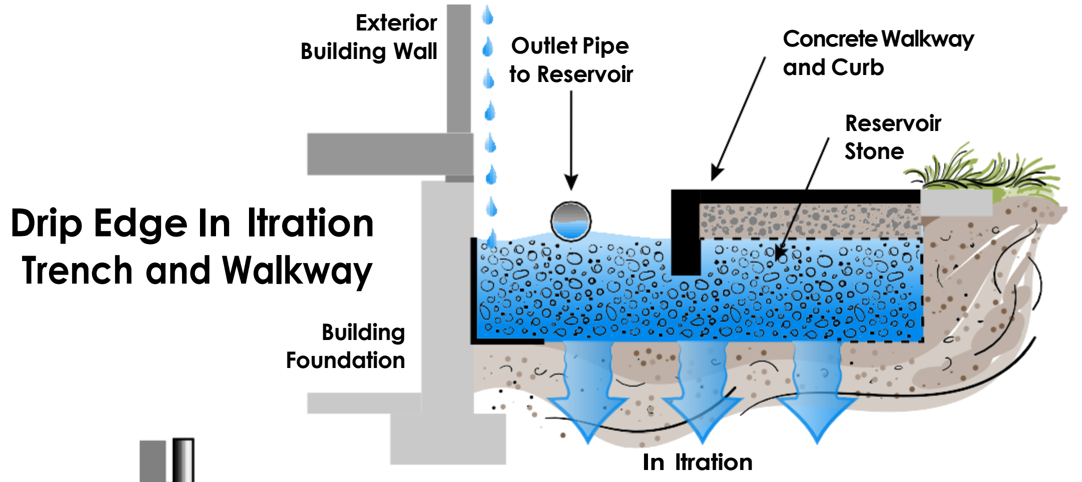


CD2.4 LID Controls Commercial Redevelopment

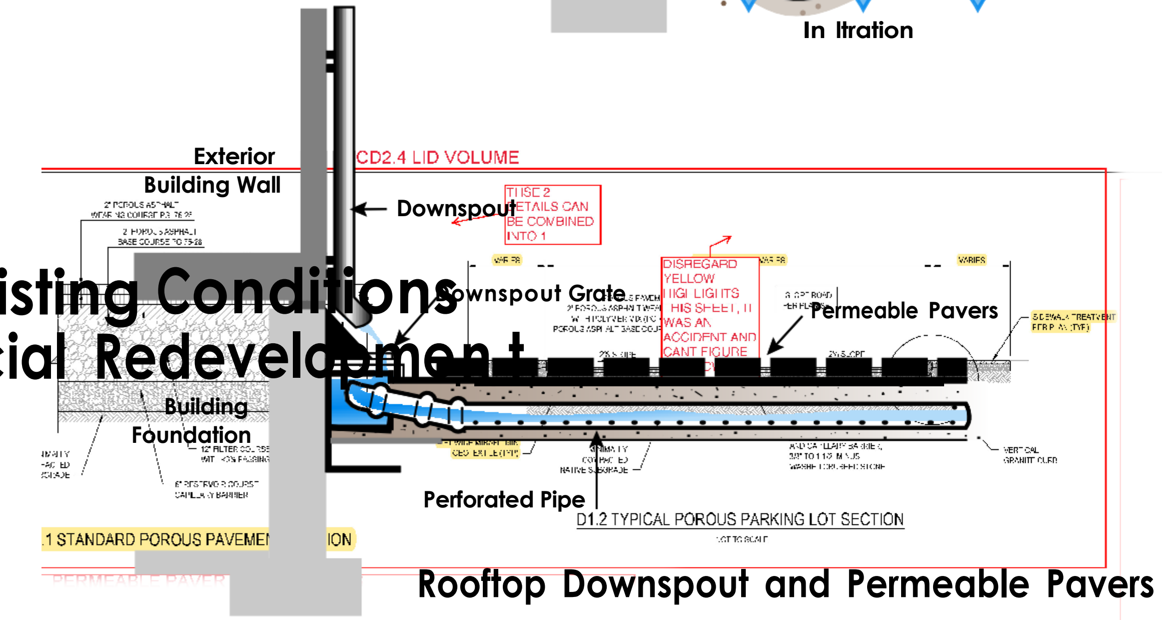
NO VOLUME

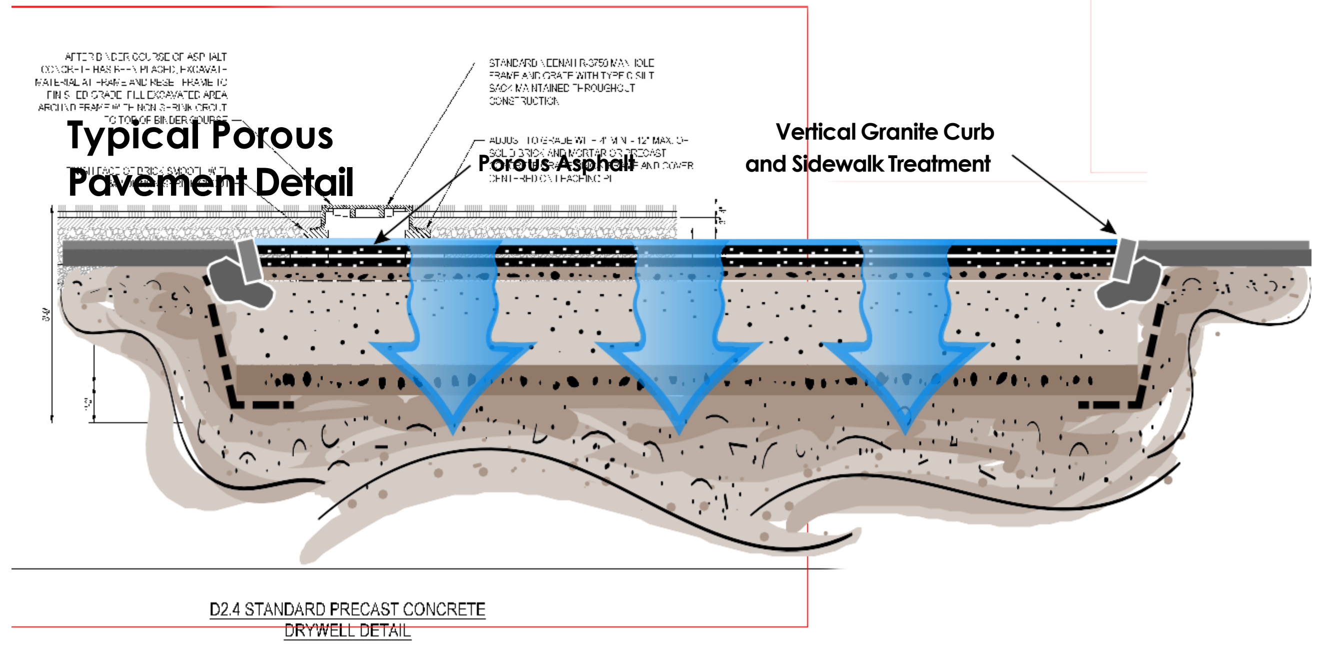
- ✗ ✓ STD 2 - PEAK FLOW CONTROL
- ✗ ✓ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ ✓ STD 4 - TSS 80% REMOVAL (90% MS4)
  - –TP 60% REMOVAL
- ✗ ✓ NO INCREASE IN NUTRIENT LOAD
- ✗ ✓ PREDEVELOPMENT HYDROLOGY
- ✗ ✓ RESILIENT HYDROLOGY





CD2.1 Existing Conditions Commercial Redevelopment

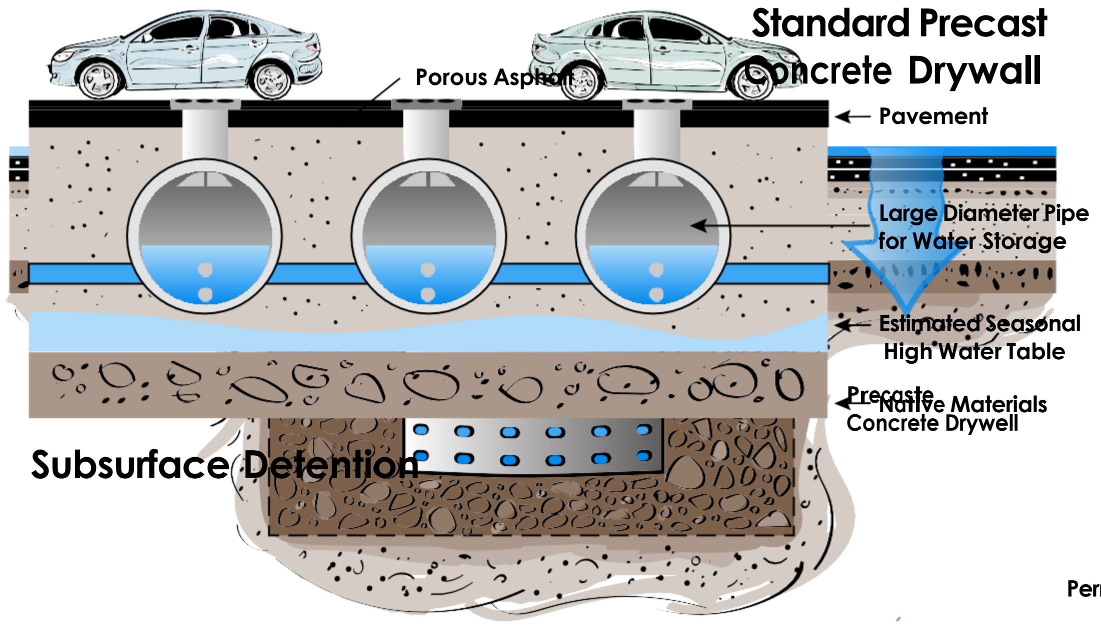


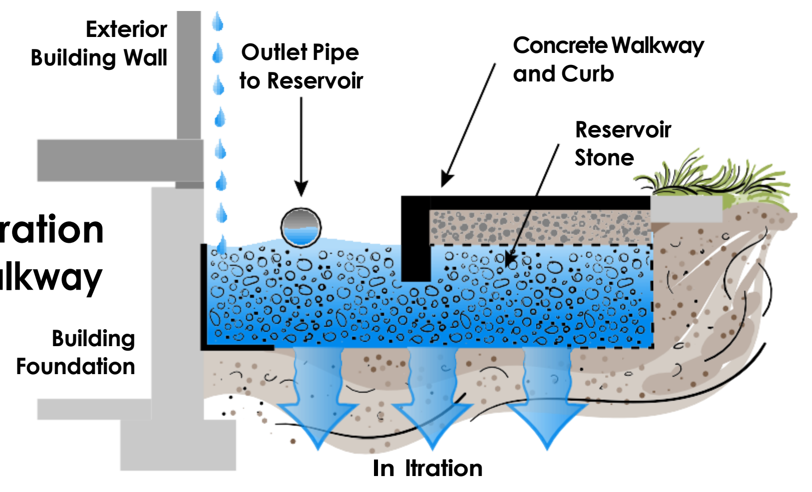


CD2.4 LID Controls Commercial Redevelopment

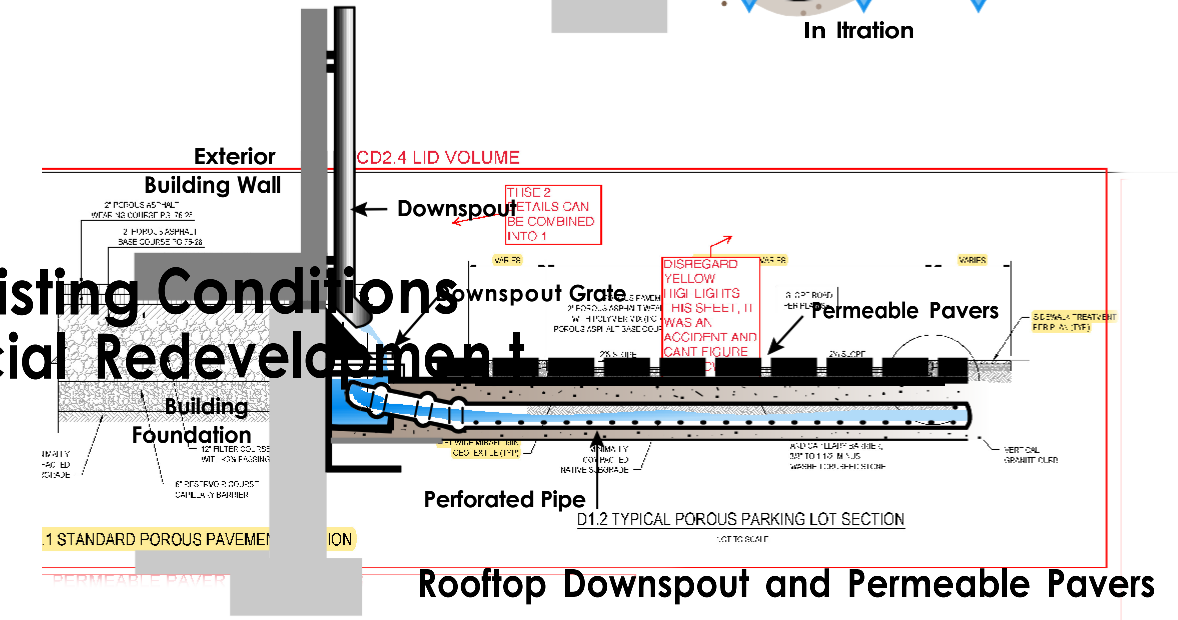
NO INCREASE IN VOLUME

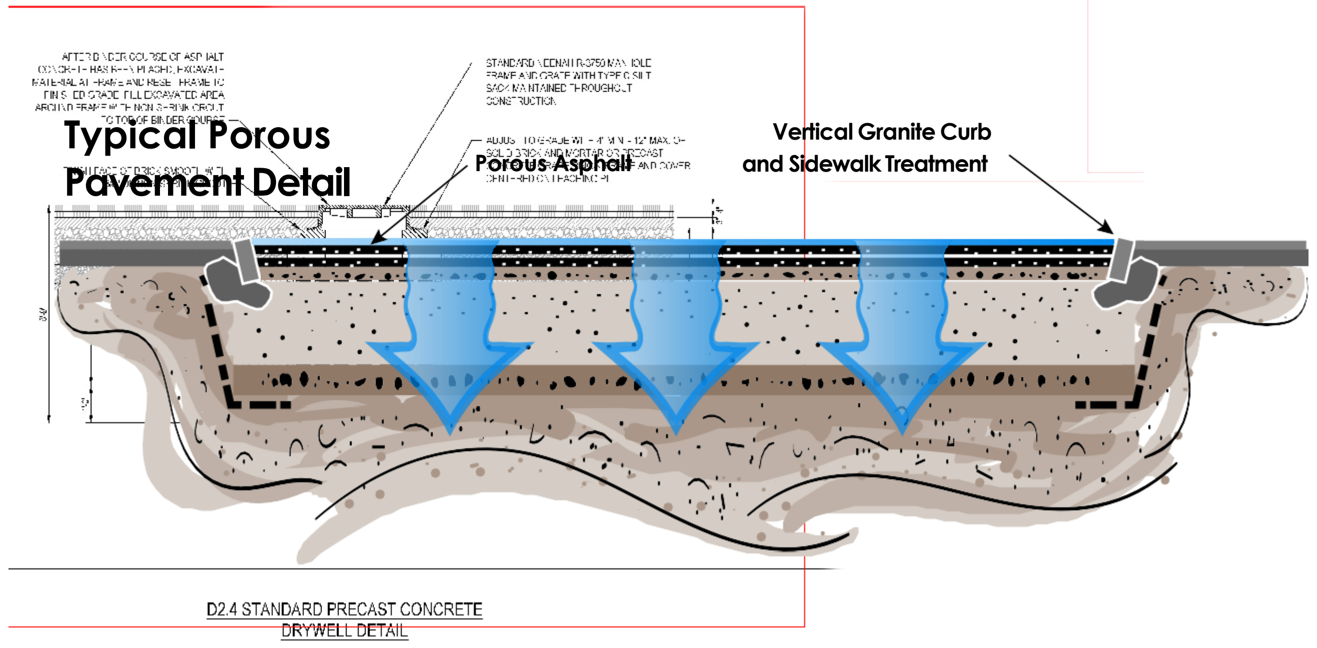
- STD 2 - PEAK FLOW CONTROL
- STD 3 - GROUNDWATER RECHARGE VOLUME
- STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- NO INCREASE IN NUTRIENT LOAD
- PREDEVELOPMENT HYDROLOGY
- RESILIENT HYDROLOGY





CD2.1 Existing Conditions Commercial Redevelopment



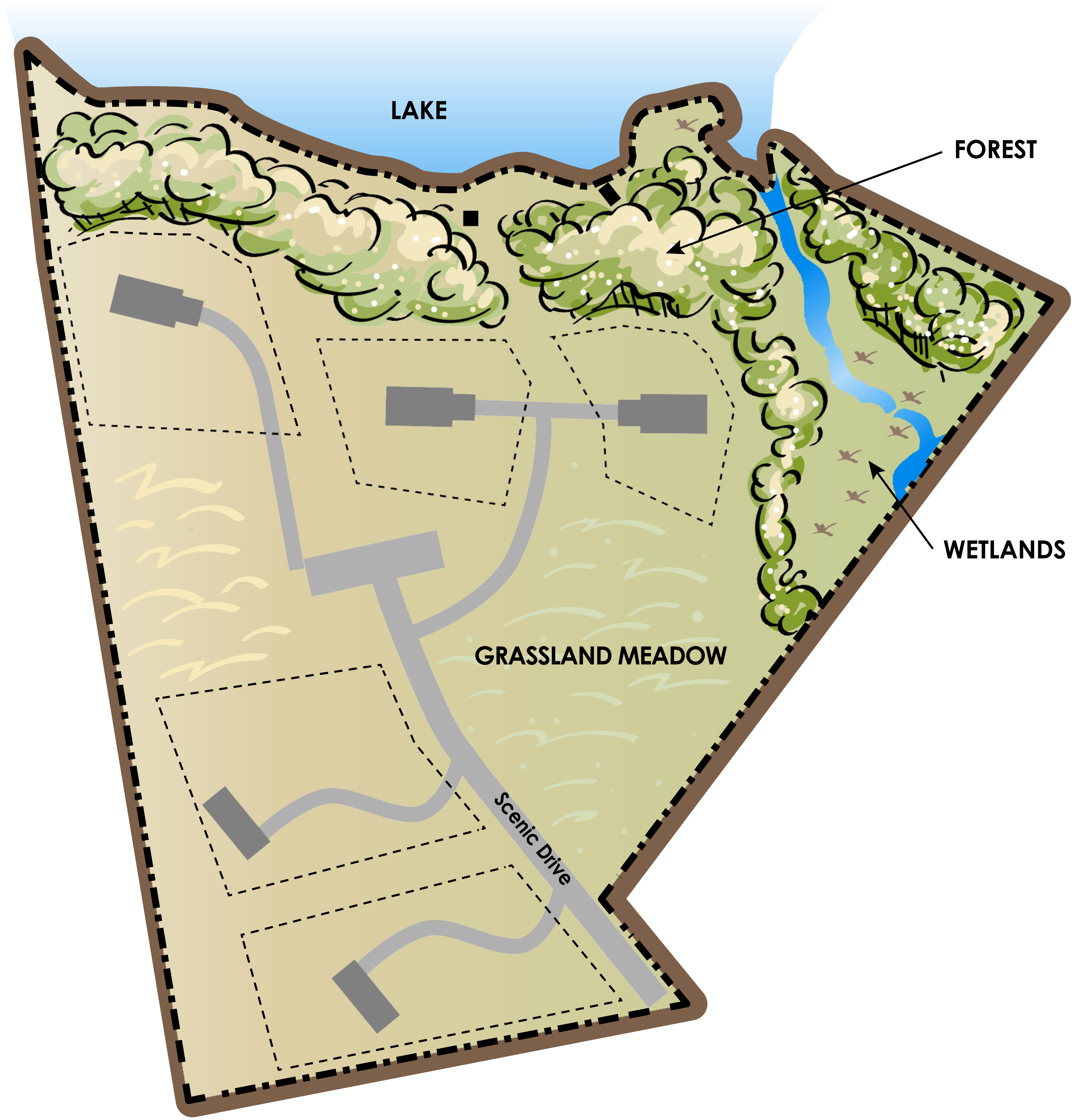


CD3.1 Existing Conditions
Low Density Residential

CD3.2 No Controls
Low Density Residential

NO CONTROL

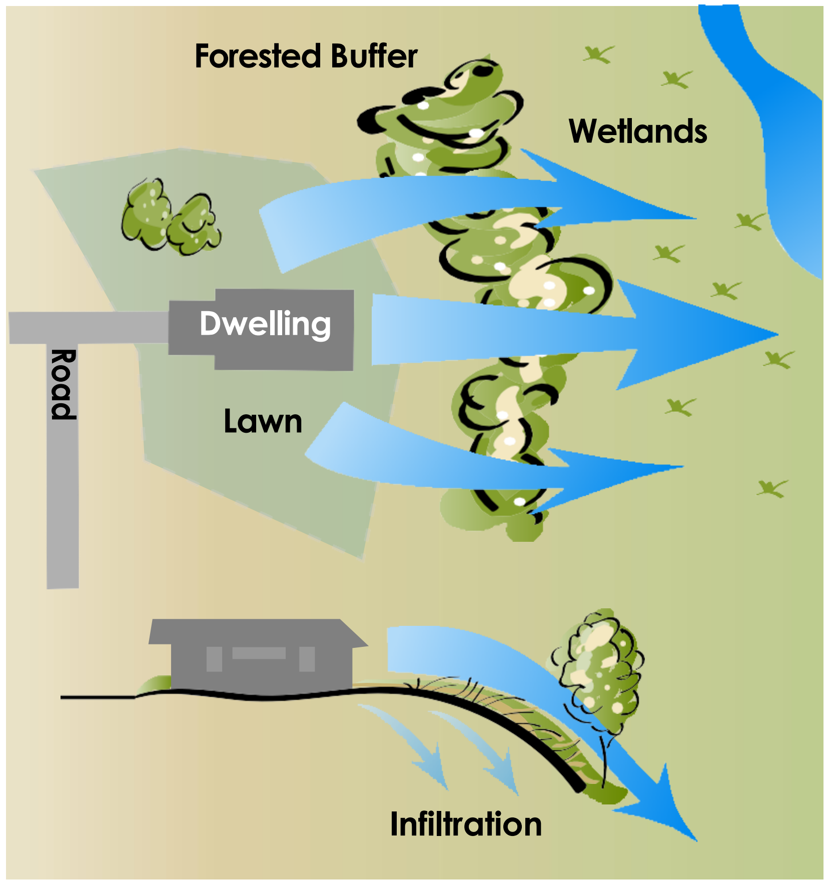
- ✗ STD 2 - PEAK FLOW CONTROL
- ✗ STD 3 - GROUNDWATER RECHARGE VOLUME
- ✗ STD 4 - TSS 80% REMOVAL (90% MS4)
  - TP 60% REMOVAL
- ✗ NO INCREASE IN NUTRIENT LOAD
- ✗ PREDEVELOPMENT HYDROLOGY
- ✗ RESILIENT HYDROLOGY



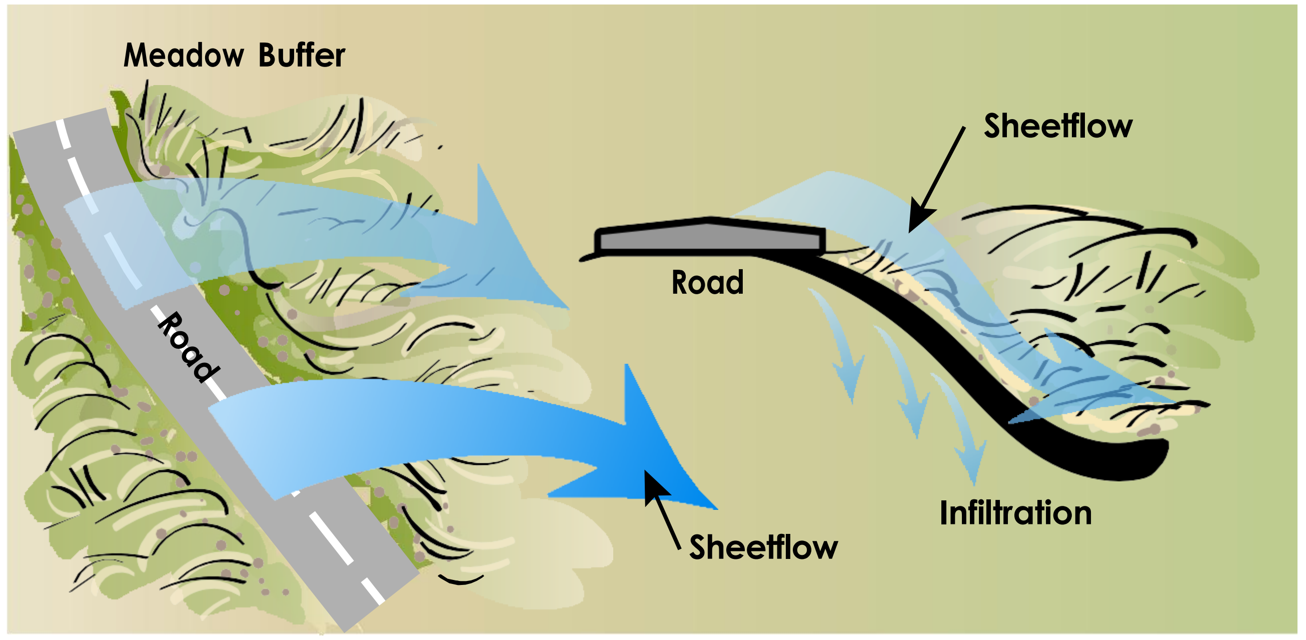
CD3.3 LID MADEP
Low Density Residential

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



Residential Forested Meadow Buffer

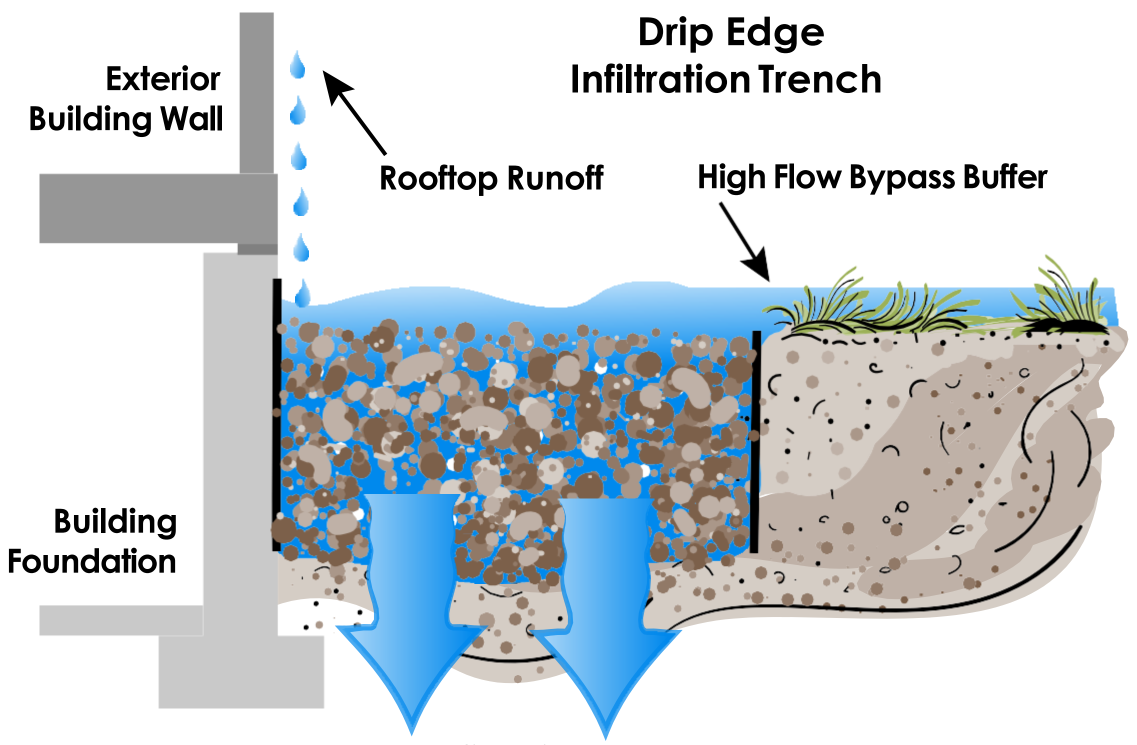


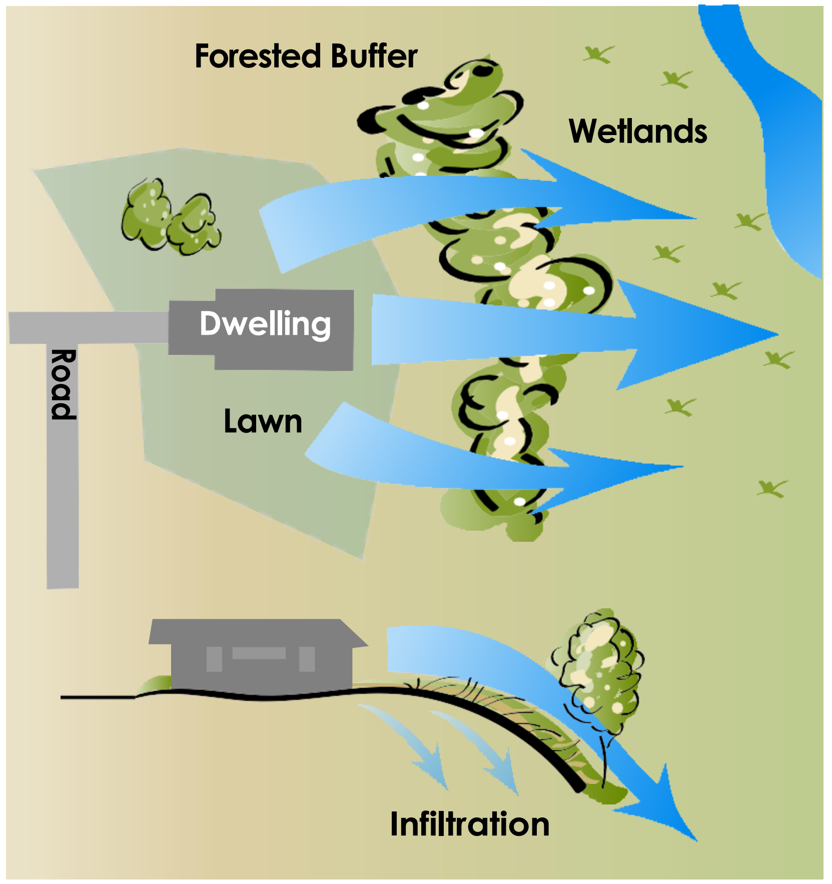
Roadway Buffer and Infiltration

CD3.4 LID Peak
Low Density Residential

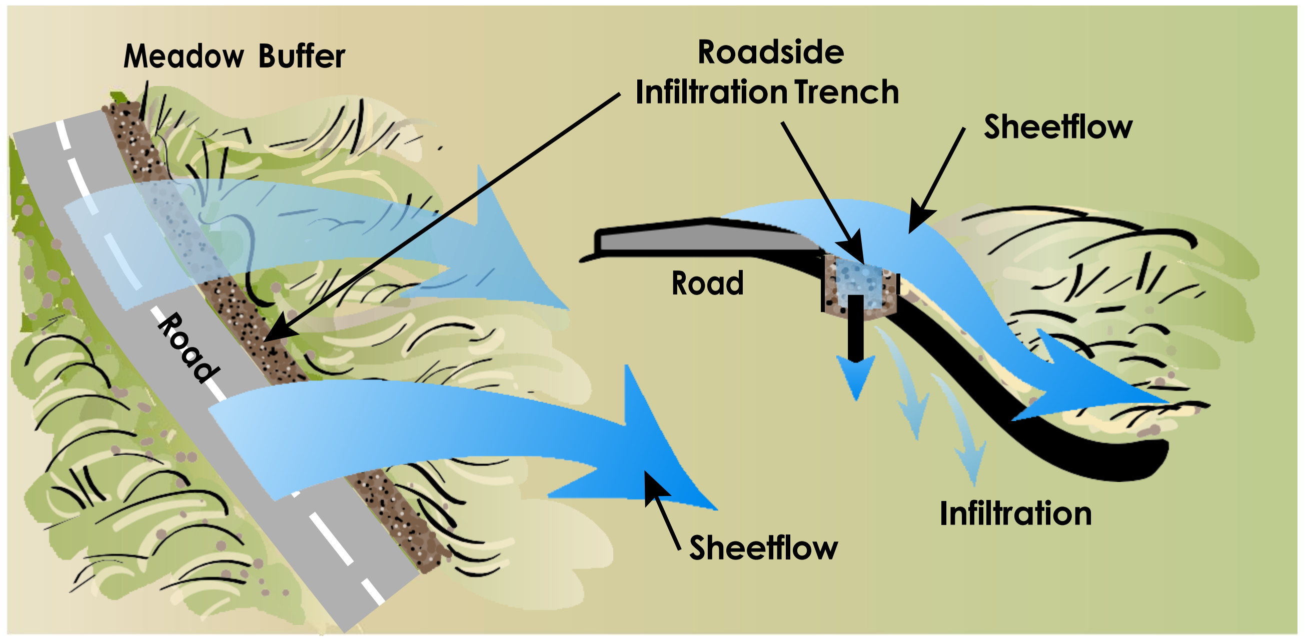
LID VOLUME

- ✓ 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

APPENDIX F. BYLAW REVIEW CHECKLIST FOR THE TOWN OF EASTON, MA

MA Open Space Residential Design Best Practices Factors	Conventional	Better	Best Practice	Community's OSRD
Permit Type	Special Permit	By Right	Mandatory	BEST - Planning Board Subdivision Application
Land area to which the zoning is applicable	Only a small amount of developable land	Land of particular environmental sensitivity	All developable land zoned residential	BEST - Residential Zoning Districts
Minimum Open Space	50-65%	65-75%	≥ 75%	Not Specified
Yield Calculation	Full plan with full percolation tests	Sketch plan with selected percolation test(s)	By formula	Not Specified
Minimum parcel size	≥ 10 acres	5-10 acres	None	Not Specified
Review Process	No detailed analysis of site characteristics in relation to design	Cluster layout	Flexible "OSRD" 4 Step	Conventional - Traditional Subdivision Application
Ownership of Open Space	Appropriate to the resources present. For example, agricultural land by the farmer, watershed land by a water dept. or district, habitat land by the conservation commission, or recreational open space by a parks and recreation commission or homeowners association.			Donated Land? Ownership not specified
Dimensional Standards; area, frontage, etc.	Specified, < than for standard subdivision	Formulaic reduction with specified minimums	None set or small minimums	Not Specified as deviating from traditional dimensional requirements
Quality of open space conserved: Specificity of local priorities for natural, cultural, and historic resource conservation	No indication of local conservation priorities, or language that refers only to regulated resource areas.	Lack of specificity regarding local conservation priorities; no map of priority locations	Local priorities clearly and unambiguously stated and mapped for use in site design.	BETTER - Detailed submission requirements, existing conditions plan, OS design standards, protection of natural features, solar orientation
Contiguity of open space; relationship to previously protected open space	No contiguity requirement	Contiguity required within subdivision	Contiguity required; adjacent land considered	BEST - OS Design Standards; contintuity of OS land on property and consideration of features on adjacent properties
Quality of open space conserved: Allowed uses of open space	Allowed use of open space not addressed	Vague language regarding use of conserved open space	Clear list of allowed uses consistent with conservation and recreation goals	BETTER - OS Design Standards and OS Use Plan

MA Open Space Residential Design Best Practices Factors	Conventional	Better	Best Practice	Community's OSRD
Quality of open space conserved: Submission requirements - GIS maps, data, etc. to inform the review process	Vague or no language regarding submission of information on site resources and no specified process for the use of the data submitted	General non-comprehensive data and mapping requirements; vague process for the application of the data to site design and open space conservation	Specific plans, maps, & comprehensive data regarding natural, cultural, and historic resources required and used as the basis for open space conservation	BETTER - Existing conditions plan details; OS Design Standards
Relationship to Plans	Relationship to plans not discussed	Optional consideration of open space goals of OSRP, master, and/or regional policy plan	Required consideration of open space goals of OSRP, master, and/or regional policy plan	Not Specified
Low Impact Design	Not addressed	Encouraged	Required	Not Specified
Density bonus for enhanced public benefit(s)	No bonus offered	Bonus by special permit	Automatic or formulaic bonus	Not Specified
Review Entity	ZBA, council or selectmen as special permit authority	Planning Board	Planning Board	BEST - Planning Board Subdivision Application
Flexibility re: open space protection to facilitate wastewater treatment facilities	No flexibility provided	Aggregate calculations allowed by board of health	If necessary, required open space may be reduced by < 10% to accommodate; disposal area deed restricted; aggregate calculations allowed by BoH, etc.	Not Specified
Monitoring of open space	No specified monitoring requirements and no requirements that would assist the party responsible for monitoring	Loose provisions to facilitate, municipal monitoring, or no specificity regarding monitoring interval	Specific provisions to aid endowed monitoring by a conservation org at stated intervals	Not Specified

APPENDIX G. METHODOLOGY FOR THE DEVELOPMENT OF A WATERSHED PROTECTION STANDARD

Technical Memorandum

Methodology for the Development of a Watershed Protection Standard

To: File of Compendium for Watershed Protection Standard: Taunton Watershed Project

From: Mark Voorhees, EPA Region 1 Stormwater Program, Khalid Alvi, Paradigm Environmental, Robert Roseen, PE, PHD, Waterstone Engineering

Date: 10/16/2022

1. Introduction - Watershed Protection Standard for Managing Post-Construction Stormwater Runoff

A Watershed Protection Standard (WPS) has been developed to provide communities with resilient alternative site development stormwater (SW) management performance standards designed to protect and restore watershed and water resource health from impacts associated with future development activities. This memorandum describes development of the WPS that defines post-construction SW management performance standards for controlling SW runoff from impervious cover (IC) associated with new and redevelopment activities. The WPS specifies SW control levels to achieve predevelopment average annual groundwater recharge volumes and predevelopment SW nutrient load export (total phosphorus (TP) and total nitrogen (TN)). The WPS is intended to emphasize dispersed Green Infrastructure (GI) and Low Impact Development (LID) techniques including minimizing the disturbance of area with natural soils and vegetation, preservation of hydrologic function for on-site areas of soil disturbance, and the importance of maintaining on-site predevelopment drainage patterns. Therefore, the WPS not only specifies levels of SW control to achieve predevelopment recharge and SW nutrient load export on site but emphasizes the importance of the adopting the following site design principals for minimizing impacts and preserving natural watershed functions:

- Maintain predevelopment drainage and groundwater recharge patterns.
- Apply dispersed green infrastructure (GI) across site to achieve WPS performance standards prior to finalizing design to manage for peak flow control.
- Minimize disturbance of natural soils, and restore all disturbed soils not built on to predevelopment hydrologic conditions.

The WPS provides two options related to on-site SW runoff management for communities to consider:

1. Right sizing (add footnote) of infiltration SW control measures (SCMs) based on varying soil permeability using EPA region 1's SCM performance curves based on long-term continuous simulation modelling (Boston, MA, 1992-2020); and

2. Simple one-inch (1”) retention design standard for which all controls are designed to have a Design Storage Volume (DSV add foot note) equal to 1” depth of runoff from contributing IC.

The WPS SW performance standards are derived from examining how natural vegetated land with varying soil conditions functions under existing climatic conditions over a long-periods of time. A combination of continuous simulation hydrologic modeling, climatic data, research conducted in the development of SW nutrient load export rates for the MA and NH MS4 permits, and literature on evapotranspiration were used to estimate SW runoff volumes, groundwater recharge, and nutrient export conditions associated with predevelopment natural conditions and post development IC.

2. Unit Area Hydrologic and Stormwater Nutrient Load Export Changes From Impervious Cover

The modeling analyses presented in the following sections allowed for the estimation of the change in hydrologic conditions (runoff and groundwater recharge volumes) and SW runoff nutrient load export (TP and TN) associated with the replacement of natural vegetated land with IC. This section summarizes the estimated changes based on the analyses described in more detail in the following sections. Table 1 provides average annual estimates associated with predevelopment conditions, identified as grass-meadow/forested according to hydrologic soil group, and IC. Figures 1 through 4 illustrate the magnitude of change in runoff, recharge, SW TP, and SW TN export, respectively, associated with converting natural vegetated areas to IC depending on soil permeability (capacity of soils to infiltrate water into the ground)

Table 1: Estimated unit-area annual hydrologic yields and stormwater (SW) nutrient load export rates for naturally vegetated predevelopment conditions and impervious cover

Land Area Type and Condition	Hydrologic Soil Group	Average Annual Precipitation, MG/acre/year*	Average Annual Runoff Yield, MG/acre/year	Average Annual Recharge Volume, MG acre/year	Average Annual SW TP Load Export Rate lbs/acre/year	Average Annual SW TN Load Export Rate lbs/acre/year
Grass-Meadow/Forested with well-drained soils	A	1.16	0.017	0.57	0.03	0.3
Grass-Meadow/Forested with moderately well-drained soils	B	1.16	0.076	0.50	0.13	1.3
Grass-Meadow/Forested with less well drained soils	C	1.16	0.16	0.43	0.26	2.6
Grass-Meadow/Forested with poorly drained soils	D	1.16	0.25	0.33	0.42	4.2
Impervious cover	Not Applicable	1.16	1.09	0.00	1.82	14.6

Notes: * MG/acre/yr - Million Gallons/acre/year. Runoff Yields estimated using the StormWater Management Model (SWMM) v5.0 with climatic data (hourly precipitation and daily temperature) for Boston, MA (1992-2020). Average annual precipitation depth for this record is 42.8 inches with a low of 28.3 inches and a high of 54.5 inches. Nutrient export rates are based on the rates derived for that MA and NH MS4 permits (appendix F attachment 3) and adjusted proportionally according to runoff yields.

Figure 1.

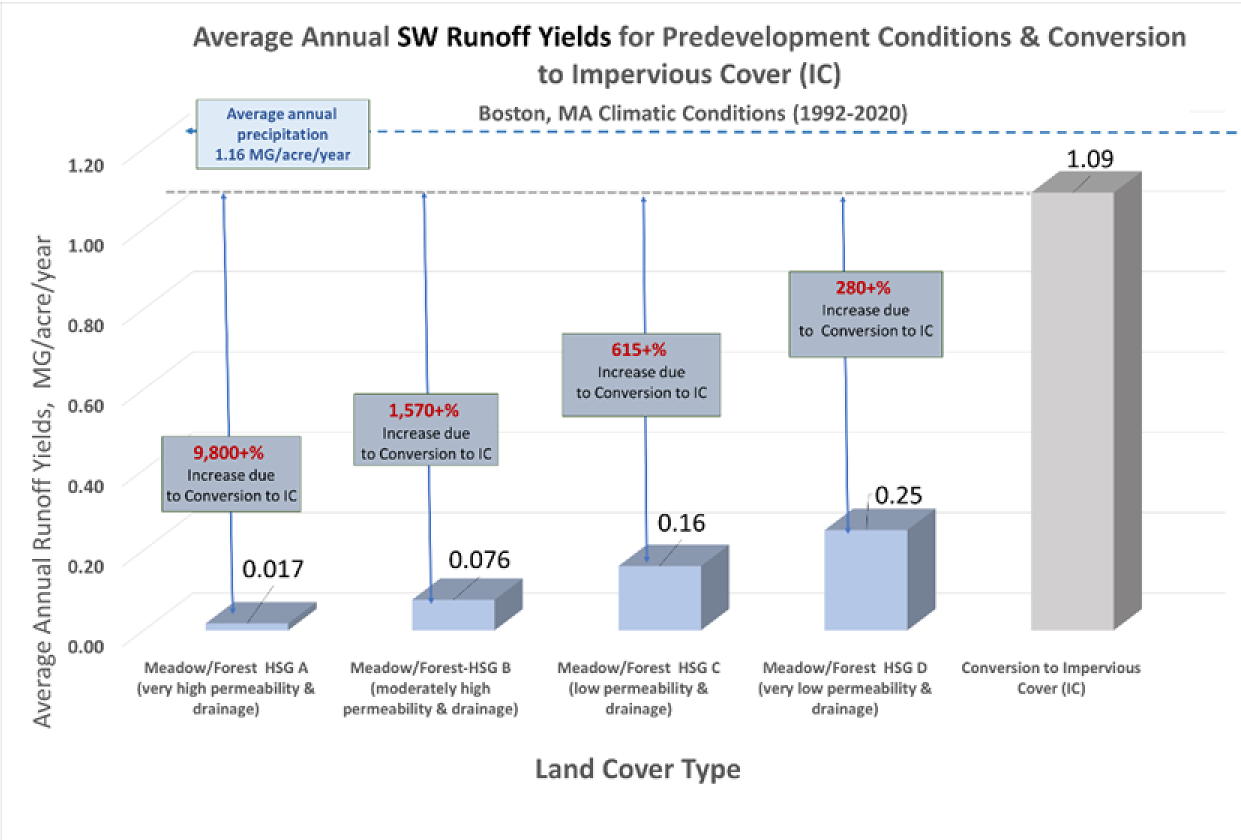


Figure 2.

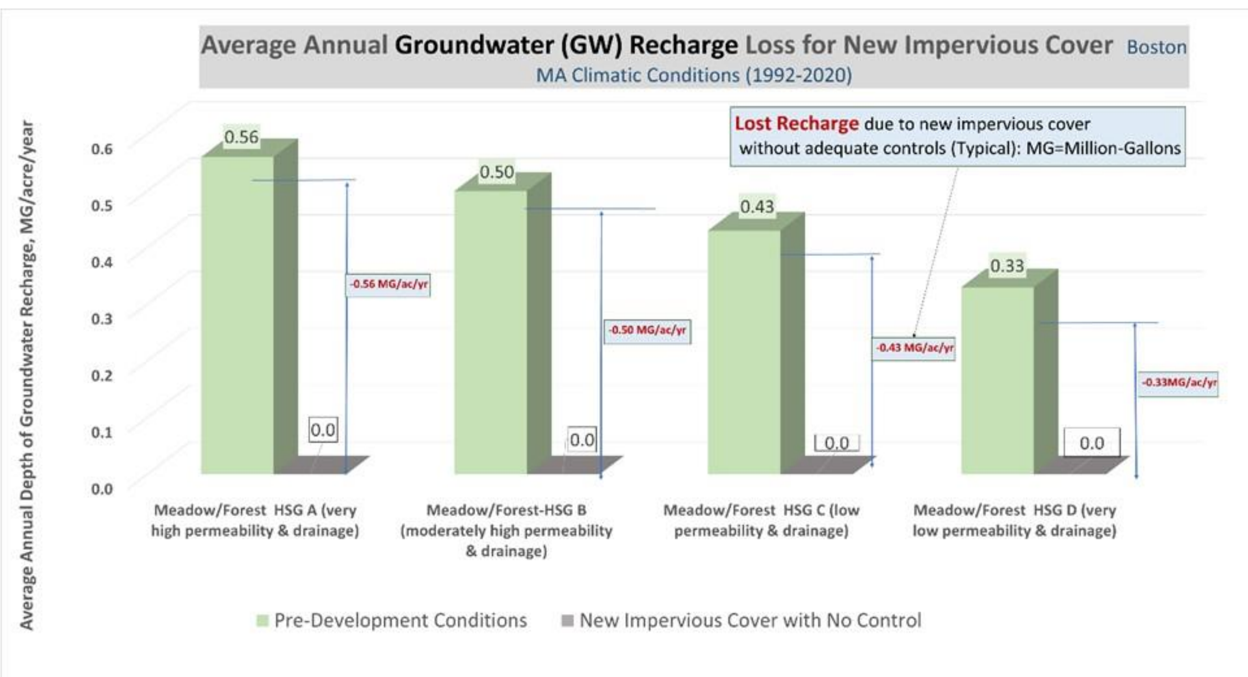


Figure 3.

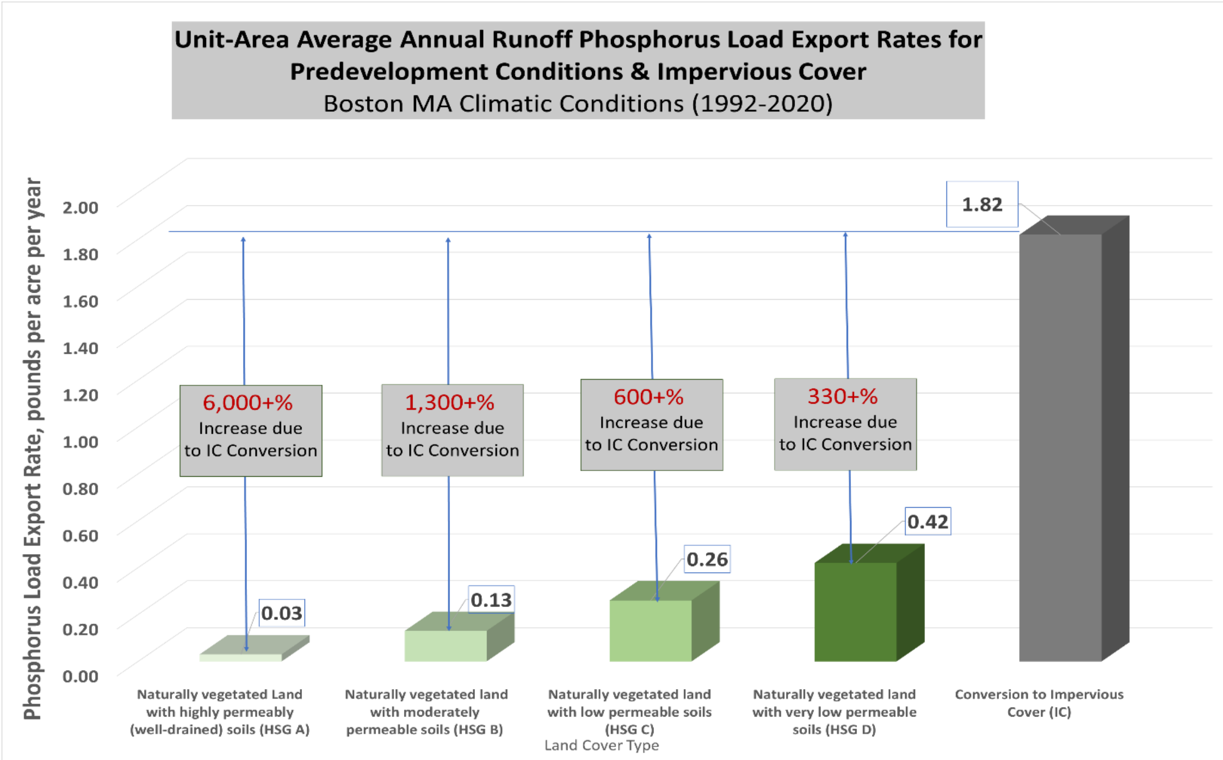
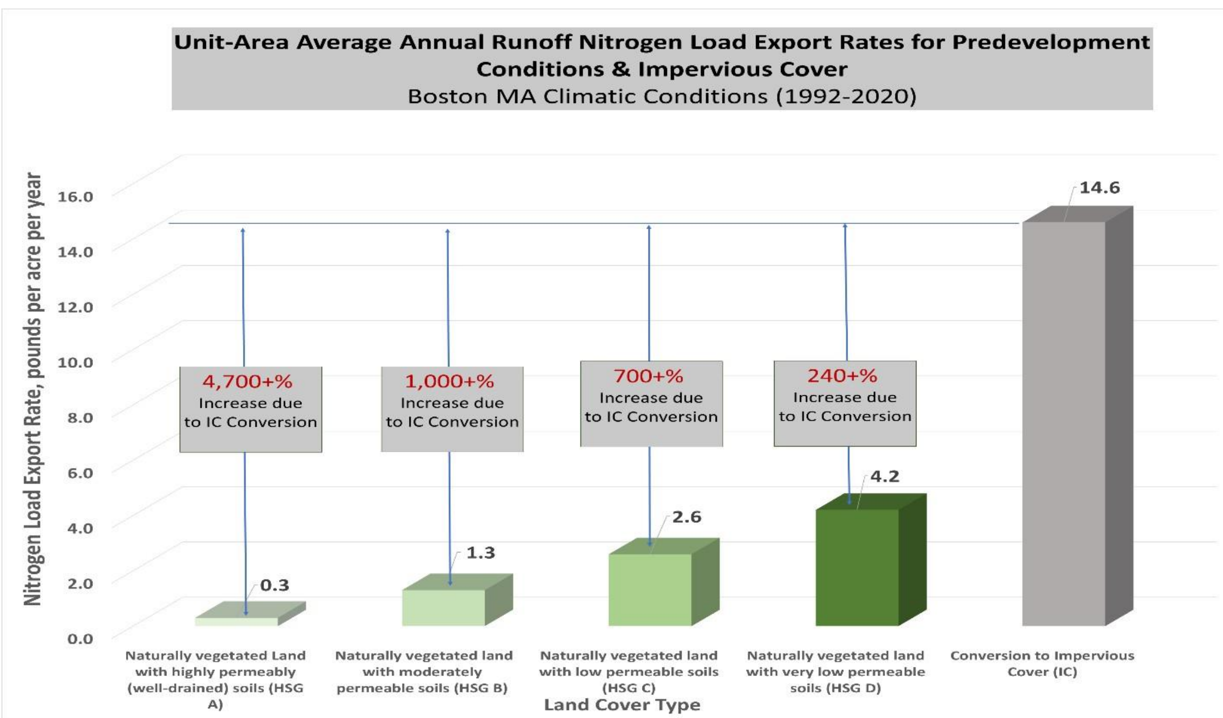

Unit-Area Average Annual Runoff Phosphorus Load Export Rates for Predevelopment Conditions & Impervious Cover
Boston MA Climatic Conditions (1992-2020)
Phosphorus Load Export Rate, pounds per acre per year
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.82
6,000+% Increase due to IC Conversion
1,300+% Increase due to IC Conversion
600+% Increase due to IC Conversion
330+% Increase due to IC Conversion
0.42
0.26
0.13
0.03
Naturally vegetated Land with highly permeably (well-drained) soils (HSG A)
Naturally vegetated land with moderately permeable soils (HSG B)
Naturally vegetated land with low permeable soils (HSG C)
Naturally vegetated land with very low permeable soils (HSG D)
Conversion to Impervious Cover (IC)
Land Cover Type

Figure 4.


Unit-Area Average Annual Runoff Nitrogen Load Export Rates for Predevelopment Conditions & Impervious Cover
Boston MA Climatic Conditions (1992-2020)
Nitrogen Load Export Rate, pounds per acre per year
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
14.6
4,700+% Increase due to IC Conversion
1,000+% Increase due to IC Conversion
700+% Increase due to IC Conversion
240+% Increase due to IC Conversion
4.2
2.6
1.3
0.3
Naturally vegetated Land with highly permeably (well-drained) soils (HSG A)
Naturally vegetated land with moderately permeable soils (HSG B)
Naturally vegetated land with low permeable soils (HSG C)
Naturally vegetated land with very low permeable soils (HSG D)
Conversion to Impervious Cover (IC)
Land Cover Type

As indicated, there are substantial unit area hydrologic and nutrient export changes resulting from the conversion of natural land to IC. On a per acre basins average annual runoff volumes are estimated to increase by 280% to 9,800% or by more than 0.8 to over 1 million gallons per IC acre per year. Since IC effectively results in zero (0) groundwater recharge, the results presented in Table 1 and illustrated in figure 1 show unit-area losses in average annual recharge volumes due to IC that range from 0.33 million-gallons/acre/year (MG/ac/yr) for very-low permeable HSG D to 0.56 MG/ac/yr for the very-high permeable HSG A. The conversion of naturual vegetated land area to IC also substantially increases runoff nutrient load export compared to predevelopment natural vegetated conditions as indicated in Figures 3 and 4. Natural vegetated land area has substantially lower runoff nutrient export rates compared to IC because of the much lower runoff yields as shown in figure 1. Additionally, vegetated permeable areas also provide filtering and recyling of accumulated nutrients whereas IC has relatively little capacity to capture and hold pollutants during the numerous runoff events that occur each year.

3. <u>Predevelopment Groundwater Recharge</u>

The conversion of natural vegetated pervious land area to IC results in lost groundwater recharge, the process in which precipitation is captured and infiltrated into the ground. Groundwater recharge is an essential source of water to subsurface groundwater reservoirs that supply baseflows and moisture to surface waters and wetlands and deeper aquifer storage commonly relied upon for potable water consumption. This section presents the magnitude of lost groundwater recharge volumes due to the creation of IC and the level of control needed in postconstruction SW management to replenish groundwater recharge to predevelopment conditions.

The water balance method was used to estimate average annual groundwater recharge volumes for four (4) predevelopment conditions based on hydrologic soil groups (HSGs) A, B, C and D as defined by the National Resource Conservation Service (NRCS). HSGs are commonly used in hydrologic modelling to estimate SW runoff potential based on soil characteristics. Table 2 Summarizes the description of HSGs which indicates that runoff potential is lowest for HSG A and highest for HSG D.

Table 2: Description of Hydrologic Soil Groups For Hydrologic Modelling

Hydrologic Soil Group	Description
A	Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil.
B	Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded.
C	Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted.
D	Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted.

Source: USDA, NRCS National Engineering Handbook Chapter 7:
https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba

The water balance method is expressed with the following equation:

P=RO+R+ET
where P = total precipitation, RO = runoff, R = recharge, and ET = evapotranspiration:

Given measurements for P and independent estimates of RO and ET, R can be calculated. In this case, estimates of average annual RO, ET and measured P are used to solve for average annual groundwater recharge (R).

R=P-RO-ET

Because site development and associated SW management activities are conducted at the relatively small site scale vs. larger watershed scale, estimates have been developed on a unit area basis of 1 acre assuming homogenous land cover and soil conditions. Following is a summary of the information used to estimate predevelopment recharge volume required for the WPS.

3.1. Precipitation

Hourly precipitation data for Boston, MA (station MA0770) for the period of 01/01/1992 to 12/31/2020 was compiled determine annual precipitation statistics for Boston, MA that are presented in Table 3.

Table 3: Annual precipitation summary, Boston MA (1992-2020)

Value	inches	MG/acre/yr
Average	42.78	1.16
Median	43.67	1.19
Minimum	28.26	0.77
Maximum	54.46	1.48

3.2. Runoff Volumes

Continuous simulation hydrologic response unit (HRU) modelling was conducted using the EPA supported Stormwater Management Model (SWMM) to estimate average annual runoff volumes for predevelopment natural vegetated land cover conditions with HSGs A, B, C and D. For this analysis, HRU models represent unique combinations of homogenous land cover and HSG (e.g., meadow – HSG A). Two continuous simulation modelling approaches available in SWMM were used to estimate annual predevelopment HRU runoff volumes for the period of interest (1992 – 2020) using Boston, MA climatic data consisting of hourly precipitation and daily temperature data :

- SWMM: Horton Infiltration model for pervious vegetated lands with HSGs A, B, C and D (see Table 4 for model parameters).

Table 4: Horton Infiltration Model Parameters used in SWMM HRU Modelling to Estimate Predevelopment Average Annual Runoff Volumes for Hydrologic Soil Groups A, B, C and D (Boston, MA Climatic Conditions- 1992-2020

Model Parameter	Hydrologic Soil Group (HSG)			
	A	**B**	**C**	**D**
MaxRate, in/hr	6	4	3	2
MinRate, in/hr	0.25	0.1	0.05	0.03
Decay, 1/hr	3.24	3.24	3.24	3.24
DryTime, days	7	7	7	7

- SWMM: NRCS Curve Number (CN) method for grass, meadow, and woods in good condition with HSGs A, B, C and D (see Table 5).

Table 5: Curve number (CN) values used in SWMM CN HRU modeling to estimate predevelopment average annual runoff volumes for hydrologic soil groups A, B, C, and D (Boston, MA Climatic Conditions, 1992-2020)

A total of 16 HRU model simulations, four for each HSG, were used in this analysis to estimate average annual runoff volumes and are summarized in Table 6. The final estimated average annual predevelopment runoff volume for each HSG used in this analysis is equal to the average of the Horton infiltration model result and the average of the CN model results. For example, the final estimate for HSG A is:

HSG A Runoff Volume = (HSG A Horton + ((CN25 + CN30 + CN39)/3))/2

0.017 million gallons (MG)/acre/year = (0.011 + ((0.014+0.020+034)/3))/2

Table 6: Stormwater management model (SWMM) continuous simulation modelling estimates of average annual runoff volumes for predevelopment land cover by hydrologic soil group (HSG) for Boston, MA Climatic Conditions (1992-2020)

3.3. Evapotranspiration

Evapotranspiration (ET) is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. Transpiration occurs when plants take up water from the soil and release water vapor into the air from their leaves. The Northeast Regional Climate Center at Cornell University reports an estimated average annual ET for Boston, MA of 22.87 inches or 52% of the average annual precipitation (43.72 inches) for the period of 1981 to 2010. The U.S. Geological Survey (USGS) reports estimates of annual ET values of similar magnitude for MA as indicated in this map available at: https://sensorsandsystems.com/new-water-evapotranspiration-maps-provide-crucial-information-on-water-availability/ .

An ET value of 50% of total annual precipitation was selected for use in the water balance equation to estimate average annual groundwater recharge for predevelopment conditions. For example, the average annual precipitation for Boston, MA (1992-2020) is 42.78 inches and the estimated ET equals:

$$ET = 42.78 \times 50\%$$
$$= 21.39 \text{ inches}$$

Calculation of Unit Area Predevelopment Annual Groundwater Recharge Volume: The following water balance equation was applied for each year of the 29 year climatic data record:

$$R_{yr} = P_{yr} - RO_{yr} - ET_{yr};$$

For which:

R = recharge volume, MG/ac/yr;

P = Annual precipitation volume, MG/ac/yr;

RO = Runoff Volume, MG/ac/yr: and

ET = Evapotranspiration Volume, MG/ac/yr (assumed 50% of P_{yr})

Tables 7 and 8 summarize the results of the estimated annual groundwater recharge estimates derived from the water balance equation. Table 7 provide summary statistics of the estimates for the 29 year period while Table 8 provides estimates for each year of the 1992-2020 analysis period. As indicated, in Table 8 there is considerable variability in annual precipitation and estimated runoff and recharge values for the period of analysis (1992 to 2020). For example, annual precipitation ranged from a minimum of 28.26 inches to a maximum of 54.46 inches and ranges of similar magnitude are shown for runoff and recharge volumes.

Table 7: Summary statistics of estimated annual runoff and groundwater recharge volumes for unit area predevelopment conditions by hydrologic soil groups (HSG) for Boston, MA climatic conditions (1990 – 2022)

Measure	Precipitation Boston		HSG A		HSG B		HSG C		HSG D	
			Runoff,	Recharge,	Runoff,	Recharge,	Runoff,	Recharge,	Runoff,	Recharge,
	Inches	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr	MG/ac/yr
Average	42.78	1.16	0.017	0.56	0.076	0.50	0.16	0.43	0.25	0.33
Median	43.67	1.19	0.005	0.59	0.061	0.50	0.14	0.42	0.25	0.33
Minimum	28.26	0.77	0.000	0.38	0.001	0.37	0.04	0.32	0.08	0.24
Maximum	54.46	1.48	0.098	0.72	0.21	0.65	0.34	0.55	0.44	0.42
90th%	51.61	1.40	0.052	0.67	0.16	0.61	0.27	0.51	0.37	0.40

Table 8: Estimated annual runoff and groundwater recharge volumes for unit area predevelopment conditions by hydrologic soil group (HSG) for Boston, MA climatic conditions (1992-2020)

year	Precipitation Boston		HSG A		HSG B		HSG C		HSG A	
	Inches	MG/ac/yr	Runoff, MG/ac/yr	Recharge, MG/ac/yr	Runoff, MG/ac/yr	Recharge, MG/ac/yr	Runoff, MG/ac/yr	Recharge, MG/ac/yr	Runoff, MG/ac/yr	Recharge, MG/ac/yr
1992	43.72	1.187	0.051	0.542	0.155	0.438	0.213	0.381	0.277	0.317
1993	43.21	1.173	0.000	0.587	0.054	0.533	0.140	0.447	0.240	0.346
1994	47.62	1.293	0.005	0.642	0.095	0.552	0.188	0.459	0.316	0.331
1995	35.10	0.953	0.027	0.450	0.076	0.401	0.122	0.355	0.188	0.289
1996	48.70	1.322	0.027	0.634	0.161	0.500	0.271	0.390	0.343	0.318
1997	28.26	0.767	0.000	0.384	0.004	0.380	0.044	0.340	0.084	0.300
1998	51.28	1.393	0.098	0.598	0.206	0.490	0.337	0.359	0.435	0.261
1999	37.77	1.026	0.086	0.426	0.141	0.372	0.186	0.327	0.248	0.265
2000	44.52	1.209	0.016	0.589	0.098	0.506	0.164	0.440	0.255	0.350
2001	29.64	0.805	0.000	0.402	0.029	0.374	0.085	0.317	0.137	0.265
2002	39.92	1.084	0.000	0.542	0.020	0.522	0.073	0.469	0.148	0.394
2003	44.37	1.205	0.000	0.602	0.037	0.565	0.135	0.468	0.261	0.342
2004	44.57	1.210	0.023	0.583	0.107	0.498	0.209	0.396	0.301	0.304
2005	43.67	1.186	0.000	0.593	0.061	0.532	0.127	0.466	0.208	0.385
2006	52.89	1.436	0.009	0.709	0.147	0.571	0.271	0.447	0.363	0.355
2007	39.47	1.072	0.024	0.512	0.079	0.457	0.169	0.367	0.248	0.288
2008	54.46	1.479	0.023	0.717	0.131	0.608	0.243	0.497	0.379	0.361
2009	43.49	1.181	0.000	0.591	0.026	0.565	0.082	0.509	0.175	0.415
2010	49.66	1.349	0.054	0.621	0.176	0.499	0.317	0.358	0.436	0.238
2011	52.39	1.423	0.000	0.711	0.059	0.652	0.157	0.554	0.308	0.404
2012	36.73	0.997	0.000	0.499	0.034	0.464	0.085	0.413	0.184	0.315
2013	40.36	1.096	0.020	0.528	0.064	0.484	0.160	0.388	0.254	0.294
2014	45.25	1.229	0.013	0.601	0.091	0.523	0.164	0.450	0.260	0.355
2015	34.69	0.942	0.000	0.471	0.021	0.450	0.063	0.408	0.143	0.328
2016	32.89	0.893	0.000	0.447	0.001	0.446	0.039	0.408	0.139	0.308
2017	41.23	1.120	0.000	0.560	0.042	0.517	0.110	0.450	0.200	0.360
2018	49.52	1.345	0.016	0.657	0.052	0.621	0.140	0.532	0.267	0.406
2019	48.41	1.315	0.000	0.657	0.031	0.626	0.131	0.527	0.259	0.398
2020	36.83	1.000	0.000	0.500	0.018	0.482	0.081	0.419	0.165	0.335

Note: Runoff (RO) estimates generated by SWMM v. 5.0 using hourly precipitation and daily temperature data for Boston, MA (1992-2020). Water Balance equation used to estimate groundwater recharge (R) and assume 50% of annual precipitation (P) is evapotranspiration (ET). Water Balance equation for groundwater recharge is R = P - RO - (0.5XP).

Selecting a protective groundwater recharge volume for SW management requires consideration of the uncertainty associated with hydrologic modelling estimates as well as changing climatic conditions. Recent hydrologic modelling of the Taunton watershed conducted for various future climatic conditions indicates recharge will be diminished due to increasing ambient air temperatures and greater ET rates (reference). For these reasons and because the creation of IC will continue to exist long-term into the future and under changing climatic conditions, a margin of safety is warranted in the derivation of predevelopment groundwater recharge volume targets. Therefore, the 90th percentile groundwater recharge volume for each HSG identified in Table 7 and summarized in Table 9 are selected as the target level of control for groundwater recharge in SW management to address IC. Translation of how these target recharge volumes can be implemented through appropriate sizing of SW control measures (SCMs) throughout the New England region are described in the next section.

Table 9: Annual Predevelopment Groundwater Recharge Targets for Stormwater Management

Hydrologic Soil Group	Target Groundwater Recharge Volume (depth)
A	0.67 MG/ac/yr (24.67 inches)
B	0.61 MG/ac/yr (22.46 inches)
C	0.51 MG/ac/yr (17.92 inches)
D	0.40 MG/ac/yr (14.05 inches)

3.4. Infiltration SCMs for Achieving Predevelopment Annual Groundwater Recharge

The goal of the SW management recharge target is to redirect an adequate volume of surface runoff from IC into the ground by means of infiltration SCMs. First, it is necessary to determine what percentage of annual IC runoff volume needs to be captured and treated by infiltration SCMs to achieve the specified groundwater recharge volume for each HSG type. Two factors determine the necessary capture volume by infiltration SCMs to achieve the recharge goal: 1) groundwater recharge volume as determined above; and 2) an additional volume that would be lost within the SCM due to ET. Research of infiltration SCM has indicated ET losses in the northeast region of the U.S. are around 10% (reference). Therefore, a 10% ET loss is assumed for infiltration SCMs in this analysis.

Table 10 presents the estimated percent reductions in annual IC runoff volumes (column 5) necessary to achieve the predevelopment recharge targets by infiltration SCMs. Also shown are the Design Storage Volumes (DSV) of surface and subsurface infiltration SCMs for eight infiltration rates (columns 9 and 10) that will achieve the recharge targets for creating IC in HSGs A, B, C and D. The DSV is the physical storage capacity of the SCM equal to the volume of water that can be statically held within the SCM before overflow or bypass. Based on the cumulative distribution of cumatlive IC runoff volume by depth shown in Figure 2, the average annual percent reduction in IC runoff volume was translated into cumulative IC runoff depth (column 6) to provide another expression of the level of control being provided. For example, predevelopment HSG A recharge of 68% IC runoff volume reduction (column 5) is approximately equal to capturing the cumulative IC runoff depth 0.69 inches, which includes all runoff events with depths equal to or less than 0.69 inches and the 0.69 inches of all runoff events greater than 0.69 inches depth.

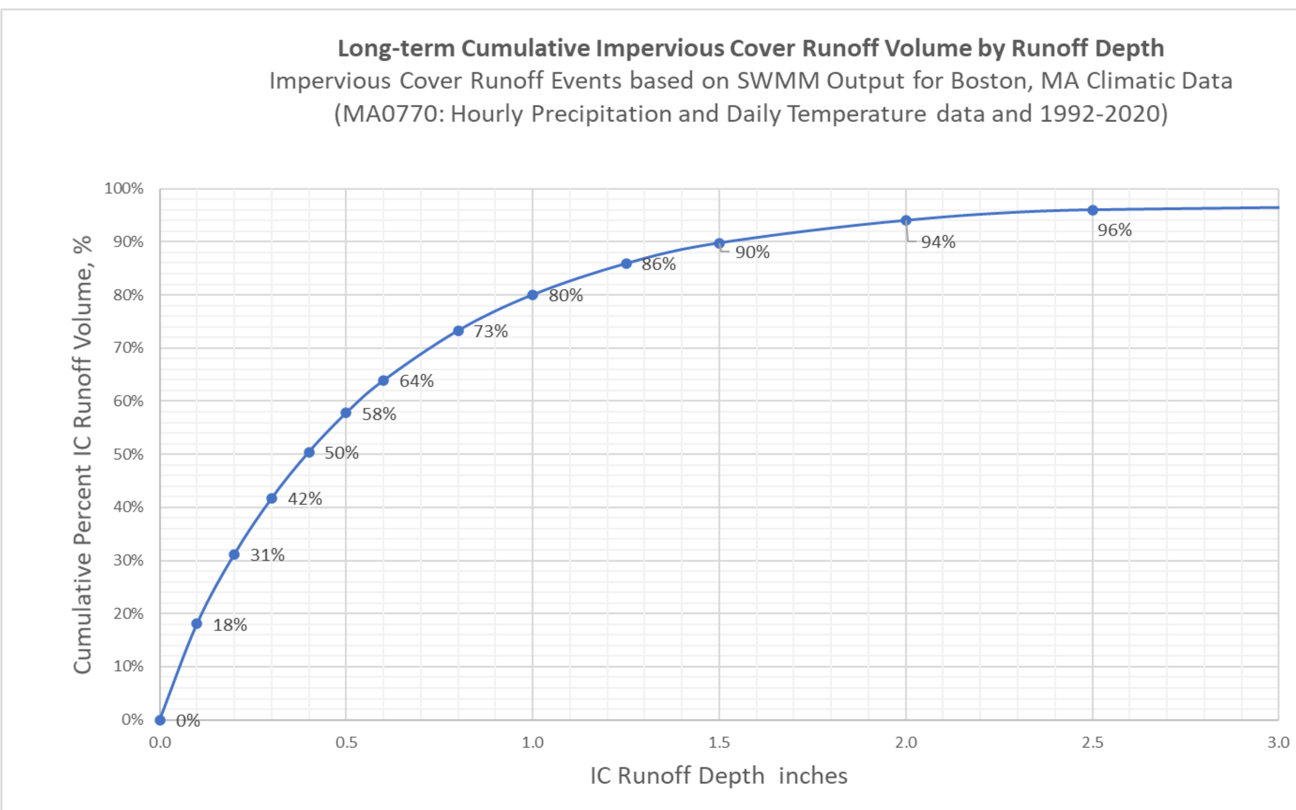
Infiltration SCM DSVs shown in Table 10 (columns 9 and 10) were determined using EPA Region 1 cumulative performance information developed for a variety of SCMs that allow users to estimate long-term cumulative performance of SCMs for reducing average annual runoff volume and pollutant loads (total phosphorus (TP), total nitrogen (TN), total suspended solids, zinc, and indicator bacteria). The curves allow users to estimate cumulative reductions based on SCM DSV relative to runoff depth (inches) from contributing IC area for relatively small (e.g., 0.1 inch) to large (e.g., 2.0 inches) SCM design capacities. A description of using the performance curves can be found in the recently (2022) published New England SW Retrofit Manual prepared by the Southern New England Program (SNEP).

Table 10: Sizing of Infiltration Practices for IC Runoff Reduction to Achieve Annual Groundwater Recharge Targets

Predevelopment Land Cover being Converted to Impervious Cover	Annual Impervious Cover Runoff yield*, MG/ac/yr	Target Annual Recharge Volume, MG/ac/yr	% IC Runoff Reduction & Level of Control By Infiltration SCMs			Subsoil Type		Surface Infiltration	Subsurface Infiltration
			Required Recharge w/ 10% for ET loss at SCM, MG/ac/yr	% Reduction in Average Annual IC Runoff Volume	IC Runoff Control Depth, inches***	HSG	Infiltration rate of Infiltration SCM, inches/hr	Design Storage Volume**, inches	Design Storage Volume**, inches
Meadow/Forest HSG A	1.091	0.67	**0.74**	**68%**	0.69	**A**	**8.27**	**0.16**	**0.23**
						A	**2.41**	**0.32**	**0.46**
Meadow/Forest HSG B	1.091	0.61	**0.67**	**62%**	0.56	**B**	**1.02**	**0.37**	**0.49**
						B	**0.52**	**0.45**	**0.60**
Meadow/Forest HSG C	1.091	0.51	**0.56**	**51%**	0.41	**C**	**0.27**	**0.40**	**0.55**
						C	**0.17**	**0.49**	**0.68**
Meadow/Forest HSG D	1.091	0.40	**0.44**	**40%**	0.28	**D**	**0.1**	**0.50**	**0.72**
						D	**0.05**	**0.86**	**1.25**

Notes: *Runoff Yields estimated using the StormWater Management Model (SWMM) v5.0 with climatic data (hourly precipitation and daily temperature) for Boston, MA (1992-2020). ** **Design Storage Volume** is the physical storage capacity of the SCM that is equal to the volume of water that can be statically held before overflow or bypass.

Figure 2.



Updated SCM performance information for surface and subsurface infiltration SCM based on the same Boston, MA climatic data (1992-2020) used in estimating the recharge targets was used to determine the surface and subsurface infiltration SCM DSVs for achieving recharge targets. The updated performance information was developed using the calibrated HRU SWMM models for runoff quantity and quality that are included in the EPA Region 1 Opti-Tool package and the calibrated SUSTAINS SCM models in Opti-Tool (v2). Tables 11 and 12 provide tabulated results of cumulative IC runoff volume and pollutant load reductions for surface (basin) and subsurface (e.g., trench) SCMs, respectively.

Table 11: Cumulative performance estimates of surface infiltration stormwater control measures (SCMs)

HSG A High - Infiltration Basin (8.27 in/hr) BMP Performance Table Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	55.1%	78.3%	94.4%	98.3%	99.4%	99.8%	100.00%	100.0%
Cumulative TP Load Reduction	71.0%	90.3%	98.5%	99.7%	99.9%	100.0%	100.0%	100.0%
Cumulative TN Load Reduction	75.6%	91.7%	98.6%	99.7%	99.9%	100.0%	100.0%	100.0%
Cumulative TSS Load Reduction	60.5%	81.6%	95.4%	98.8%	99.6%	99.9%	100.0%	100.0%
Cumulative ZN Load Reduction	59.8%	81.1%	95.3%	98.8%	99.6%	99.9%	100.0%	100.0%
Cumulative Ecoli Load Reduction	59.4%	88.2%	99.4%	100.0%	100.0%	100.0%	100.0%	100.0%
HSG A Low - Infiltration Basin (2.41 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	33.2%	54.4%	78.8%	89.7%	94.9%	97.3%	99.5%	99.9%
Cumulative TP Load Reduction	51.0%	73.2%	92.1%	97.5%	99.1%	99.6%	100.0%	100.0%
Cumulative TN Load Reduction	64.1%	82.3%	94.9%	98.3%	99.4%	99.7%	100.0%	100.0%
Cumulative TSS Load Reduction	58.9%	79.0%	93.1%	97.6%	99.0%	99.6%	100.0%	100.0%
Cumulative ZN Load Reduction	57.7%	78.0%	92.6%	97.4%	98.9%	99.6%	100.0%	100.0%
Cumulative Ecoli Load Reduction	40.0%	65.1%	90.5%	97.7%	99.5%	99.9%	100.0%	100.0%
HSG B High- Infiltration Basin (1.02 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	24.6%	42.4%	66.4%	80.5%	88.3%	93.0%	97.5%	99.1%
Cumulative TP Load Reduction	42.2%	62.5%	84.7%	93.5%	97.1%	98.7%	99.7%	99.9%
Cumulative TN Load Reduction	59.7%	77.4%	91.9%	96.7%	98.5%	99.3%	99.9%	100.0%
Cumulative TSS Load Reduction	59.3%	78.3%	92.3%	96.8%	98.6%	99.4%	99.9%	100.0%
Cumulative ZN Load Reduction	58.0%	77.1%	91.5%	96.3%	98.4%	99.3%	99.9%	100.0%
Cumulative Ecoli Load Reduction	33.0%	54.1%	81.1%	92.5%	97.0%	98.9%	99.9%	100.0%
HSG B Low -Infiltration Basin (0.52 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	20.1%	35.6%	58.4%	73.3%	82.8%	88.6%	95.6%	97.8%
Cumulative TP Load Reduction	37.5%	56.4%	79.0%	89.8%	94.9%	97.3%	99.4%	99.8%
Cumulative TN Load Reduction	57.3%	74.7%	89.8%	95.5%	97.8%	98.9%	99.7%	99.9%
Cumulative TSS Load Reduction	60.2%	78.3%	91.9%	96.5%	98.3%	99.1%	99.8%	100.0%
Cumulative ZN Load Reduction	58.8%	76.8%	90.9%	95.9%	98.0%	98.9%	99.8%	99.9%
Cumulative Ecoli Load Reduction	29.1%	48.3%	74.7%	88.0%	94.3%	97.3%	99.6%	99.9%
HSG C High - Infiltration Basin (0.27 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	16.0%	29.4%	50.7%	66.0%	76.7%	83.8%	93.1%	96.4%
Cumulative TP Load Reduction	33.4%	51.4%	74.1%	86.1%	92.4%	95.7%	98.9%	99.6%
Cumulative TN Load Reduction	55.2%	72.4%	87.9%	94.2%	97.0%	98.4%	99.6%	99.8%
Cumulative TSS Load Reduction	61.1%	79.0%	91.6%	95.9%	97.9%	98.9%	99.7%	99.9%
Cumulative ZN Load Reduction	59.6%	77.4%	90.5%	95.2%	97.5%	98.7%	99.7%	99.9%
Cumulative Ecoli Load Reduction	26.1%	43.6%	69.2%	83.5%	91.2%	95.3%	99.0%	99.7%
HSG C Low - Infiltration Basin (0.17 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	12.7%	24.0%	43.5%	59.0%	70.7%	79.1%	90.6%	95.2%
Cumulative TP Load Reduction	30.7%	47.7%	70.0%	82.7%	90.1%	94.2%	98.4%	99.4%
Cumulative TN Load Reduction	53.7%	70.4%	86.0%	92.9%	96.2%	97.9%	99.4%	99.8%
Cumulative TSS Load Reduction	62.2%	79.6%	91.6%	95.6%	97.6%	98.7%	99.7%	99.9%
Cumulative ZN Load Reduction	60.6%	78.0%	90.4%	94.8%	97.1%	98.4%	99.6%	99.8%
Cumulative Ecoli Load Reduction	24.1%	40.1%	64.5%	79.4%	88.2%	93.2%	98.3%	99.5%
HSG D High - Infiltration Basin (0.10 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	8.8%	17.2%	32.9%	46.7%	58.8%	68.9%	85.1%	92.5%
Cumulative TP Load Reduction	27.9%	43.1%	64.2%	77.3%	85.6%	90.9%	97.2%	99.0%
Cumulative TN Load Reduction	51.8%	67.4%	82.9%	90.4%	94.4%	96.7%	99.1%	99.7%
Cumulative TSS Load Reduction	63.1%	80.0%	91.8%	95.4%	97.1%	98.2%	99.5%	99.8%
Cumulative ZN Load Reduction	61.3%	78.2%	90.4%	94.4%	96.5%	97.8%	99.3%	99.8%
Cumulative Ecoli Load Reduction	22.1%	36.0%	58.4%	73.2%	82.7%	89.0%	96.6%	98.9%
HSG D Low - Infiltration Basin (0.05 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	4.9%	9.7%	19.3%	28.6%	37.6%	46.2%	65.5%	79.7%
Cumulative TP Load Reduction	25.1%	38.2%	56.5%	68.8%	77.3%	83.4%	92.4%	96.6%
Cumulative TN Load Reduction	49.7%	63.9%	78.2%	85.9%	90.5%	93.4%	97.3%	98.9%
Cumulative TSS Load Reduction	63.0%	79.6%	90.7%	94.3%	96.1%	97.3%	98.8%	99.5%
Cumulative ZN Load Reduction	61.2%	77.6%	89.1%	93.1%	95.2%	96.6%	98.5%	99.4%
Cumulative Ecoli Load Reduction	20.1%	31.7%	50.8%	64.7%	74.2%	80.7%	90.8%	95.9%
Notes: Performance Estimates generated by EPA Region 1 calibrated SWMM HRU and Opti-Tool SUSTAINS models for Boston, MA climatic conditions (1992-2020). Surface infiltration SCMs include basins, swales, rain gardens/bioretention and permeable pavements.								

Table 12: Cumulative performance estimates of subsurface infiltration stormwater control measures (SCMs)

HSG A High - Infiltration Trench (8.27 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	42.2%	64.6%	85.6%	93.7%	97.1%	98.6%	99.6%	100.0%
Cumulative TP Load Reduction	57.9%	79.4%	94.3%	98.1%	99.3%	99.7%	100.0%	100.0%
Cumulative TN Load Reduction	68.3%	85.6%	96.0%	98.6%	99.5%	99.8%	100.0%	100.0%
Cumulative TSS Load Reduction	50.4%	72.1%	89.1%	95.2%	97.9%	99.1%	99.8%	100.0%
Cumulative ZN Load Reduction	45.5%	67.8%	86.9%	94.3%	97.5%	98.9%	99.8%	100.0%
Cumulative Ecoli Load Reduction	49.0%	74.1%	94.2%	98.7%	99.6%	99.9%	100.0%	100.0%
HSG A Low - Infiltration Trench (2.41 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	25.3%	43.0%	66.4%	80.0%	87.7%	92.4%	97.5%	99.2%
Cumulative TP Load Reduction	40.3%	60.2%	82.1%	91.7%	95.9%	98.0%	99.6%	99.9%
Cumulative TN Load Reduction	58.6%	76.4%	90.8%	95.9%	98.1%	99.0%	99.8%	99.9%
Cumulative TSS Load Reduction	44.5%	63.9%	81.8%	89.7%	94.2%	96.8%	99.2%	99.8%
Cumulative ZN Load Reduction	37.9%	57.0%	77.0%	86.7%	92.4%	95.8%	99.0%	99.7%
Cumulative Ecoli Load Reduction	34.1%	54.8%	80.5%	92.0%	96.7%	98.6%	99.8%	100.0%
HSG B High - Infiltration Trench (1.02 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	19.1%	33.8%	55.5%	70.0%	79.7%	86.1%	94.3%	97.2%
Cumulative TP Load Reduction	33.7%	51.5%	73.7%	85.9%	92.1%	95.5%	98.7%	99.5%
Cumulative TN Load Reduction	55.7%	72.9%	88.0%	94.2%	97.0%	98.4%	99.6%	99.8%
Cumulative TSS Load Reduction	43.9%	62.0%	79.0%	87.4%	92.2%	95.2%	98.6%	99.5%
Cumulative ZN Load Reduction	36.4%	54.0%	72.8%	83.2%	89.4%	93.4%	97.9%	99.3%
Cumulative Ecoli Load Reduction	29.7%	47.5%	72.5%	86.5%	93.1%	96.4%	99.2%	99.8%
HSG B Low - Infiltration Trench (0.52 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	15.6%	28.4%	48.5%	63.1%	73.6%	81.0%	91.4%	95.6%
Cumulative TP Load Reduction	30.3%	46.7%	68.6%	81.8%	89.1%	93.3%	97.9%	99.1%
Cumulative TN Load Reduction	54.4%	71.2%	86.4%	93.1%	96.2%	97.9%	99.4%	99.8%
Cumulative TSS Load Reduction	44.3%	61.6%	77.8%	86.2%	91.1%	94.3%	98.1%	99.3%
Cumulative ZN Load Reduction	36.4%	52.8%	70.8%	81.3%	87.6%	91.9%	97.2%	98.9%
Cumulative Ecoli Load Reduction	27.5%	43.8%	67.9%	82.6%	90.3%	94.5%	98.6%	99.6%
HSG C High - Infiltration Trench (0.27 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	11.9%	22.5%	40.5%	55.0%	66.3%	74.9%	87.5%	93.5%
Cumulative TP Load Reduction	27.6%	42.9%	63.9%	77.3%	85.8%	90.9%	96.8%	98.7%
Cumulative TN Load Reduction	53.8%	69.8%	84.8%	91.8%	95.4%	97.3%	99.2%	99.7%
Cumulative TSS Load Reduction	45.8%	62.3%	77.4%	85.3%	90.3%	93.3%	97.6%	99.1%
Cumulative ZN Load Reduction	37.2%	52.8%	69.7%	79.5%	86.2%	90.4%	96.4%	98.5%
Cumulative Ecoli Load Reduction	26.0%	41.0%	63.6%	78.3%	87.0%	92.1%	97.6%	99.2%
HSG C Low - Infiltration Trench (0.17 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	9.1%	17.5%	33.0%	46.3%	57.7%	67.2%	83.1%	90.9%
Cumulative TP Load Reduction	25.9%	40.2%	60.0%	73.3%	82.1%	88.1%	95.6%	98.1%
Cumulative TN Load Reduction	53.6%	68.9%	83.4%	90.4%	94.2%	96.5%	98.9%	99.6%
Cumulative TSS Load Reduction	47.0%	63.0%	77.4%	84.7%	89.3%	92.6%	97.1%	98.8%
Cumulative ZN Load Reduction	37.8%	52.9%	68.9%	78.3%	84.5%	89.2%	95.6%	98.1%
Cumulative Ecoli Load Reduction	25.3%	39.3%	60.2%	74.4%	83.3%	89.1%	96.4%	98.7%
HSG D High - Infiltration Trench (0.10 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	6.1%	12.0%	23.4%	34.0%	43.9%	53.0%	71.5%	84.0%
Cumulative TP Load Reduction	24.4%	37.9%	56.8%	69.2%	77.8%	83.9%	92.8%	96.8%
Cumulative TN Load Reduction	54.1%	68.4%	82.1%	88.8%	92.7%	95.1%	98.1%	99.3%
Cumulative TSS Load Reduction	48.5%	63.9%	77.4%	84.2%	88.6%	91.7%	96.1%	98.3%
Cumulative ZN Load Reduction	38.6%	53.2%	68.5%	77.3%	83.3%	87.7%	94.1%	97.3%
Cumulative Ecoli Load Reduction	24.5%	38.0%	58.0%	71.1%	79.6%	85.3%	93.6%	97.4%
HSG D Low - Infiltration Trench (0.05 in/hr) BMP Performance Table: Long-Term Load Reduction								
SCM Capacity: Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Runoff Volume Reduction	3.3%	6.6%	13.2%	19.7%	26.1%	32.4%	47.3%	60.7%
Cumulative TP Load Reduction	21.2%	33.3%	51.1%	62.6%	70.8%	77.0%	86.5%	92.0%
Cumulative TN Load Reduction	52.4%	66.0%	79.2%	85.8%	89.8%	92.5%	96.1%	97.9%
Cumulative TSS Load Reduction	47.7%	62.5%	75.5%	81.9%	86.3%	89.4%	93.9%	96.4%
Cumulative ZN Load Reduction	37.4%	51.1%	65.7%	74.0%	79.9%	84.3%	90.8%	94.5%
Cumulative Ecoli Load Reduction	22.2%	34.3%	53.3%	65.7%	73.8%	79.5%	88.1%	93.0%

Notes: Performance Estimates generated by EPA Region 1 calibrated SWMM HRU and Opti-Tool SUSTAINS models for Boston, MA climatic conditions (1992-2020). Subsurface infiltration practices include infiltration trenches, chambers, galleys, etc.

4. Predevelopment Runoff Nutrient Load Export and Stormwater Managment

The other primary goal for developing the WPS is to specify SW management performance standards designed to minimize impacts of IC runoff nutrient loads associated with future development activities and the creation of IC. To this end, the level of postconstruction SW management control for IC was determined for surface and subsurface infiltration SCMs to achieve estimated predevelopment SW nutrient load export. This section describes the basis of the estimates. If infiltration is determined to be infeasible there are other SCMs that will reduce SW nutrient loads although in the cases where predevelopment conditions have well-drained soils, most non-infiltration SCMs (e.g., biofiltration, gravel wetlands) will not likely achieve predevelopment SW nutrient loading rates. This will be addressed and recommendations on sizing of such controls is presented.

4.1. SW Nutrient Load Export for Predevelopment and Post-Development Conditions

SW nutrient export loads were determined for natural predevelopment conditions for HSGs A, B, C and D and postconstruction IC using the hydrologic estimates presented in sections II and III. The estimates of nutrient quality in SW runoff from IC and natural lands (i.e., predevelopment) is largely based on previous analyses conducted for determining SW nutrient load export rates included in the MA and NH MS4 general permits (Attachment 3 to Appendix F). This information was further evaluated and adjusted to represent more recent hydrologic conditions for the climatic period of 1992 to 1992 compared to the climate periods used in developing the export rates in the MS4 permits (1998-2002 for TP and 1985-2005 for TN). Table 13 summarize the average annual flow-weighted SW TP and TN concentrations and the resulting TP and TN SW export load rates for natural land cover and IC.

Table 13: Representative stormwater nutrient concentrations and annual load export rates by landcover for Boston, MA, Cliatic Conditions (1992-2020)

Land CoverType	Hydrologic Soil Group	Average Annual Runoff Yield, MG/acre/year	Annual Flow-weighted Mean TP concentration, mg/L	Average Annual SW TP Load Export Rate lbs/acre/year	Annual Flow-weighted Mean TN concentration, mg/L	Average Annual SW TN Load Export Rate lbs/acre/year
Grass-Meadow/Forested with well-drained soils	A	0.017	0.20	0.03	2.0	0.3
Grass-Meadow/Forested with moderately well-drained soils	B	0.076	0.20	0.13	2.0	1.3
Grass-Meadow/Forested with less well drained soils	C	0.16	0.20	0.26	2.0	2.6
Grass-Meadow/Forested with poorly drained soils	D	0.25	0.20	0.42	2.0	4.2
Impervious cover	Not Applicable	1.09	0.20	1.82	1.6	14.6
Notes: * MG/acre/yr - Million Gallons/acre/year. Runoff Yields estimated using the StormWater Management Model (SWMM) v5.0 with climatic data (hourly precipitation and daily temperature) for Boston, MA (1992-2020). Nutrient export rates are based on the rates derived for that MA and NH MS4 permits (appendix F attachment 3) and adjusted proportionally according to runoff yields.						

These rates are consistent with the basis of the MS4 SW nutrient load export rates except that only one IC export rate each for TP and TN is used to develop the WPS level of control for nutrients. The selected IC rates in Table 13 are intended to represent the typical average SW quality associated with IC and are approximately equal to the 25 percentile of the simulated nutrient event mean concentrations (EMCs) for all IC runoff events for the 29 year period (1992-2020). SWMM IC HRU models include modelling of the build-up of pollutants on IC and the wash-off of pollutants associated with each precipitation event. The IC HRU build-up and wash-off models were calibrated during the development of Opti-Tool and documentation of the model calibration process can be found in Technical Memorandums that are included in the Opti-Tool package. Only one IC export rate was chosen for each nutrient as a practical matter for streamlining and reducing complexity for implementation process for the WPS.

4.2. Level of SCM Control for Achieving Predevelopment SW Nutrient load Export

Percent SW nutrient load reductions for postconstruction IC were estimated for the four predevelopment conditions such that the resulting SW nutrient load export form IC would equal predevelopment SW nutrient export. Table 14 provides the necessary SW TP and TN load reductions which range from 77% to 98% for TP and 71% to 98% for TN for the four predevelopment conditions HSGs. Design Storage Volumes of surface and subsurface infiltration SCM to achieve these reductions were determined using the cumulative performance estimates provided in Tables 11 and 12 and provided in Table 14. In all cases, DSVs needed to achieve TP control exceeds the DSVs needed for TN.

Table 14: Sizing of infiltration practices for impervious cover SW control to achieve predevelopment annual SW nutrient export rates

Land Cover Type	SW Nutrient Control for Impervious Cover				Design Storage Volumes of Infiltration SCMs			
					Subsoil Type		Surface Infiltration	Subsurface Infiltration
	Annual SW TP Load Export, lbs/ac/yr	% Reduction In SW TP Load, %	Annual SW TN Load Export, lbs/ac/yr	% Reduction In SW TN Load, %	HSG	Infiltration Rate for SCM, inches/hr	Design Storage Volume** , inches	Design Storage Volume** , inches
Meadow/Forest HSG A	0.03	98%	0.3	98%	A	8.27	0.39	0.60
					A	2.41	0.67	1.00
Meadow/Forest HSG B	0.13	93%	1.3	91%	B	1.02	0.59	0.86
					B	0.52	0.73	0.99
Meadow/Forest HSG C	0.26	86%	2.6	82%	C	0.27	0.60	0.81
					C	0.17	0.69	0.93
Meadow/Forest HSG D	0.42	77%	4.2	71%	D	0.1	0.60	0.79
					D	0.05	0.80	1.00
Impervious Cover	1.82	N/A	14.6	N/A				

Notes: ** **Design Storage Volume** is the physical storage capacity of the SCM that is equal to the volume of water that can be statically held before overflow or bypass.

4.3. Infiltration in Low Permeable Soils (HSG)

The WPS recommends the use of infiltration practices to the maximum extent feasible in all site development project including in lower permeable HSG D. Research indicates that infiltration SCMs are effective at achieving cumulative reductions of runoff volume and associated pollutants providing that SCMs are designed and constructed appropriately and have long-term inspections and maintenance to keep the SCM functioning as designed. (refereces). See Tables 11 and 12 for model estimated cumulative performance reductions for infiltration SCMs in HSG D (infiltration rates 0.1 and 0.05 inches/hr)

The predominant reason that infiltration SCMs in low permeable soils are still effective is due to the precipitation patterns that exist throughout the New England region in which the majority of precipitation depths are relatively low. Figure 5 displays the distribution of precipitation events by depth for Boston, MA (1992-2020) showing that 74% of events have depths less than 0.5 inches. Similar patterns were observed in an analysis of precipitation data from stations across the New England region (see chapter 2 of the BMP Performance Report prepared by Tetra Tech, Inc. for EPA Region 1in 2010). Research and evaluation of the HRU models of natural vegetated land with varying soil conditions and permeability indicate that precipitation is substantially attenuated even when soil permeability is low (i.e., HSG D).

Figure 5.

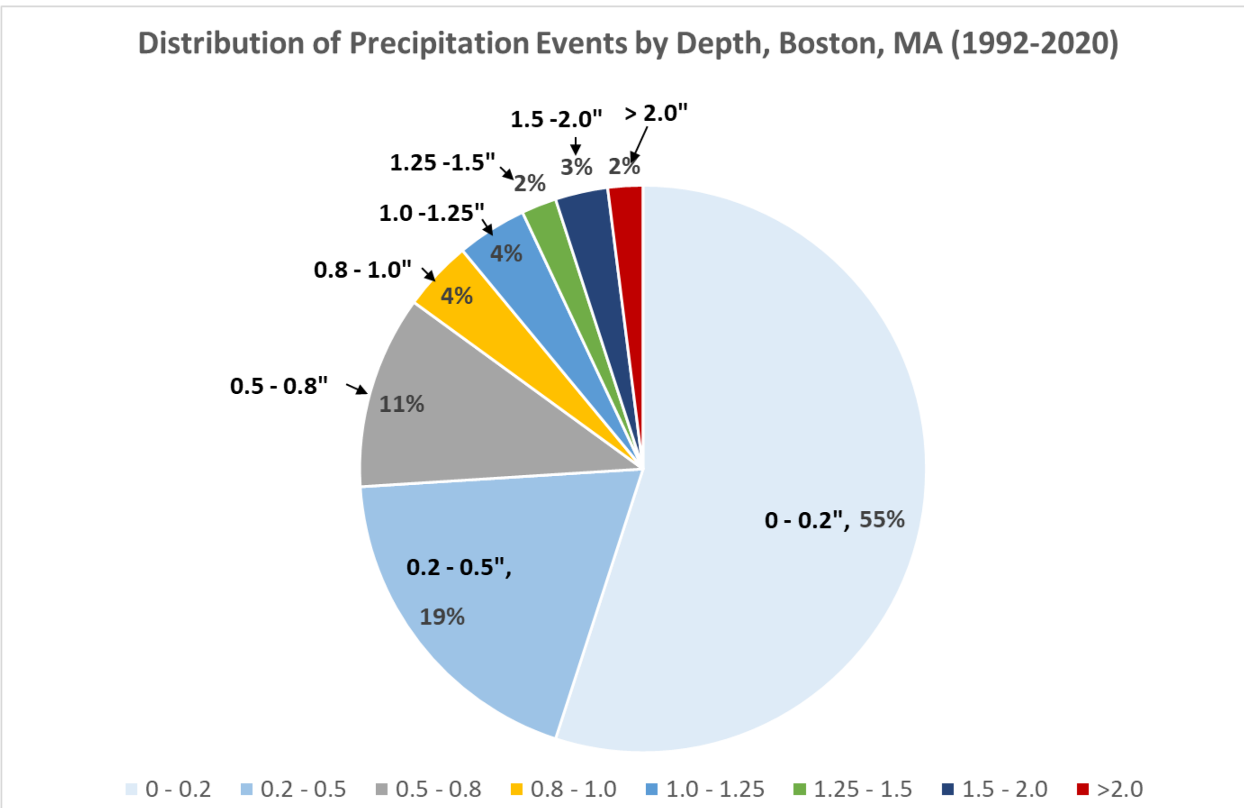


Table 16 summarizes continuous simulation SWMM HRU model predictions of the average number of annual runoff events for IC and the natural land predevelopment conditions for Boston, MA climatic conditions. While on average there 78 precipitation events, the model results indicates that natural land conditions provide substantial attenuation of precipitation events that results in substantially fewer runoff events even for HSG D at 19. Also, the lowest precipitation depths that triggered runoff events ranged from 0.56 inches for HSG D to 1.72

inches for HSG A. When infiltration SCMs are evaluated on a long-term cumulative basis using actual precipitation data, as is done in the development of the cumulative performance information (Tables 11 and 12) and typically in SCM performance research, it become clear that infiltration SCMs in low permeability soils are effective at capturing IC runoff and associated pollutant loads for most of the actual precipitation events that regularly occur in New England.

Table 15: Summary of precipitation and simulated 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 impervious cover and predevelopment pervious conditions for Boston, MA climatic conditions, 1992 - 2022., NA= not applicable						

4.4. Non-Infiltration SCMs for Nutrient Control

In cases where infiltration is not feasible (e.g., prohibited land use activity for recharge), or where opportunities for infiltration are limited on-site such that the WPS cannot be entirely met through infiltration SCMs then non-infiltration SCMs are necessary. The WPS recommends use of either an Enhanced Biofilter with Internal Storage Reservoir (ISR) or a gravel wetland system. Both SCMs have demonstrated moderate performance in achieving SW nutrient load reductions. Cumulative performance estimates presented in Tables 16 and 17 indicate that these SCMs will not achieve the WPS predevelopment nutrient and recharge standards without use of infiltration on site as well.

The enhanced biofilter with ISR is an innovative SCM that provides temporary storage of runoff for filtering through an engineered soil media, augmented for enhanced phosphorus removal, followed by detention and denitrification in a subsurface internal storage reservoir (ISR) comprised of gravel. The University of New Hampshire Stormwater Center (UNHSC) developed the design of this control practice through a grant with EPA R1[1] and a design template can be found at UNHSC's website.[2]

[1] Roseen, R., R. Stone, et al. (2011-2013). Evaluation and Optimization of the Effectiveness of Stormwater Control Measures for Nitrogen Removal. Funded by USEPA Region 1, Duration: 2 Years, 2011-2013, EPA-R1, UNHSC. DOI# 10.13140/RG.2.2.19211.36643 https://www3.epa.gov/region1/npdes/stormwater/research/epa-final-report-filter-study.pdf.

[2] https://www.unh.edu/unhsc/sites/default/files/media/bioretention_isr_detail_v4_2020-unh.pdf

Table 16: Enhanced biofiltration with internal storage reservoir SCM performance table: long term load reduction

SCM Design Storage Volume (Capacity): Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.25	1.5	2.0
Cumulative TP Load Reduction	24.9%	37.4%	51.9%	60.2%	65.6%	69.5%	**72.7%**	75.9%	80.1%
Cumulative TN Load Reduction	27.2%	40.3%	54.8%	62.9%	68.2%	71.9%	**75.0%**	78.1%	82.0%
Cumulative TSS Load Reduction	41.4%	61.5%	79.3%	87.0%	91.3%	93.8%	**95.2%**	96.7%	97.8%
Cumulative ZN Load Reduction	35.6%	54.8%	73.6%	82.6%	87.7%	90.8%	**92.7%**	94.6%	96.2%
Cumulative Ecoli Load Reduction	31.1%	49.6%	69.9%	80.1%	85.2%	87.9%	**89.4%**	90.9%	92.5%
Notes: Performance Estimates generated by EPA Region 1 calibrated SWMM HRU and Opti-Tool SUSTAINS models for Boston, MA climatic conditions (1992-2020).									

Table 17: Gravel wetland SCM performance table: long term load reduction

SCM Design Storage Volume (Capacity): Depth of Runoff Treated from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.25	1.5	2.0
Cumulative TP Load Reduction	27.1%	39.2%	51.6%	57.3%	60.9%	63.6%	**66.5%**	69.3%	73.5%
Cumulative TN Load Reduction	30.9%	43.9%	56.7%	62.3%	65.7%	68.1%	**70.6%**	73.0%	76.7%
Cumulative TSS Load Reduction	38.1%	57.2%	77.1%	86.6%	91.4%	93.7%	**94.7%**	95.7%	96.2%
Cumulative ZN Load Reduction	29.7%	47.1%	67.4%	78.0%	83.7%	86.5%	**88.0%**	89.4%	90.5%
Cumulative Ecoli Load Reduction	30.3%	48.2%	68.6%	75.8%	78.5%	80.0%	**81.3%**	82.6%	84.8%
Notes: Performance Estimates generated by EPA Region 1 calibrated SWMM HRU and Opti-Tool SUSTAINS models for Boston, MA climatic conditions (1992-2020).									

Table 18 identifies the recommended DSVs and the associated cumulative SW nutrient load reduction performances for the enhanced biofiltration with ISR and gravel wetlands for sites where infiltration is entirely infeasible. As indicated, the performance of these SCMs fall short of the achieving the predevelopment targets because they are lined so they provide no groundwater recharge.

Table 18: Non-infiltration SCMs and design storage volumes for the Watershed Protection Standard

Non-Infiltration SCM	Recommended Design Storage Volume, Inches	Percent Annual SW TP Load Reduction	Percent Annual SW TN Load Reduction
Enhanced Biofiltration w/ ISR	1.25	73%	75%
Gravel Wetland System	1.25	67%	71%
Design Storage Volume is the physical storage capacity of the SCM that is equal to the volume of water that can be statically held before overflow or bypass.			

5. Recommended SW Management Performance Standards for Watershed Protection Standard

Table 19: Watershed protection standard for impervious cover stormwater management: Infiltration SCM design storage volumes (DSVs) to achieve predevelopment groundwater recharge and SW nutrient load export

SCM Category	SCM Types	HSG	Infiltration Rate, in/hr	Controlling DSV, in.	PreDevel. Recharge* DSV*, in.	Pre Development TP Export**, DSV, in.	Pre Development TN Export,** DSV, in.	WPS Recommended DSV,in
Surface Infiltration	Basin, swale, raingarden (i.e., bioretention), permeable pavement	A	8.27	**0.39**	0.16	0.39	0.39	**0.4**
		A	2.41	**0.67**	0.32	0.67	0.60	**0.7**
		B	1.02	**0.59**	0.37	0.59	0.39	**0.6**
		B	0.52	**0.73**	0.45	0.73	0.42	**0.75**
		C	0.27	**0.60**	0.40	0.60	0.33	**0.6**
		C	0.17	**0.69**	0.49	0.69	0.35	**0.7**
		D	0.1	**0.60**	0.50	0.60	0.25	**0.6**
		D	0.05	**0.86**	0.86	0.80	0.30	**0.9**
Subsurface Infiltration	Trench, Chambers, drywell, tree filter retention	A	8.27	**0.60**	0.23	0.60	0.60	**0.6**
		A	2.41	**1.00**	0.46	1.00	0.80	**1.0**
		B	1.02	**0.86**	0.49	0.86	0.53	**0.9**
		B	0.52	**0.99**	0.60	0.99	0.53	**1.0**
		C	0.27	**0.81**	0.55	0.81	0.38	**0.85**
		C	0.17	**0.93**	0.68	0.93	0.39	**0.95**
		D	0.1	**0.79**	0.72	0.79	0.25	**0.8**
		D	0.05	**1.25**	1.25	1.00	0.22	**1.25**

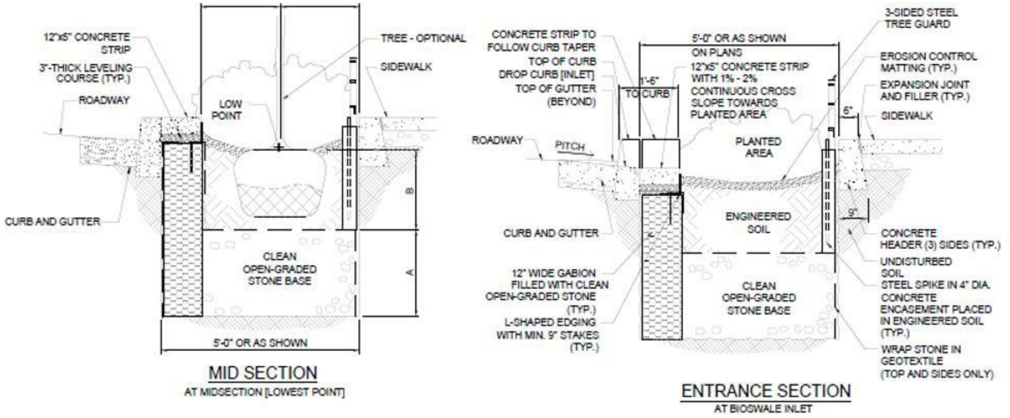
*Predevelopment Recharge based on Water Balance method for Boston MA, 1992-2020 using average annual runoff yields from continuous simulaltion hydrologic SWMM HRU models of meadow and forested lands for HSGs A, B, C and D. Predevelopment recharge conditions will be met when Infiltration practices are sized (DSVs) to capture 66%, 63%, %51% and 40% of average annual IC runoff volumes for HSGs A, B, C and D, respectively.

**Predevelopment Nutrient export is the nutreint load delivered in surface runoff from natural wooded and meadow lands according to HSG. Required % Reductions to IC runoff TP export are 98%, 93%, 86% and 77%, for predevelopment HSGs A, B, C, and D. Required % Reductions to IC runoff TN export are 98%, 91%, 82% and 71%, for predevelopment HSGs A, B, C, and D.

APPENDIX H. COMPENDIUM OF SITE-DEVELOPMENT STORMWATER MANAGEMENT SOLUTIONS FOR WATER RESOURCE PROTECTION

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

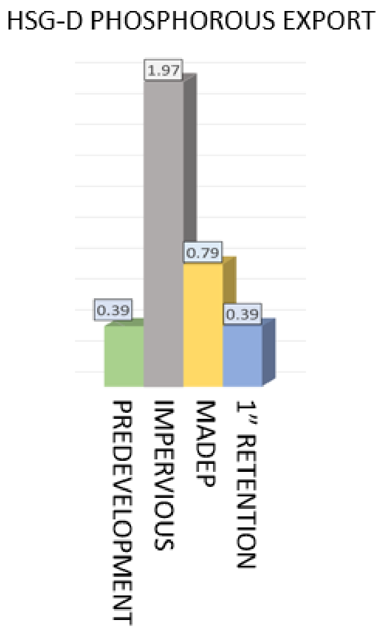
- The “Compendium” offers guidance on stormwater management strategies for site development
- Details a Watershed Protection Standard to ***Maintain Predevelopment Hydrology and Nutrient Load, and Resilient Landscapes***.
- Target audience is local government officials reviewing and approving site plans.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

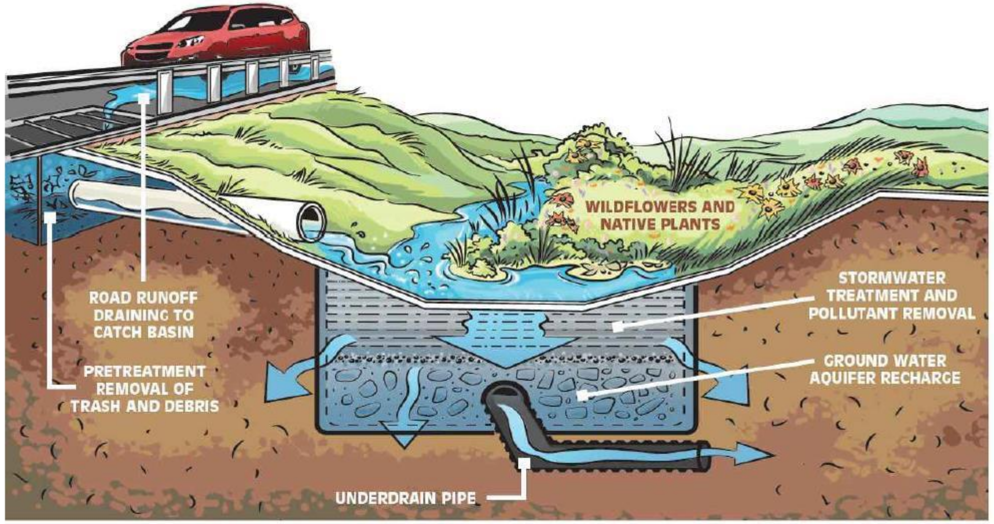


Compendium Overview

- 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

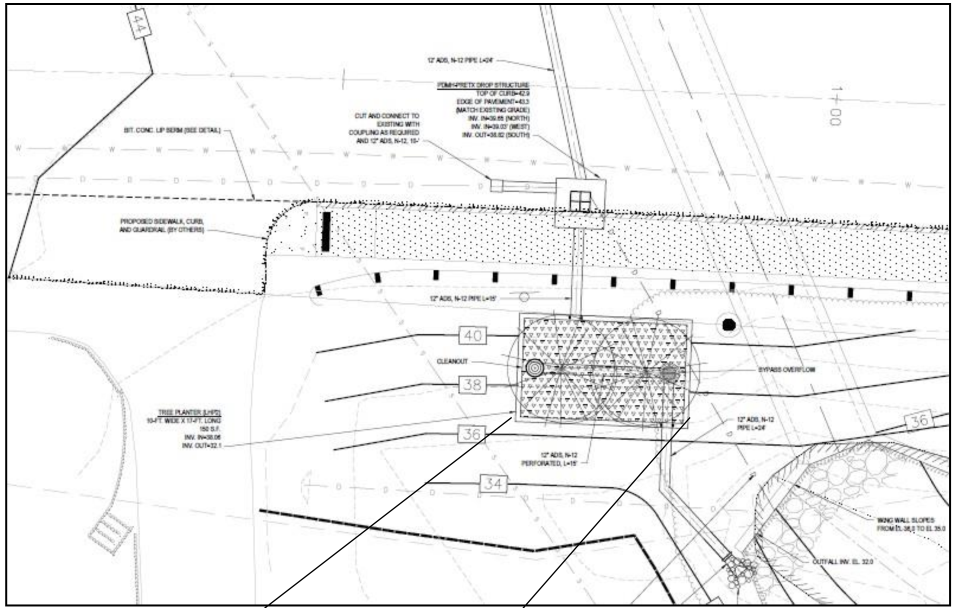


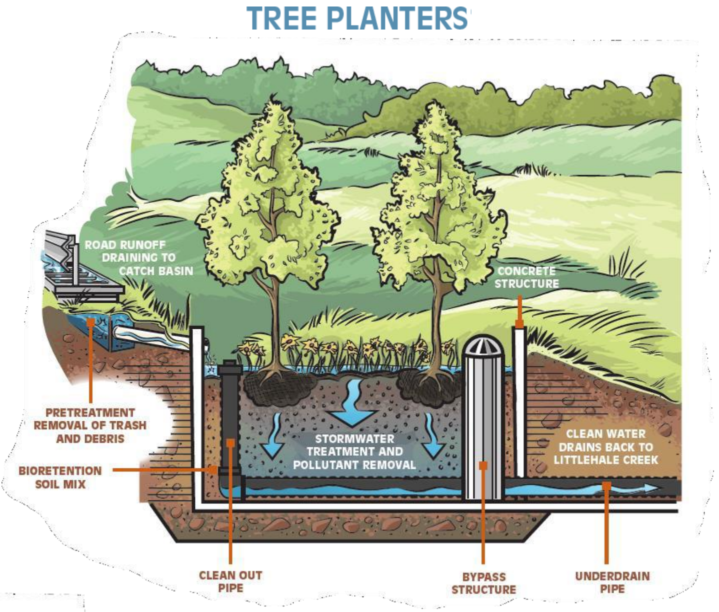


URBAN BIOSWALE/TREE PLANTER ONLINE/OFFLINE

<u>Description:</u> 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.

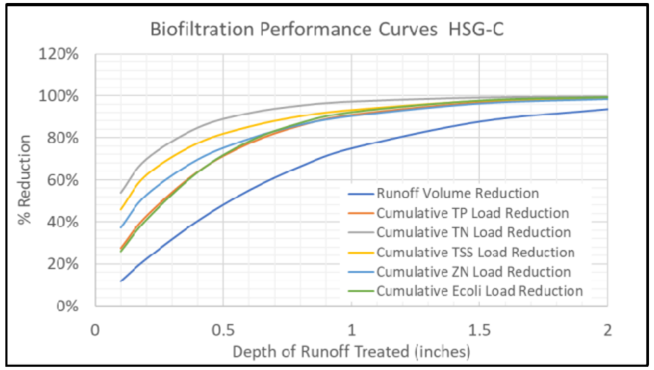
<u>Water Resource Protection Standard:</u> Approximates the 1" WQV static retention for IC that will: 1) Not exceed the long-term average annual predevelopment runoff nutrient load export; 2) Achieve average annual predevelopment groundwater recharge volumes; and 3) Maintain resilient landscape.

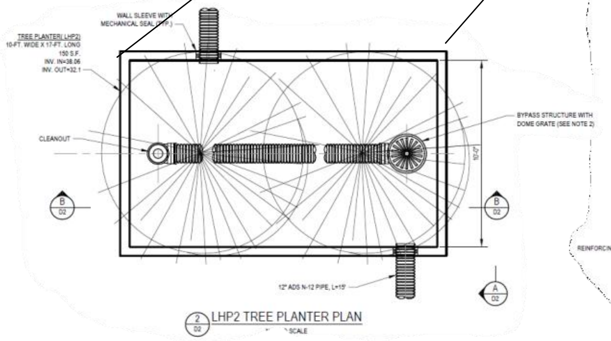


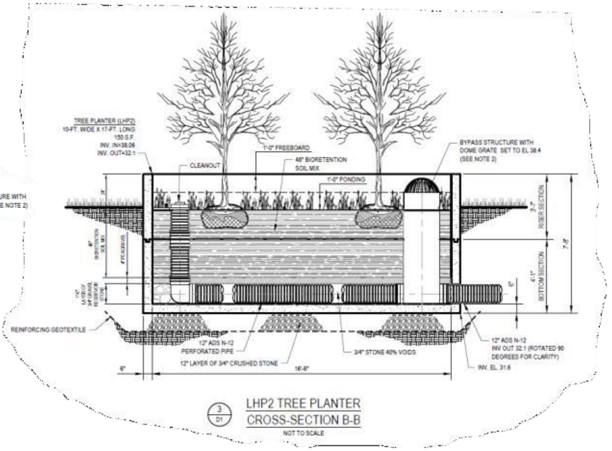


Surface Biofiltration Practice Design Details

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

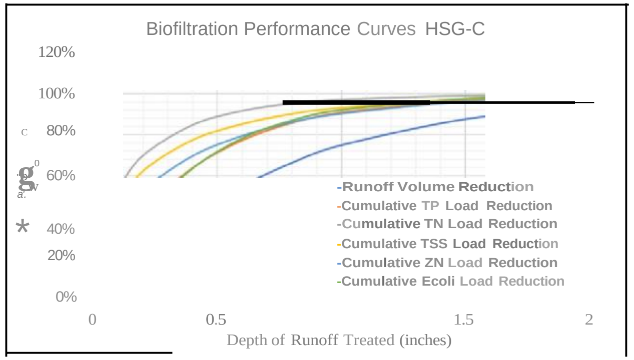
HSG	Infiltration Rate, in/hr	DSV[2], inches	Stormwater Control Measure Physical Storage Capacity based on Contributing IC Drainage area in acres , Cubic Feet																			
			Impervious Cover Drainage Area to SCM, acres																			
			0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	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.

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, tt'	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



Surface Biofiltration Practice Design Details

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