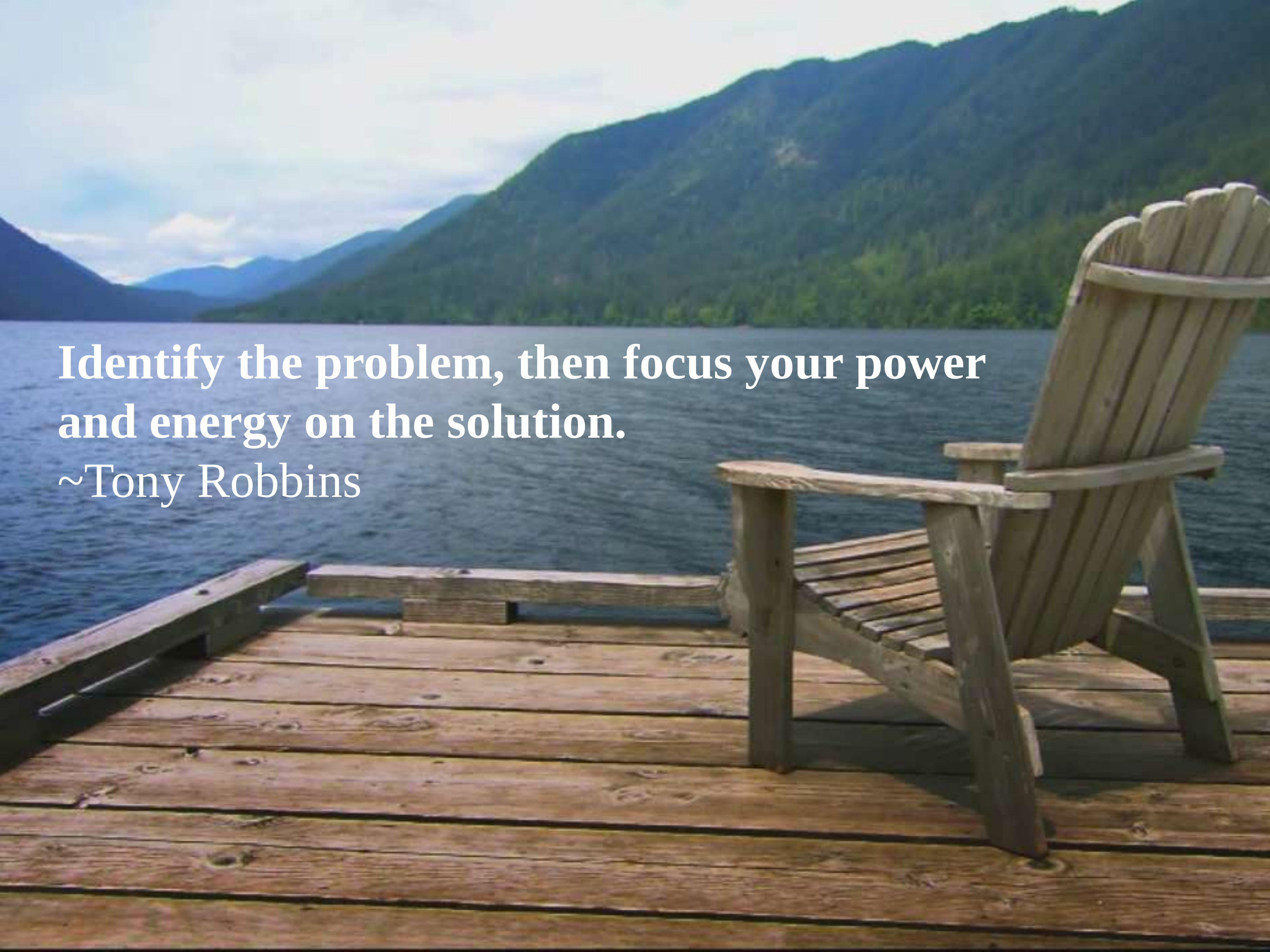

Identify the problem, then focus your power and energy on the solution.
~Tony Robbins


A‘ohe hana nui ke alu ‘ia
No task is too big when done together by all

Urbanization Impacts
Local Hydrology and Water Quality

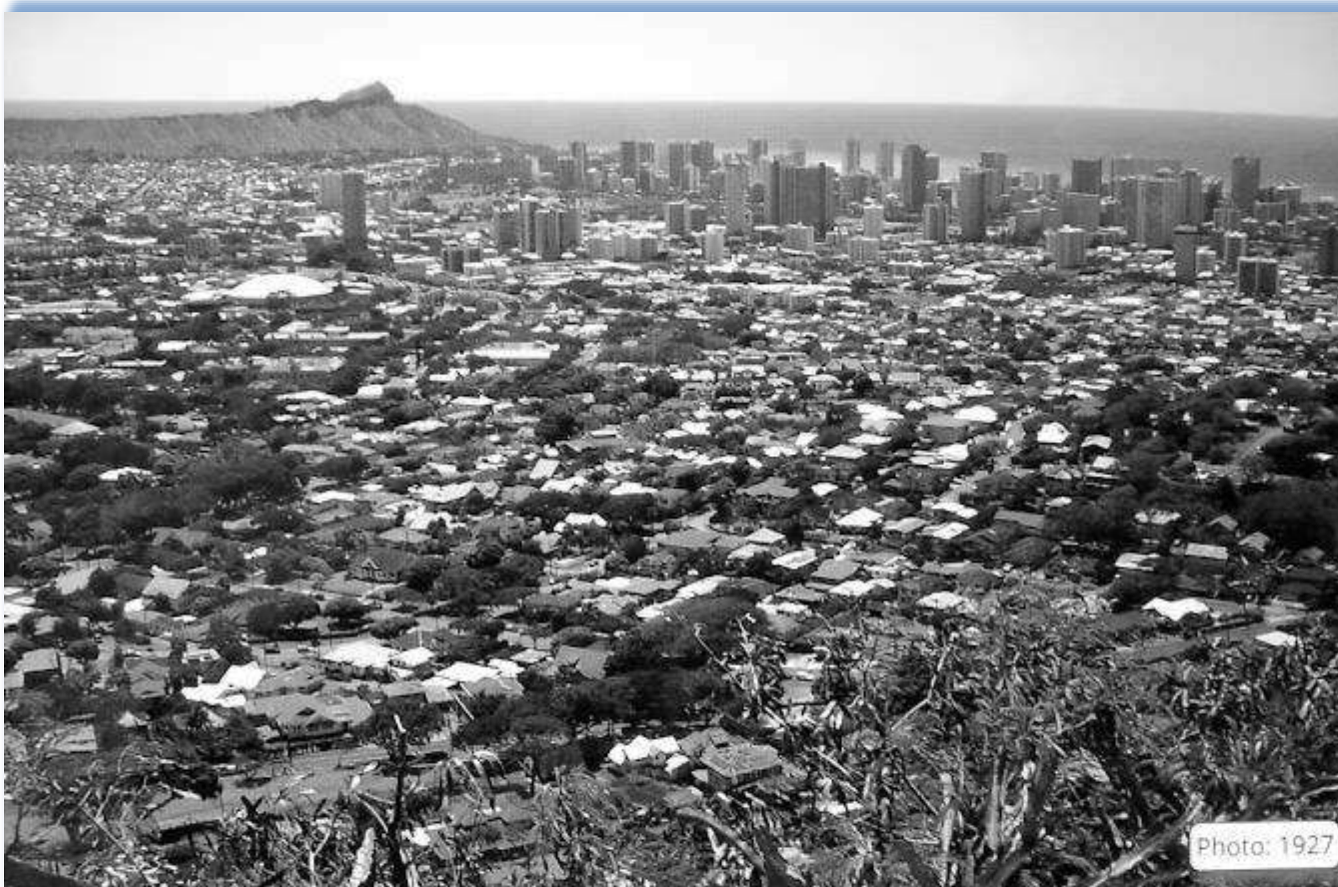


Photo Credit: Bernice Pauahi Bishop Museum

Hydrologic Impacts of Development

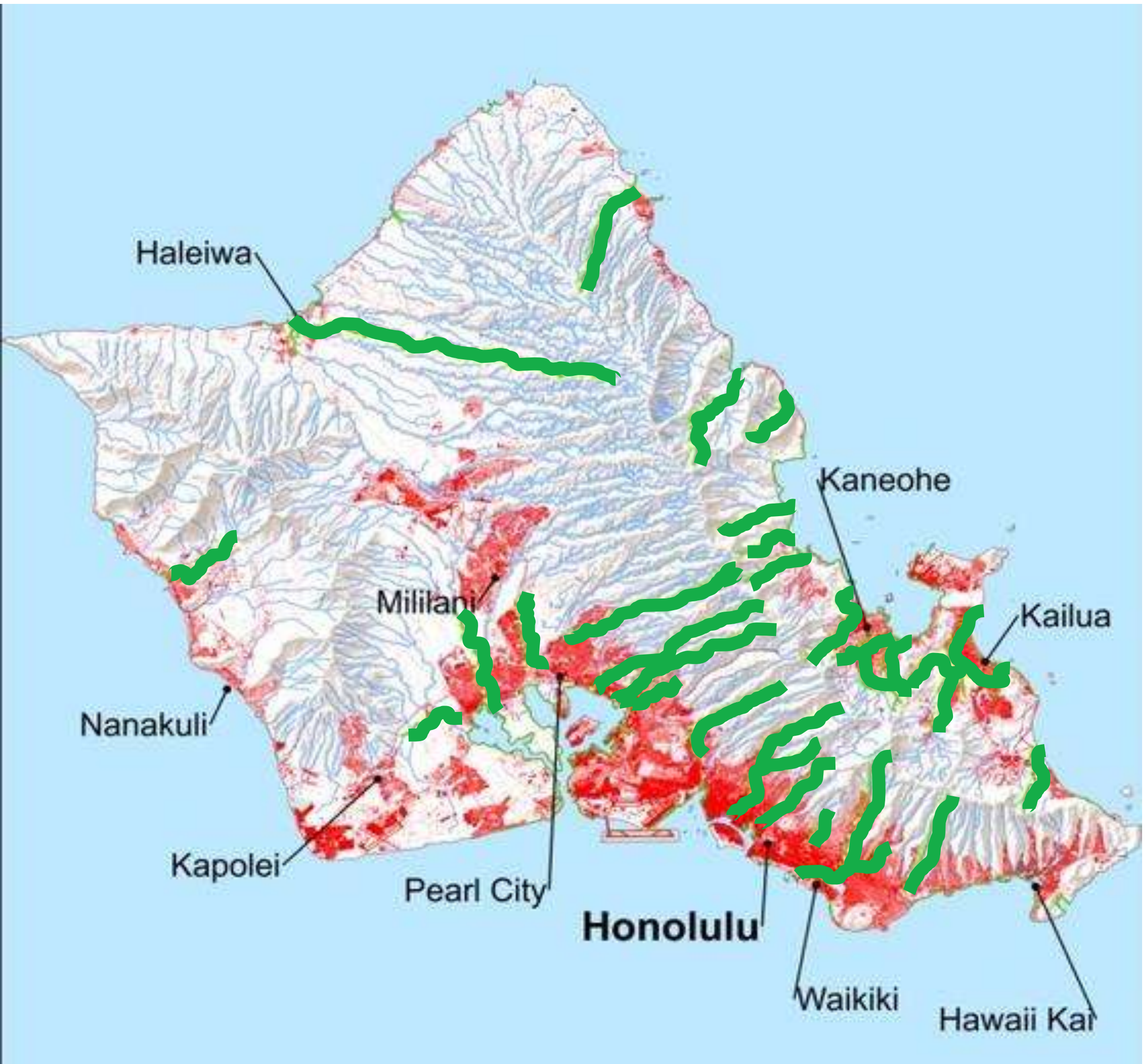
Stormwater Outlet Pipe:
Cromwell's Beach

Photo Credit: Amanda Cording

Pollutants Found in Stormwater:

bacteria
pathogens
cadmium
chromium
copper
lead
mercury
zinc
phosphorus
nitrogen
oil and grease
total suspended solids

Water Quality Impacts of Development



Definition 303(d): waters that are too polluted or otherwise degraded to meet water quality standards.

2,324 Miles of
Rivers and Streams
are Impaired In Hawai'i

Date: January 2012
Source:
ESRI Online Basemap;
State of Hawaii, DLNR, Division of Aquatic Resrources;
NOAA 2005 CCAP Data; EPA

2,324 Miles of Rivers and Streams are Impaired In Hawai‘i

Causes of Impairment
Hawaii Rivers and Streams 2010

Description of this table

Cause of Impairment	Cause of Impairment Group	Miles Threatened or Impaired
Turbidity	Turbidity	1,993.9
Nitrate/Nitrite (Nitrite + Nitrate as N	Nutrients	1,275.8
Nitrogen, Total	Nutrients	1,049.9
Phosphorus, Total	Nutrients	944.9
Enterococcus Bacteria	Pathogens	184.7
Trash	Trash	183.2
Total Suspended Solids (TSS)	Turbidity	121.2
Dieldrin	Pesticides	36.8
Chlordane	Pesticides	33.0
Nitrate/Nitrite	Nutrients	31.0
Metals	Metals (other than Mercury)	1.9
Lead	Metals (other than Mercury)	1.9
Phosphate	Nutrients	1.1

Source: EPA (2010) Hawaii Water Quality Assessment Report

Makiki Stream at King St. Bridge: Oahu, HI

Can discharge between 0.01 and 6 tons of TSS in one day

USGS National Water Information System Mapper (2011 – 2013)

Sedimentation Impacts Reef Health

Puʻukoholā Heiau National Historic Site and

Kawaihae Harbor, Hawaiʻi

Image Source: USGS Pacific Coastal and Marine Science Center
Reference: Anthony, K. R. N., & Connolly, S. R. (2004).

Water Quality Notices

- Kailua Bay, Hawaii June 12th 2017 = 1,000 gallons sewage
- Puhi Bay, Hawaii June 5th = Hilo WWTP Leakage
- Honolua Bay, Maui January 29th 2017
- Hanaka’o, Maui December 1, 2016

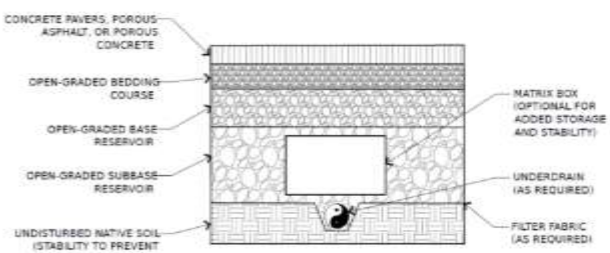
“The public is advised to stay out of flood waters and storm water runoff due to possible overflowing cesspools, sewer manholes, pesticides, animal fecal matter, dead animals, pathogens, chemicals, and associated flood debris”

- *State Dept. of Health*

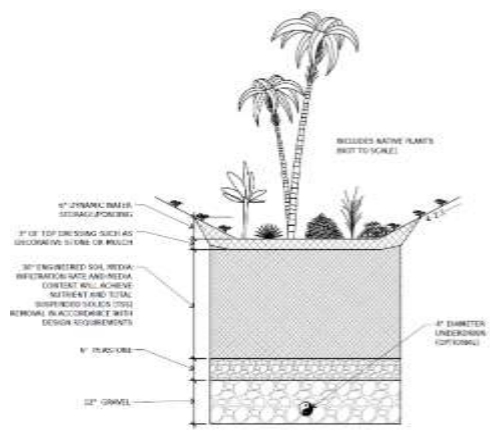
Low Impact Design & Development

LID is an approach to development that aims to mimic pre-development hydrology and uses ecological engineering to remove pollutants in stormwater and wastewater for re-use and/or replenishment of groundwater supplies.

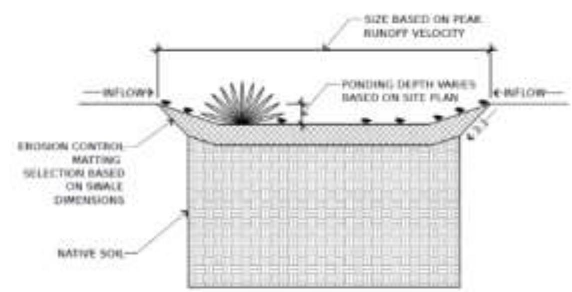


Porous Materials



Bioretention “Green Streets”



Vegetated Swales

City and County of Honolulu Requiring Low Impact Development

Storm Drainage Standards Update

- LID Requirements for all new development and redevelopment projects greater than 1 acre (Priority A and B)
- Expand the types of smaller projects for post-construction BMPs
  (Priority B) to include
  - Parking Lots greater than 20 stalls
  - Buildings greater than 100-feet tall
  - Retail Malls
  - Industrial Parks
- Require 1.5x the Water Quality Volume (WQV) for any treat and release practices (i.e. biofiltration)

Presented by Randal Wakumoto, City and County of Honolulu, Stormwater Branch
UH Sea Grant's Green Infrastructure Workshop , October 29, 2015

National and Local Proponents of Low Impact Development

Sustainable Sites

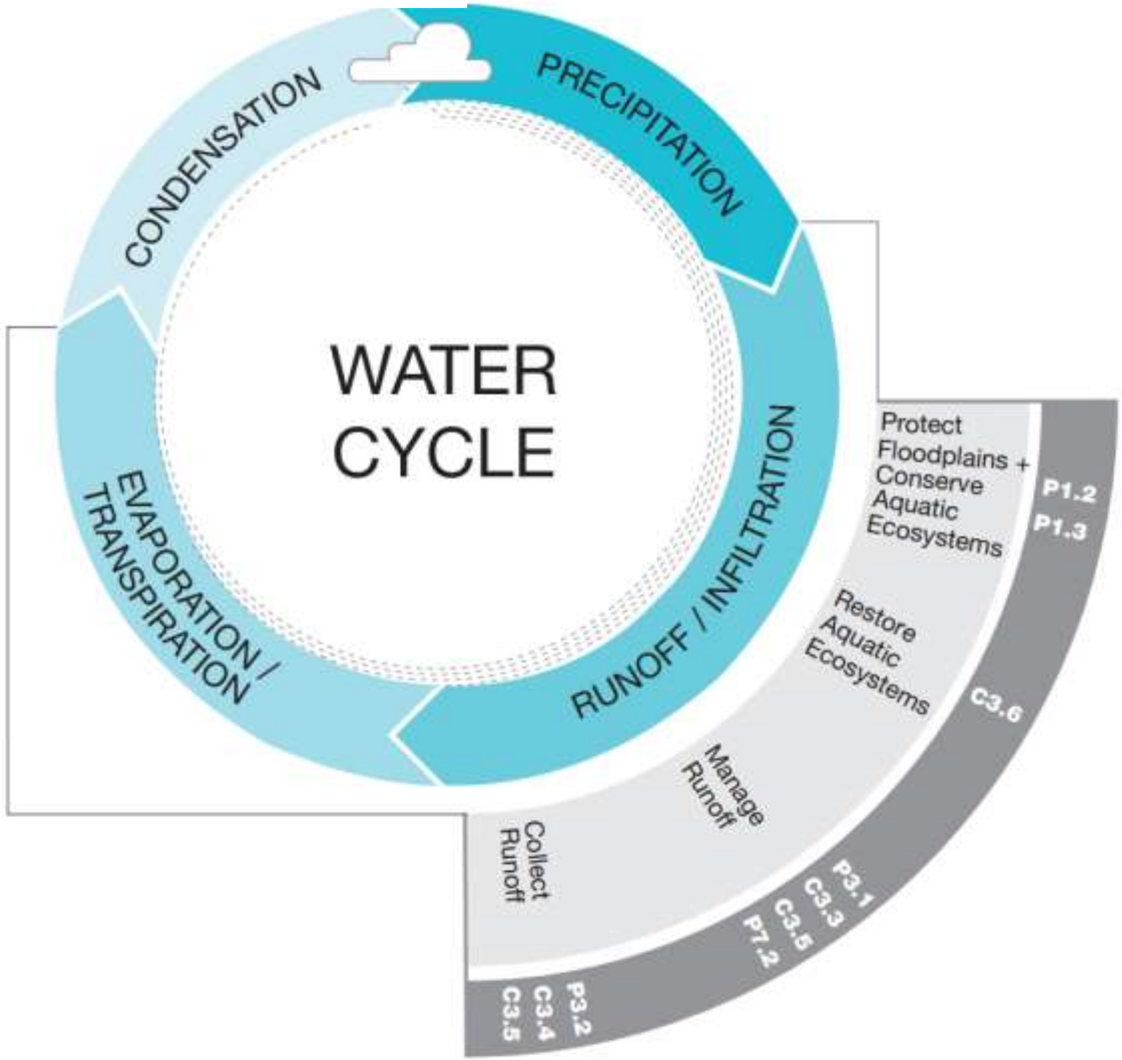


Table 35. LEED for New Construction Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP
Sustainable Sites	5.1	Site Development, Protect or Restore Habitat	1	Appropriate native plant selection, protect sensitive areas
	5.2	Site Development, Maximize Open Space	1	Minimize construction footprint
	6.1	Stormwater Design, Quantity Control	1	Multiple LID BMPs
	6.2	Stormwater Design, Quality Control	1	Multiple LID BMPs
	7.1	Heat Island Effect, Non-roof	1	Shade from trees, light colored pervious paving
	7.2	Heat Island Effect, Roof	1	Vegetated roof
Water Efficiency	1.1	Water Efficient Landscaping, Reduce by 50%	2	Rain barrels, cisterns, select appropriate plant species
	1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	4	Soil amendments, capture/reuse
	2.1	Innovative Wastewater Technologies, Reduce potable by 50%	2	Capture/reuse
	3.1	Water Use Reduction, 30% Reduction	2	Capture/reuse
	3.2	Water Use Reduction, 35% Reduction	3	Capture/reuse
	3.3	Water Use Reduction, 40% Reduction	4	Capture/reuse
	3.1	Material Reuse, 5%	1	Multiple LID BMPs
Materials & Resources	3.2	Material Reuse, 10%	1	Multiple LID BMPs
	4.1	Recycled Content, 10%	1	Multiple LID BMPs
	4.2	Recycled Content, 20%	1	Multiple LID BMPs
	5.1	Regional Materials, 10%	1	Multiple LID BMPs
	5.2	Regional Materials, 20%	1	Multiple LID BMPs
		Total Possible Points:	**22**	

Source: The Low Impact Development Center, Inc.

Cost of LID vs Traditional Development

TABLE 3-3 Conventional Option Piping	TYPE	QUANTITY	COST
Distribution	6 to 30-inch piping	9,680 linear feet	$298,340
Detention	36 and 48-inch piping	20,800 linear feet	$1,356,800

TABLE 3-4 LID Option Piping	TYPE	QUANTITY	COST
Distribution	4 to 36-inch piping	19,970 linear feet	$457,780
Detention*	—	0	$0

Brown, S., Sanneman, C., 2017. Working with the Market: Economic Instruments to Support Investment in Green Stormwater Infrastructure.

Cost of LID vs Traditional Development

TABLE 3-1
Comparison of Unit Costs for Materials for Boulder Hills LID Subdivision

(SFC, 2009)

ITEM	CONVENTIONAL	LID	DIFFERENCE
Site Preparation	$23,200.00	$18,000.00	–$5,200.00
Temp. Erosion Control	$5,800.00	$3,800.00	–$2,000.00
Drainage	$92,400.00	$20,100.00	–$72,300.00
Roadway	$82,000.00	$128,000.00	$46,000.00
Driveways	$19,700.00	$30,100.00	$10,400.00
Curbing	$6,500.00	$0.00	–$6,500.00
Perm. Erosion Control	$70,000.00	$50,600.00	–$19,400.00
Additional Items	$489,700.00	$489,700.00	$0.00
Buildings	$3,600,000.00	$3,600,000.00	$0.00
PROJECT TOTAL	$4,389,300.00	$4,340,300.00	–$49,000.00

Brown, S., Sanneman, C., 2017. Working with the Market: Economic Instruments to Support Investment in Green Stormwater Infrastructure.

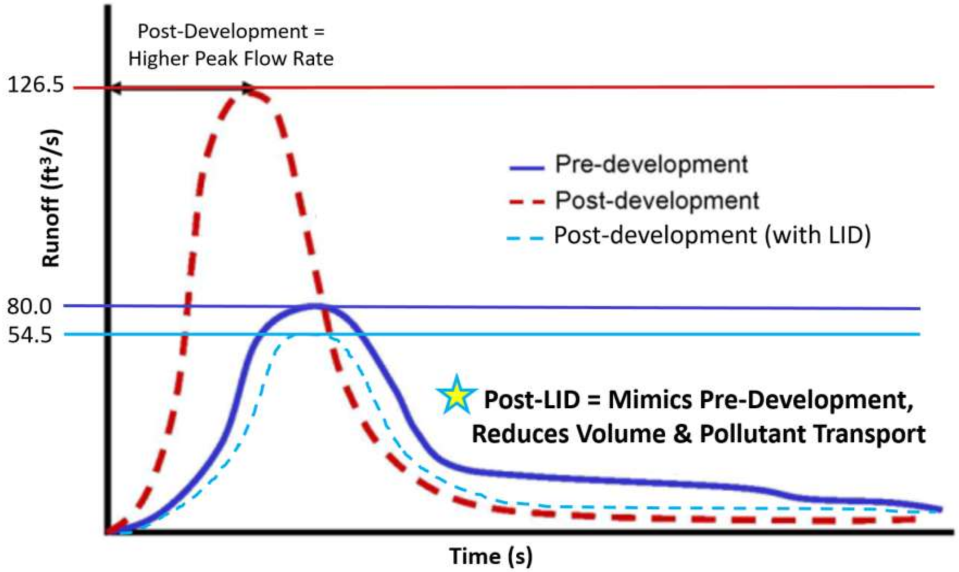
Cost of LID vs Traditional Development

Item	Conventional Option	LID Option	Cost Difference
Mobilization / Demolition	$555,500	$555,500	$0
Site Preparation	$167,000	$167,000	$0
Sediment / Erosion Control	$378,000	$378,000	$0
Earthwork	$2,174,500	$2,103,500	–$71,000
Paving	$1,843,500	$2,727,500	$884,000
Stormwater Management	$2,751,800	$1,008,800	–$1,743,000
Addtl Work-Related Activity (Utilities, Lighting, Water & Sanitary Sewer Service, Fencing, Landscaping, Etc.)	$2,720,000	$2,720,000	$0
Project Total	$10,590,300	$9,660,300	–$930,000

TABLE 3-2
Comparison of Unit Costs for Materials for Greenland Meadows Commercial Development

Brown, S., Sanneman, C., 2017. Working with the Market: Economic Instruments to Support Investment in Green Stormwater Infrastructure.

LID Hydrologic Performance



Attenuate Peak Flow:
75 - 99%
Reduce Volume:
60 - 90%

References: Liu et al. (2014), Hunt et al. (2008); Debusk et al. (2011)

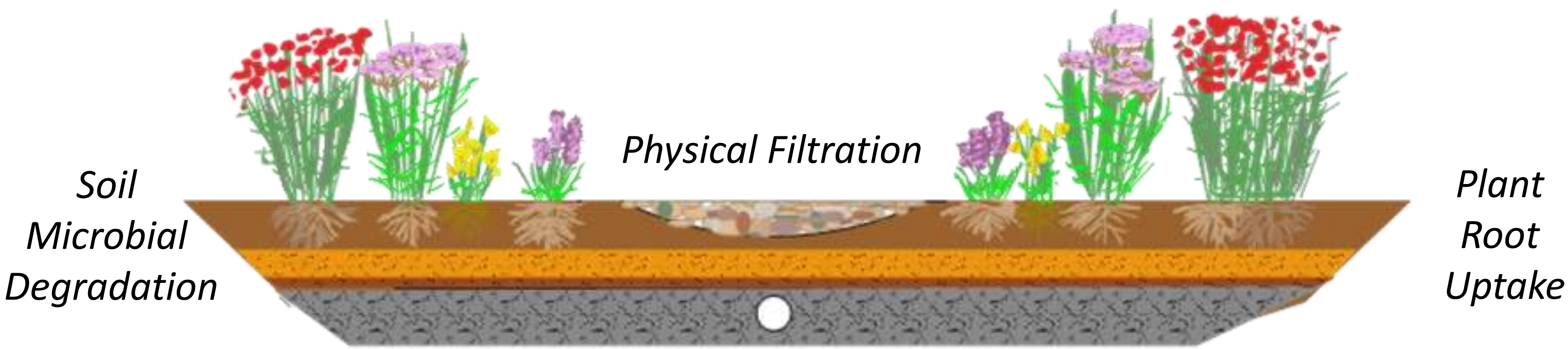
LID Sediment Removal Performance

Removal of
Total Suspended Solids:
80% - 99%

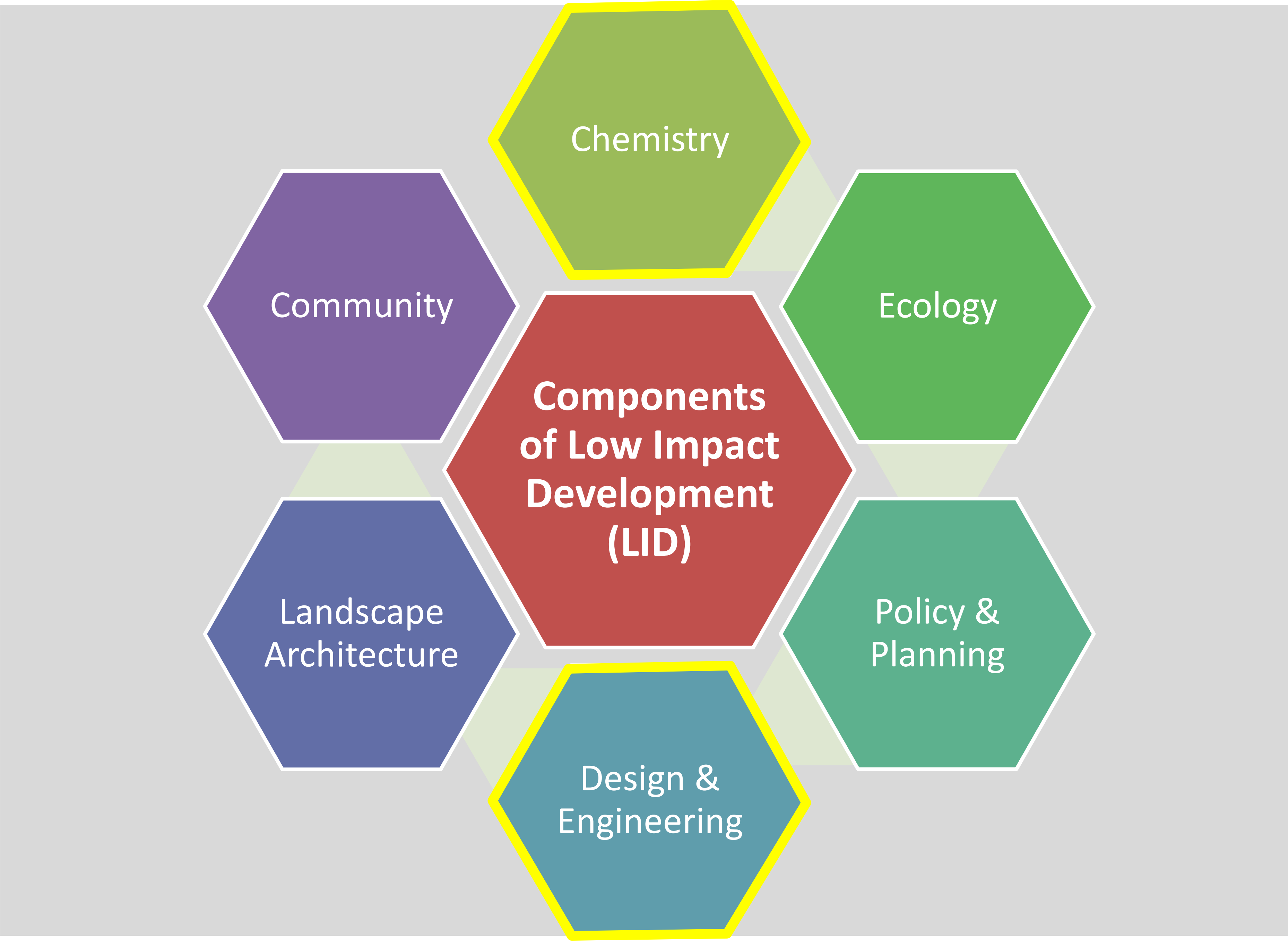
References: Cording et al. (2017); Brown and Hunt (2011); Bratieres et al. (2008); Hatt et al. (2008)

LID Nutrient Removal Performance

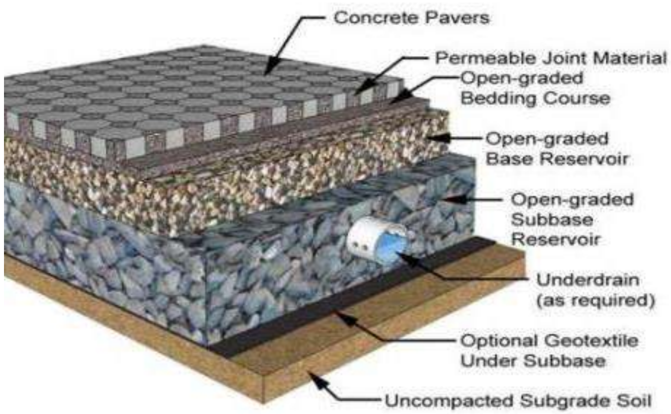
Removal of Total Nitrogen and Phosphorus:
70% - 90%

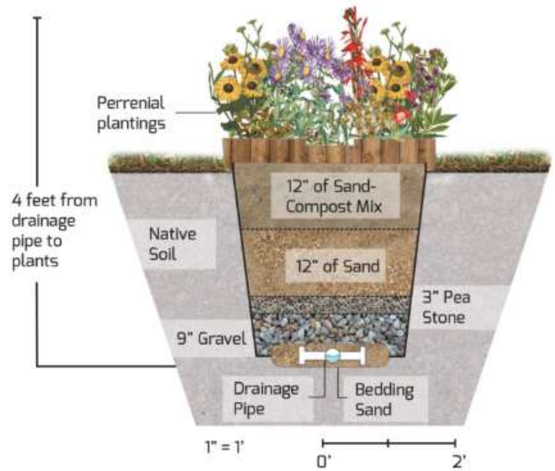


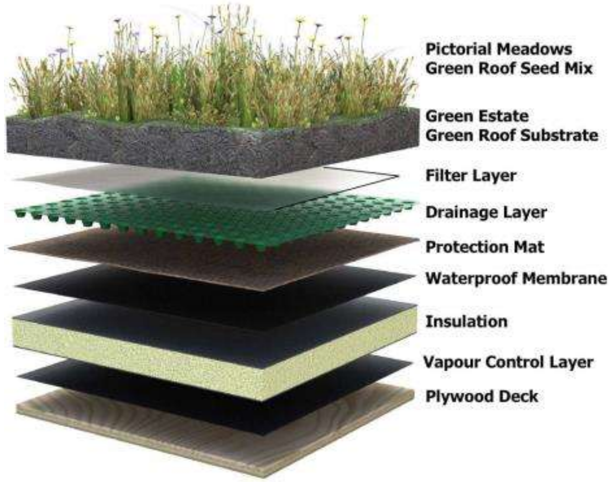
References: Cording et al. (2017); Davis et al. (2001); Hunt et al. (2006); Debusk et al. (2011)


Chemistry
Community
Ecology
Components of Low Impact Development (LID)
Landscape Architecture
Policy & Planning
Design & Engineering

Green Stormwater Infrastructure (GSI)





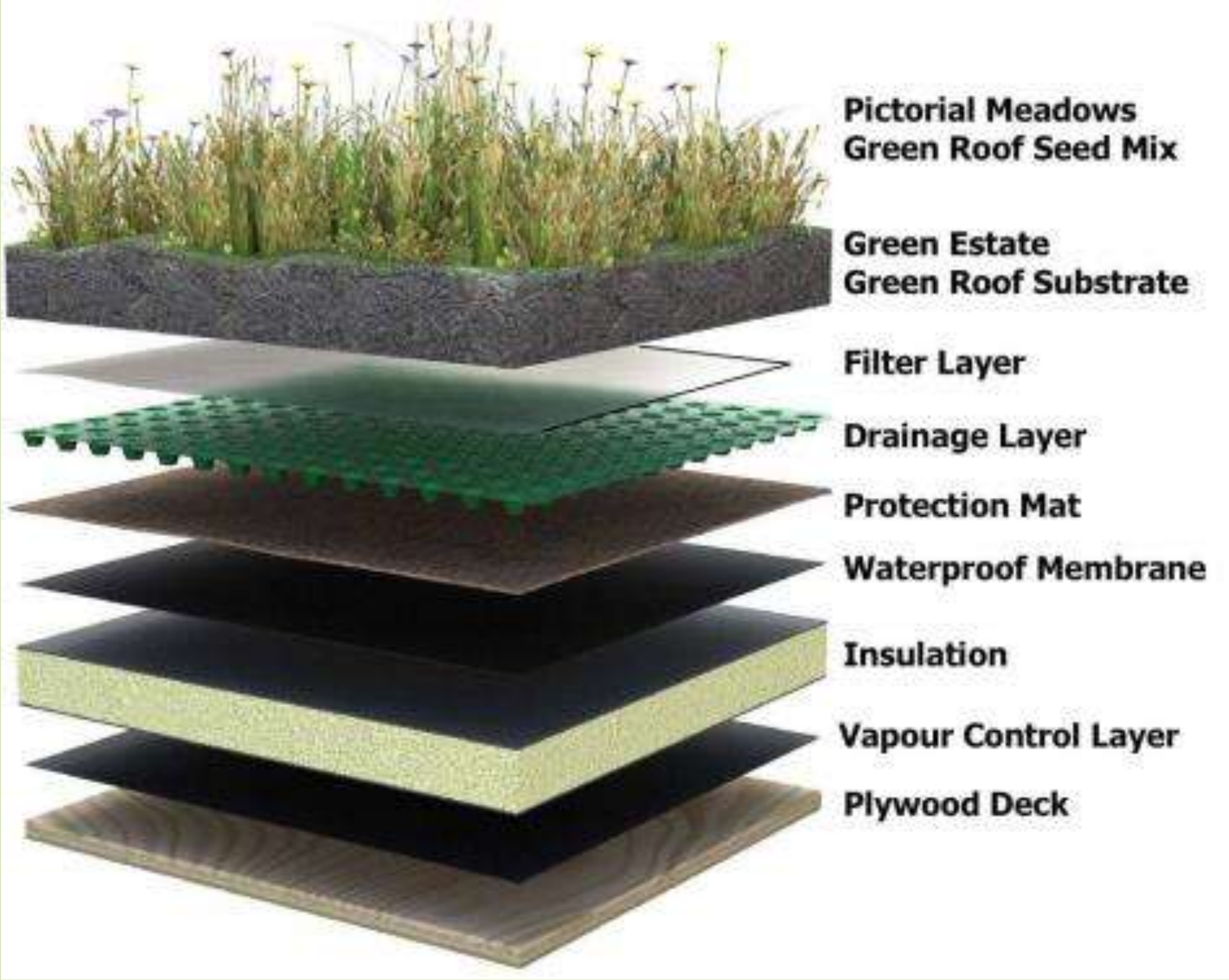


Davis 2008; Dietz and Clausen 2006; Zinger et al. 2013; Collins et al. 2010.

Green Roofs

Design Strengths:
Reduce Volume
Reduce Peak Flows
Reduce Heat Island
Provide Insulation
Reduce Energy Cost
Provide Urban Habitat
Increase Biodiversity

Design Weaknesses:
Less Pollutant Removal
Maintenance
Cost



University of Hawaii Center for Microbial Oceanography Research & Education

Location: Honolulu, Hawaii

Project Size: 2,768 sq ft

Installation Date: September 23, 2010

Grower: Hawaiian Sunshine Nursery

Turtle Bay Resort

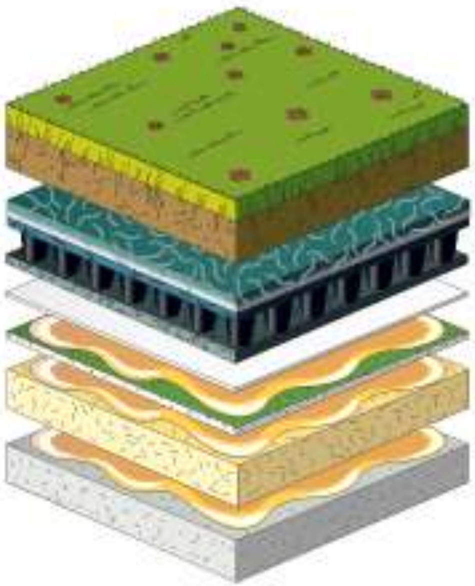
Location: Oahu’s North Shore, Hawaii

Project Size: 60,000 sq ft

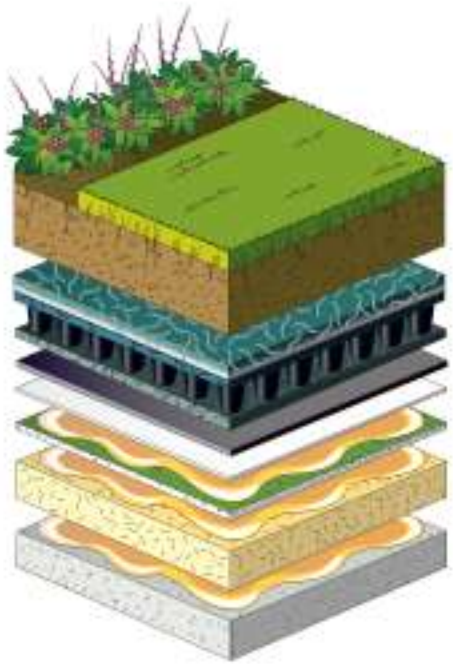
Partners: Honolulu Roofing Company, Division Seven, Walters, Kimura, Motoda, Lazo, Hui Ku Maoli Ola

Nehe, akulikuli, carex, sedum, herb garden

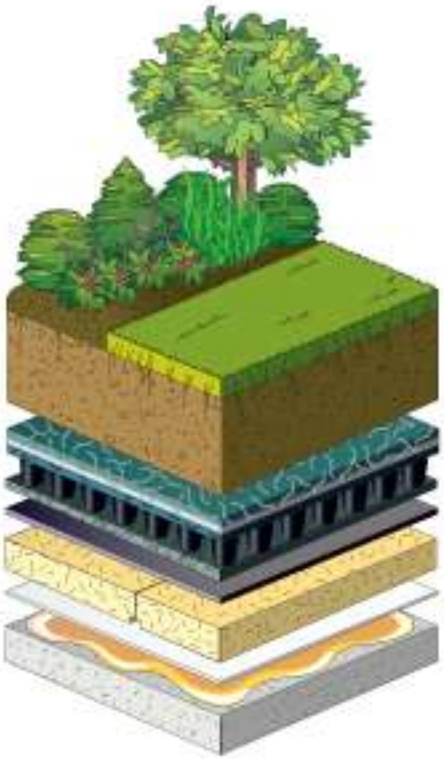
GREEN ROOF ASSEMBLY EXAMPLES



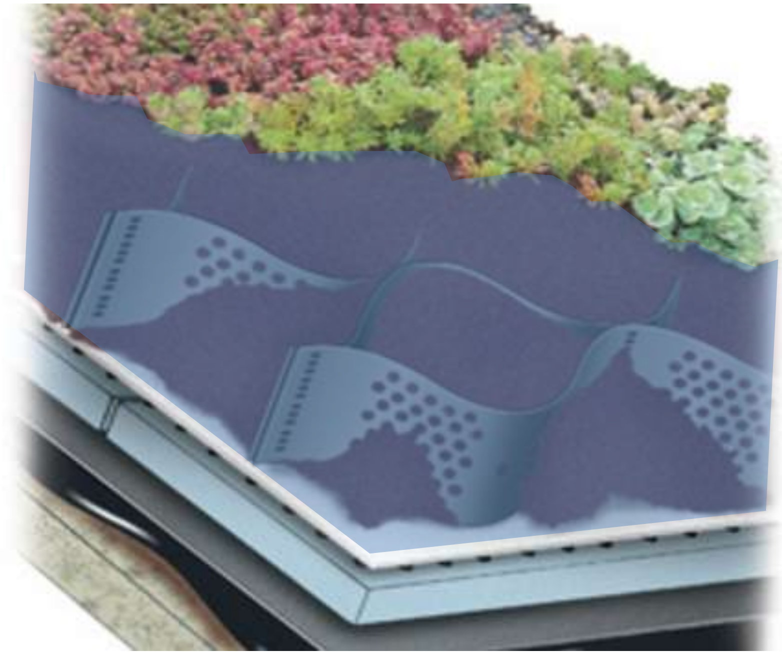
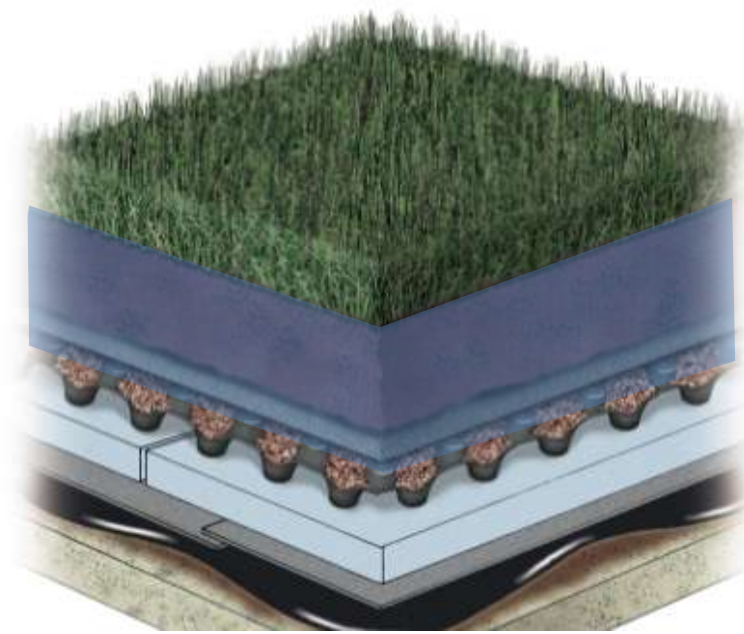
Ultra-Extensive
2.5" - 4" Media Depth

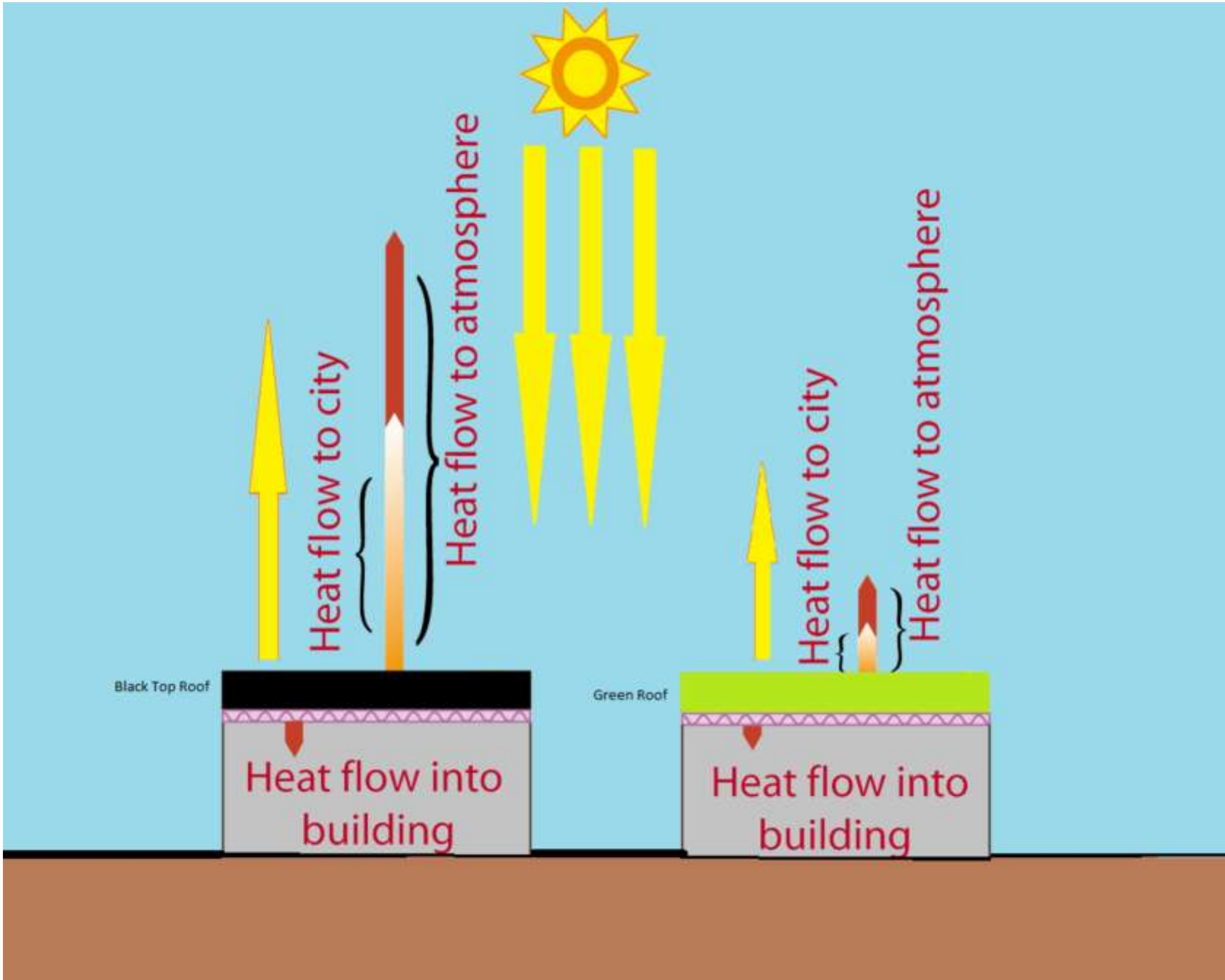


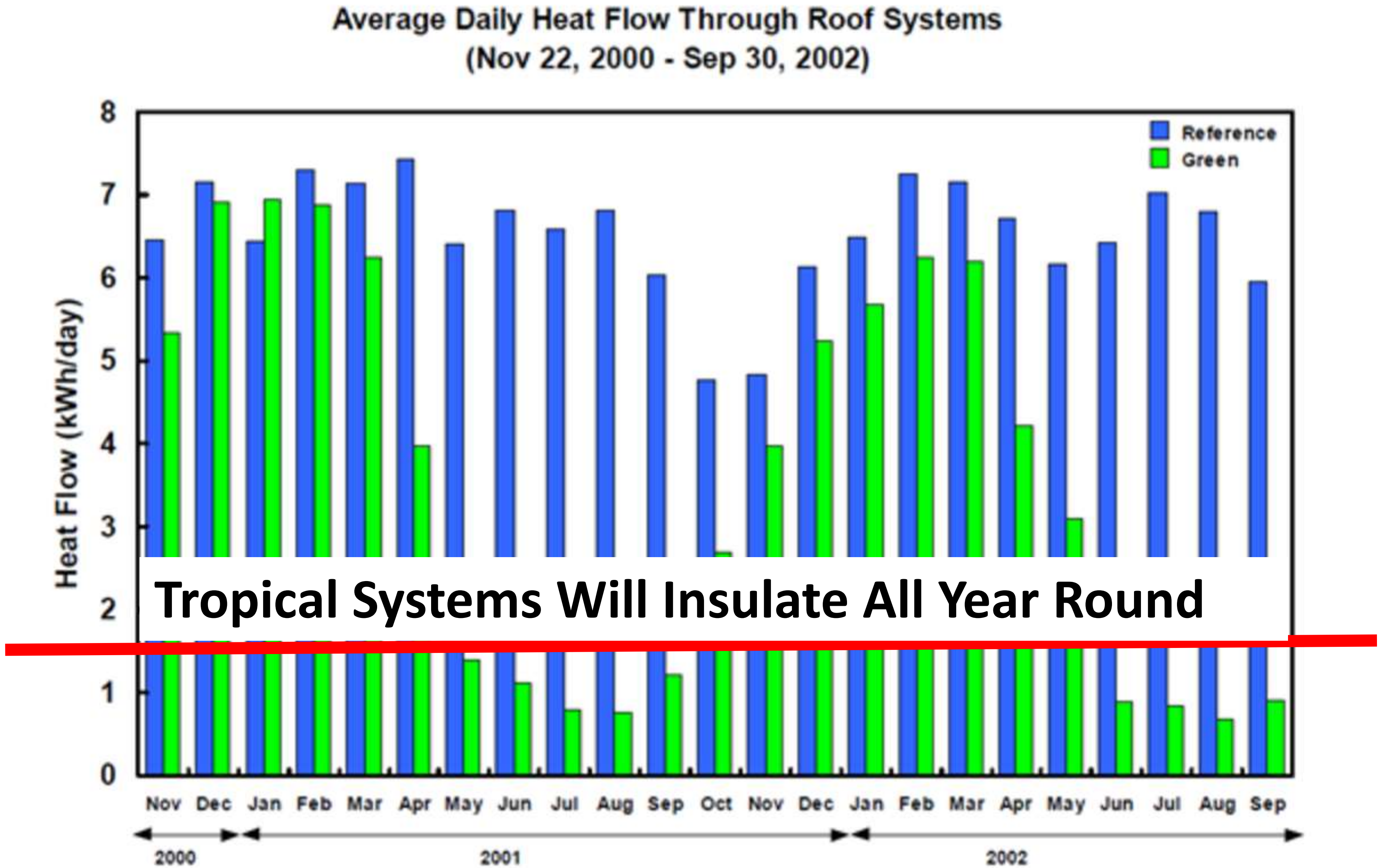
Extensive
5" - 8" Media Depth



Intensive
8"+ Media Depth


Heat flow to city
Heat flow to atmosphere
Black Top Roof
Heat flow into building
Heat flow to city
Heat flow to atmosphere
Green Roof
Heat flow into building


Average Daily Heat Flow Through Roof Systems
(Nov 22, 2000 - Sep 30, 2002)
Heat Flow (kWh/day)
8
7
6
5
4
3
2
1
0
Reference
Green
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
2000
2001
2002
Tropical Systems Will Insulate All Year Round

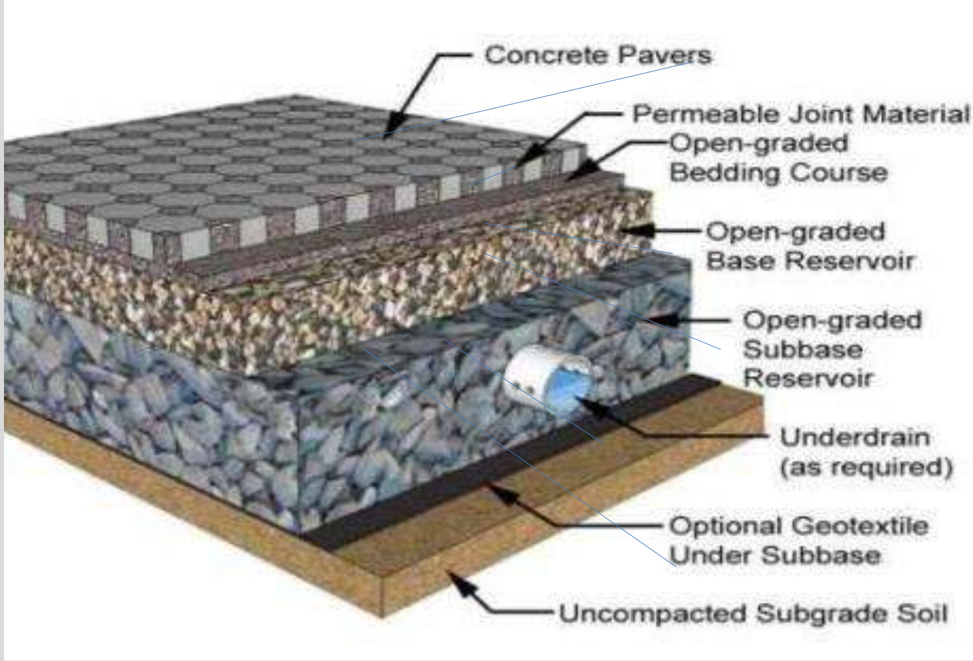
Vertical
Living Walls

Design Strengths:
Reduces Volume & Peak Flows
Provides Habitat
Insulation
Green Screen
Improves Air Quality

Design Challenges:
Maintenance
Pumping




Porous Materials



Design Strengths:
Reduces Storm Volume
Reduces Peak Flows
Particulate Pollutant Removal
Removes Hydrocarbons

Design Challenges:
Getting both strength and permeability (target infiltration > 3in/hr)
Control siltation from offsite flows
Maintenance
Soluble nutrient removal

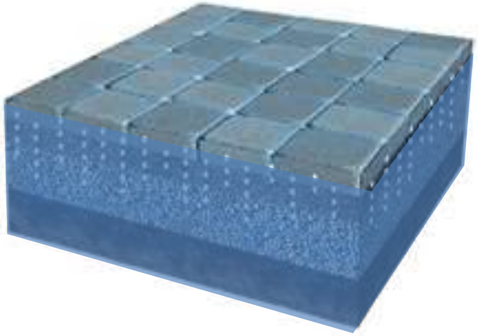



Porous Materials for Water Infiltration

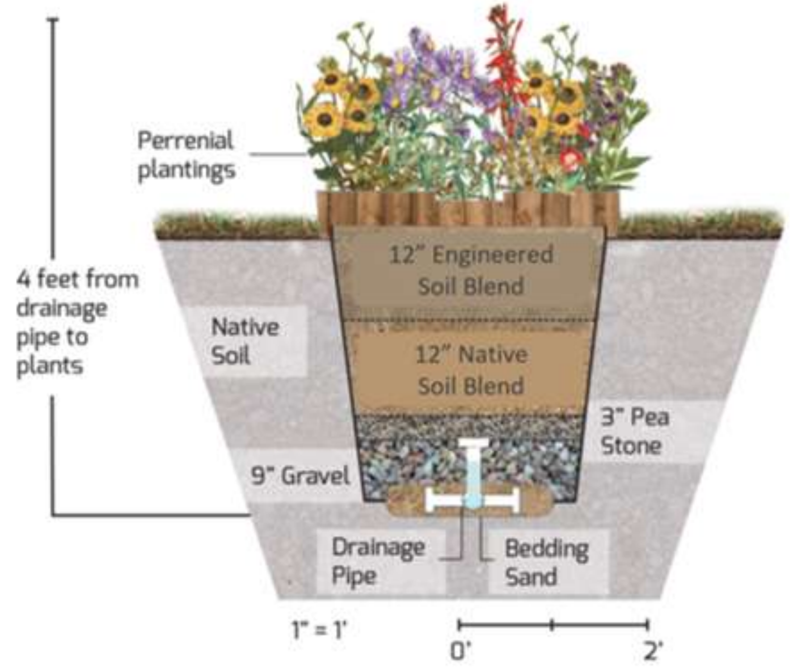
Permeable Asphalt

Permeable Concrete

Permeable Pavers




Bioretention & Green Streets



Design Strengths:
Reduces Volume & Peak Flows
Removes Total Suspended Solids
Removes Nutrients
Improved Aesthetics
Urban Habitat

Design Challenges:
Obtaining/keeping proper infiltration
Directing flow into feature (conveyance)
Maintenance




DOEE Curbside Bioretention

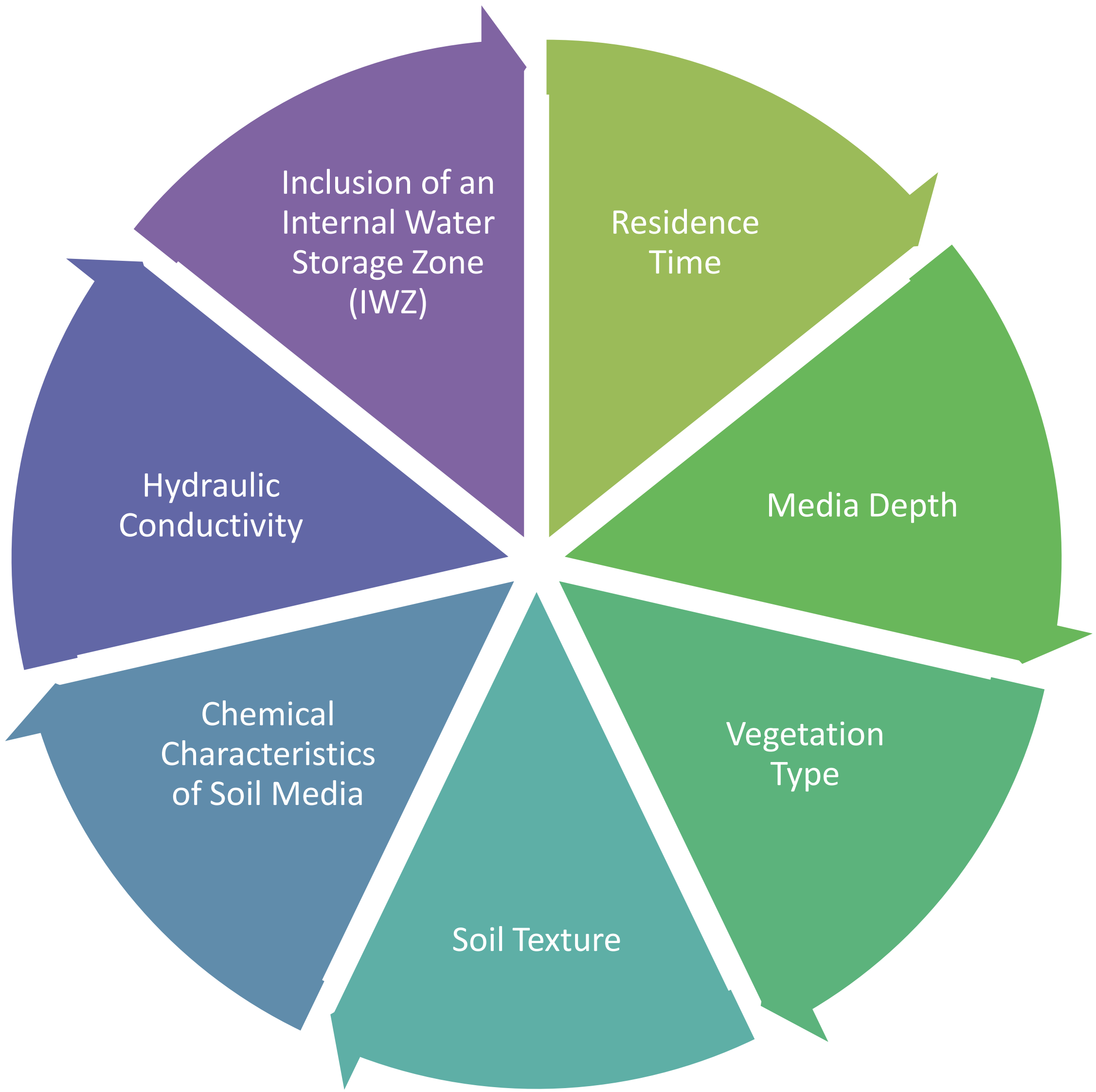
Second Prize: Best Ultra-Urban BMP Competition

ECOSOLUTIONS
innovative designs - living systems


ROAD WORK AHEAD

Commercial Scale Bioretention
NOMA District Washington, DC

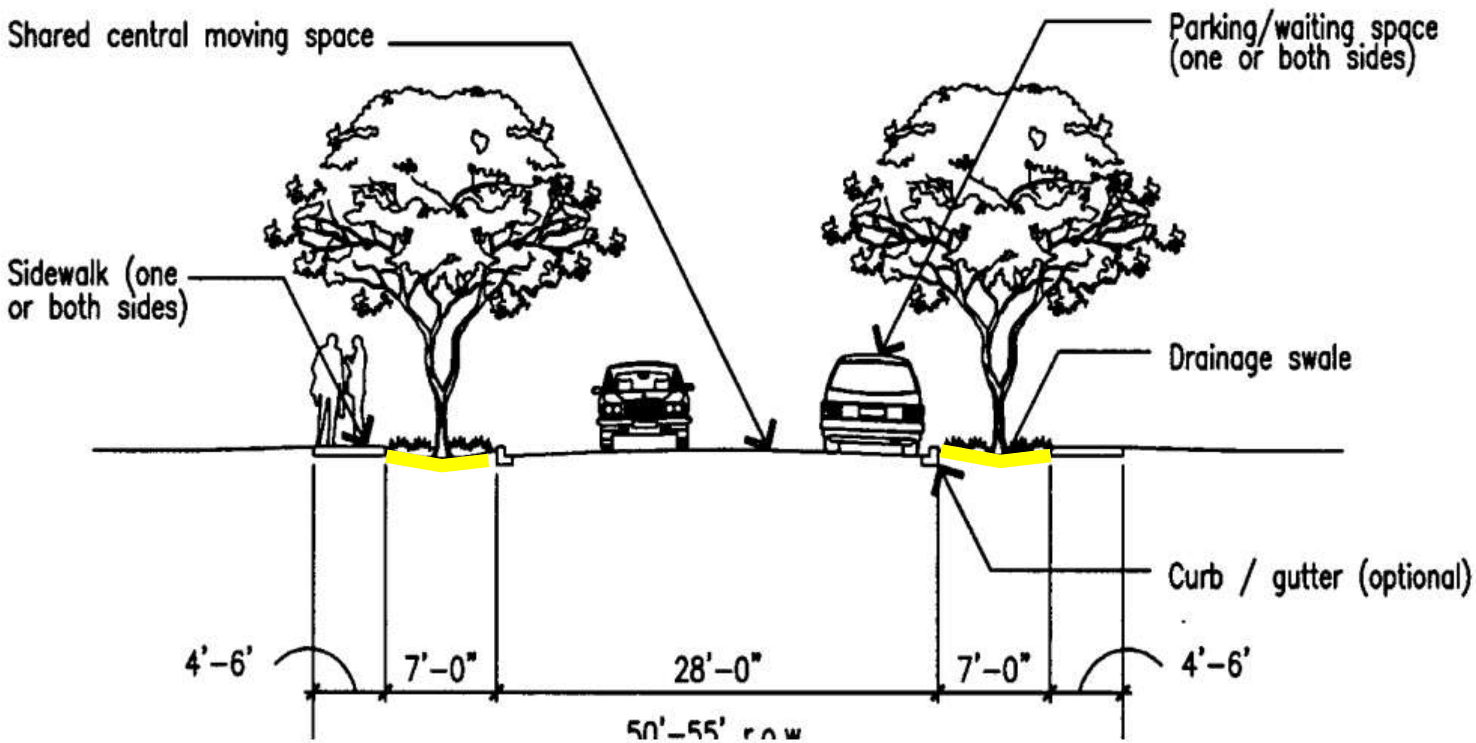
What Design Factors Influence Bioretention Performance?



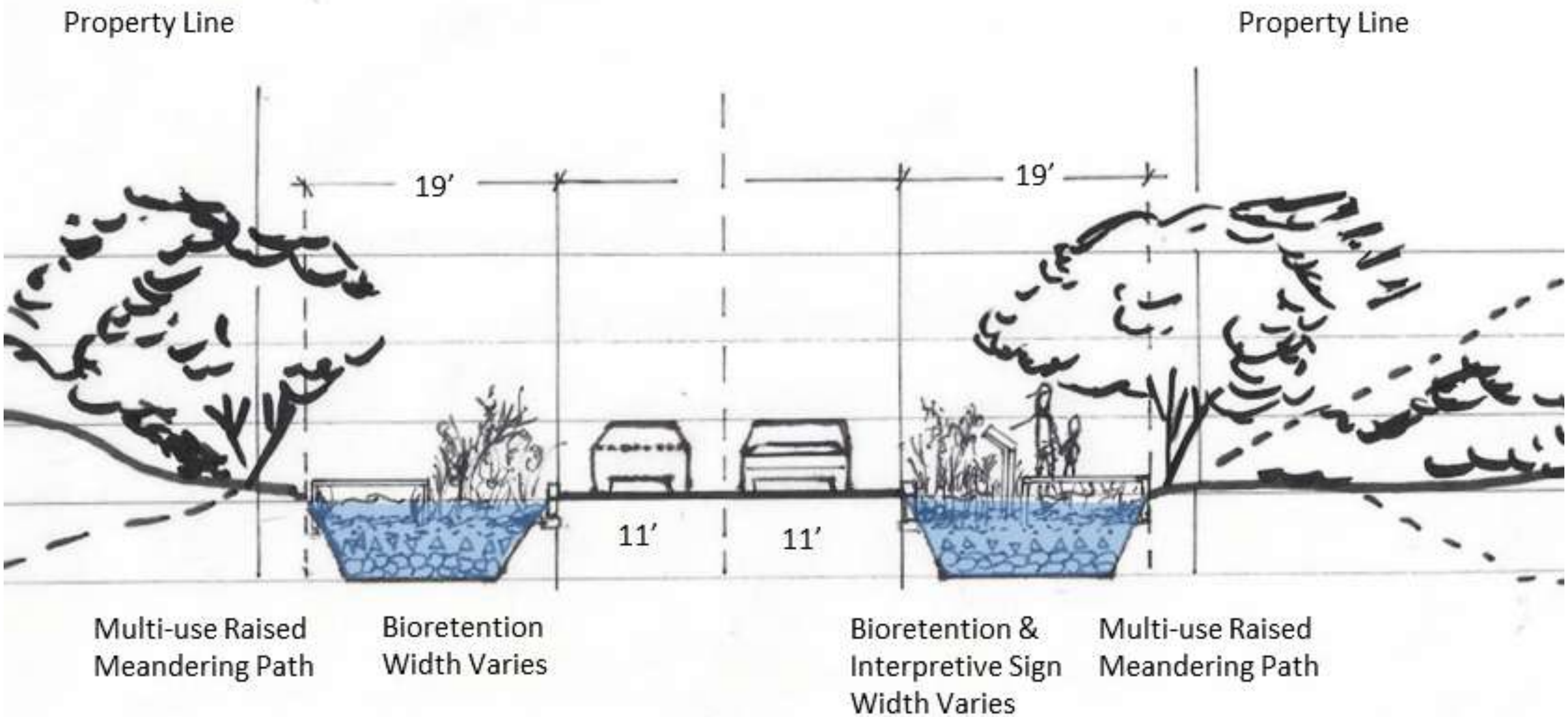
Bioretention Design Considerations

1. Location
2. Conveyance
3. Ponding/Settling Velocity
4. Shape/Size
5. Bioretention Soil Media
6. Plants
7. Overflow
8. Underdrain

Access street: urban neo-traditional standard

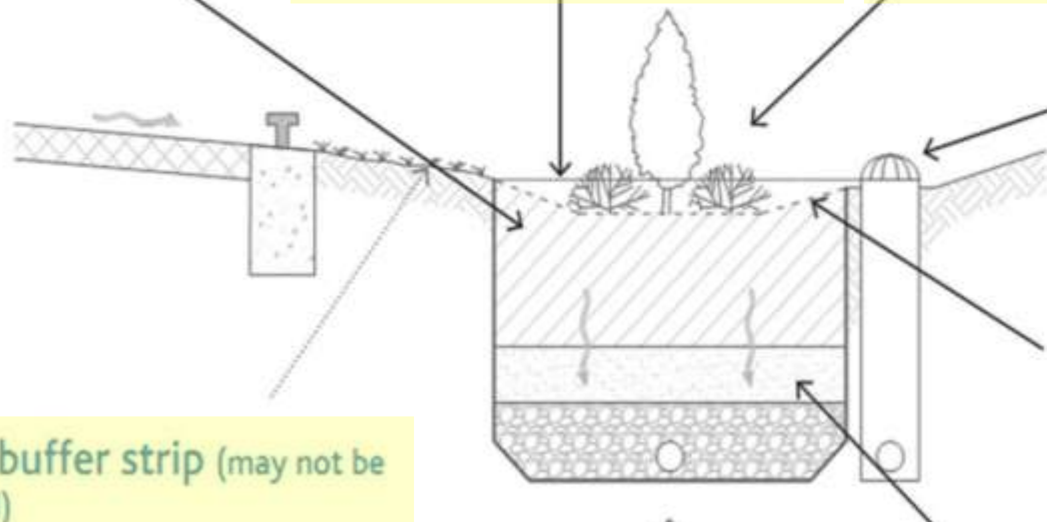


Bioretention Green Streets



ECOSOLUTIONS
innovative designs – living systems

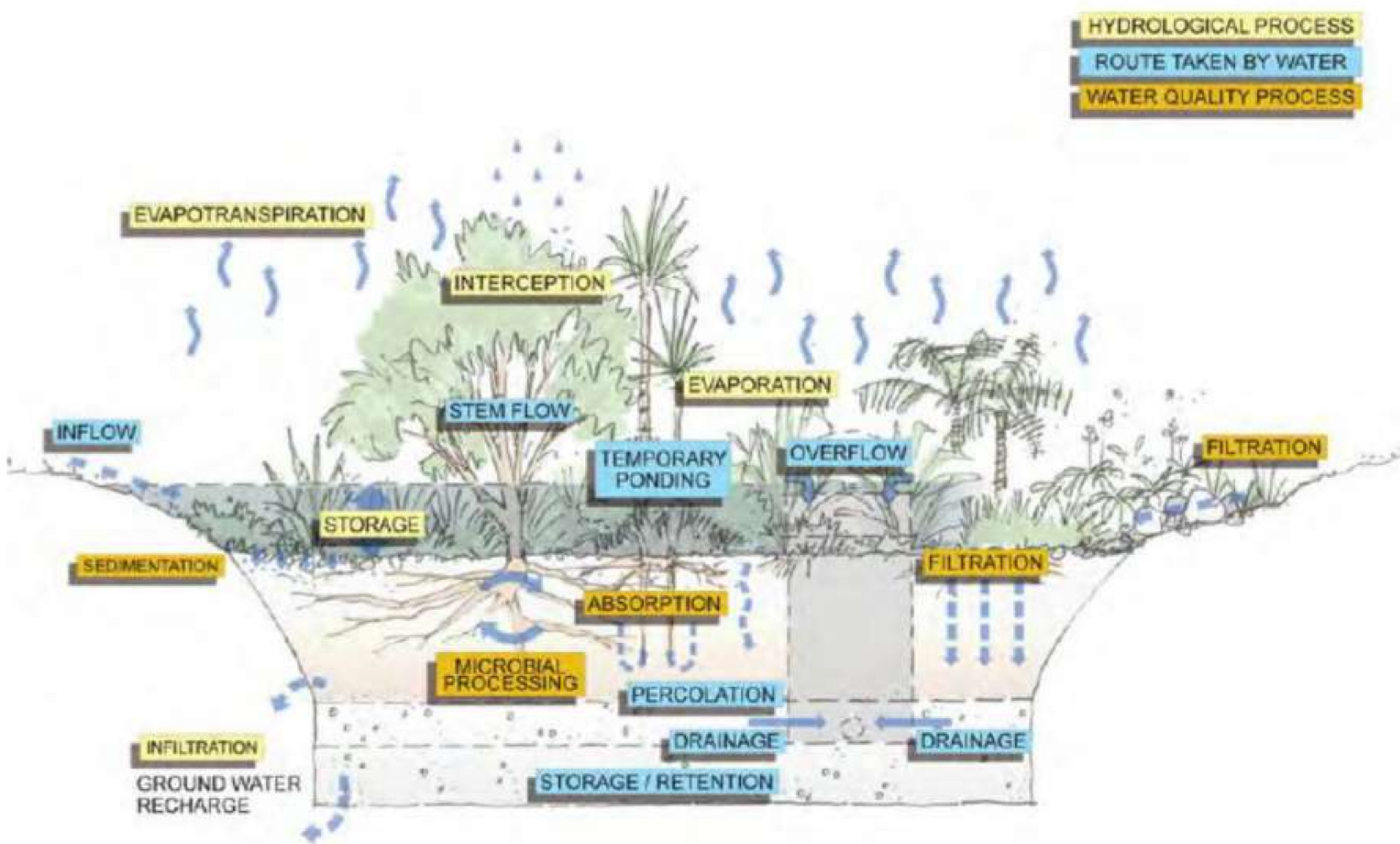
Figure 1 Bioretention cell components



Adapted from Auckland Council Rain Garden Construction Guide (2011)

Fassman, E., Simcock, R., Wang, S., 2013. Media specification for stormwater bioretention devices.

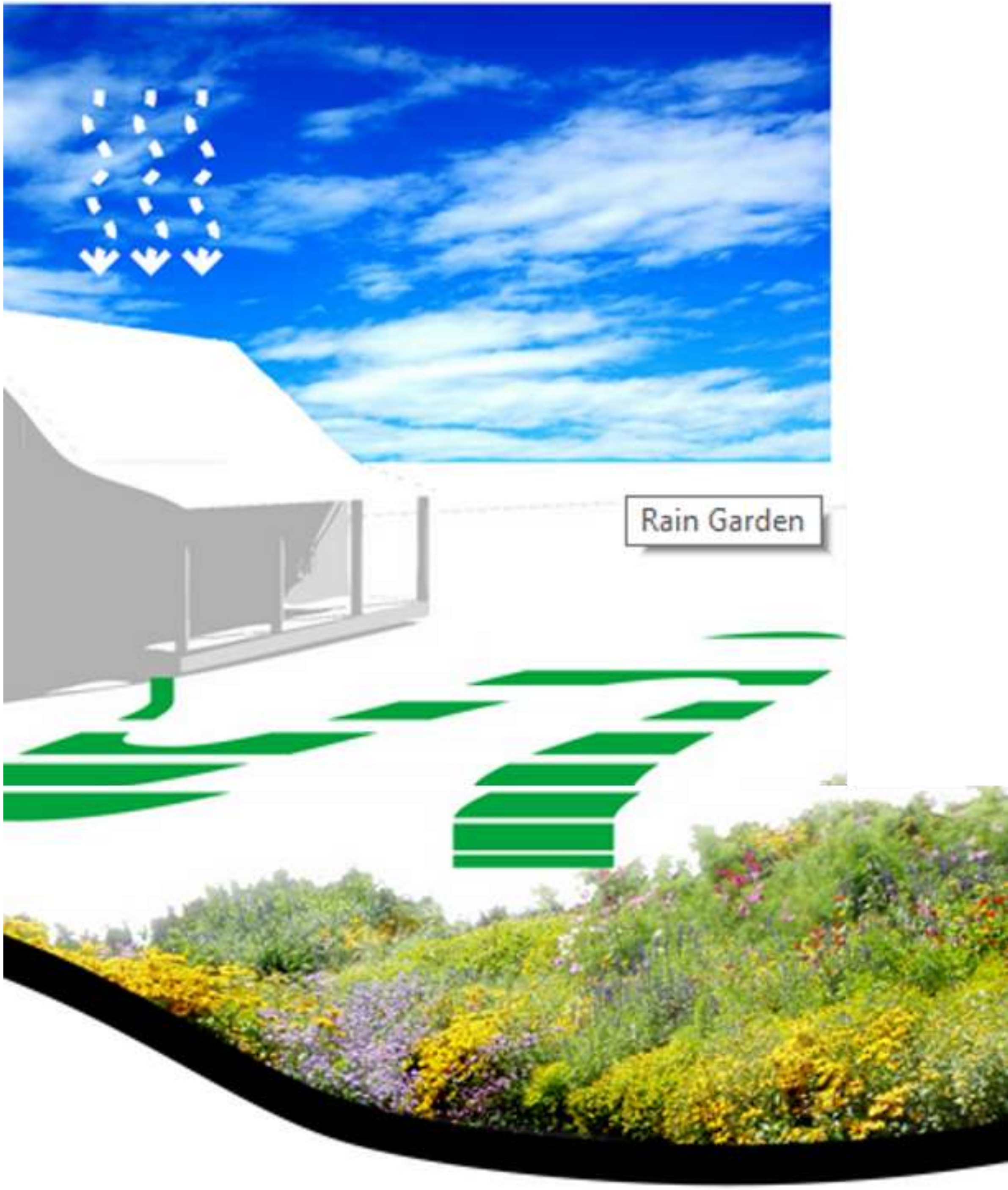
Figure 2 Bioretention hydrologic processes and pollutant removal mechanisms



Source: North Shore City Council (NSCC) Bioretention Guidelines (2008a)

Fassman, E., Simcock, R., Wang, S., 2013. Media specification for stormwater bioretention devices.

Conveyance



Conveyance

Conveyance

Conveyance

Conveyance

getyourbotanyon.blogspot.com


STOP

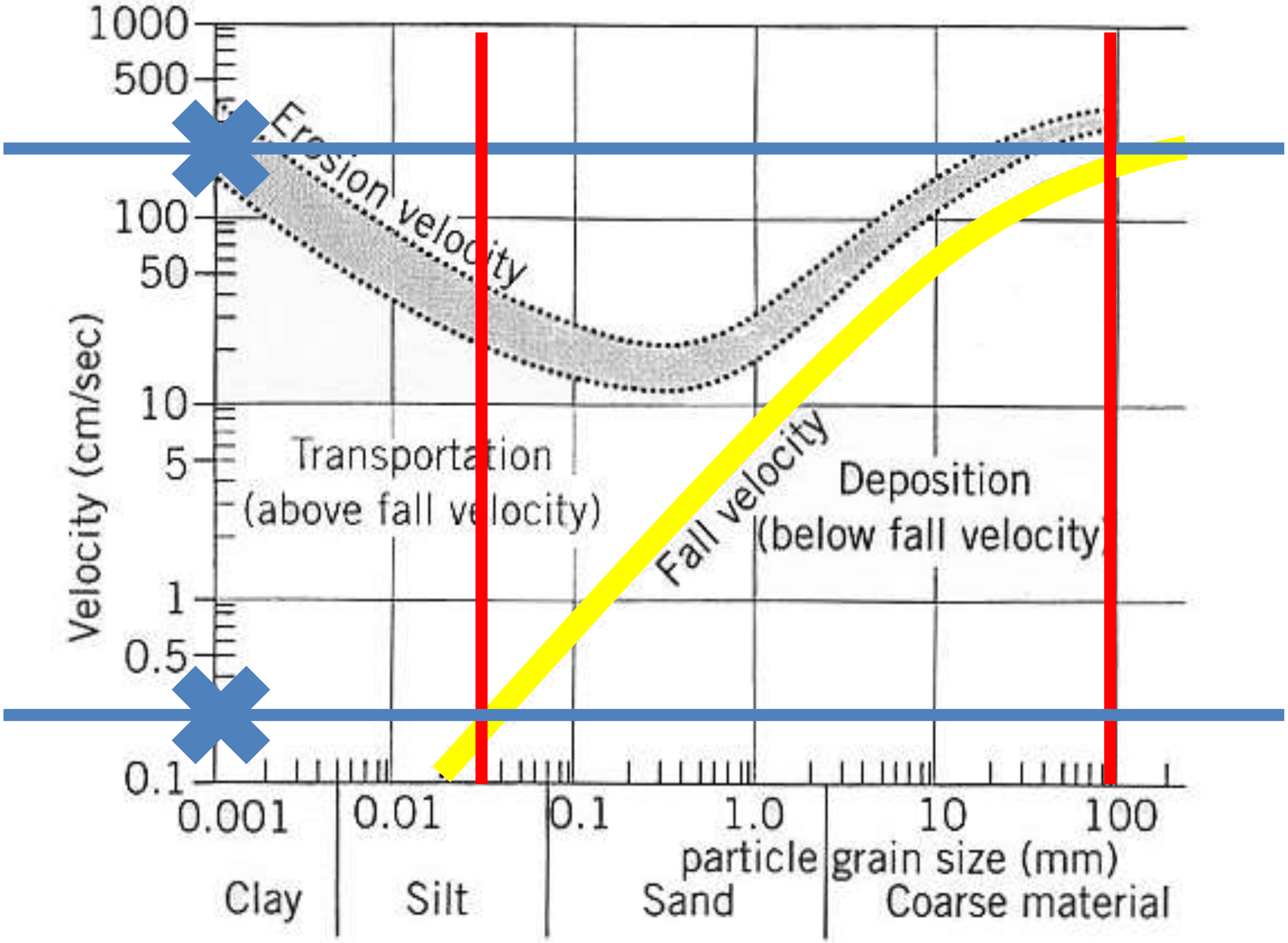

STOP

Ponding

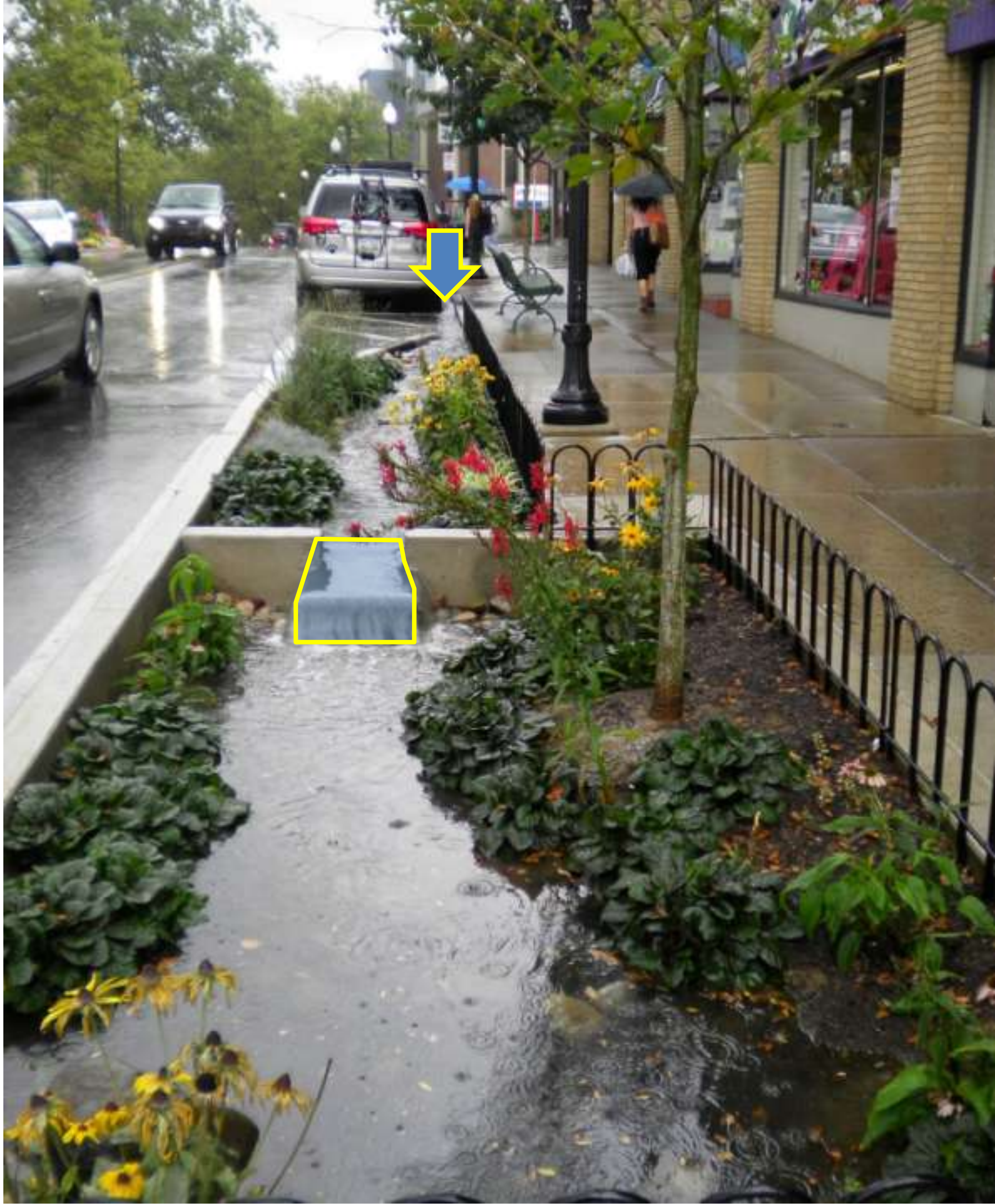
Ponding

Commercial Scale Bioretention

Achieving Settling Velocity

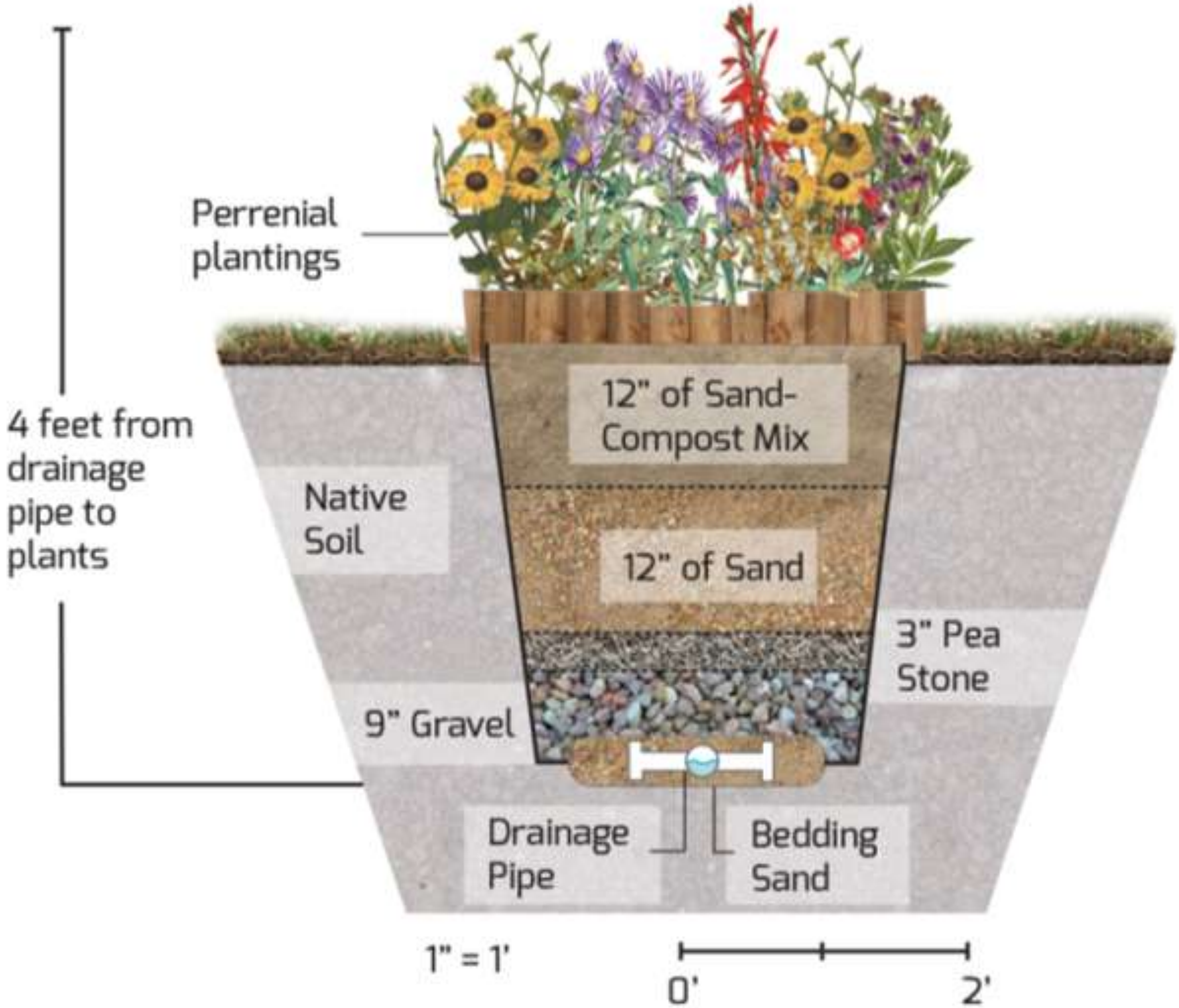


Green Streets



Green Streets

Bioretention Soil Media



Capturing the Outflow Hydrograph: Estimating Hydraulic Conductivity

$$K_z = \frac{D}{\sum_{i=1}^{n} \frac{d_i}{k_i}}$$

Where,
K_z is the vertical hydraulic conductivity for the layered system (m s^{-1})
D is the total cumulative depth of the layers (m)
d_i is the depth of a given layer (m)
k_i is the hydraulic conductivity of a given layer (m s^{-1})

$$K_x = \sum_{i=1}^{n} \frac{K_i d_i}{d}$$

Where,
K_x is the horizontal hydraulic conductivity (m s^{-1})
d_i is the depth of a given layer (m)
K_i is the hydraulic conductivity of a given layer (m s^{-1})
d is the horizontal distance of the given layer (m)

Capturing the Outflow Hydrograph: Estimating Hydraulic Conductivity

Bioretention Media	Depth (m)	Hydraulic Conductivity ($m\ s^{-1}$)	d_i/k_i
Sand/Compost Mixture	0.3048	1.50E-04	2.03E+03
Medium Sand	0.3048	6.90E-04	4.42E+02
Pea Gravel	0.0762	6.40E-03	1.19E+01
Gravel	0.2286	9.14E-03	2.50E+01
			Total d_i/k_i = 2.51E+03
			Total Depth = 0.9144 m
			K_z ($m\ s^{-1}$) = 3.64E-04

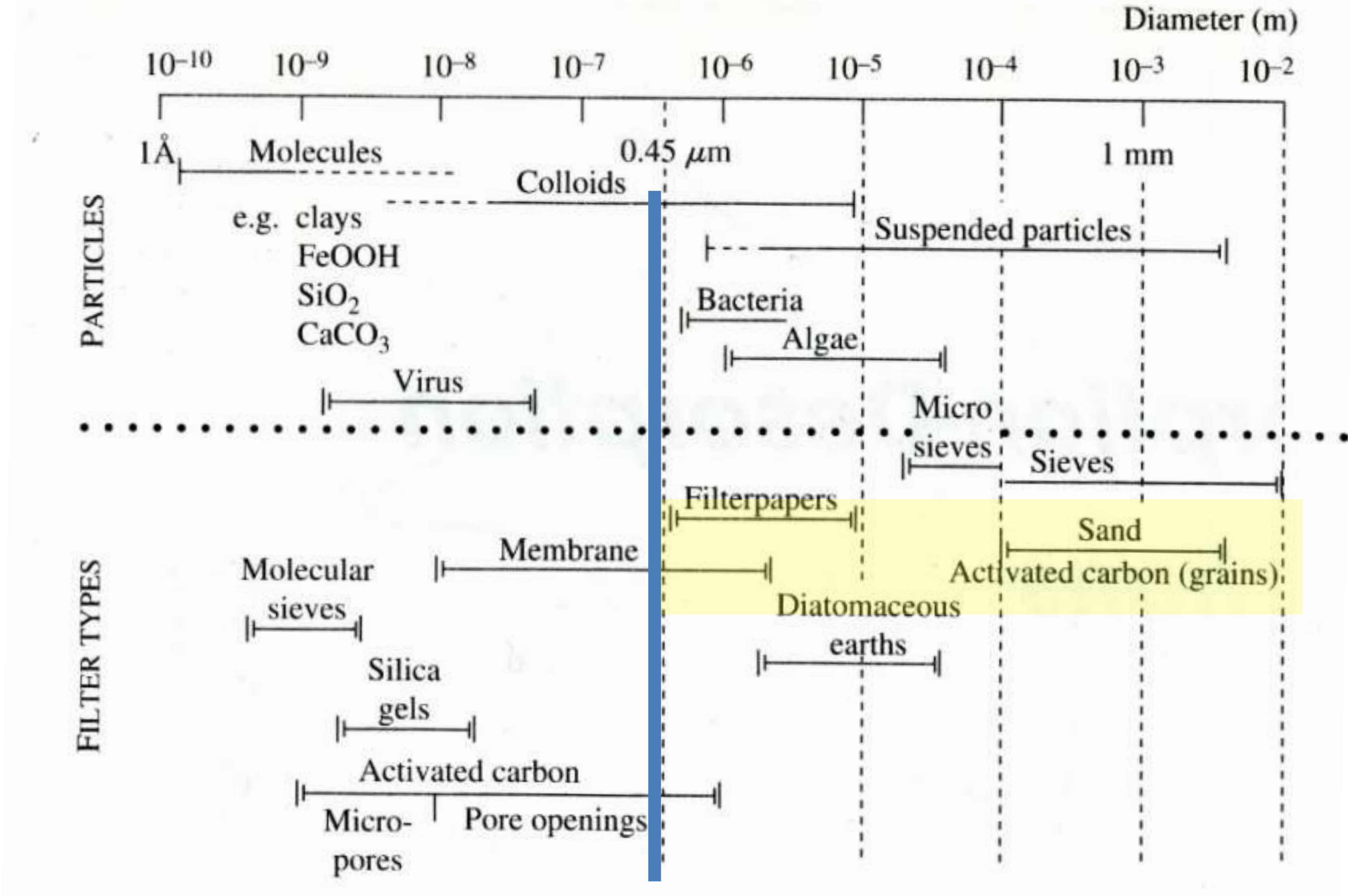
K_z = 131.04 cm hr^{-1} or 51.59 in hr^{-1}

Media Infiltration Rates

Reference	Infiltration Rate
This study	Modelled Rate at Installation: 131 cm hr^{-1}
Arias et al (2001)	Actual Rate: 463 cm hr^{-1}
Brix et al. (2001)	Actual Rate: 92 cm hr^{-1}
Chen et al (2013)	Actual Rate: 1.3 cm hr^{-1}
Davis et al. (2009)	Recommends > 2.5 cm hr^{-1}
Debusk et al. (2011)	Actual Rate: 11.8 cm hr^{-1}
Dietz and Clausen (2005)	Design Rate: 10 – 13 cm hr^{-1}. Actual Rate: 3.5 cm hr^{-1}
Hatt et al. (2008)	Actual Rate: 26.028 cm hr^{-1} to 232.92 cm hr^{-1} in different treatments
Hunt et al. (2006)	Actual Rate: 7.62 cm hr^{-1} to 38.1 cm hr^{-1}
Li and Davis (2008)	Actual Rate: Reduction from 43 – 164 cm hr^{-1} to 3-11 cm hr^{-1}
Lucas and Greenway (2011)	Vegetated: 27.7 cm hr^{-1} to 59.6 cm hr^{-1}
Thompson et al. (2008)	Actual Rate: 150 to 178 cm hr^{-1} (sand/compost mix)
Washington State University Pierce County Extension (2012)	Recommends > 2.54 cm hr^{-1}

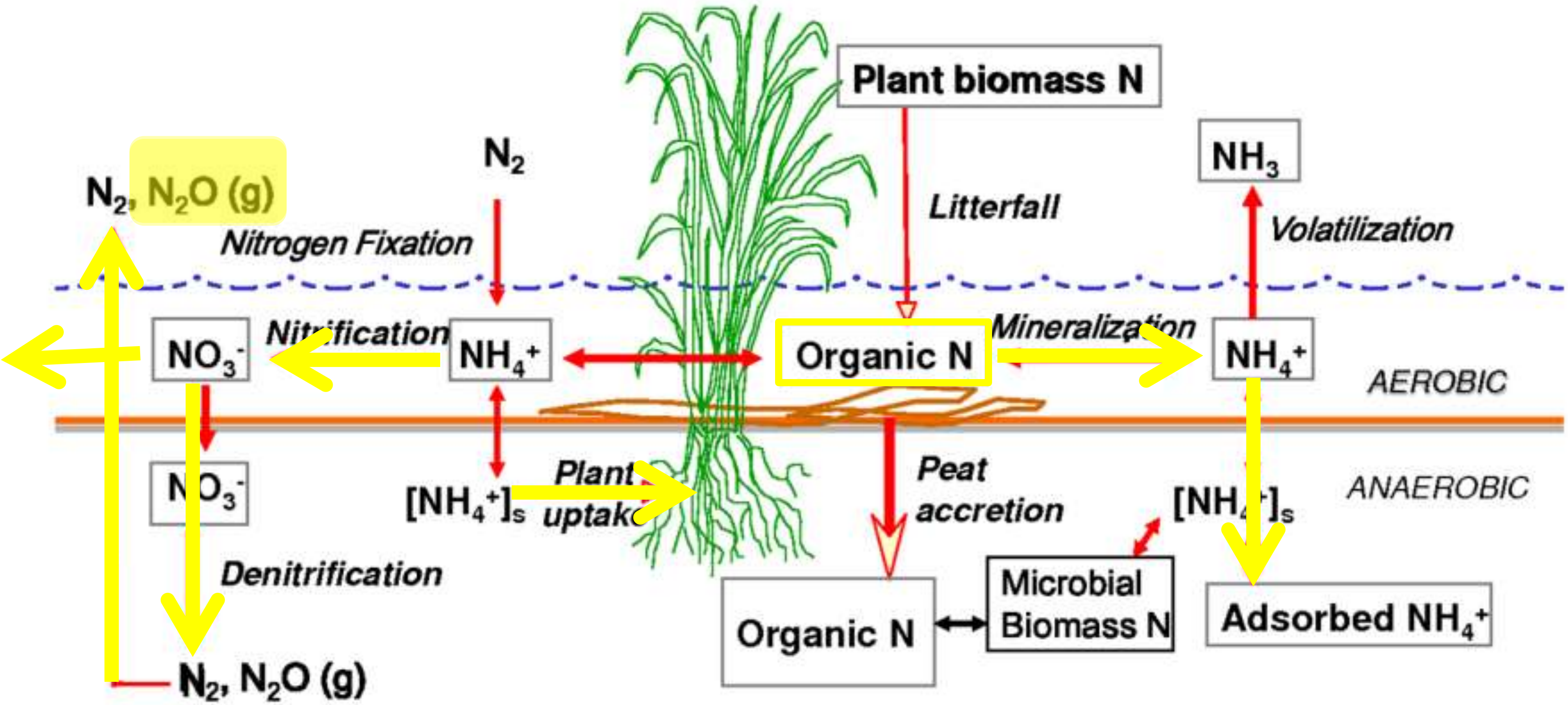
Target > 3 in/hr (7.62 cm)

Filtration

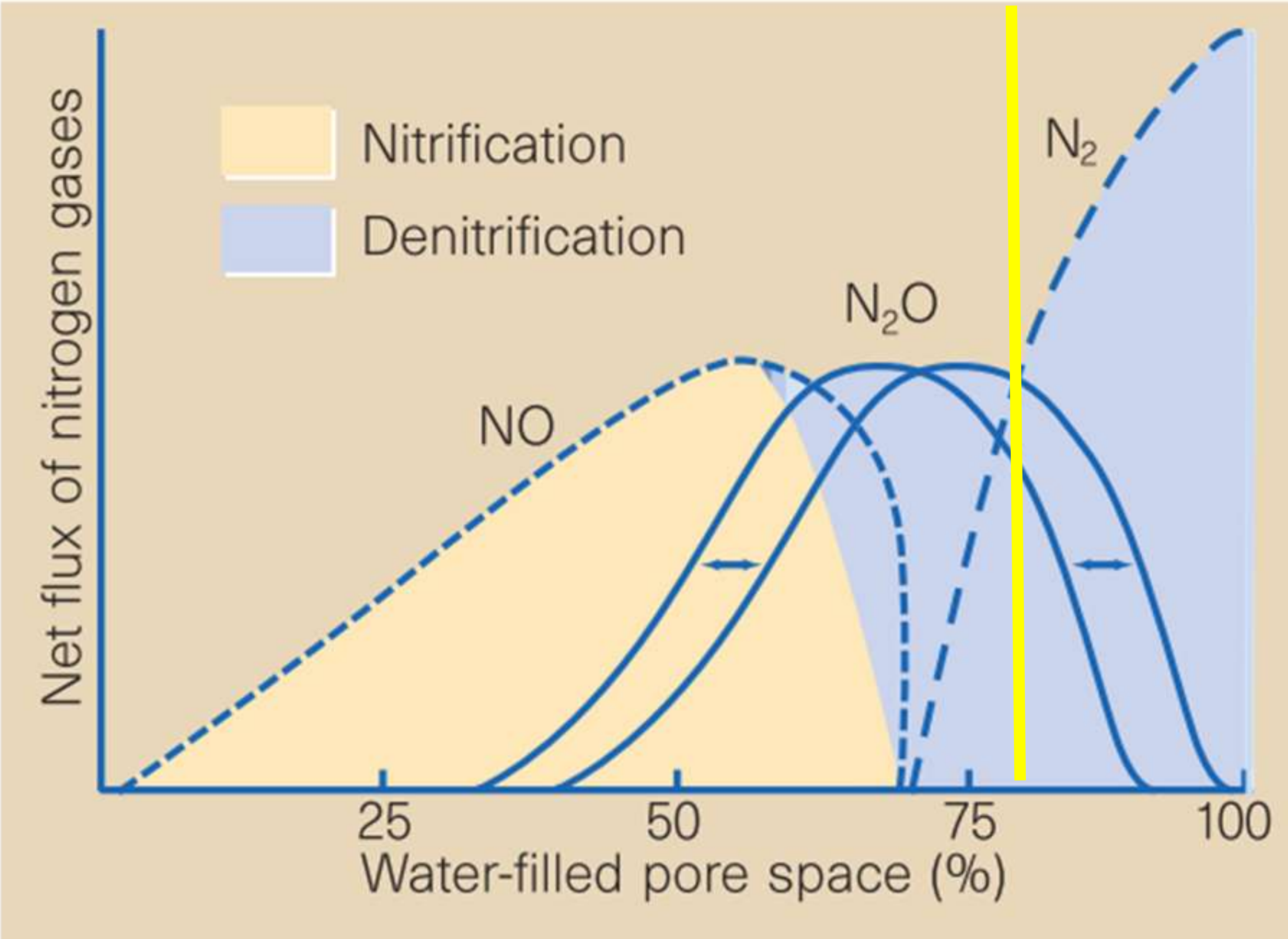


Diameter (m)
10−10
10−9
10−8
10−7
10−6
10−5
10−4
10−3
10−2
1Å
Molecules
0.45 μm
1 mm
Colloids
e.g. clays
FeOOH
SiO2
CaCO3
Suspended particles
Bacteria
Algae
Virus
PARTICLES
Micro
sieves
Sieves
Filterpapers
Sand
Membrane
Molecular
sieves
Activated carbon (grains)
Diatomaceous
earths
Silica
gels
Activated carbon
Micro-
pores
Pore openings
FILTER TYPES

Nitrogen Removal Mechanisms



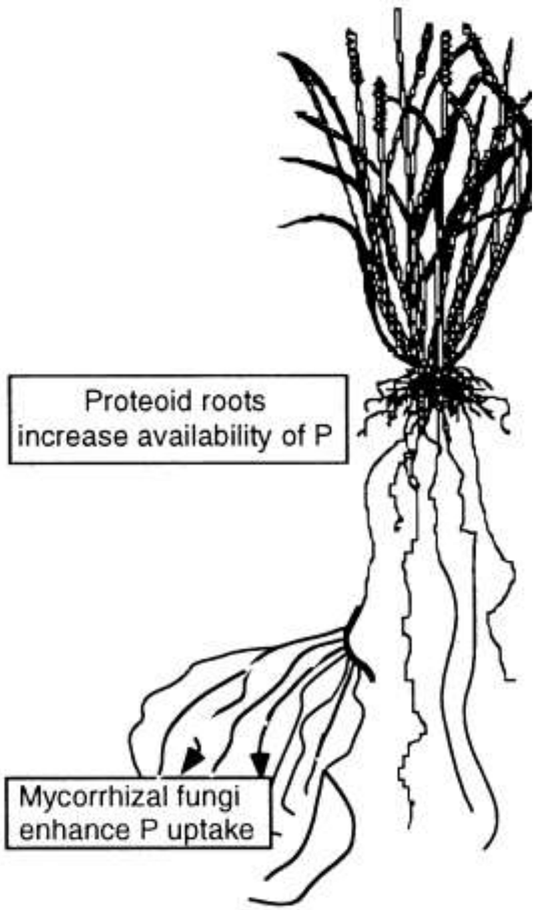
Davis et al. (2006); Bratieres et al. (2008); Kim et al. (2003); Charpuis-Lardy et al. (2007)


Nitrification
Denitrification
N_2
N_2O
NO
Net flux of nitrogen gases
25
50
75
100
Water-filled pore space (%)

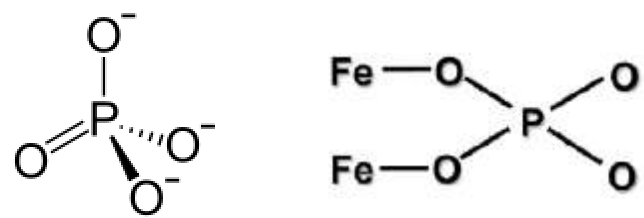
Green Streets

Raise underdrain for NO_3^- removal

Phosphorus Removal Mechanisms



1. Physical Filtration: Non-labile P
2. Sorption of SRP: Fe, Ca, and Al in Soil



$$2{\equiv}FeOH^{-0.5} + PO_4^{3-} + 2H^+ = ({\equiv}FeO)_2PO_2^{2-} + 2H_2O$$

3. Plant Uptake: SRP

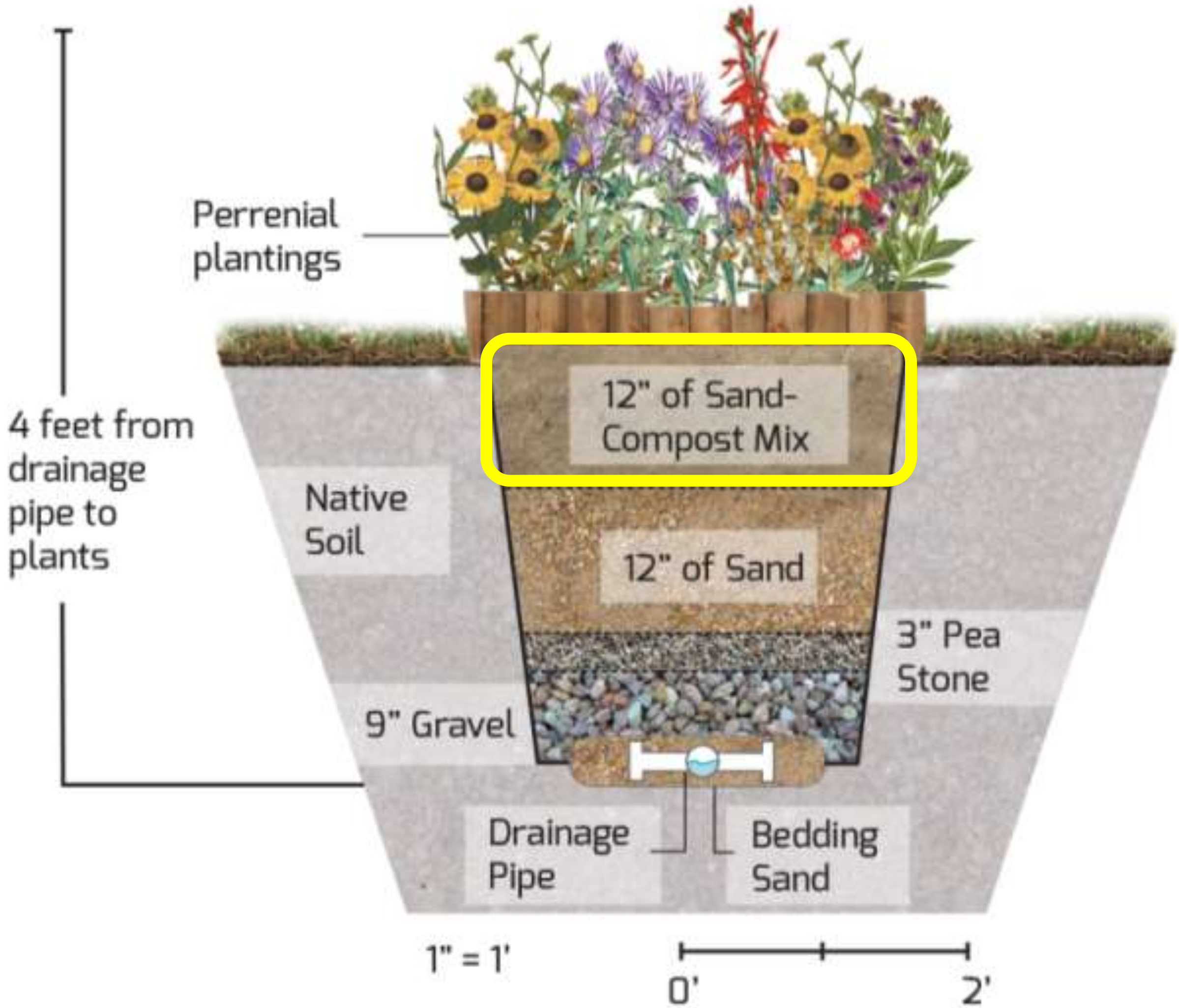
Tanner (1996); Arias et al. (2001); Lucas and Greenway (2011); Liping et al. (2012)

Soil Media Chemical Characteristics

Table 1 Recommended bioretention filter media mixes from worldwide sources[1]

Guideline	Aggregate	Organic	Note
Auckland Regional Council (2003), Waitakere City Council (2004)	Sandy loam, loamy sand, loam, loam/sand mix (35 - 60% v/v sand)	Not specified	Clay content < 25% v/v
Prince George's County, Maryland (2007)	50 - 60% v/v sand	20 - 30% v/v well aged leaf compost, 20 - 30% v/v topsoil2	Clay content < 5% v/v
The SUDS manual (Woods-Ballard et al. 2007)	35 - 60% v/v sand, 30 - 50% v/v silt	0 - 4% v/v organic matter	10 - 25% v/v clay content
Facility for Advanced Water Biofiltration (FAWB, 2009a)	Washed, well graded sand with specified PSD band	3% w/w organic material	Clay content < 3% w/w, top 100 mm to be ameliorated with organic matter and fertilizer
Seattle Public Utilities (2008)	60 - 65% v/v mineral aggregate, PSD limit ("clean sand" with 2 - 5% passing #200 sieve), U3 ≥ 4	35 - 40% v/v fine compost which has > 40% w/w organic matter content	
Puget Sound Partnership (2009)		40% v/v compost, or 8 - 10% w/w organic matter	
North Carolina Cooperative Extension Service (Hunt & Lord 2006)	85 - 88% v/v washed medium sand4	3 - 5% v/v organic matter	8 - 12% v/v silt and clay

Conventional Bioretention Design



Recommended By:

1. Vermont Agency of Natural Resources (2002)
2. Washington State University Pierce County Extension (2012)
3. Center for Watershed Protection

Image Credit: Hurley, S., Zeitz, G.,(unpublished)

Bioretention Layout View

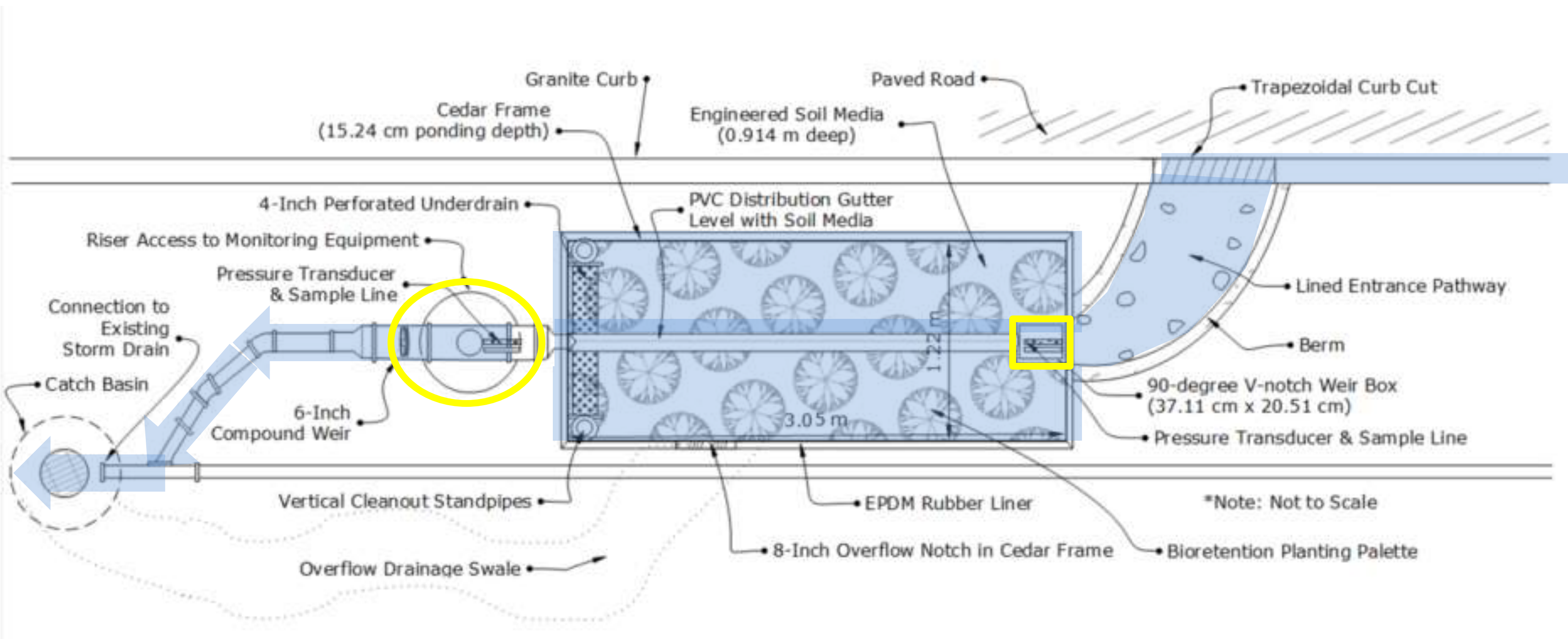
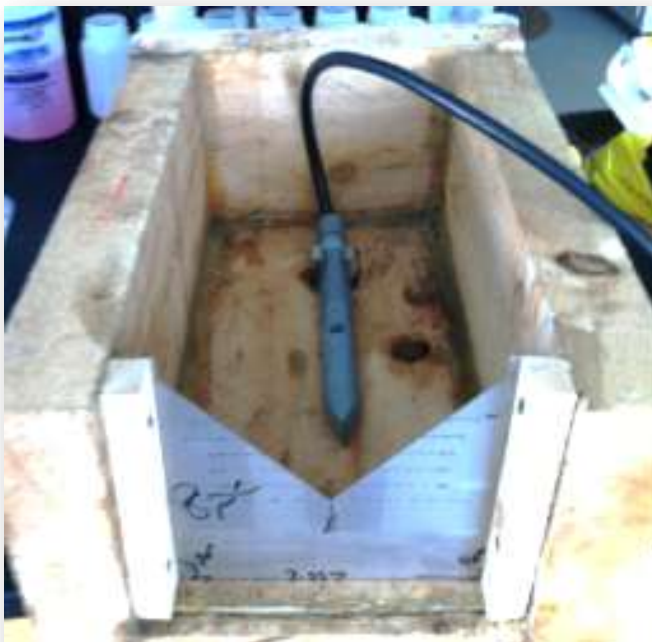
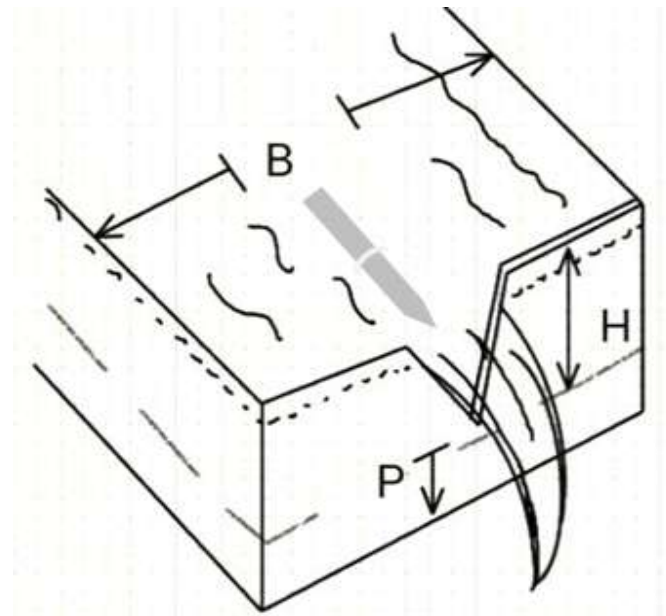


Image Reference: Cording, A., Hurley, S., Whitney, D. (**In Press**) Monitoring methods and designs for evaluating bioretention performance. Journal of Environmental Engineering.

How do you measure the runoff from the road surface?



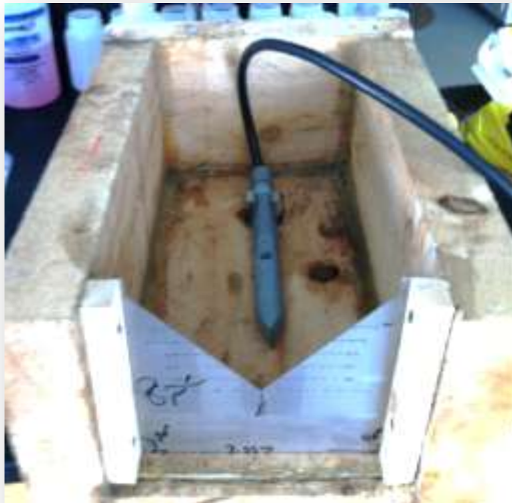
Weir thickness = 1.59 mm stainless steel
Teledyne™ ISCO Model 720 Pressure Transducer



Maximum Capacity = 10.05 L

ASTM –D5242; U.S. Bureau of Reclamation (2001)

Monitoring Bioretention Systems



Inflow 90^{o} Weir Box

Outflow Thel-Mar™ Weir

$$Q=CH^n$$

Where:

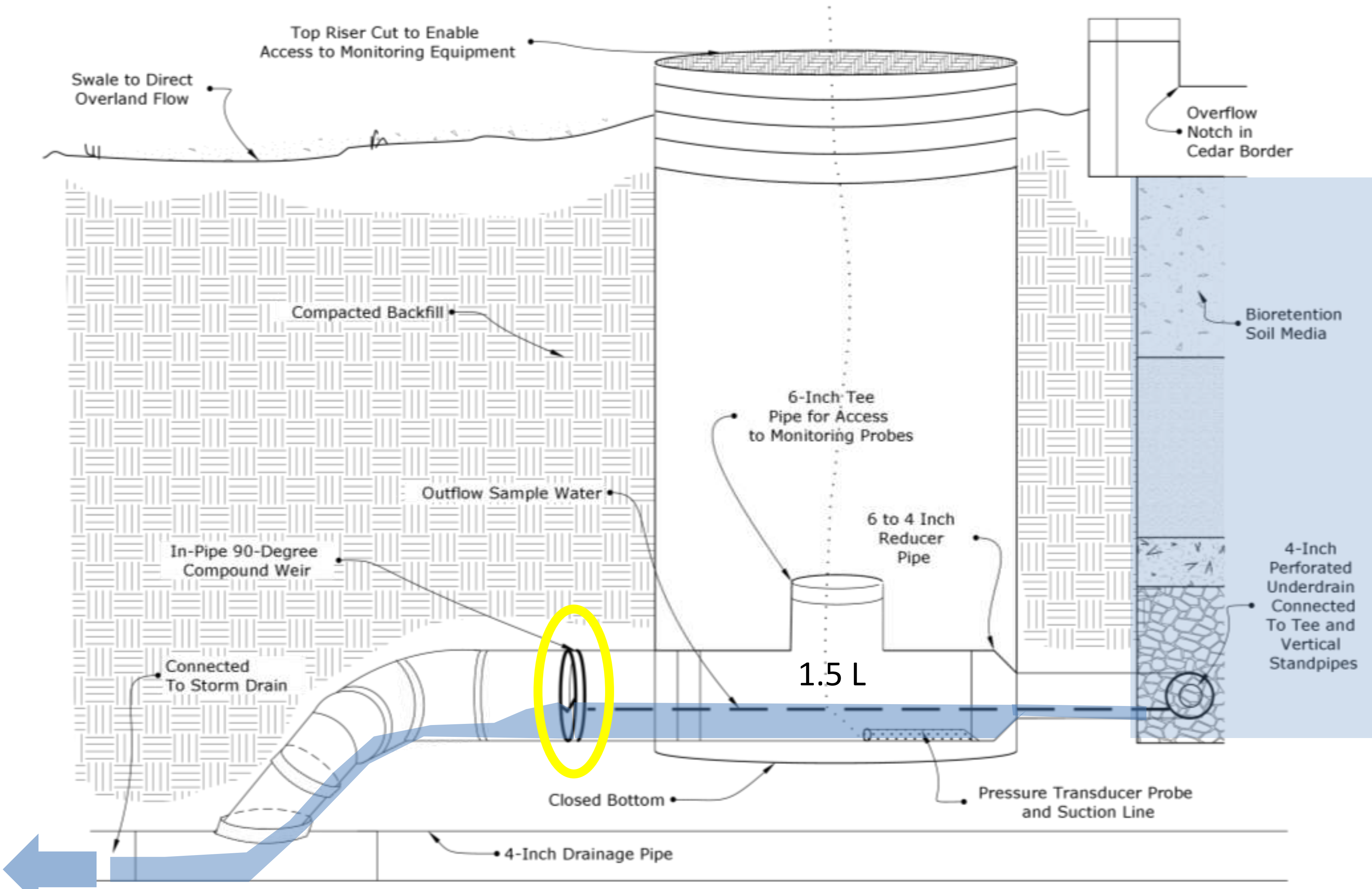
Q = flow rate over the weir (cfs, L s^{-1})

C= coefficient of discharge, or weir coefficient

H= height of water behind the weir (pressure transducer)

n = an empirical exponent (dimensionless)

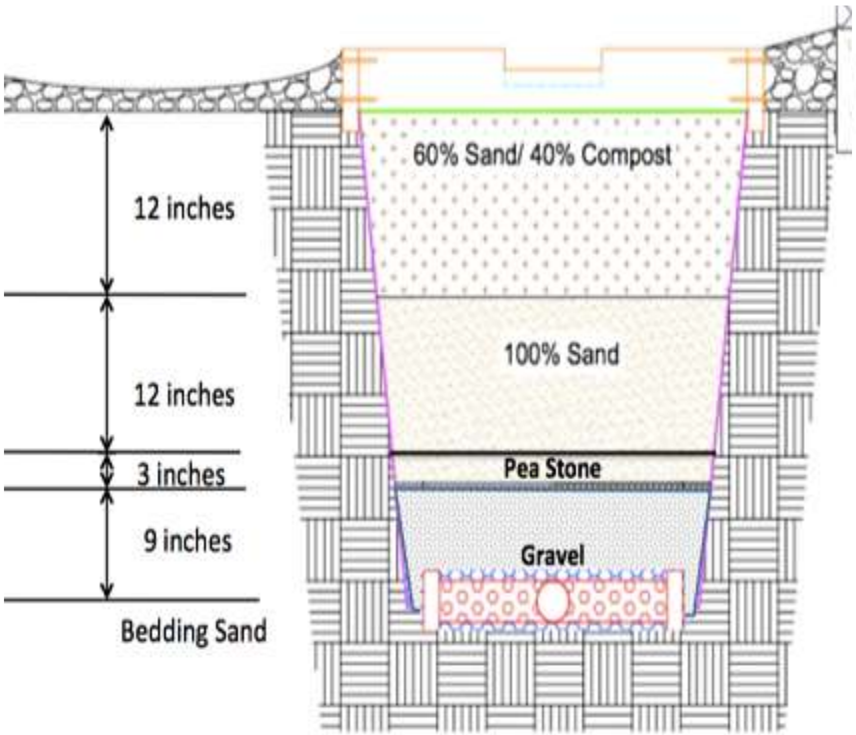
How to Capture the Outflow Hydrograph?



Cording, A., Hurley, S., Whitney, D. (**In Press - 2017**) Monitoring methods and designs for evaluating bioretention performance. Journal of Environmental Engineering.

Comparing Soil Media Treatments

Conventional Media (CM)



Sorbtive Media ™ (SM)

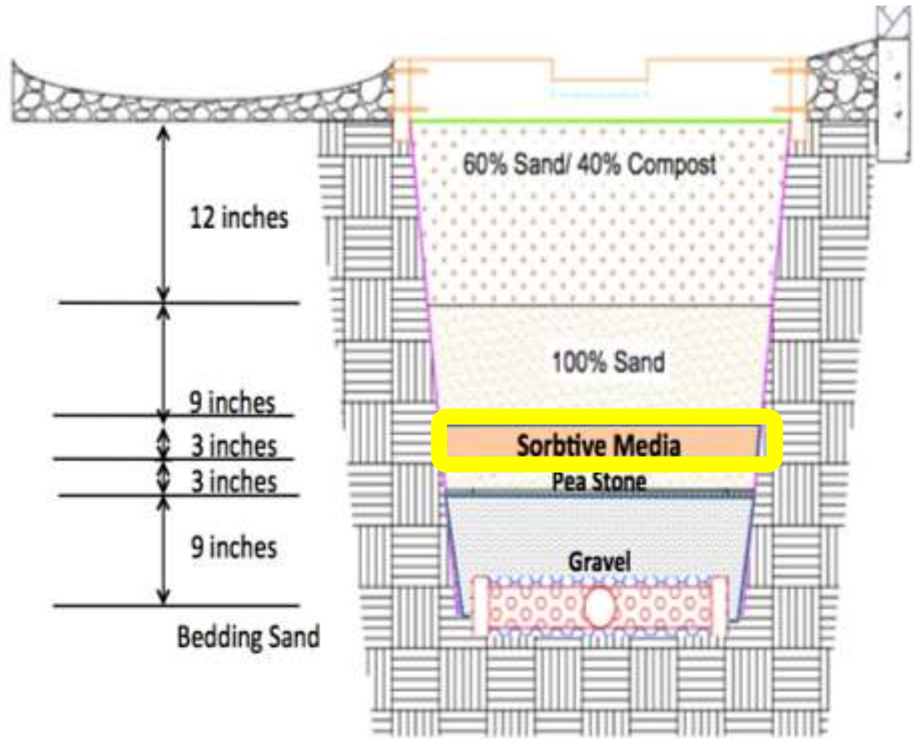


Image Credit: J. Schultz, C. Brackett, J. Nummy, O. Lapierre (unpublished).

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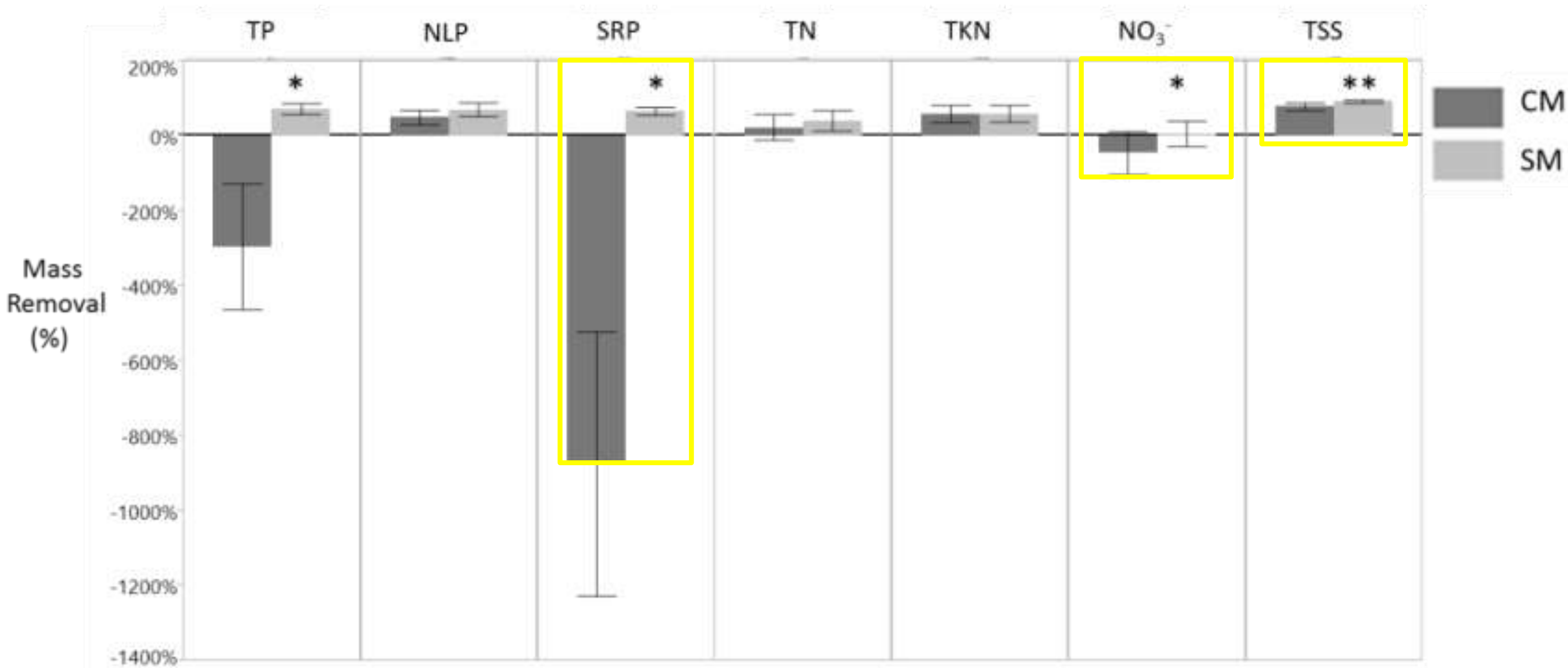
imbrium

Results: Outflow Mass Between Soil Media Treatments



ns = p > 0.05, * = p ≤ 0.05, ** = p ≤ 0.01, *** = p ≤ 0.001, **** = p ≤ 0.0001.

Outflow mass from SM was lower than the CM for SRP, NO_3^-, and TSS

Cording, A., Hurley, S., Adair, E. (**In Preparation**). *Evaluating critical bioretention designs features in the context of climate change*.

Windward Mall Commercial Bioretention Kane’ohe, Hawai’i

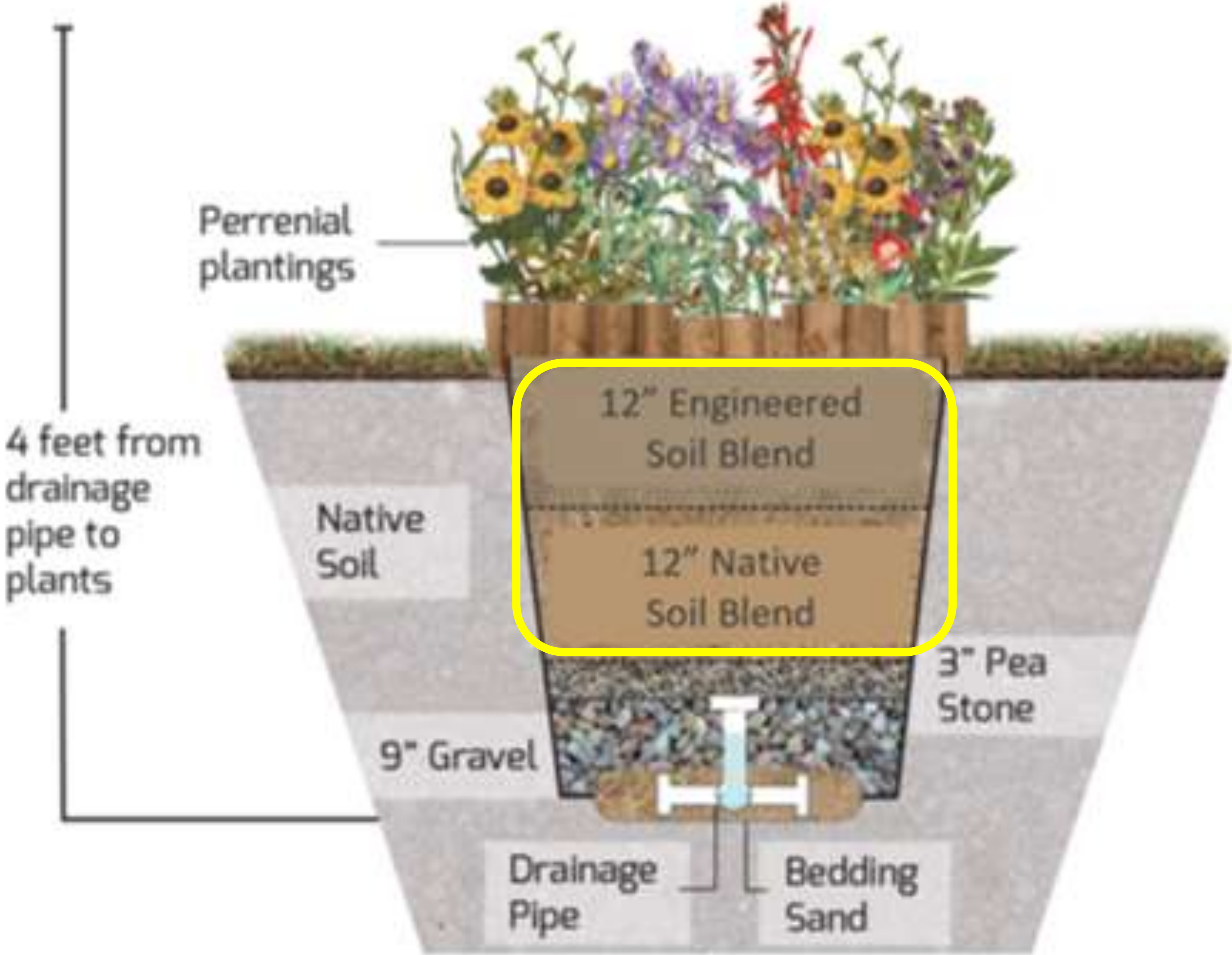
hui o ko'olaupoko

Protecting ocean health by restoring the 'āina: mauka to makai

ECOSOLUTIONS

Innovative designs - living systems

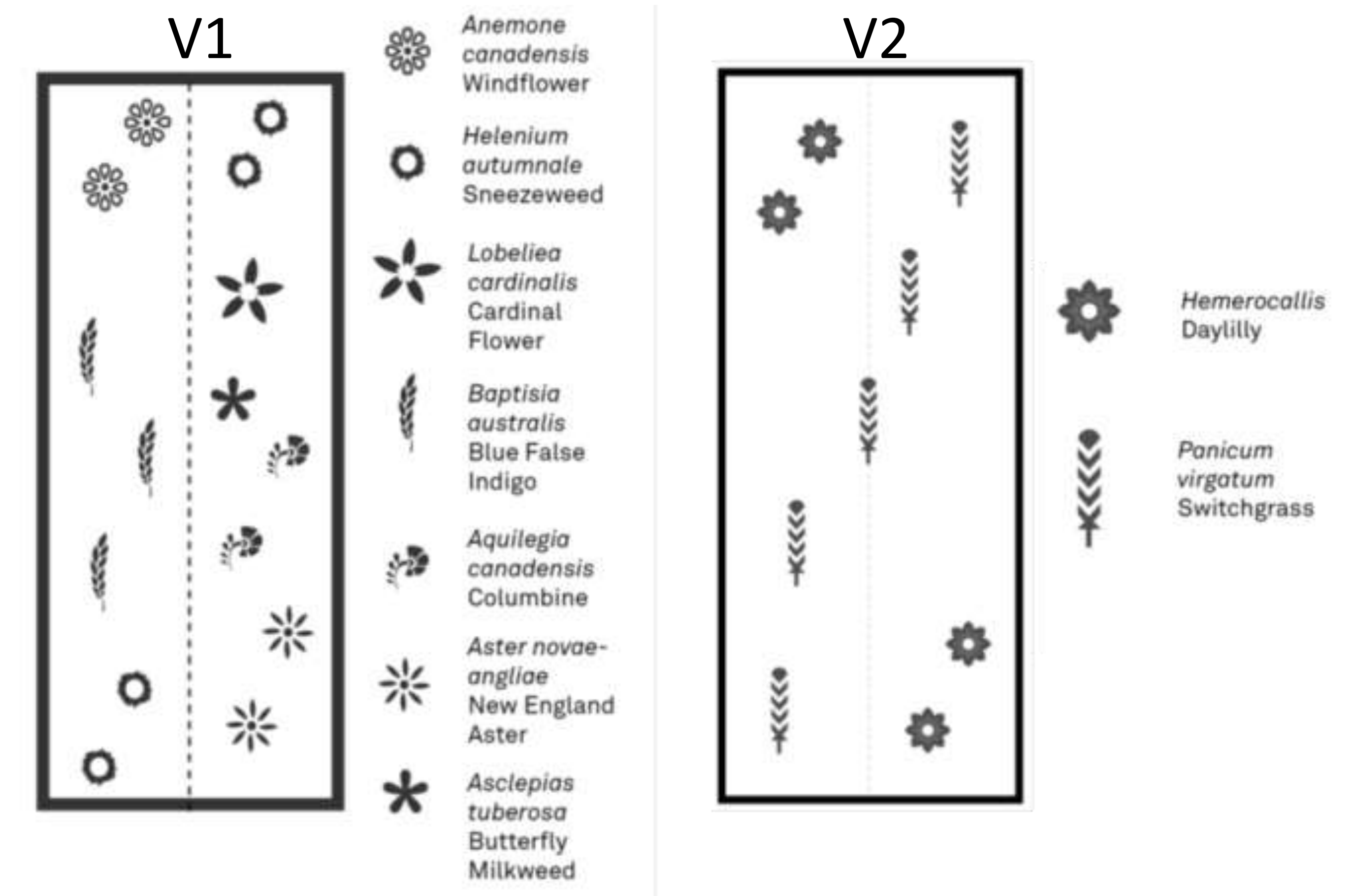
ROTH ECOLOGICAL DESIGN INTERNATIONAL, LLC


Perrenial
plantings
4 feet from
drainage
pipe to
plants
Native
Soil
12" Engineered
Soil Blend
12" Native
Soil Blend
3" Pea
Stone
9" Gravel
Drainage
Pipe
Bedding
Sand

The Role of Plants

- Sedimentation and erosion control. Dense foliage physically protects the substrate surface from erosion and slows stormwater velocity; both help minimise surface re-suspension of deposited sediment. Foliage also impedes movement of floating materials (litter and some organic mulches) into overflows.
- Microbial processes. Plants provide organic substrates on which many microbial processes are based, particularly in the rhizosphere (around roots) and decomposing leaf litter.
- Nitrogen and phosphorus removal. Plants extract these macro-nutrients when actively growing; decomposing leaves and roots gradually release these but at a rate that can be re-used by the plants (rather than leached).
- Metal removal. Soluble metals are taken up by plants during active growth periods and incorporated into leaves and roots. High biomass is usually associated with greater metal removal.
- Stormwater volume attenuation. Evapotranspiration creates air-filled pore volume within the media to store stormwater, therefore contributing to the volume that can be treated before overflow occurs.

Comparing Vegetation Treatments



Planting Configuration: Vegetation Palette 1 (left) and Vegetation Palette 2 (right) (Diagram created by S. Hurley and A. Zeitz, unpublished).

Vegetation Planted: May 2013

Low Diversity (2 species) vs. High Diversity (7 species)

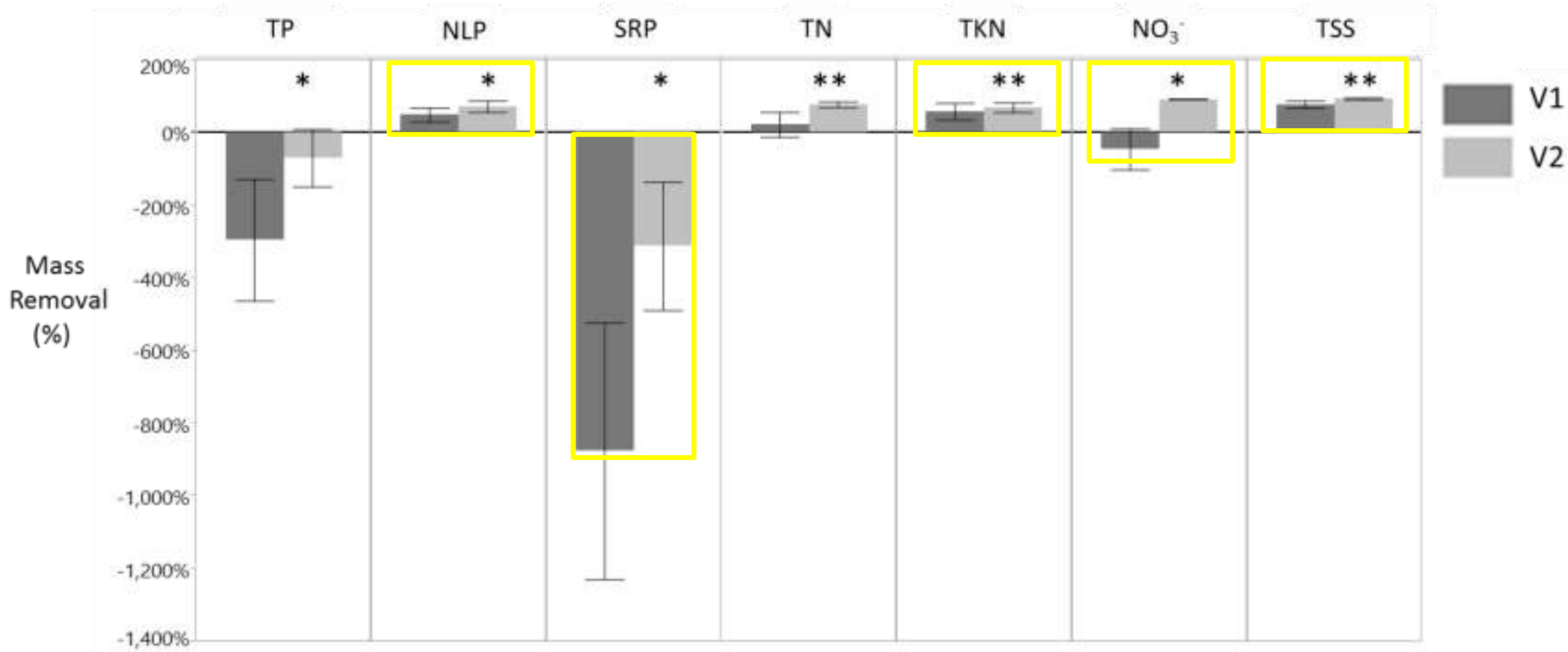
Established Vegetation: August 2013

Low Diversity (2 species) vs. High Diversity (7 species)

Vegetation 1 (V1)

Vegetation 2 (V2)

Results:
Outflow Mass between Vegetation Treatments



ns = p > 0.05, * = p ≤ 0.05, ** = p ≤ 0.01, *** = p ≤ 0.001, **** = p ≤ 0.0001.

Paired t-test (n = 6) results indicate that outflow mass from V2 was significantly lower than V1 for all constituents

Cording, A., Hurley, S., Adair, E. (**In Preparation**). *Evaluating critical bioretention designs features in the context of climate change*.

Discussion: Vegetation Treatments

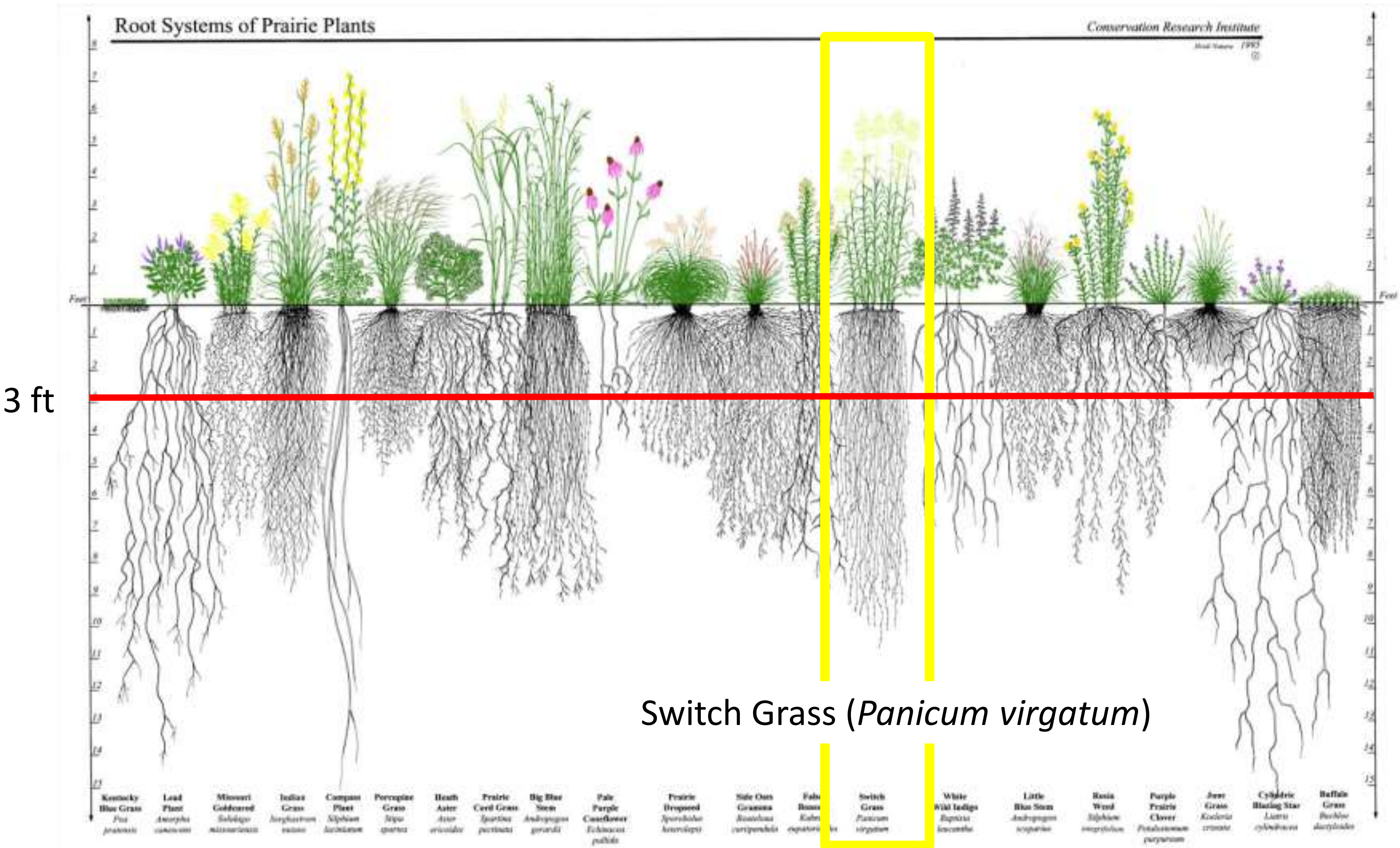


Image Source: Conservation Research Institute; Mann et al. (2013)

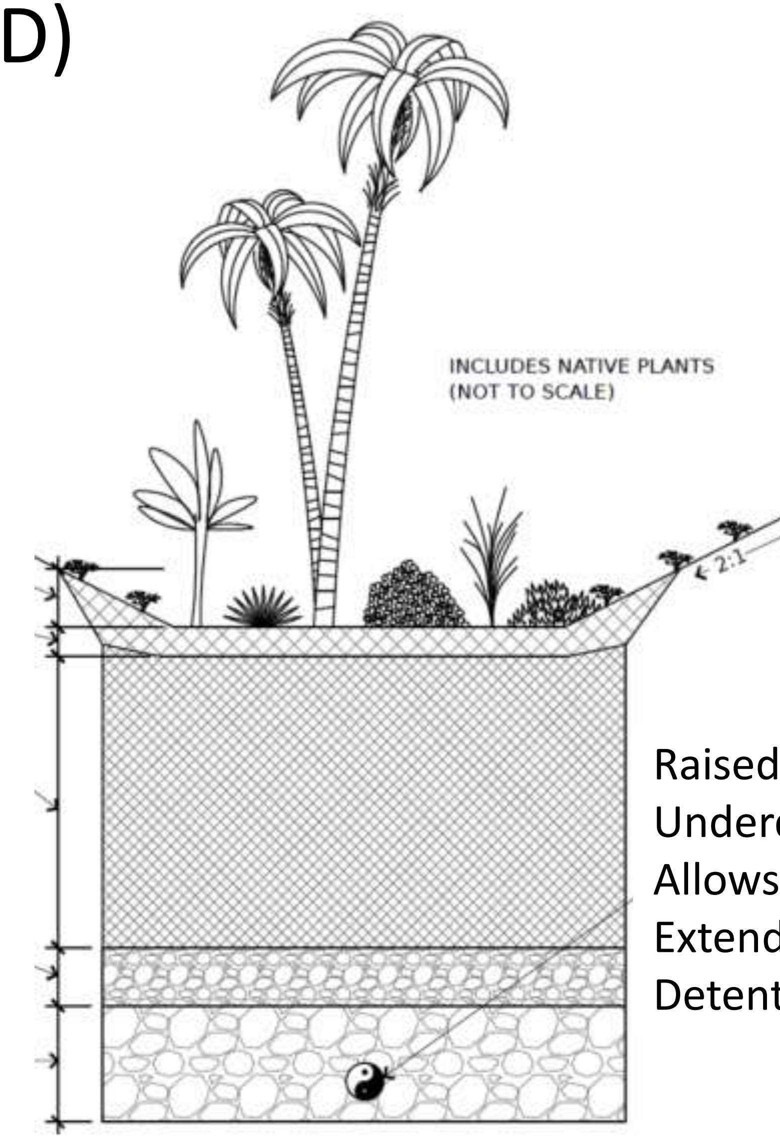
Effective Bioretention (LID) Design Criteria

Native Soil Blend:
Target Infiltration Rate 7.62 - 100 cm/hr
High Mineral Contents (Ca, Fe)

Extended Retention, NO_3^- Removal:
Target Retention Time > 6hrs

Native Plants:
Target >75% Cover
Target Root Depths 1 to 4 ft

- Low Nutrient Compost (<30%)
- Mulch or Stone Top Dressing



Raised Underdrain Allows for Extended Detention

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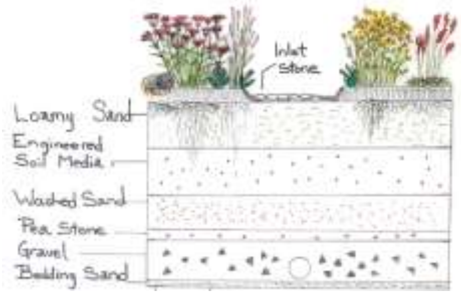
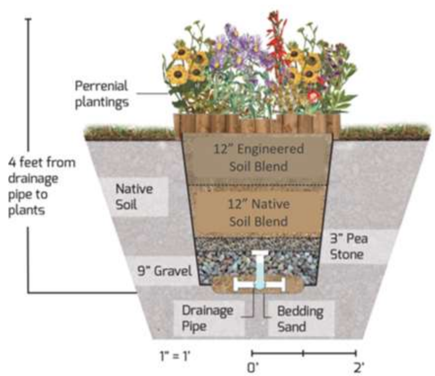
Future Research Needs





1. Chemical characteristics of soil media to minimize soluble N and P contributions (compost, mulch, soil), but achieve target infiltration rate?

2. Retention time, carbon requirements for thorough denitrification in different medias?

3. Planting options to achieve maximium soil stability and pollutant uptake, given soil conditions (#1) above?

Images: Drawing: A. Cording (2016) Unpublished, (Middle) Cording, A., Hurley, S., Adair, E., Ross, D. (In Preparation). *Evaluating critical bioretention designs features in the context of climate change*. (Bottom) 2012 Nature Education, Conservation Research Institute, Heidi Natura.

Collaboration

What percentage of compost?

- Provide nutrients for plants
- Increase water holding capacity

What chemical characteristics of soil?

- Provide P sorption
- Enhance denitrification

What soil texture (% sand, silt, clay)?

- Provide adequate drainage/infiltration

What amendments can be added?

Lorra
Naholowaʻa

Growth Trials:

Bioretention
Green Roofs

Preliminary Results
Coming Soon!

ECOSOLUTIONS

ISLAND TOPSOIL

Large Scale LID:
Pre-Development Conditions



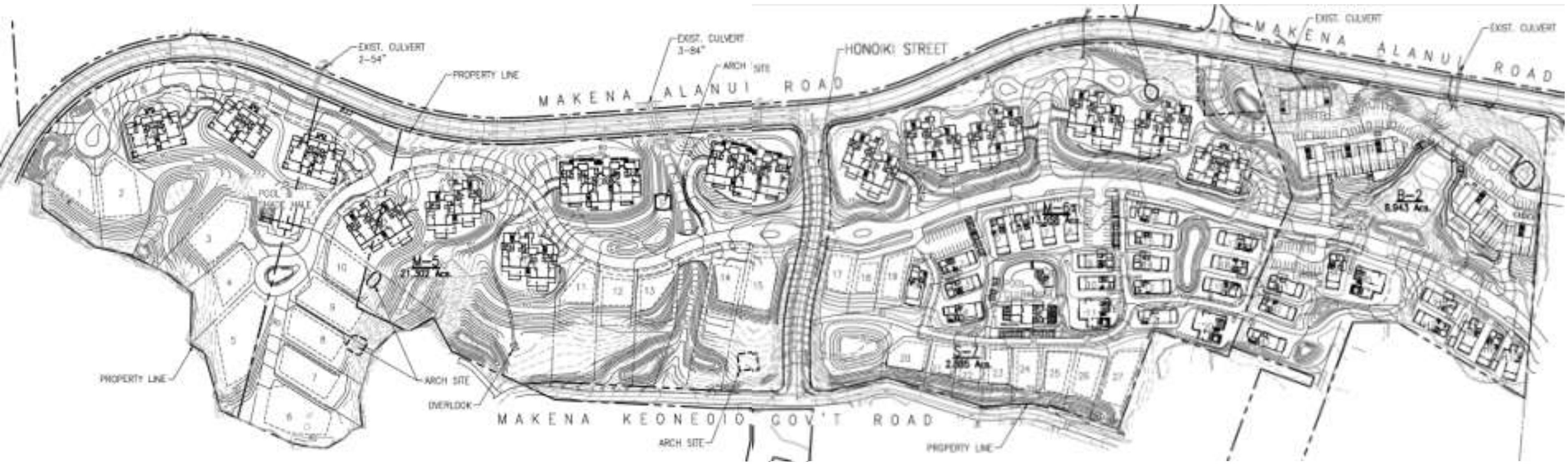





CULTURE & HERITAGE CENTER
B-2
M-6
M-5
S-7
H-M
MAKENA LANDING
KEAWALA'I CHURCH
Preservation Site
Sidewalks
Trails
TO MALUAK
BEACH PAR
MALUAKA BEACH

Proposed M5/M6/S7/B2 Low Impact Development (LID) Site Plan

Traditional Development Basemap

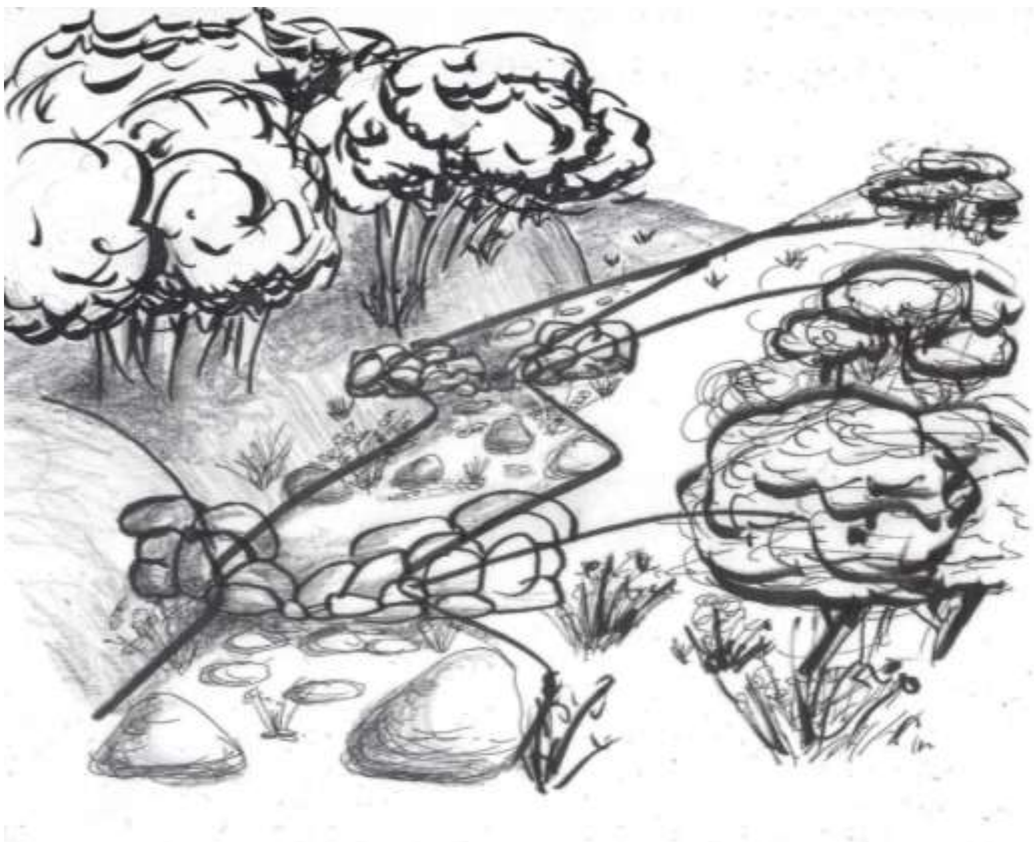


Required to **retain**:

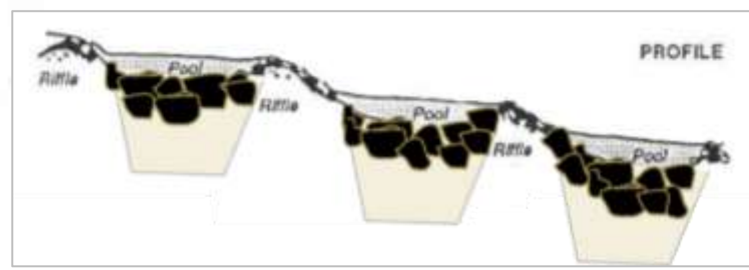
➢ 100% of the 2.5" (50-yr, 1-hr) storm event

LID Opportunities

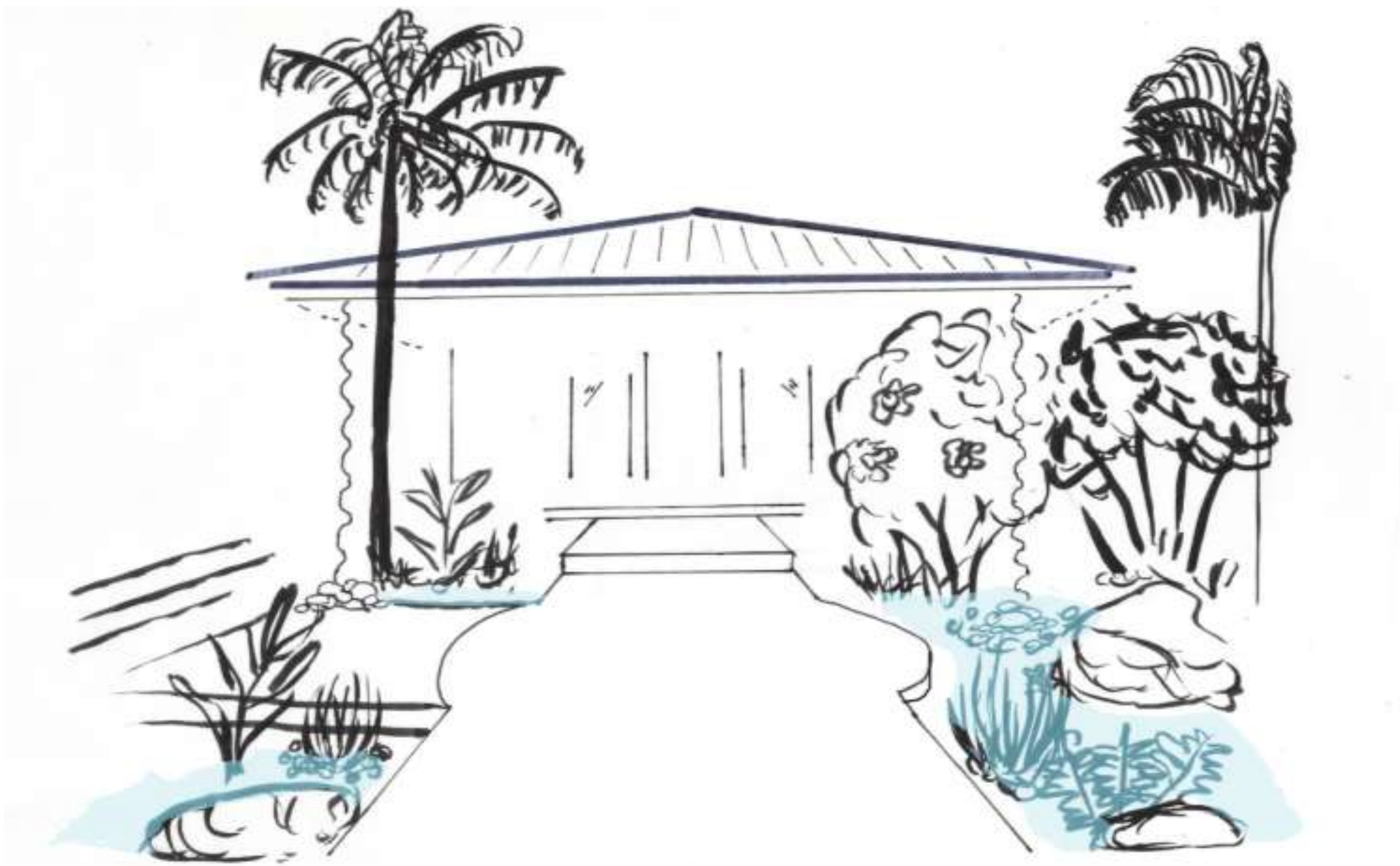
Forest Restoration and Natural Slope Stabilization



- Restoration of native forest
- Bank stabilization
- Naturalized rock check dams
- Reduction of peak flow rate
- Removal of sediment



Residential Bioretention



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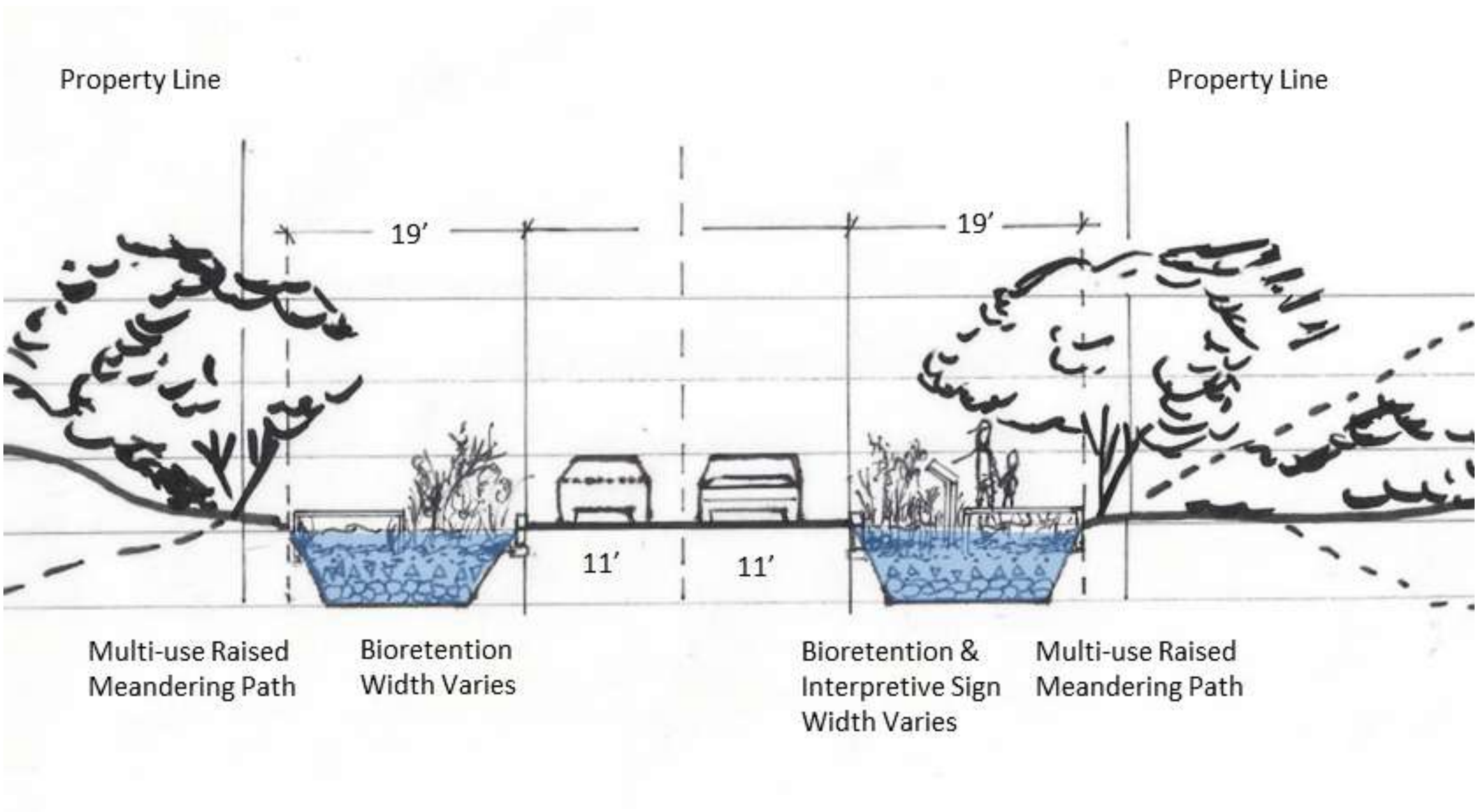
Bioretention Green Streets



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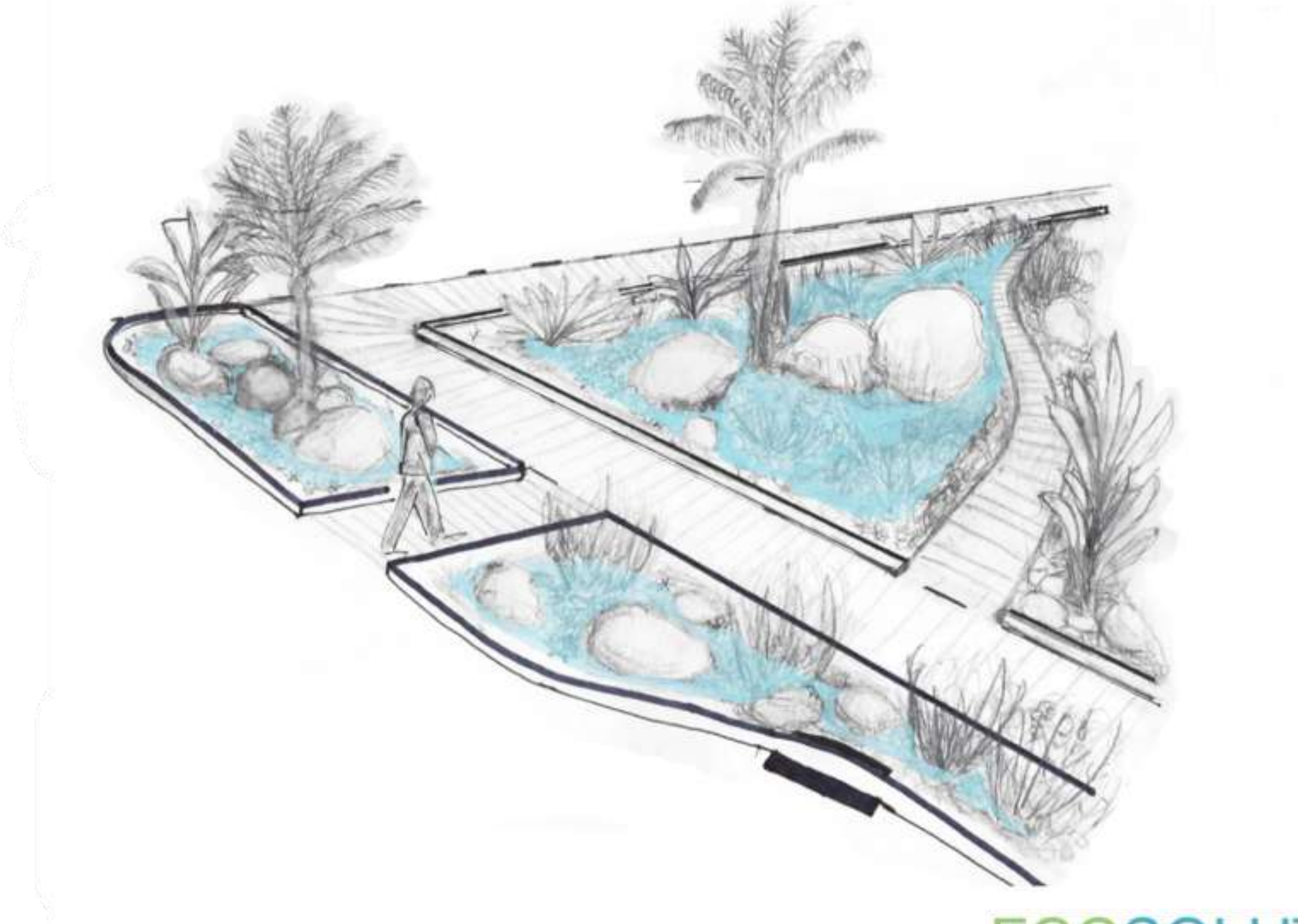
Bioretention Green Streets



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Neighborhood Scale Bioretention

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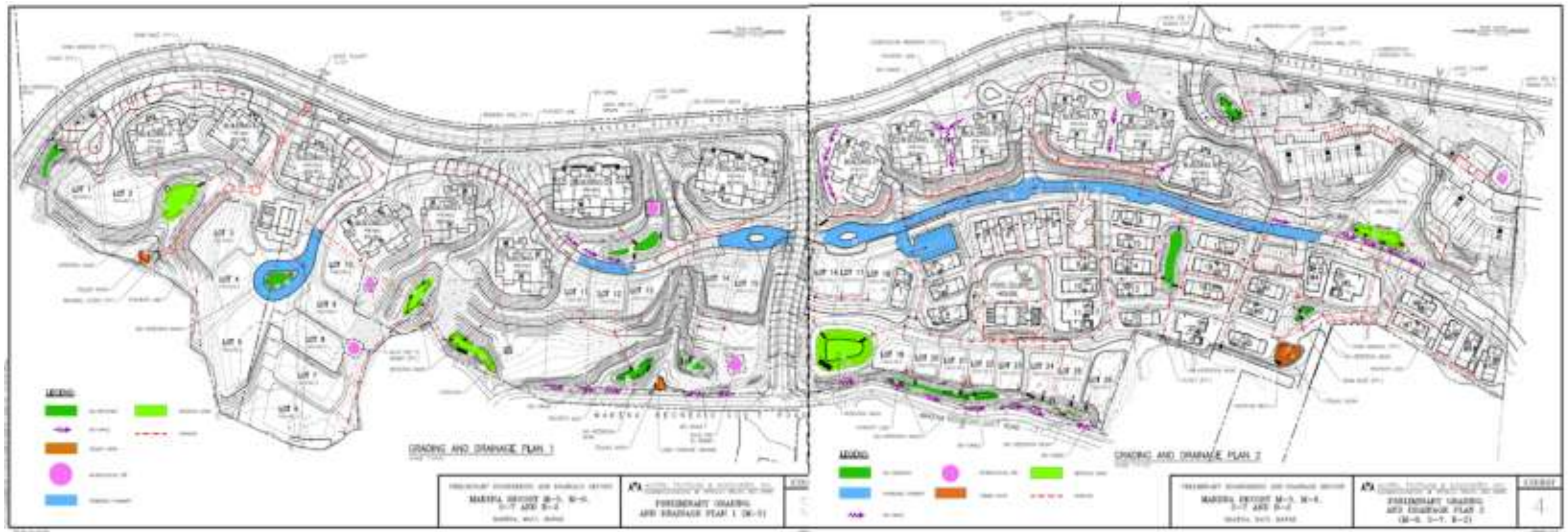
Progression of the Drainage Plan

Early Plan:
Retain
50-Yr
Storm



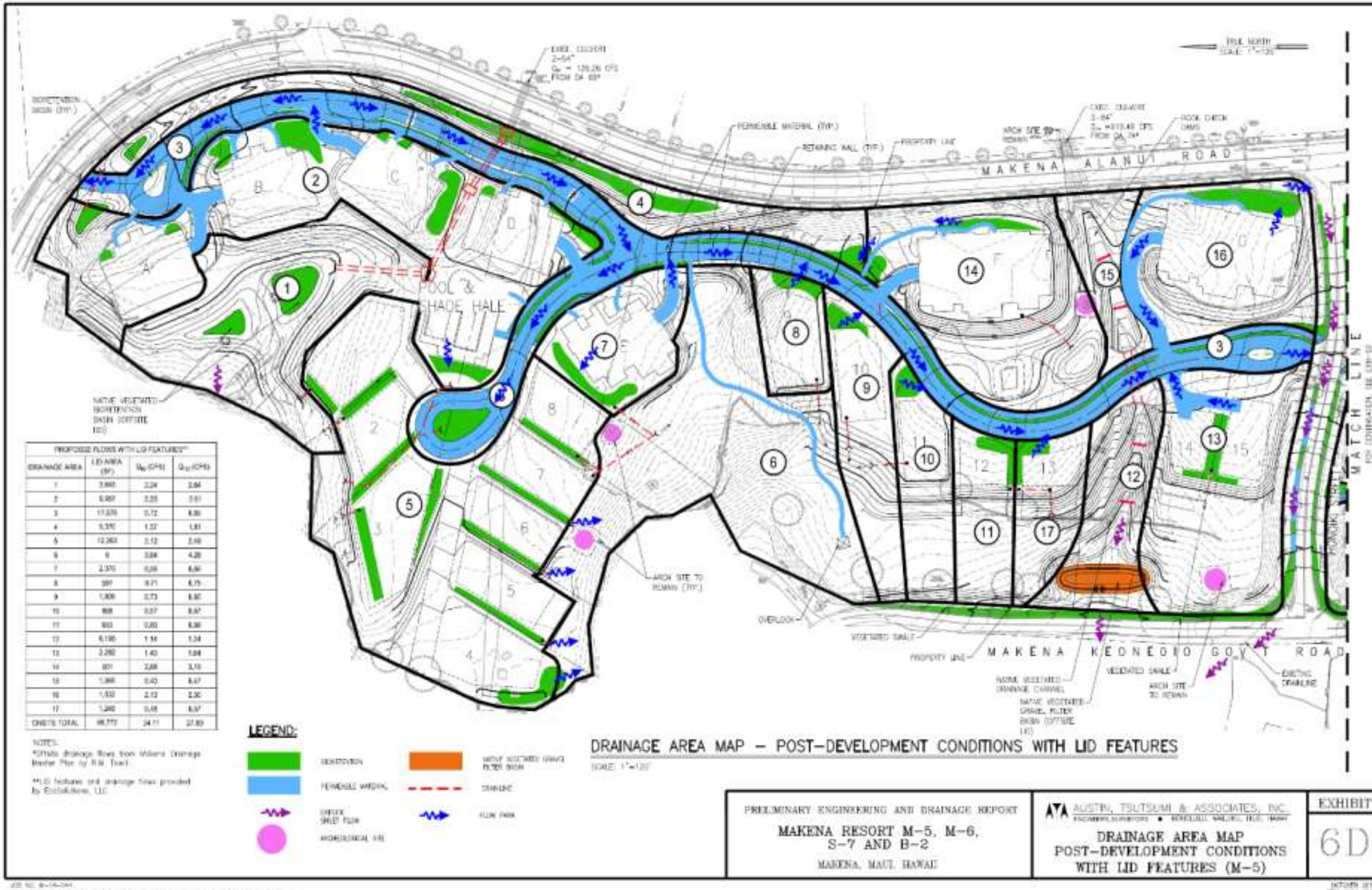
Final Plan:
Retain + *Treat*
100-Year
Storm
&
Improve
Current
Conditions


Rendering Produced by Jeff Brink

Low Impact Development Basemap

Bioretention & porous materials can **retain + treat**:

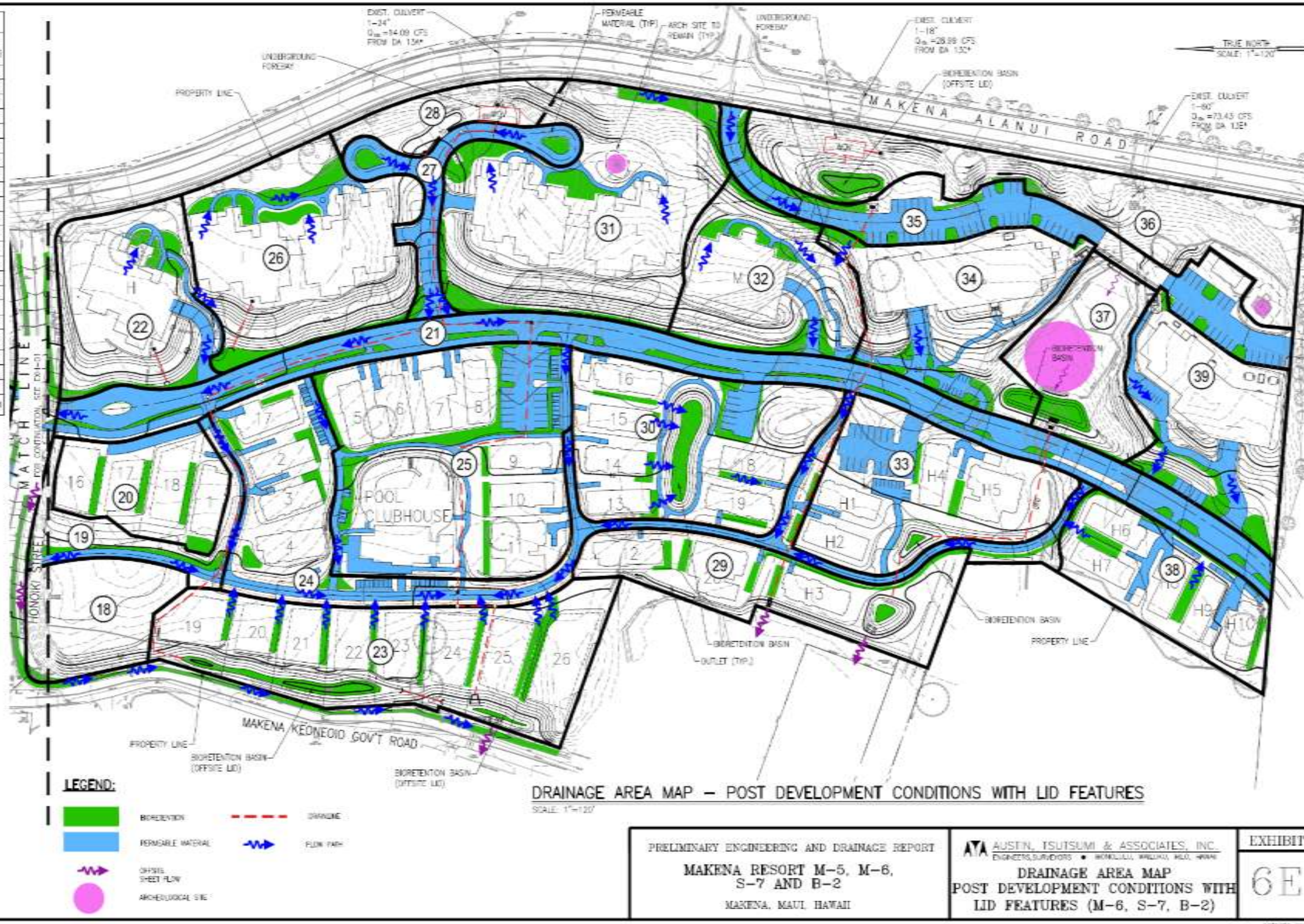
- 100% of the 2.5" (50-yr, 1-hr) storm event (REQUIRED)
- 100% of the 3.0" (**100-year, 1-hr**) storm event



Proposed M5/M6/S7/B2 Low Impact Development (LID) Features

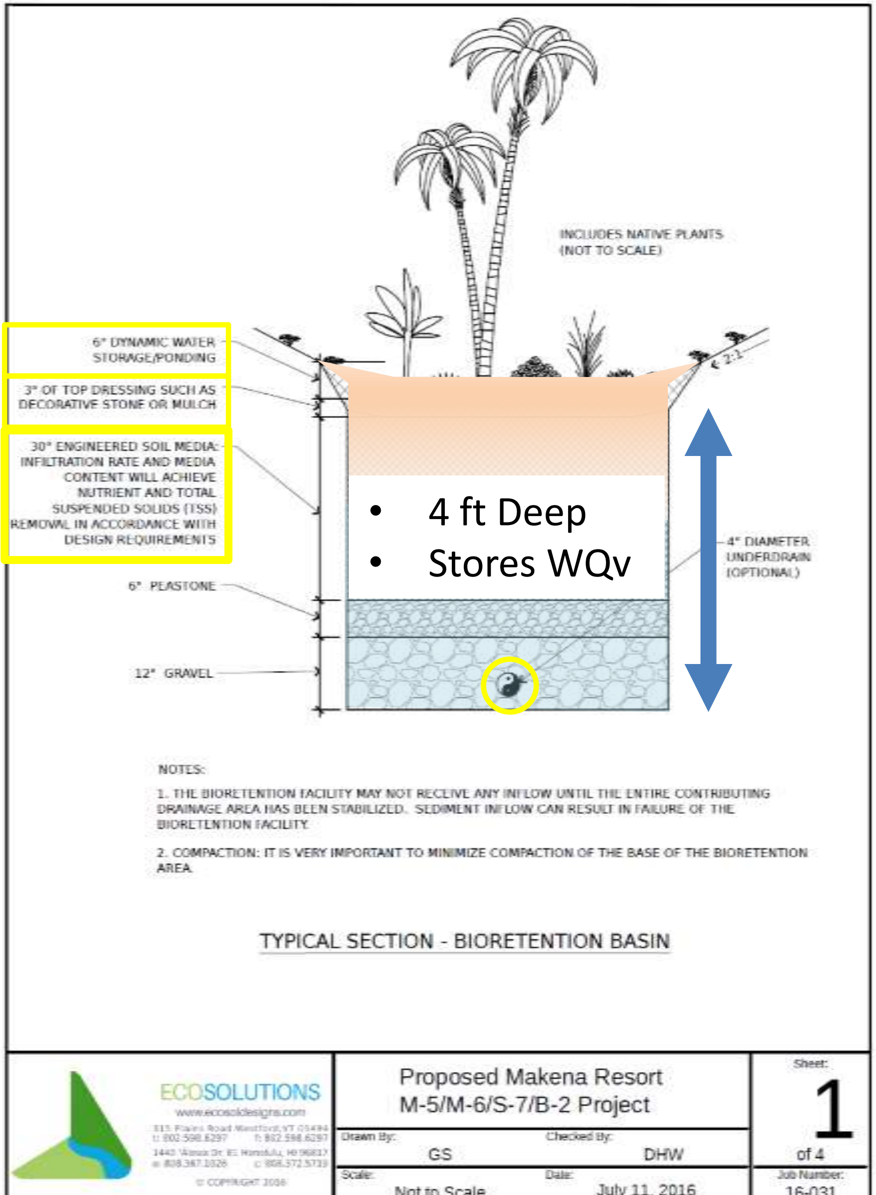
PROPOSED FLOWS WITH LID FEATURES**			
DRAINAGE AREA	LID AREA (SF)	Q_{50} (CFS)	Q_{100} (CFS)
18	0	0.62	0.66
19	3,929	0.46	0.53
20	2,777	0.42	0.58
21	8,684	0.42	0.49
22	3,842	0.98	1.13
23	8,457	2.17	2.43
24	9,129	1.23	1.44
25	8,170	1.77	2.08
26	6,165	1.39	1.60
27	1,867	0.07	0.08
28	2,163	0.47	0.55
29	3,341	0.98	1.15
30	5,385	1.28	1.50
31	12,442	2.14	2.51
32	3,679	0.89	1.04
33	8,812	1.03	1.22
34	3,366	0.92	1.08
35	6,034	0.36	0.42
36	7,973	2.16	2.54
37	2,597	1.09	1.27
38	1,945	1.26	1.48
39	3,466	0.57	0.67
ONSITE TOTAL	113,428	22.86	26.71

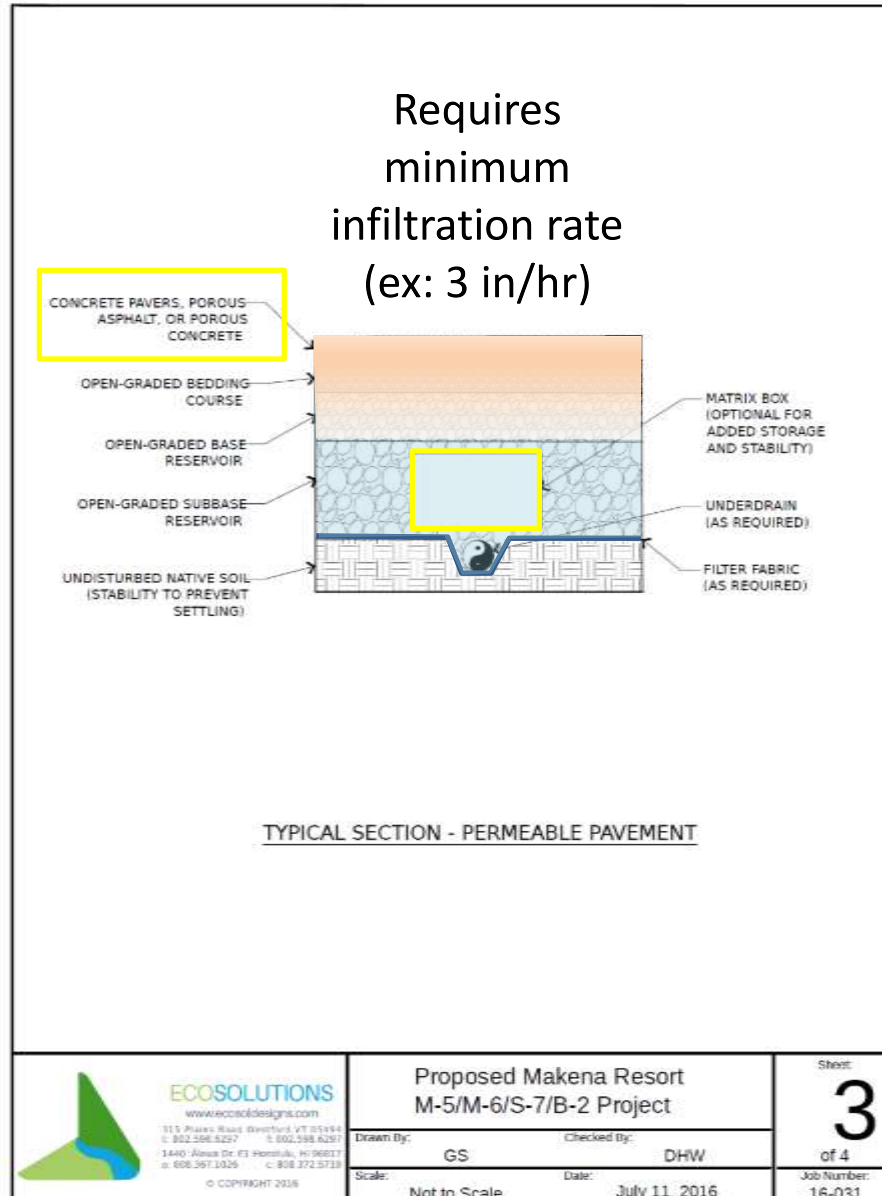
NOTES:
*Offsite drainage flows from Makena Drainage Master Plan by R.M. Towill.
**LID features and drainage flows provided by Eco Solutions, LLC



Proposed M5/M6/S7/B2 Low Impact Development (LID) Features

Bioretention & Porous Materials





<u>Required Drainage Plan:</u>

Retain Δ from **50-Year**, 1-Hour Storm (2.5 in/hour)

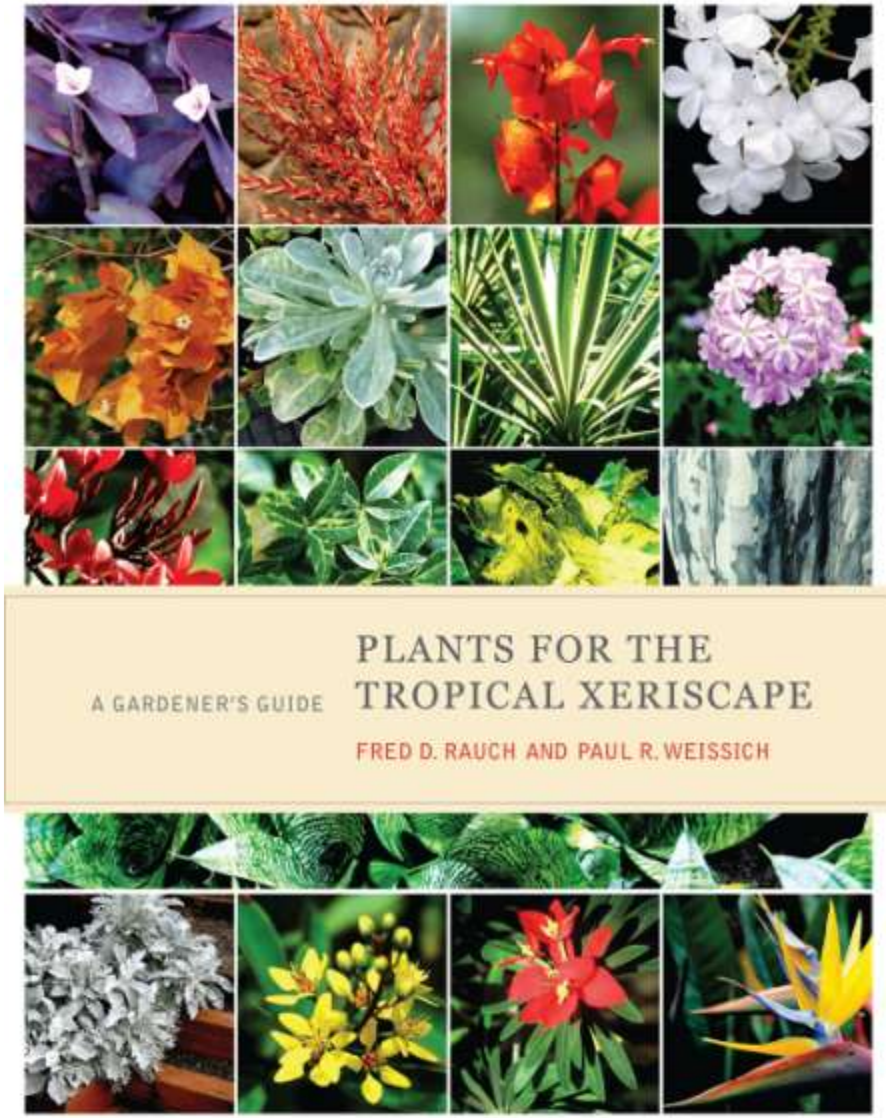
➡ **Required Retention = 40.9 cfs**

<u>Proposed Drainage Plan:</u>

Retain + treat Δ **100-Year**, 1-Hour Storm (3.0 in/hour)

➡ **Proposed Retention = 72.0 cfs**

***Retention + treatment is <u>nearly double</u> the requirement**



Makena - Lower slope, grasslands and shrub lands, dry and mesic forest

- Pili
- Kawelu
- ‘A’ali’i
- Hopseed bush
- Ko’oko’olau
- ‘Ulei
- ‘Ohi’a
- Koa
- Lama
- Wiliwili
- Olopua
- Halapepe
- Uhaloa
- T Leaf
- ‘Uala
- Hala







Native Plants: Xeriscaping


'A'ali'i


'Ākia


'Akoko


Alahe'e


Naupaka


Halapepe


'Ihi


'Ilie'e


'Ilima Papa


Ko'olau'ula


Kulu'i


Lama


Ma'o Hau Hele


Naio


Nehe


Pā'ū o Hi'iaka

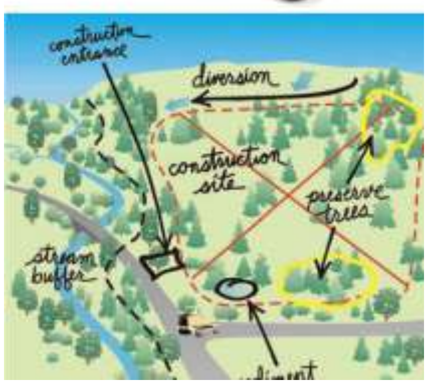

'Ohe Makai


'Ūlei

Native Plants: Canoe & Craft

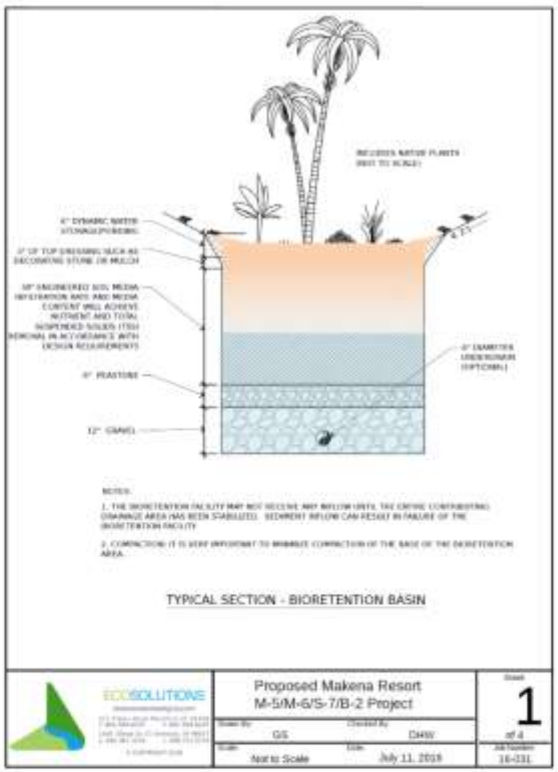
LANDSCAPE ARCHITECT HAWAII, U.S.A.

Monitoring Water Quality
Before, During, and After Construction



- Real-Time Data Collection
- Notification if Levels Exceed Target (e.g., 20 NTUs)
- Post-Construction Baseline, BMP Monitoring During Construction, LID Monitoring after Construction
- 3-5 Years Estimated Construction

Verifying LID Performance Post-Construction through Monitoring



The Carrot

- Lower Materials Cost
- Increased Available Land
- LEED Credits
- Improved Aesthetics
- Water Quality Improvement
- Urban Ecological Benefits
- The Good Guy/Gal

The Stick

- Water Quality Rules

NOMA, Washington, DC

US Embassy – Abu Dhabi, UAE

Residence – Akumal, Mexico

US Embassy – Ouagadougou, Burkina Faso

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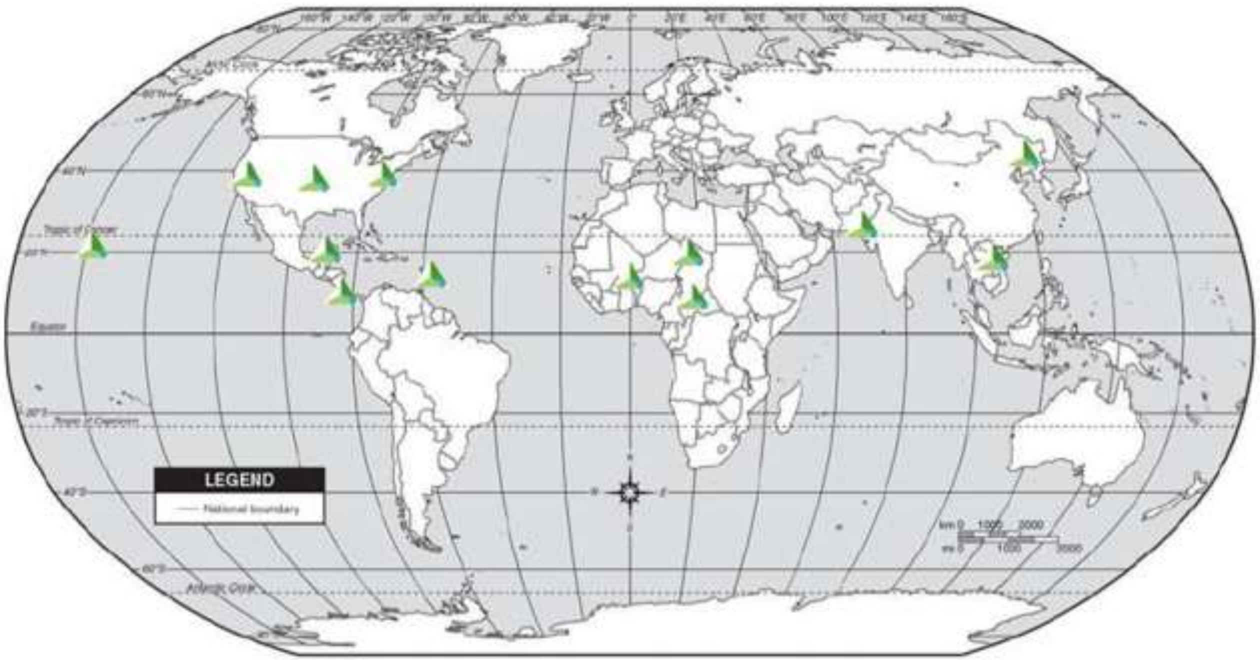

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Pacific Office: Honolulu, HI | Phone: (808) 367 – 1026 | Email: amanda@ecosoldesigns.com

Global Civil Engineering Firm Specializing In:

Low Impact Design and Development (LID) Systems

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Monitoring & Maintenance

Research & Development

Publications:

Cording, A., Hurley, S., Whitney, D. (**In Press**) Monitoring methods and designs for evaluating bioretention performance. Journal of Environmental Engineering.

Cording, A., Hurley, S., Adair, E. (**In Preparation**). *Evaluating critical bioretention designs features in the context of climate change*.

Cording, A. (**In Preparation**). *Investigating pollutant mass mobilization and speciation during the stormwater first flush*.

Lake Champlain Sea Grant | Lintilhac Foundation | Watershed | EcoSolutions | Contech Engineered Solutions | Sorbtive Media


Mahalo Nui!
Amanda Cording, Ph.D.
amanda@ecosoldesigns.com
(808) 367-1026

A‘ohe hana nui ke alu ‘ia

No task is too big when done together by all

ECOSOLUTIONS
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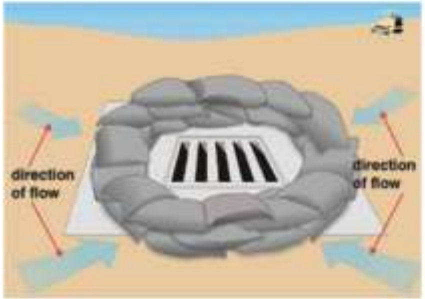
Mobile: 808-372-5719

Consultant Scoping Matrix

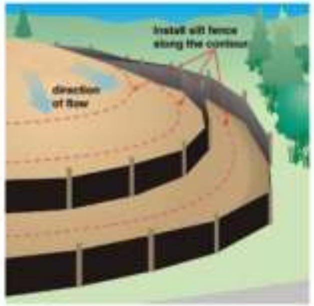
DESIGN Tasks	EcoSol	Civil	Architect	Landscape Architect	Mechanical	Electrical	Other
Site Layout							
Buildings			X				
Roads		X					
Utility Infrastructure	↔	X					
Site Grading	X			↔			
Stormwater Infrastructure							
Conveyance	X						
Treatment	X			↔			
Wastewater Infrastructure							
Conveyance		X					
Treatment	X						
Reuse	X						
Disposal	X						
Potable Water		X					
Electrical						X	
Landscaping	↔			X			

↔ *Coordination required

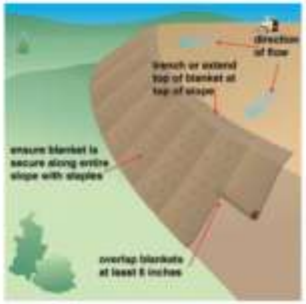
Inspecting BMPs During Construction



Protect All Stormwater Inlets

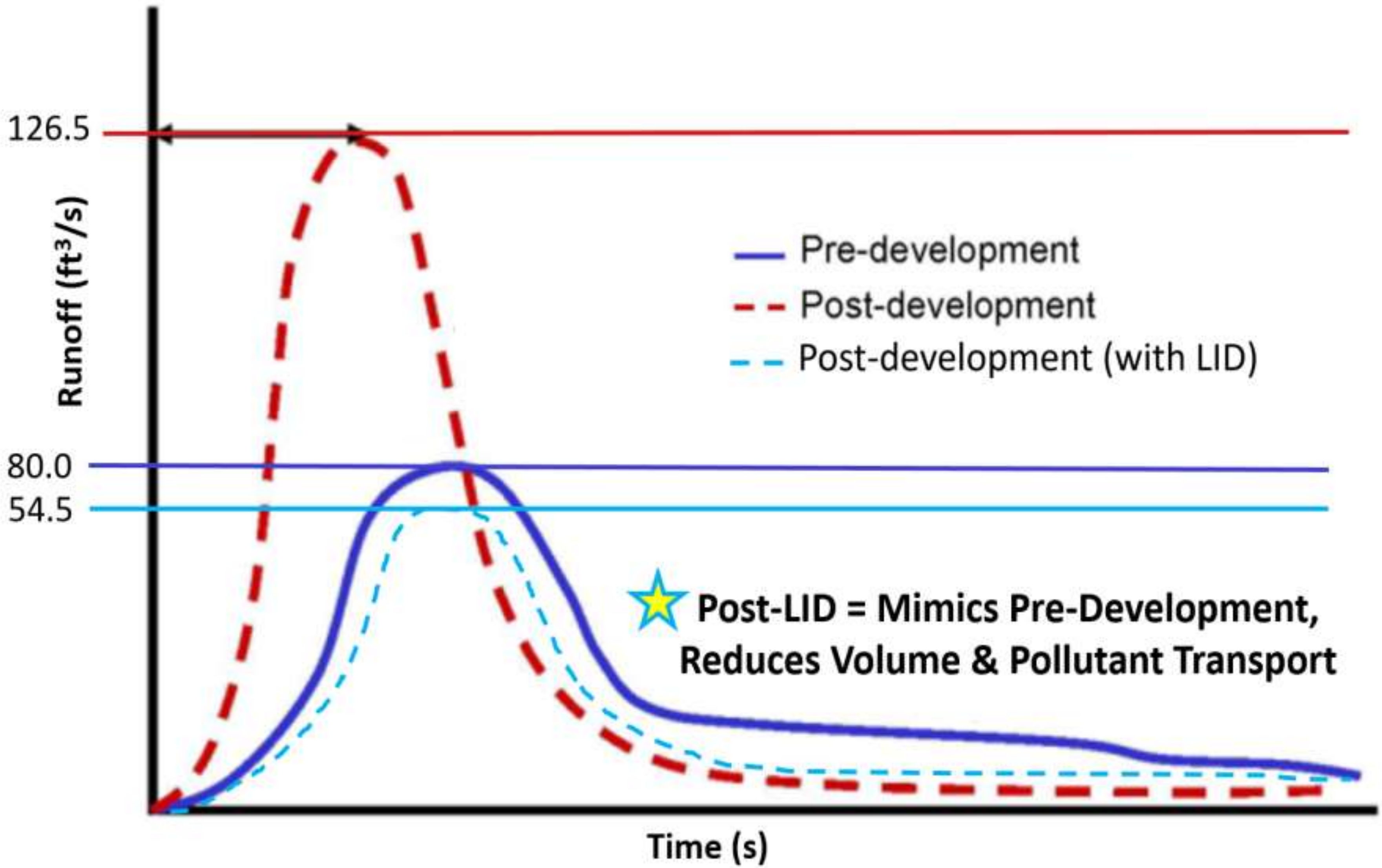


Install Silt Fence Along the Contour



Use Erosion Control Blanket on Steep Slopes

Divert Water Away From Disturbed Areas



126.5
Runoff (ft³/s)
80.0
54.5
Pre-development
Post-development
Post-development (with LID)
Post-LID = Mimics Pre-Development,
Reduces Volume & Pollutant Transport
Time (s)

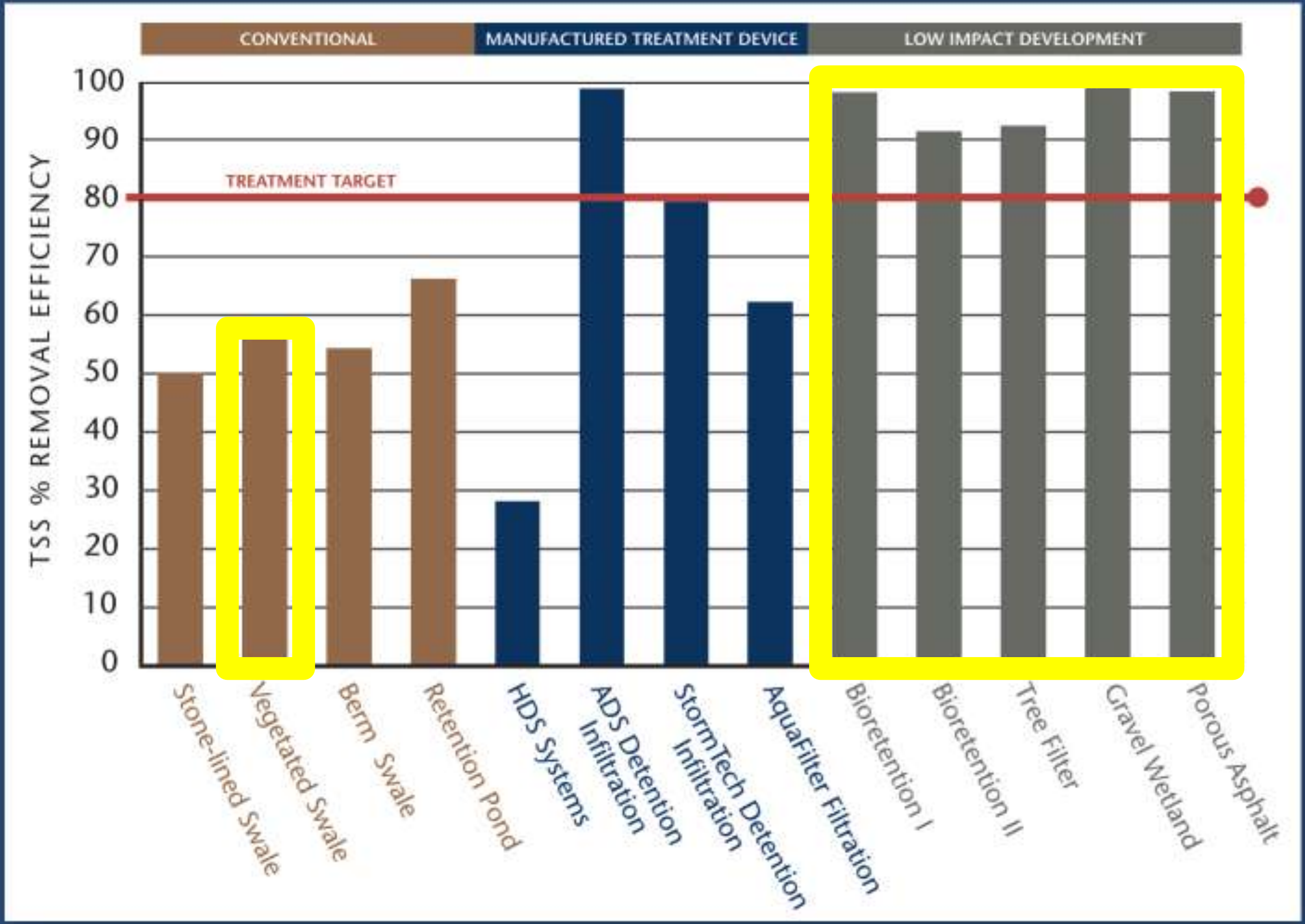
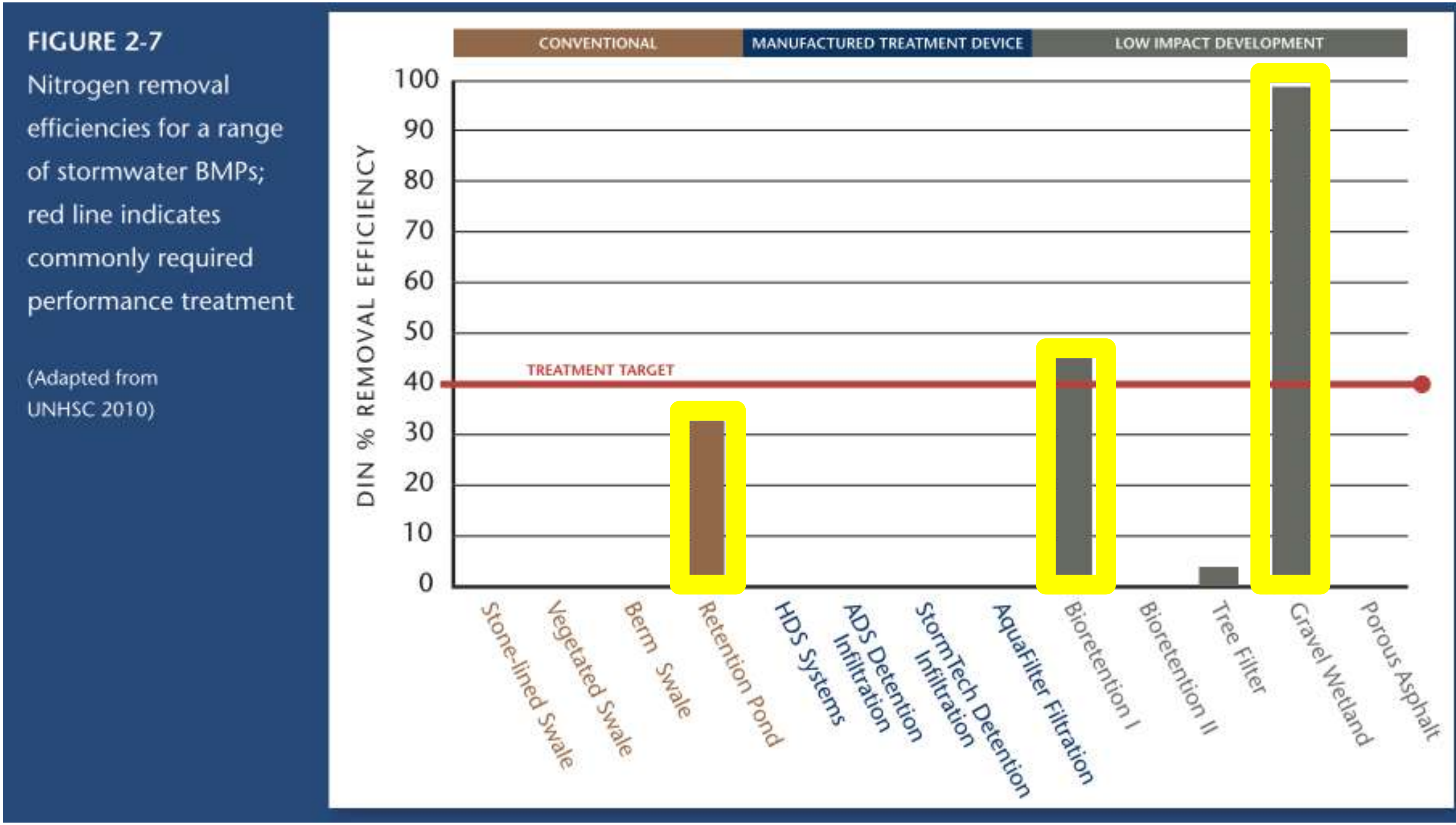


FIGURE 2-6
Total Suspended Solids (TSS) removal efficiencies for a range of stormwater BMPs; red line indicates commonly required performance treatment

(Adapted from UNHSC 2010).

Brown, S., Sanneman, C., 2017. Working with the Market: Economic Instruments to Support Investment in Green Stormwater Infrastructure.



Brown, S., Sanneman, C., 2017. Working with the Market: Economic Instruments to Support Investment in Green Stormwater Infrastructure.

WHAT MAKES A *TRULY* COMPLETE *GREEN* STREET?

SIDEWALKS

Sidewalks provide safe walking and wheelchair access. Porous materials quickly drain, preventing slippery surfaces.

BIKE LANES

Bike lanes provide safe distance away from cars.

VEHICLES

Active roadway allows vehicles to move efficiently through a multi-use area safely.

PEDESTRIANS

Clearly marked, frequently placed, cross walks allow safe transitions from one side of the road to another.

CLEAN WATER

Bioretention and other "green infrastructure" slows and filters road runoff, so it can be be re-used or recharge groundwater supplies.

COMMUNITY

Adjacent open space provides a peaceful gathering place for the community.

Image Credit: Amanda Cording (2017) Adapted from the Complete Streets Policy Manual (2012) Written by the Center for Planning Excellence. Available at http://www.connect.cpex.org/complete-streets/

HAWAII BIKE ME TO your LEEDer

TAKE A SPIN
THROUGH KAKA'AKO
ON HONOLULU'S
FIRST BIKESHARE
AND LEARN ABOUT
THE FUTURE OF GREEN
TRANSPORATION
IN HAWAI'I!

Ride along with Hawaii Bicycling League through Kaka'ako, tour past a LEED gold building, & end with a USGBC Hawai'i workshop + pau hana

SCHEDULE

5pm – Bike ride OR mingling and beverages at SALT

5:30pm – Talk story with community partners

6pm – Workshop starts, pupus served

*Bike ride starts AND ends at Salt Atrium

$20 USGBC Hawai'i Member
$25 Non-Member
Bring your own helmet!

Reserve one of 10 Bikeshare Biki bikes (must be 16+) or bring your own wheels
Ticket includes light pupus and beverages

Workshop will qualify for 1 self reported LEED CEU

Mahalo to:

SALT AT OUR KAKA'AKO

bikeshare hawaii

HAWAII BICYCLING LEAGUE www.hbl.org

HHF PLANNERS places for people

THURSDAY, JULY 13
5-7:30PM
KAKA'AKO SALT ATRIUM

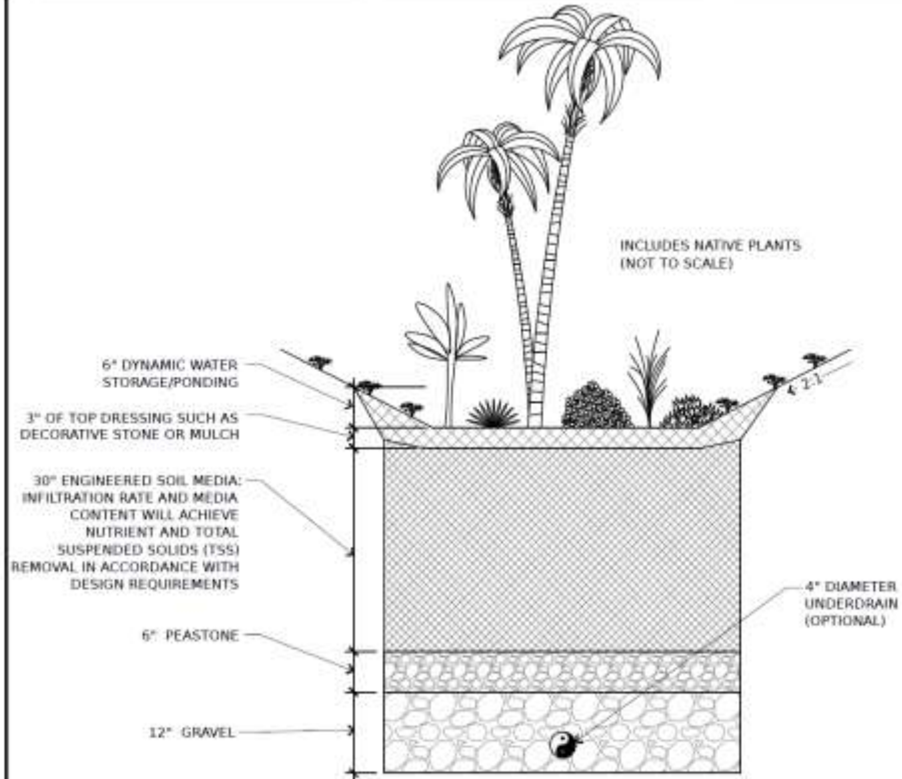
Find us on Facebook for up-to-date info

Tickets @ goo.gl/x0fHMU

Exhibit 12. Bikeshare and green infrastructure, Brooklyn, New York. A tree pit designed to capture stormwater from the street and a bikeshare station make Dean Street in Brooklyn an appealing place to walk and bike.

Figure 1. Process for implementing green infrastructure.

U.S. Environmental Protection Agency, 2017. Green Infrastructure in Parks: A Guide to Collaboration, Funding, and Community Engagement.



NOTES:

1. THE BIORETENTION FACILITY MAY NOT RECEIVE ANY INFLOW UNTIL THE ENTIRE CONTRIBUTING DRAINAGE AREA HAS BEEN STABILIZED. SEDIMENT INFLOW CAN RESULT IN FAILURE OF THE BIORETENTION FACILITY.

2. COMPACTION: IT IS VERY IMPORTANT TO MINIMIZE COMPACTION OF THE BASE OF THE BIORETENTION AREA.

TYPICAL SECTION - BIORETENTION BASIN

ECOSOLUTIONS

Proposed Makena Resort
M-5/M-6/S-7/B-2 Project

Drawn By: GS	Checked By: DHW	Sheet: 1 of 4
Scale: Not to Scale	Date: July 11, 2016	Job Number: 16-031

A Handbook for Stormwater Reclamation and Reuse Best Management Practices in Hawaii

Commission on Water Resource Management
State of Hawaii

December 2008

1.1 Bioretention filter media specifications

Most of a bioretention cell's potential benefits rely on characteristics of the filter media. The filter media should:

1. Allow adequate infiltration and permeability;
2. Have the necessary chemical properties to facilitate pollutant removal;
3. Allow adequate contact time with the stormwater for pollutant removal to take place;
4. Provide adequate nutrients, aeration, moisture storage, and physical support for plants, allowing plant root extension;
5. Remain stable over a relatively long term without shrinking, compacting or structurally collapsing.

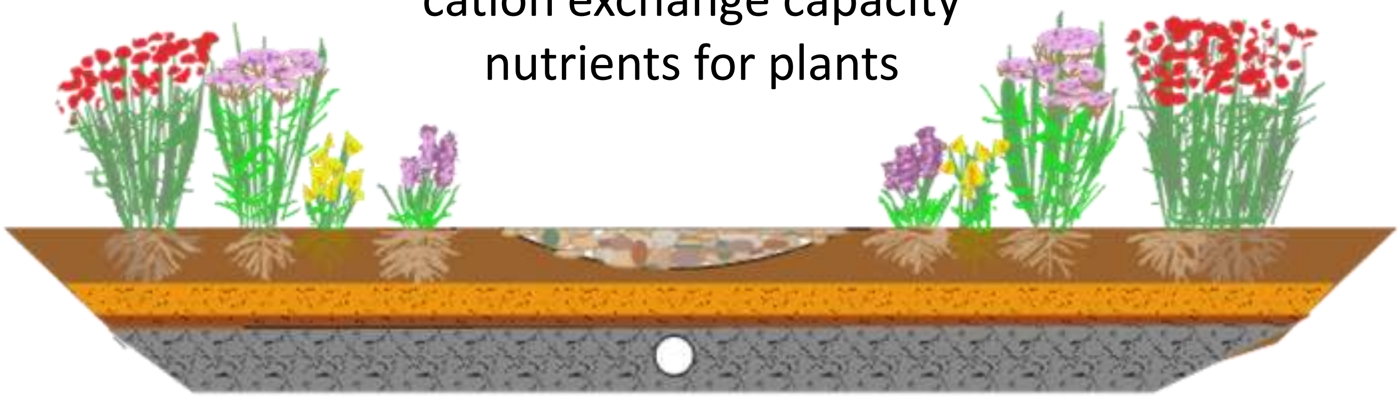
Multi-Use Amphitheater for Water Retention


PARKING

Inconsistent N & P Removal

- Some of the variability is thought to be attributed to the soil media selected
- Sand based bioretention soil designs are common
- Organic amendments (compost, mulch) are widely recommended to provide:

metals removal
soil moisture retention
cation exchange capacity
nutrients for plants

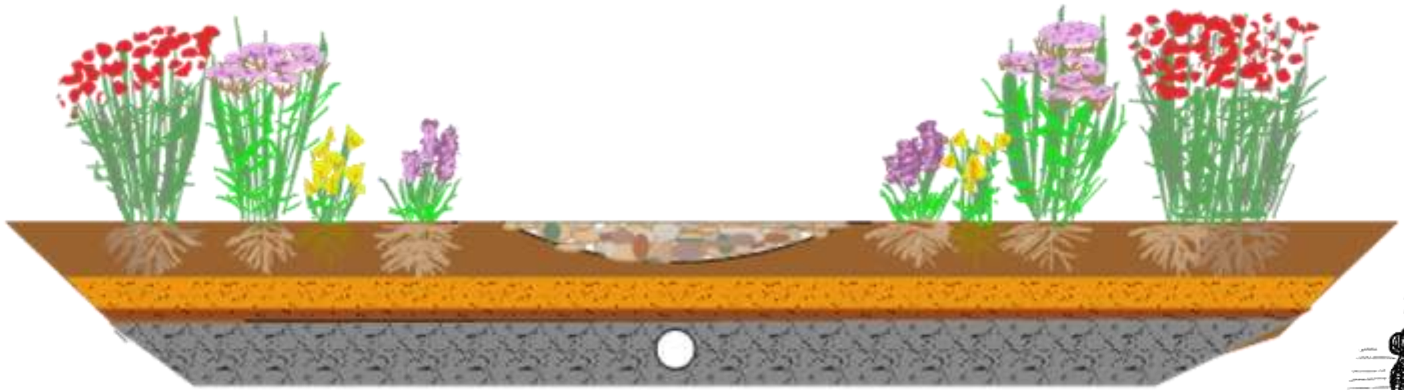


Bratieres et al. 2008; DeBusk and Wynn 2011; Michigan Department of Environmental Quality 2008; Thompson et al. 2008; Vermont Agency of Natural Resources 2002; Washington State University Pierce County Extension 2012.

Bioretention: Nutrient Removal

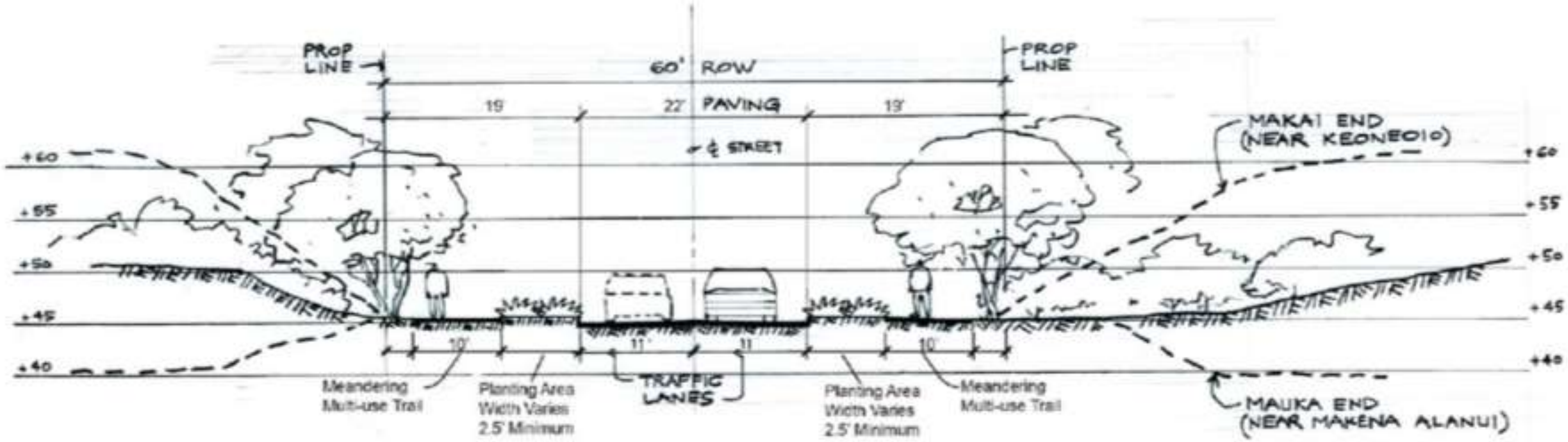
Nutrient removal is extremely variable

- Labile N (-630% to 98% removal)
- NO_3^- Effluent [ ] = 10 $\mu g\ L^{-1}$ to 2,100 $\mu g\ L^{-1}$
- Labile P (-78% to 98% removal)
- SRP Effluent [ ] = < 10 $\mu g\ L^{-1}$ to 2,200 $\mu g\ L^{-1}$

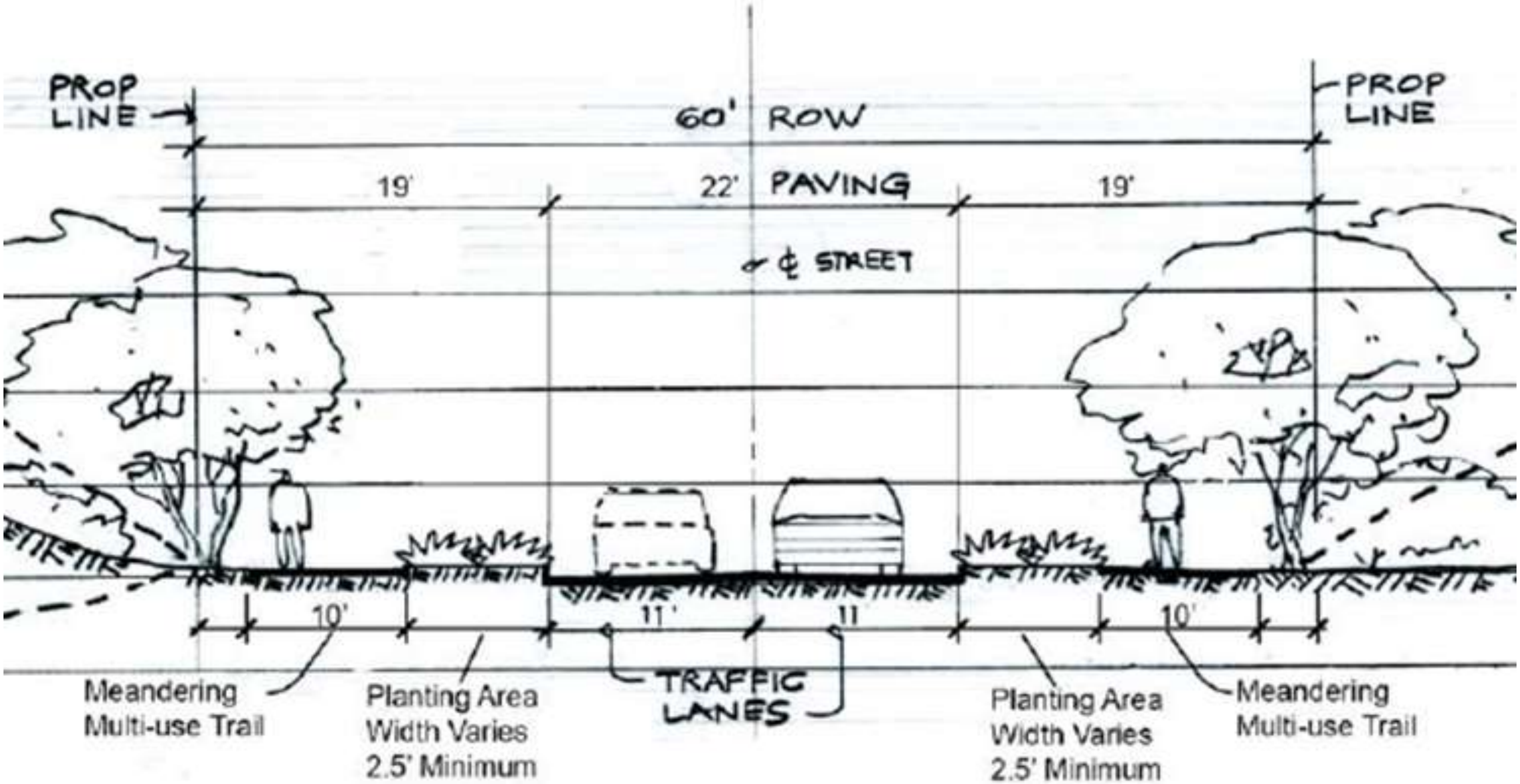


Davis et al. (2007); Bratieres et al. (2008); Debusk et al. (2011); Dietz and Claussen (2006); Hunt et al. (2006); O'Neill and Davis (2011); Image Credit: Amanda Cording

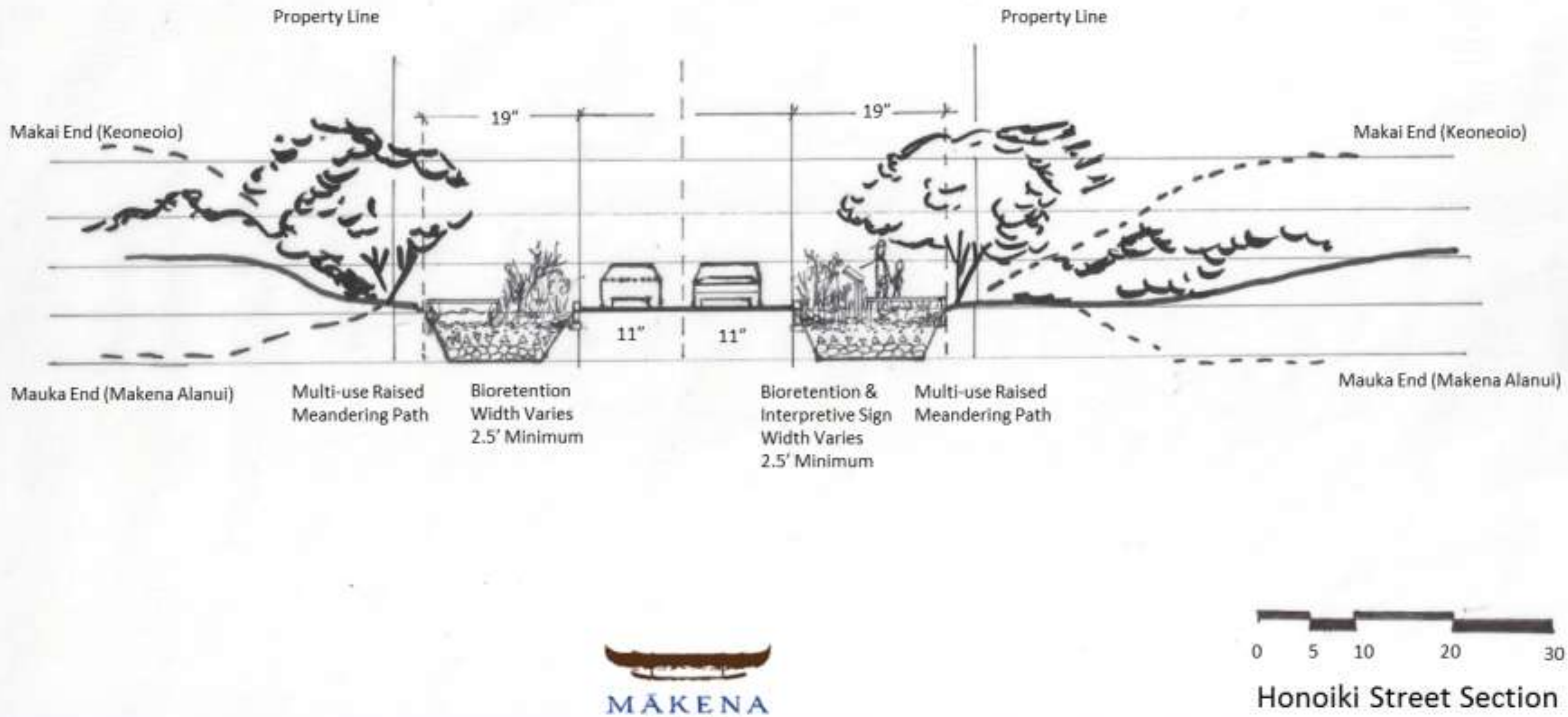
Traditional Street Profile



Traditional Street Profile



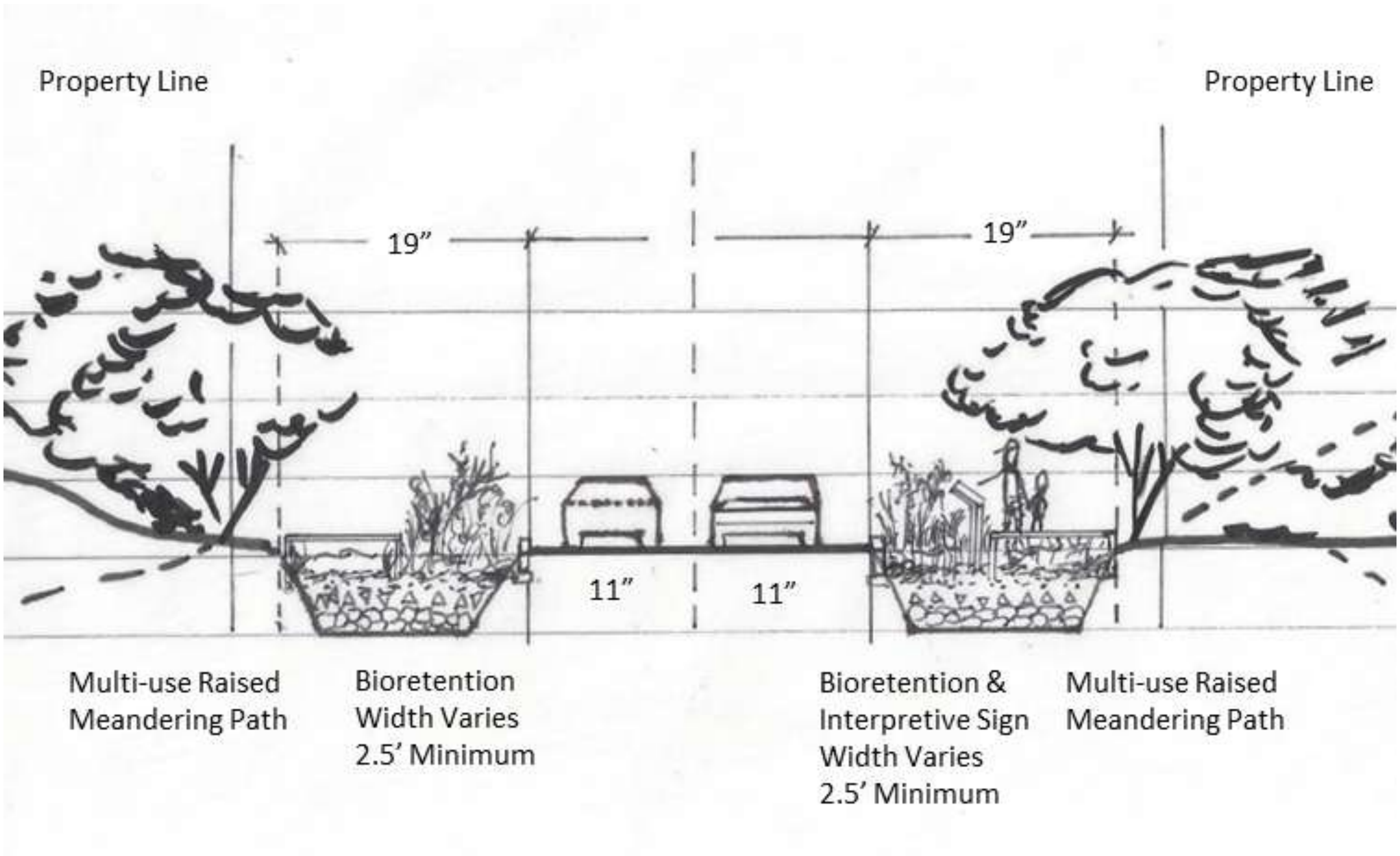
LID Green Street Profile



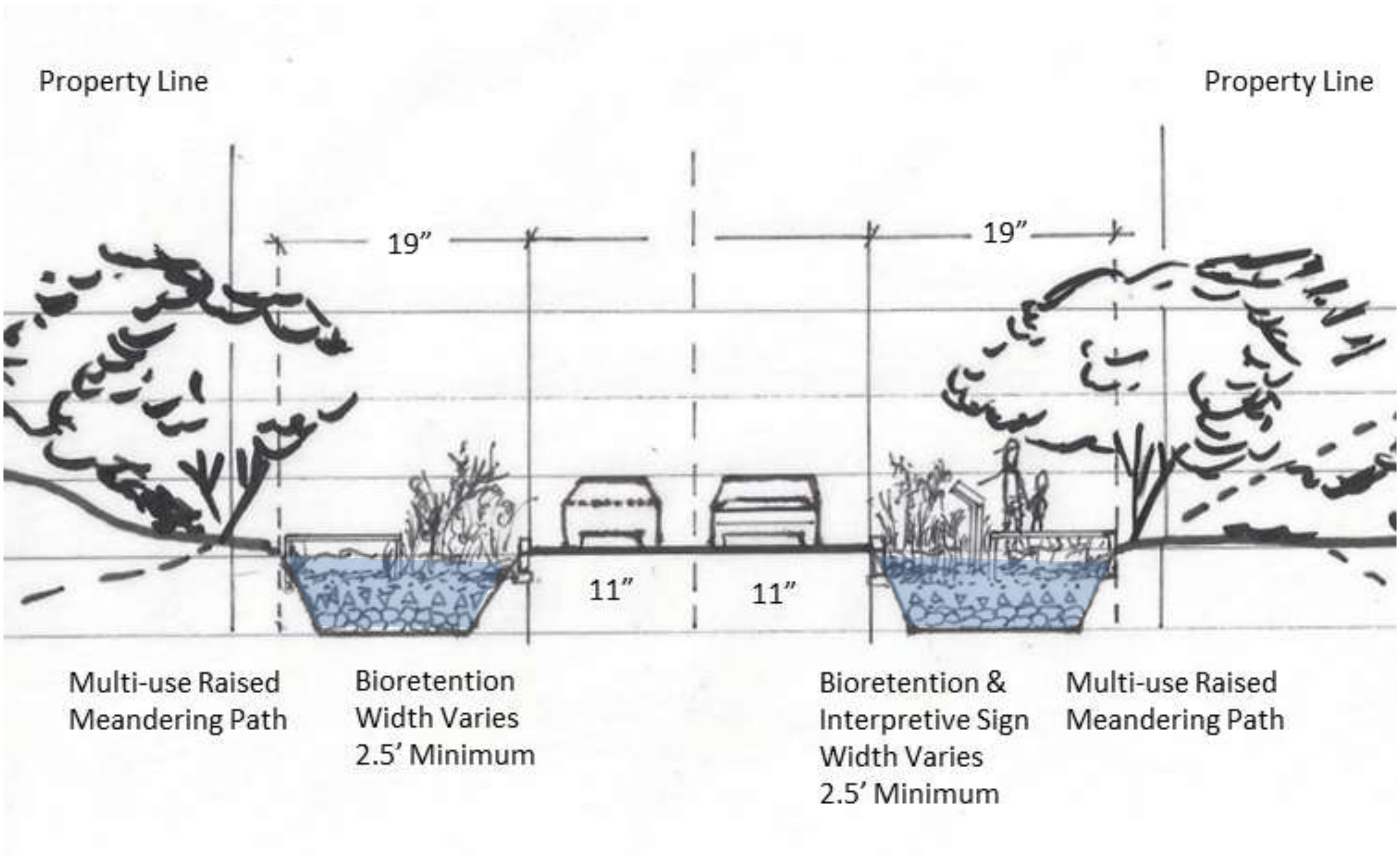
MĀKENA

ECOSOLUTIONS
innovative designs – living systems

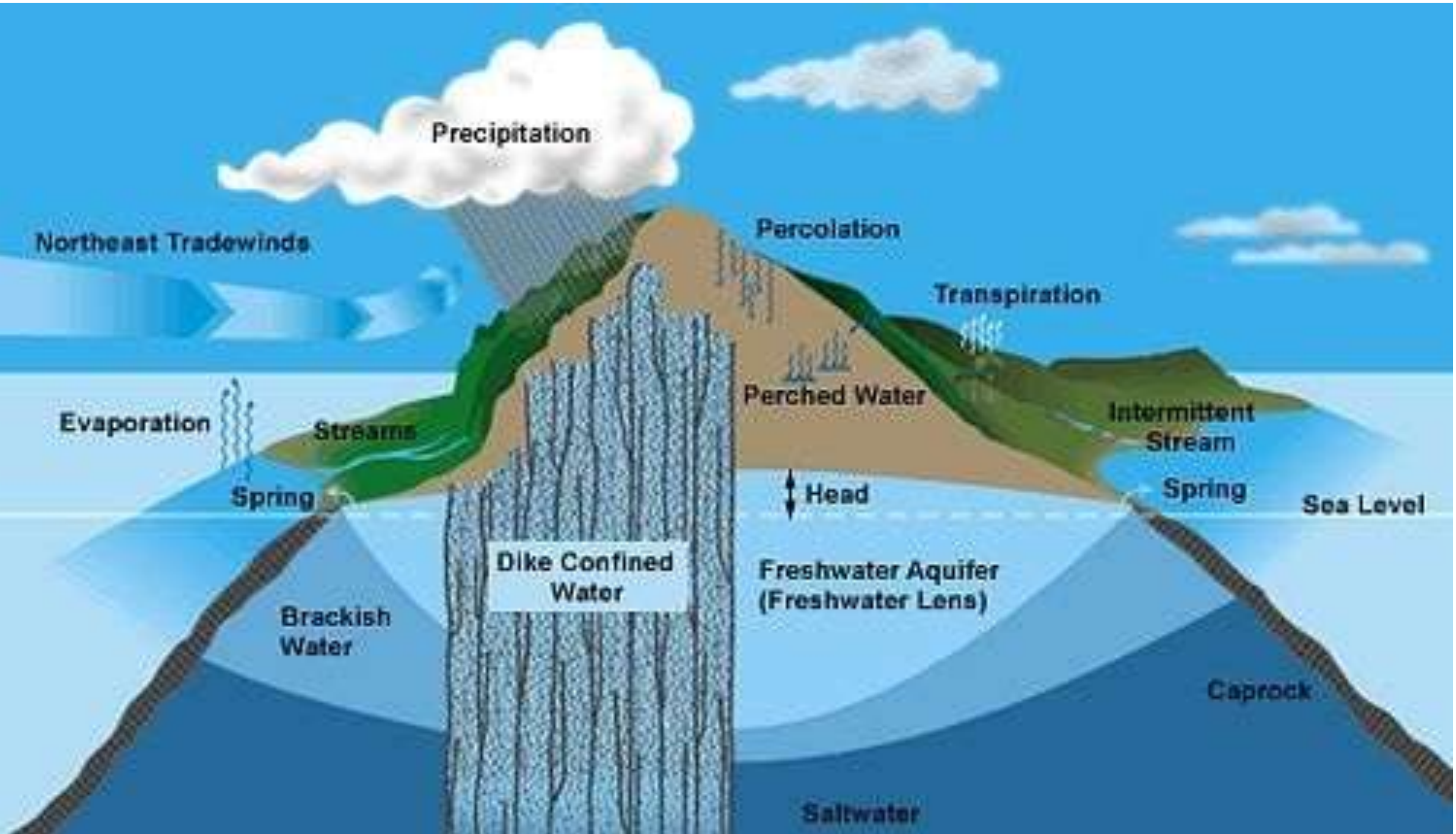
LID Green Street Profile



LID Green Street Profile



Limited Groundwater Supply in Hawai‘i



HAWAI`I CHAPTER
U.S. GREEN BUILDING COUNCIL

Sustainable Sites

SITES GOALS

Create Regenerative Systems and Foster Resiliency
- Protect and restore natural resources such as soil, water, and vegetation.
- Encourage biodiversity.
- Enhance landscapes to provide multiple ecosystem services such as cleaning air and water, providing habitat, and storing carbon.
- Mitigate for evolving hazards and natural disasters.
- Plan for monitoring and adaptive management.

Ensure Future Resource Supply and Mitigate Climate Change
- Minimize energy consumption and encourage use of low carbon and renewable energy sources.
- Minimize or eliminate greenhouse gas emissions, heavy metals, chemicals, and other pollutants.
- Reduce, reuse, recycle, and upcycle materials and resources.
- Conserve water.
- Increase the capacity of carbon sinks through re-vegetation.

Transform the Market through Design, Development, and Maintenance Practices
- Foster leadership in industry and professional practice.
- Use a systems-thinking, integrative and collaborative design approach.
- Use lifecycle analyses to inform the design process.
- Support local economies and sustainability policies.

Enhance Human Well-Being and Strengthen Community
- Reconnect humans to nature.
- Improve human health (physical, mental, and spiritual).
- Foster stewardship by providing education that promotes the understanding of natural systems, and recognizes the value of landscapes.
- Encourage cultural integrity and promote regional identity.
- Provide opportunities for community involvement and advocacy.

Research Site: University of Vermont Outdoor Bioretention Laboratory

- Constructed in November of 2012
- Total area: approx. 5,000 ft^2 or 0.1 acres
- Eight small paved road sub-watersheds
- Bioretention Surface Areas: 29.73 m^2 to 120.12 m^2

Research Site

Monitoring Objectives:

Characterize stormwater mass loads from small paved road watersheds throughout the inflow and outflow hydrograph

Methods: Measuring Stormwater Quality

Equipment	Parameter	Sampling and Analysis Methods
• 6700 Series Automatic Samplers (Teledyne™) • Model 720 Differential Pressure Transducer	1. TP 2. NLP 3. SRP 4. TN 5. TKN 6. NO_3^- 7. TSS 8. Flow Rate	• Time Based • Discrete Samples • Based on the Hydrograph • Inflow = Every 2 min for 48 min (950 mL) • Outflow = Every 4 min for 96 min (500 mL) • Inflow to Outflow, 20-L increments (n = 6) • Outflow to Outflow, 20-L increments (n = 6) • Partial Event Mean Concentration (PEMC)




Methods: Measuring Bioretention Soil Media Characteristics

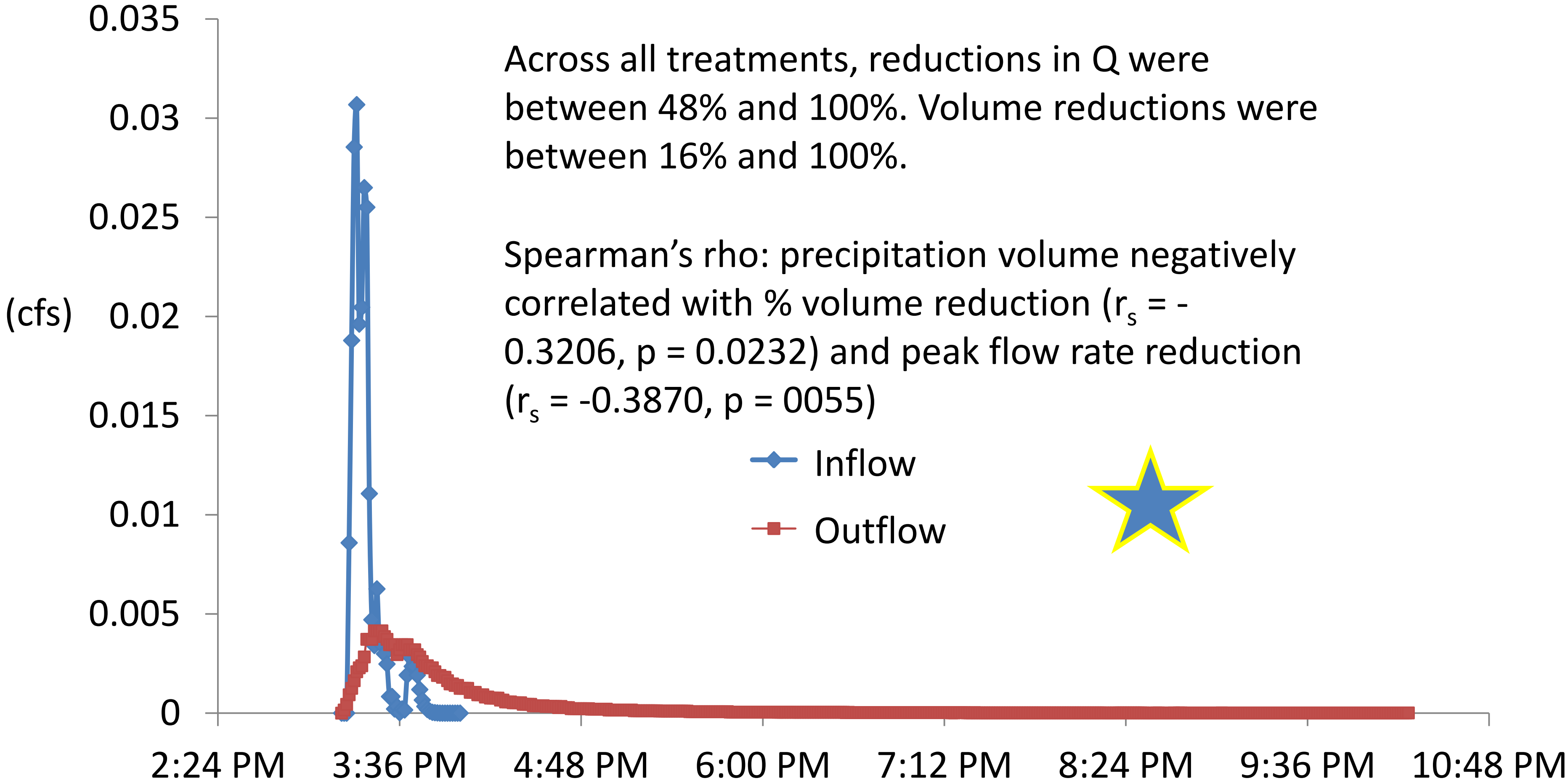
Equipment	Parameter	Sampling Method
• Soil auger • Soil core cylinder • Trowel • Decagon soil probes	1. NH_4^+ (n = 13) and NO_3^- (n = 13) 2. SRP (n = 7) 3. Bulk Density (n = 11) 4. Ca, K, Mg, Na, S, Mn, Al, Fe, Zn, Cu (n = 7) 5. Cation exchange capacity (CEC) 6. Organic matter content (n = 7) 7. Volumetric water content 8. Electrical conductivity 9. Soil temperature	1. 2 M KCl extraction 2. Modified Morgan 3. Change in mass /volume 4. Inductively coupled plasma spectroscopy 5. Ammonium acetate 6. Loss on ignition (375°C) 7. Every five minutes **3 composited sub-samples per cell**




Results:
Flow Rate Reduction Performance

Across all treatments, reductions in Q were between 48% and 100%. Volume reductions were between 16% and 100%.

Spearman's rho: precipitation volume negatively correlated with % volume reduction (r_s = -0.3206, p = 0.0232) and peak flow rate reduction (r_s = -0.3870, p = 0055)



Cording, A., Hurley, S., Adair, E. (**In Preparation**). *Evaluating critical bioretention designs features in the context of climate change*.

Cost of LID vs Traditional Development

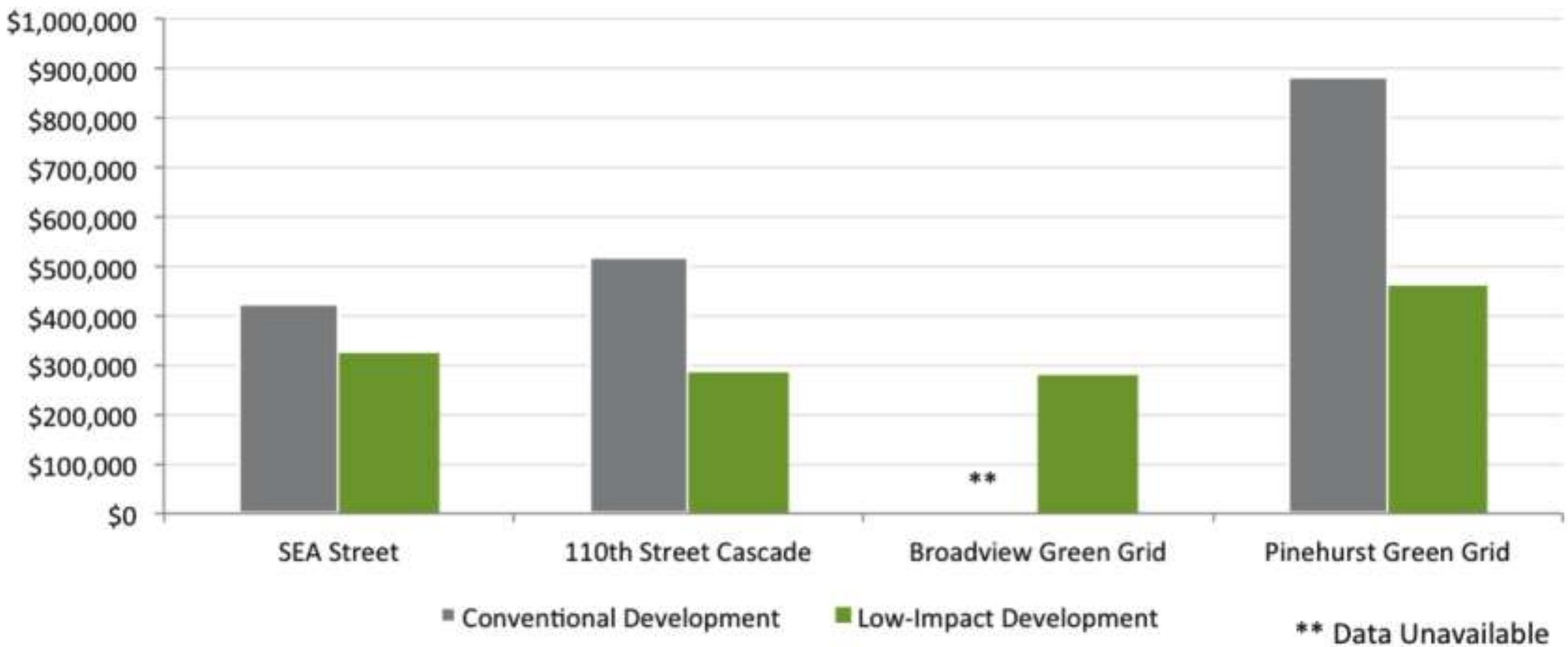


Figure 4. Cost Analysis of Seattle Public Utilities Natural Drainage Systems

American Rivers, 2012. Banking on Green: A look at how green infrastructure can save municipalities money and provide economic benefits community-wide.

Cost of LID vs Traditional Development

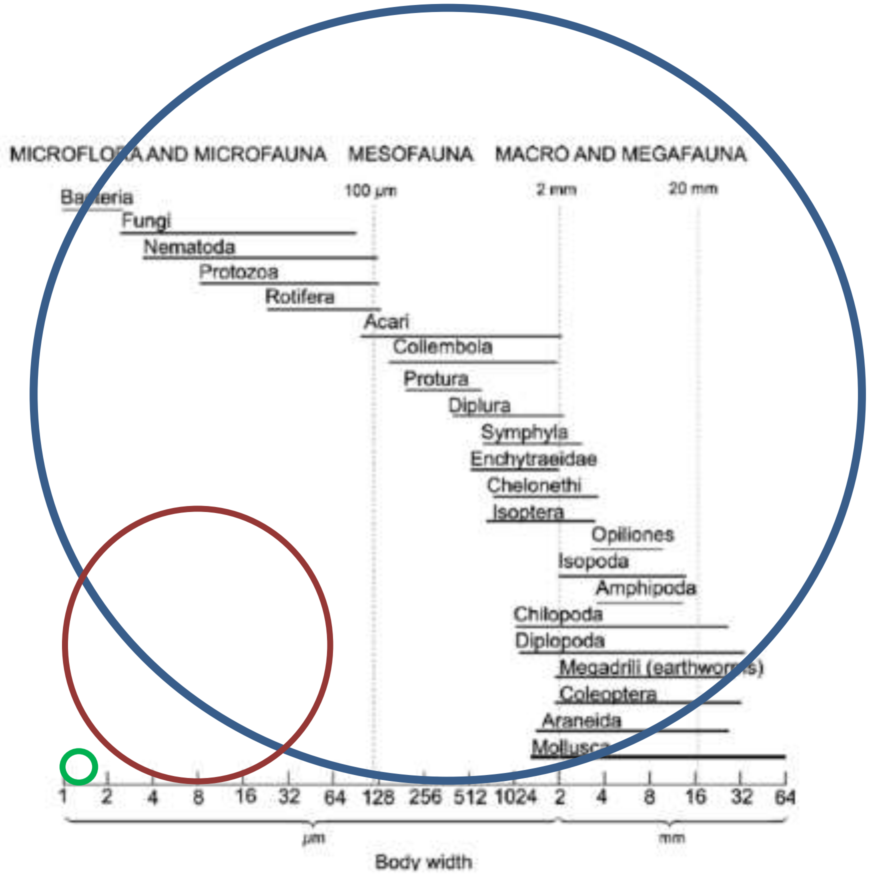
Table 2. Summary of Cost Comparisons Between Conventional and LID Approaches[a]

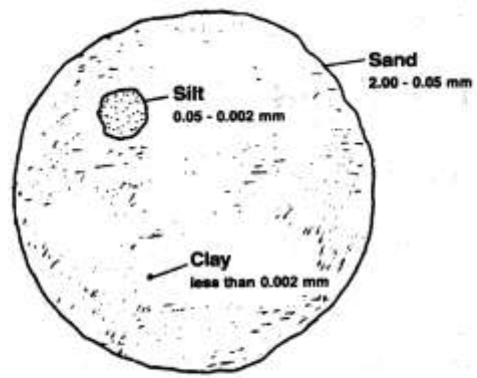
Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

[a] The Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs study results do not lend themselves to display in the format of this table.
[b] Negative values denote increased cost for the LID design over conventional development costs.
[c] Mill Creek costs are reported on a per-lot basis.

U.S. Environmental Protection Agency, 2007. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices.

The Relative Size of Things





Sand = 50 µm to 2,000 µm

Silt = 2 µm to 50 µm

Clay = smaller than 2 µm

Ponding Depth

Table 3 Recommended ponding depths (in chronological order by source)

Source	Ponding Depth
USEPA Storm Water Technology Fact Sheet Bioretention (USEPA, 1999)	152 mm (max)
Prince George's County, Maryland (1999)	152 mm (max)
Auckland Regional Council TP10 (2003)	220 mm (max)
USEPA Stormwater Best Management Practice Design Guide Volume 2, Vegetative Biofilters (USEPA, 2004)	152 - 305 mm
University of Wisconsin-Madison (2006)	457 mm (max)
Prince George's County, Maryland (2007)	152 - 305 mm
The SUDS manual (Woods-Ballard et al. 2007)	150 mm (max)
Washington State University (2007)	152 - 305 mm
FAWB (2009b)	100 - 300 mm
North Carolina (Brown & Hunt, 2011b)	300 mm (max)

100 mm = 3.9 inches

Soil Media Hydraulic Conductivity

Table 4 Recommended hydraulic conductivity of bioretention filter media

Publication	Hydraulic Conductivity
Auckland Council Rain Garden Construction Guide (2011)	12.5 mm hr^{-1} (min)
California Bioretention TC-32 (CASQA, 2003)	12.5 mm hr^{-1} (min)
City of Austin (2011)	50.8 mm hr^{-1} (min)
USEPA (2004)	12.7 mm hr^{-1} (min)
FAWB (2009b)	100 - 300 mm hr^{-1} (temperate climates) 100 - 500 mm hr^{-1} (tropical climates)
Prince George's County, Maryland (2007)	12.7 mm hr^{-1} (min)
The SUDS manual (Woods-Ballard et al. 2007)	12.6 mm hr^{-1}
North Carolina Cooperative Extension Service (Hunt and Lord 2006)	25.4 mm hr^{-1} (for nitrogen removal) 50.8 mm hr^{-1} (for phosphorus, metal and other pollutant removal)
Puget Sound Partnership (2009) Seattle Public Utilities (2011)	25.4 - 305 mm hr^{-1}

25.4 mm/hr = 1 in/hr

Soil Media Depth

Table 2 Recommended media depths (in chronological order by source).

Source	Media Depth
USEPA Storm Water Technology Fact Sheet Bioretention (USEPA, 1999)	1,219 mm
Prince George's Country, Maryland (1999)	610 - 1,219 mm
USEPA Stormwater Best Management Practice Design Guide Volume 2, Vegetative Biofilters (USEPA 2004)	610 - 1,219 mm
North Carolina Cooperative Extension Service (Hunt and Lord 2006)	610 - 1,219 mm
Prince George's Country, Maryland (2007)	762 - 1,219 mm
The SUDS manual (Woods-Ballard et al., 2007)	1000 mm (min)
Washington State University (Hinman 2007)	305 - 610 mm
FAWB (2009b)	300 - 800 mm
Washington State University (Hinman 2009)	457 mm (min)
Auckland Council Rain Garden Construction Guide (2011)	700 mm (min)
City of Austin (2011)	457 mm

1,000 mm = 3.28 feet

Plant Pallet 1: High Species Diversity (7)

Latin Name	Common Name
Aesclepius incarnata	Butterflyweed, Milkweed 'Tuberosa'
Anemone canadensis	Windflower
Aquilegia canadensis	Columbine
Aster novae-angliae	New England Aster 'Purple Dome'
Baptisia australis	Blue False Indigo 'Caspian' and 'Midnight Prairiebliss'
Helenium autumnale	Sneezeweed 'Red + Gold'
Lobeliea cardinalis	Cardinal Flower

Plant Pallet 2: Low Species Diversity (2)

Hemerocallis spp.	Daylilies 'Stella d'Oro'
Panicum virgatum	Switch Grass 'Shenandoah'