Sustainable Stormwater Management and Small Storm Design

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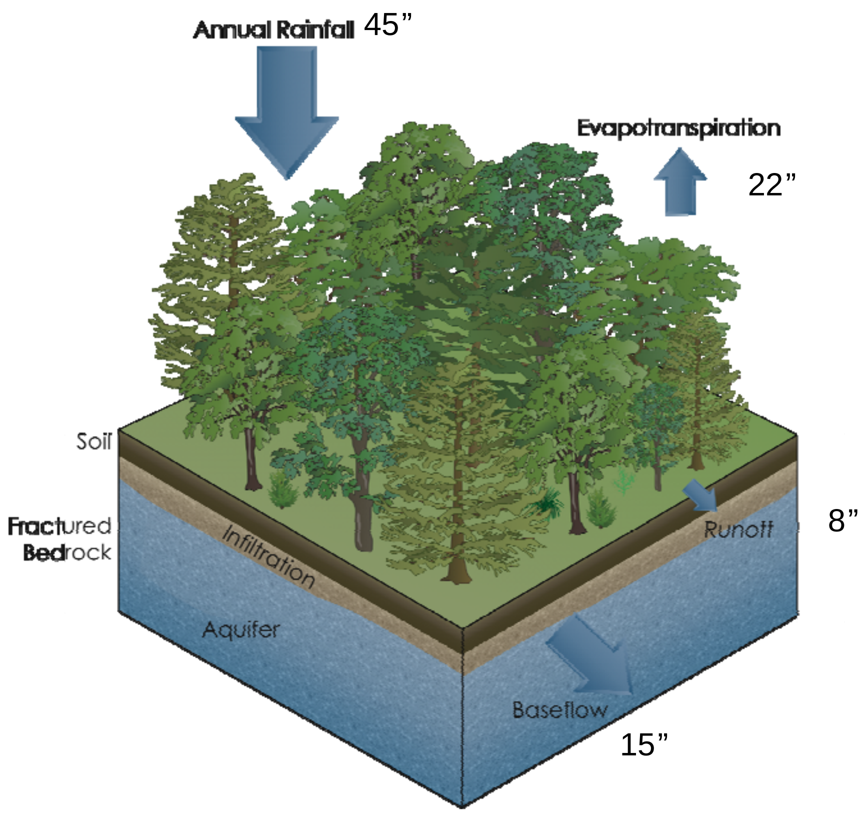
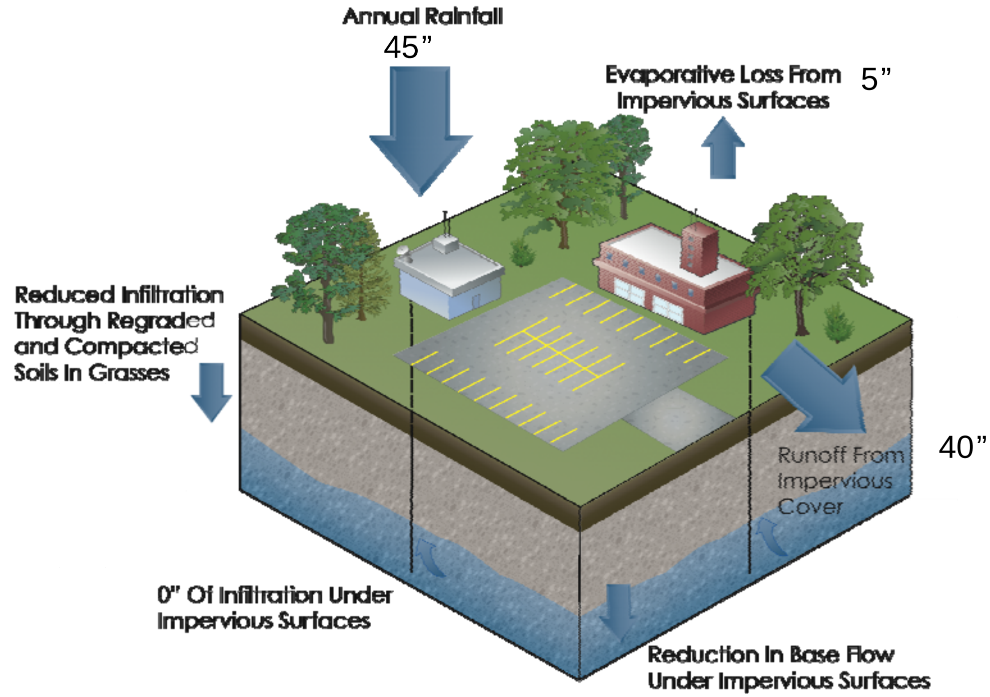
Annual Water Cycle for an Average Year – Piedmont Region Example

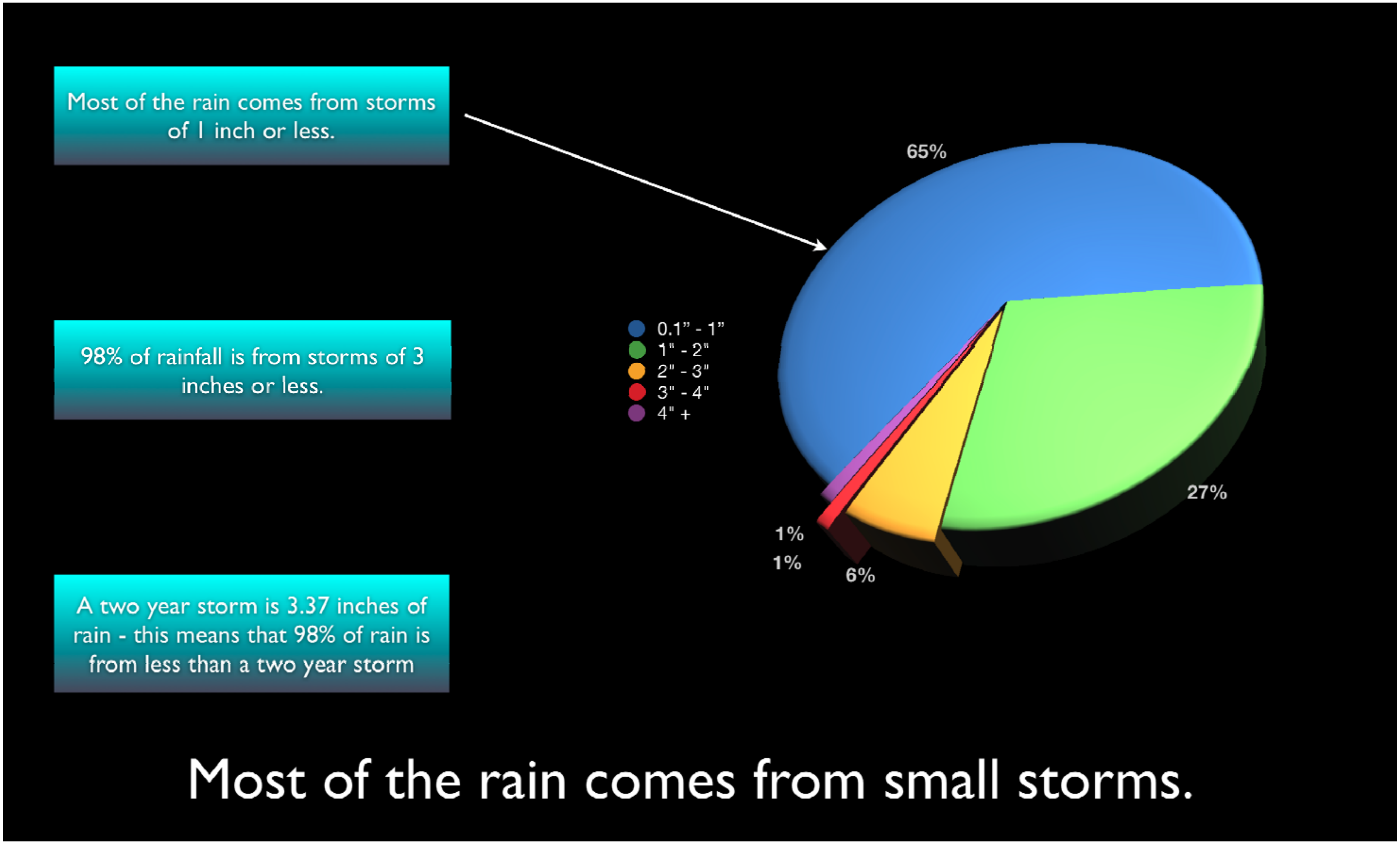


Natural Landscape



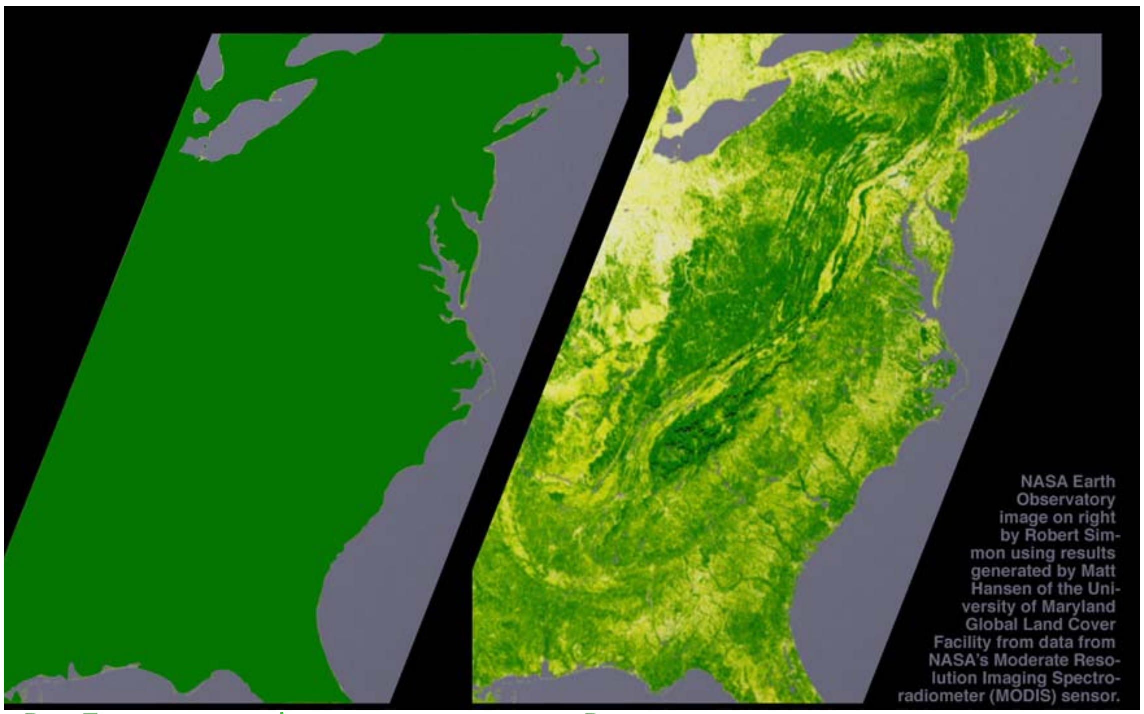
Altered Landscape

Where does most of the rain come from?



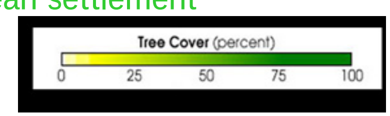
It wants to be a forest

99% of North America was covered by forest from the Atlantic shoreline to the prairies of the Great Plains.
Today only fragments remain.

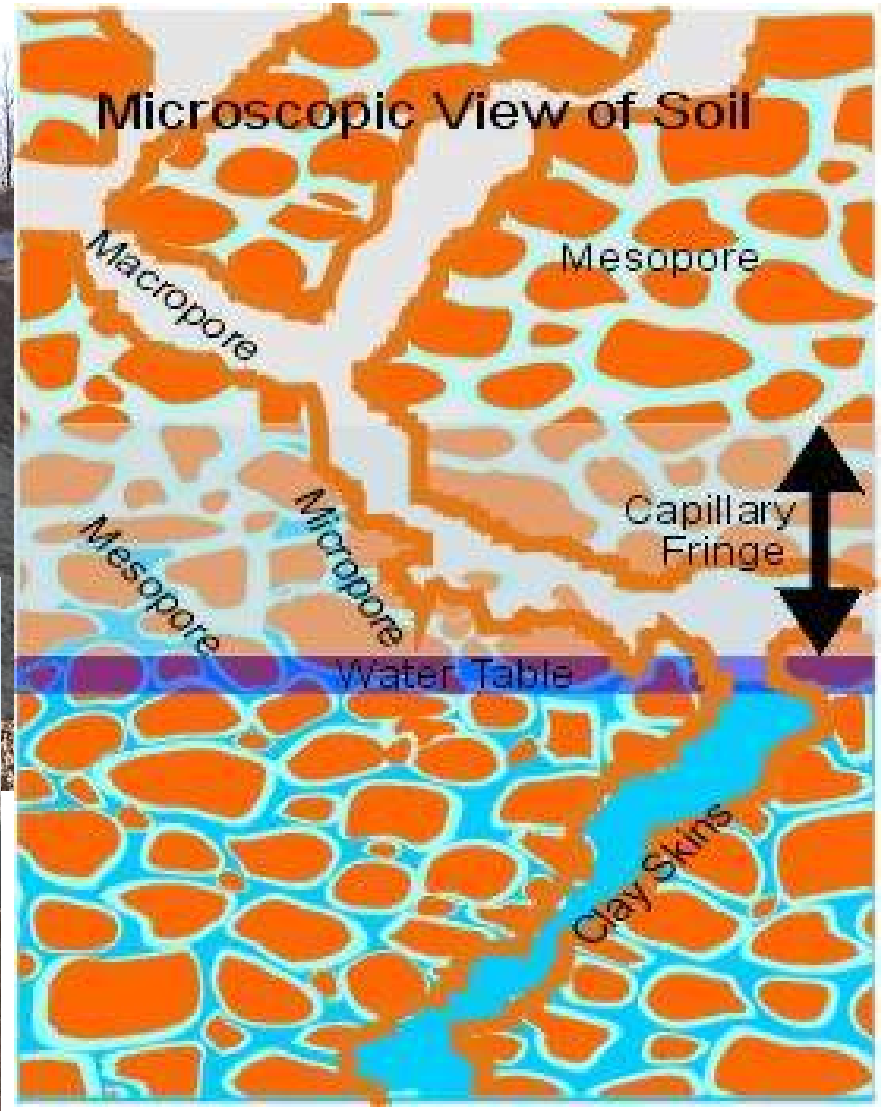


Pre-European settlement

Present

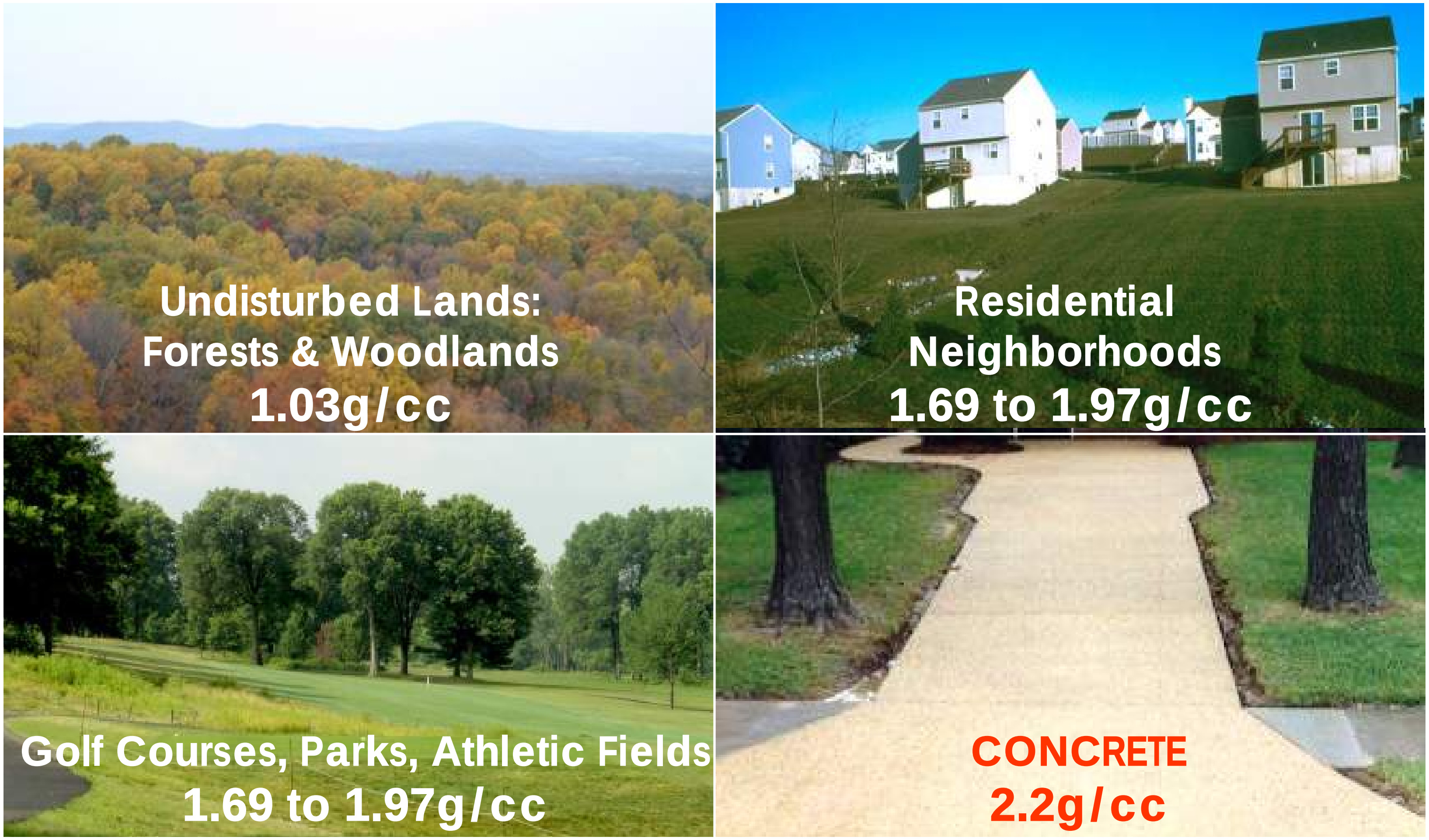


http://earthobservatory.nasa.gov 14 October 2003



Not just impervious surfaces

Common Bulk Density Measurements or How compacted is this soil?



Bulk Density is defined as the weight of a unit volume of soil including its pore space (g/cc or grams/cubic centimeter). Water and air are important components of soil and we must frame our soil concepts so that factors affecting water and air dynamics are included. Thus, we are primarily interested in bulk density and pore space as they affect water and aeration status, and root penetration and development.

Is there a different approach for stormwater?

- Volume
- Integrated into the Built Environment
  - Paths, Parking, Landscape, Street Trees, Playfields
- Importance of Soil and Vegetation
- Small and Large Storms
- Sustainable
- Maintenance and Cost

We forget that the water cycle and the life cycle are one.

- Jacques Cousteau

Low Impact Development (LID)

"Allow natural infiltration to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, costly conveyance systems can be avoided and the landscape can retain more of its natural hydrologic function."

National Association of Home Builders

Percentage of Storms 1.5” or Less

City	Annual Precipitation (in)	1.5" and less
New England		
Portland, ME	41	95%
Mid-Atlantic / Piedmont		
Philadelphia, PA	45	96%
Chapel Hill, NC	46	93%
Atlanta, GA	51	91%
Southeast		
Miami, FL	60	92%
Tampa, FL	53	93%
New Orleans, LA	62	84%
Great Lakes		
Detriot, MI	73	95%
Buffalo, NY	131	96%
Midwest		
West Lafayette, IN	36	95%
Columbus, OH	67	95%
Rapid City, SD	56	99%
Southwest		
Los Angeles, CA	17	91%
Phoenix, AZ	8	98%
Austin, TX	31	90%
West		
Boise, ID	33	99%
Denver, CO	16	99%
Northwest		
Seattle, WA	37	98%

Small Storms By Size

City	Annual Precipitation (in)	Precentage of Storms Less than 0.5"	0.5 to 1.5	More than 1.5"
New England				
Portland, ME	41	72%	23%	5%
Mid-Atlantic / Piedmont				
Philadelphia, PA	45	71%	25%	4%
Chapel Hill, NC	46	71%	22%	
Atlanta, GA	51	65%	26%	9%
Southeast				
Miami, FL	60	76%	16%	8%
Tampa, FL	53	74%	19%	7%
New Orleans, LA	62	62%	22%	16%
Great Lakes				
Detriot, MI	73	73%	22%	5%
Buffalo, NY	131	80%	16%	4%
Midwest				
West Lafayette, IN	36	73%	22%	5%
Columbus, OH	67	80%	15%	5%
Rapid City, SD	56	90%	9%	1%
Southwest				
Los Angeles, CA	17	72%	19%	9%
Phoenix, AZ	8	82%	16%	2%
Austin, TX	31	71%	19%	10%
West				
Boise, ID	33	94%	5%	1%
Denver, CO	16	86%	13%	1%
Northwest				
Seattle, WA	37	84%	14%	2%

Can we use many measures, large and small, to...

- Catch the water near the source?
- Return water to soils and vegetation?
- Slow the water?
- Clean the water?
- Restore the landscape?
- Recharge groundwater?
- Not so many pipes, basins, outfalls?

LID Project Examples

morning

New Institutional – Penn State Visitor Center

New Residential – Springbrook Residential

afternoon

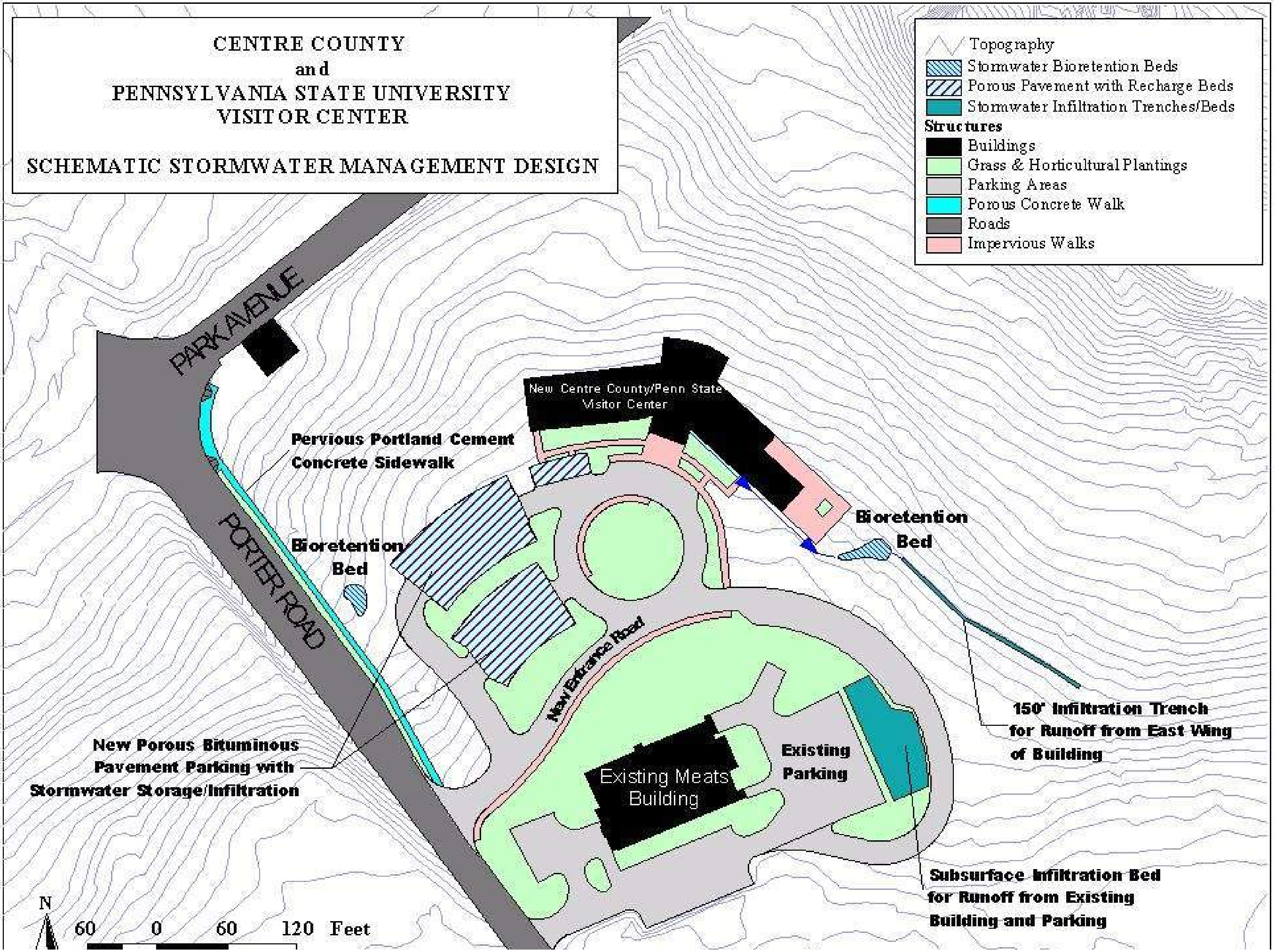
Urban Retrofit – Waterview Recreation Center and Wilmington Acme

Penn State Visitor Center

- Constructed in 1999/2000
- Funding from PaDEP Growing Greener
- Stormwater in the Landscape:
  - Porous Parking
  - Porous Sidewalks
  - Rain Gardens
  - Infiltration Trenches
  - Vegetated Infiltration Beds

Design Team Coordination

- Architect, Landscape Architect and Engineer worked together to fit design to site topography.

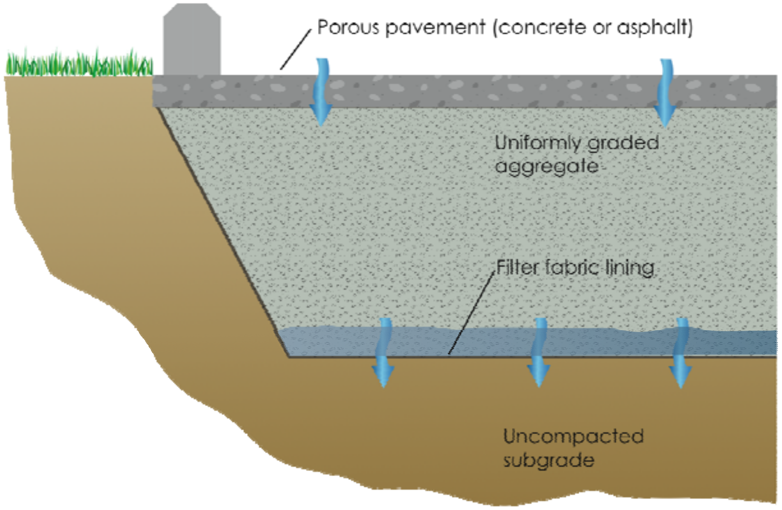

CENTRE COUNTY
and
PENNSYLVANIA STATE UNIVERSITY
VISITOR CENTER
SCHEMATIC STORMWATER MANAGEMENT DESIGN
Topography
Stormwater Bioretention Beds
Porous Pavement with Recharge Beds
Stormwater Infiltration Trenches/Beds
Structures
Buildings
Grass & Horticultural Plantings
Parking Areas
Porous Concrete Walk
Roads
Impervious Walks
PARK AVENUE
PORTER ROAD
New Centre County/Penn State Visitor Center
Pervious Portland Cement Concrete Sidewalk
Bioretention Bed
Bioretention Bed
New Entrance Road
150' Infiltration Trench for Runoff from East Wing of Building
New Porous Bituminous Pavement Parking with Stormwater Storage/Infiltration
Existing Meats Building
Existing Parking
Subsurface Infiltration Bed for Runoff from Existing Building and Parking
N
60 0 60 120 Feet

Porous Asphalt Parking with Groundwater Recharge Beds

- Fitting stormwater into the built environment.
- Reducing the disturbance footprint.
- Eliminating detention basin
- Returning rainfall to groundwater

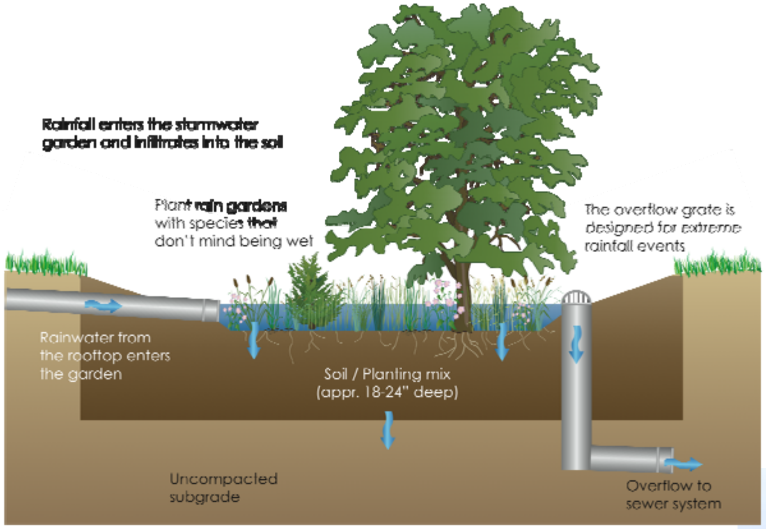
Porous Concrete Sidewalk

Reducing impervious surfaces



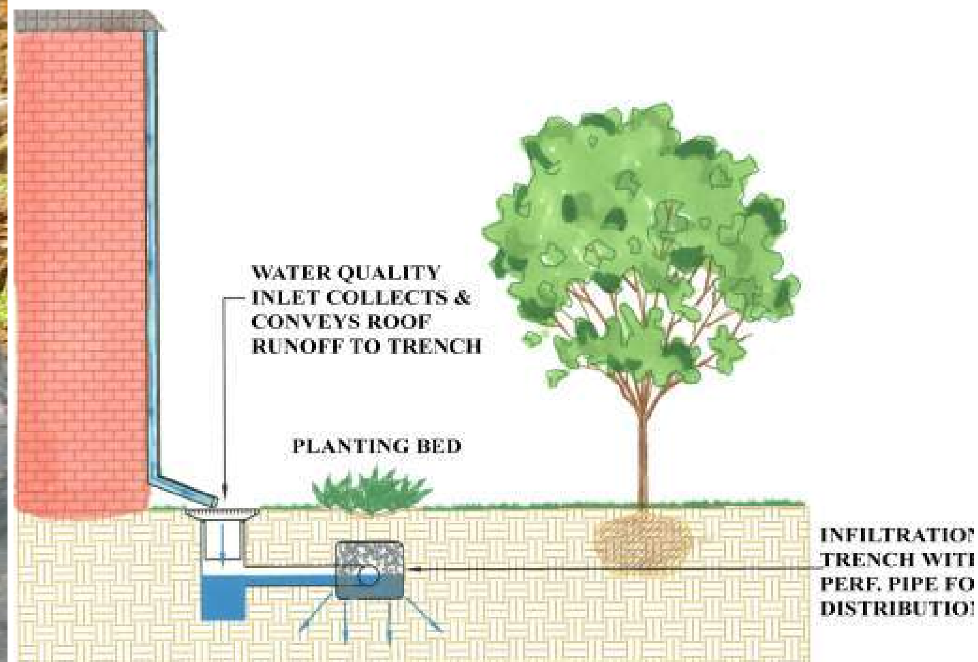
POROUS PAVEMENT

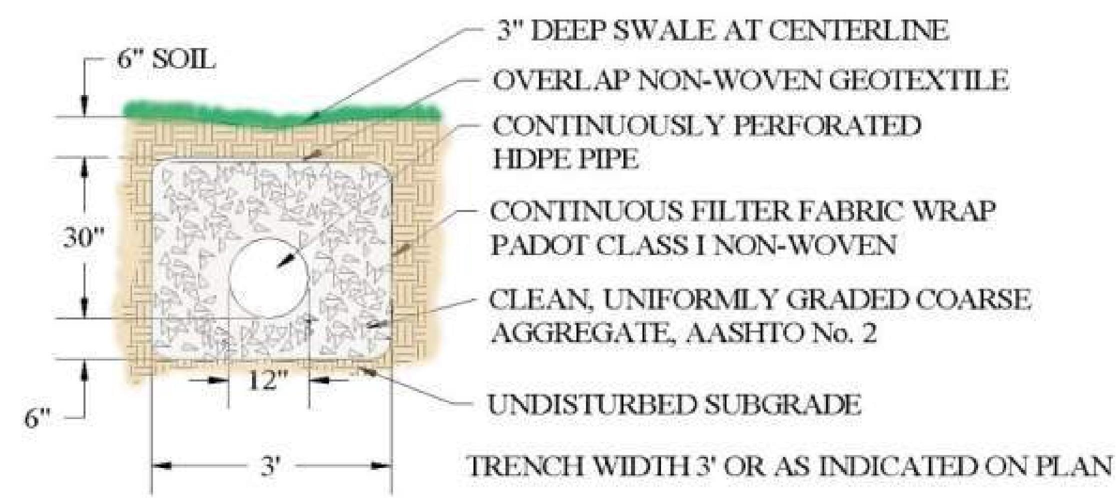
Rain Gardens / Bioretention



Using Soils and Vegetation to Reduce Volume

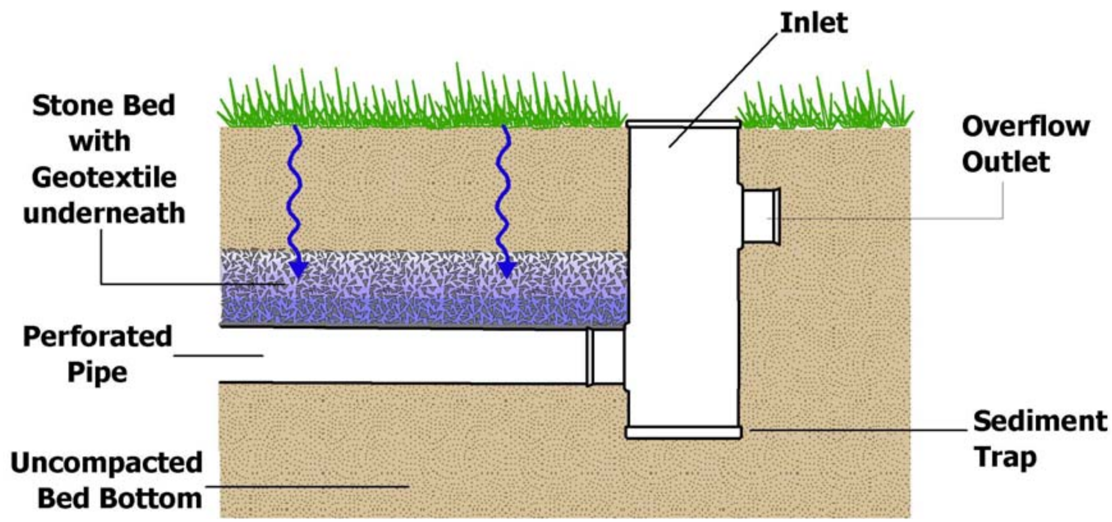
Infiltration Trenches

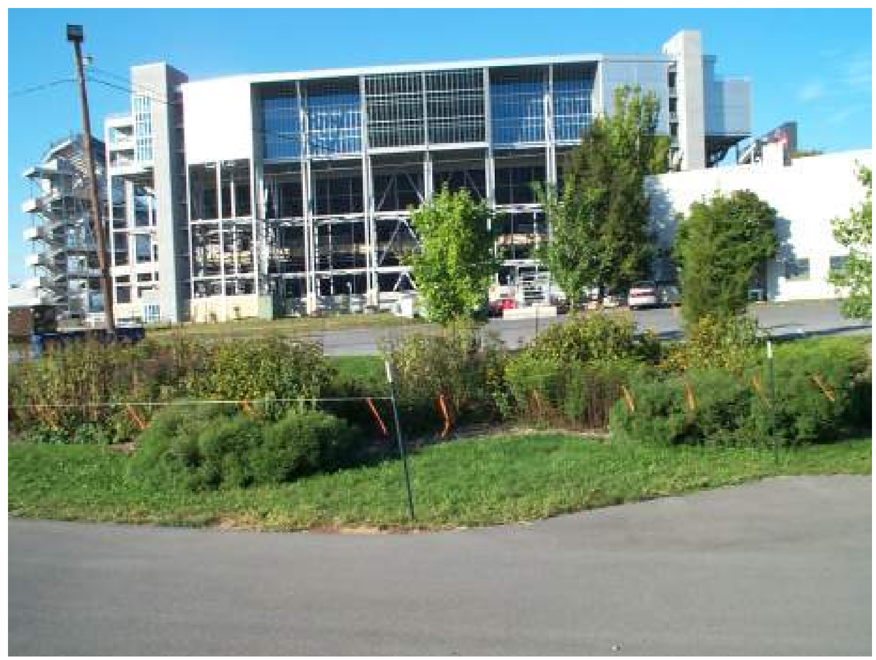


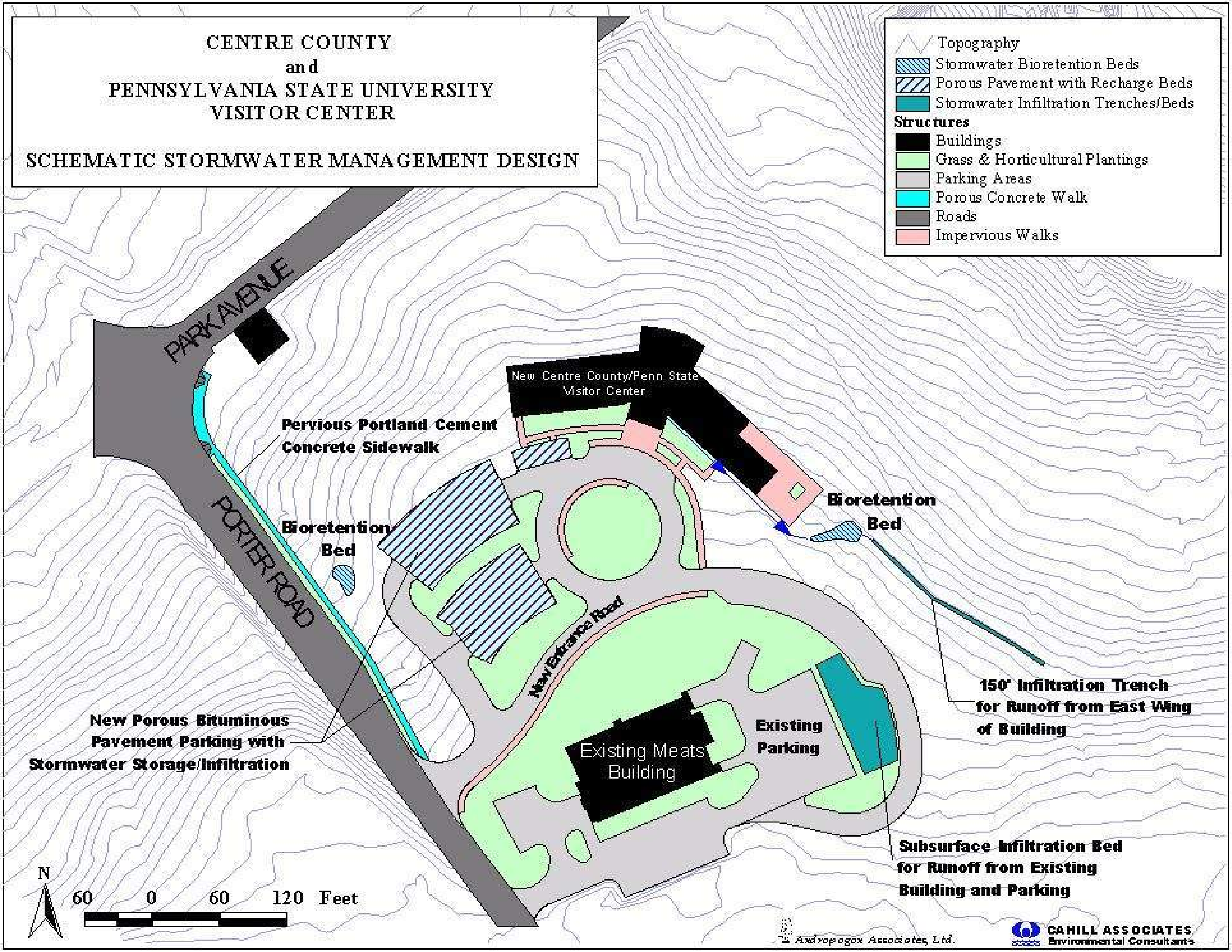


Vegetated Infiltration Beds

Stormwater Below Planting Bed



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Subsurface Infiltration Bed for Runoff from Existing Building and Parking
N
60 0 60 120 Feet
Andropogon Associates, Ltd.
CAHILL ASSOCIATES
Environmental Consultants

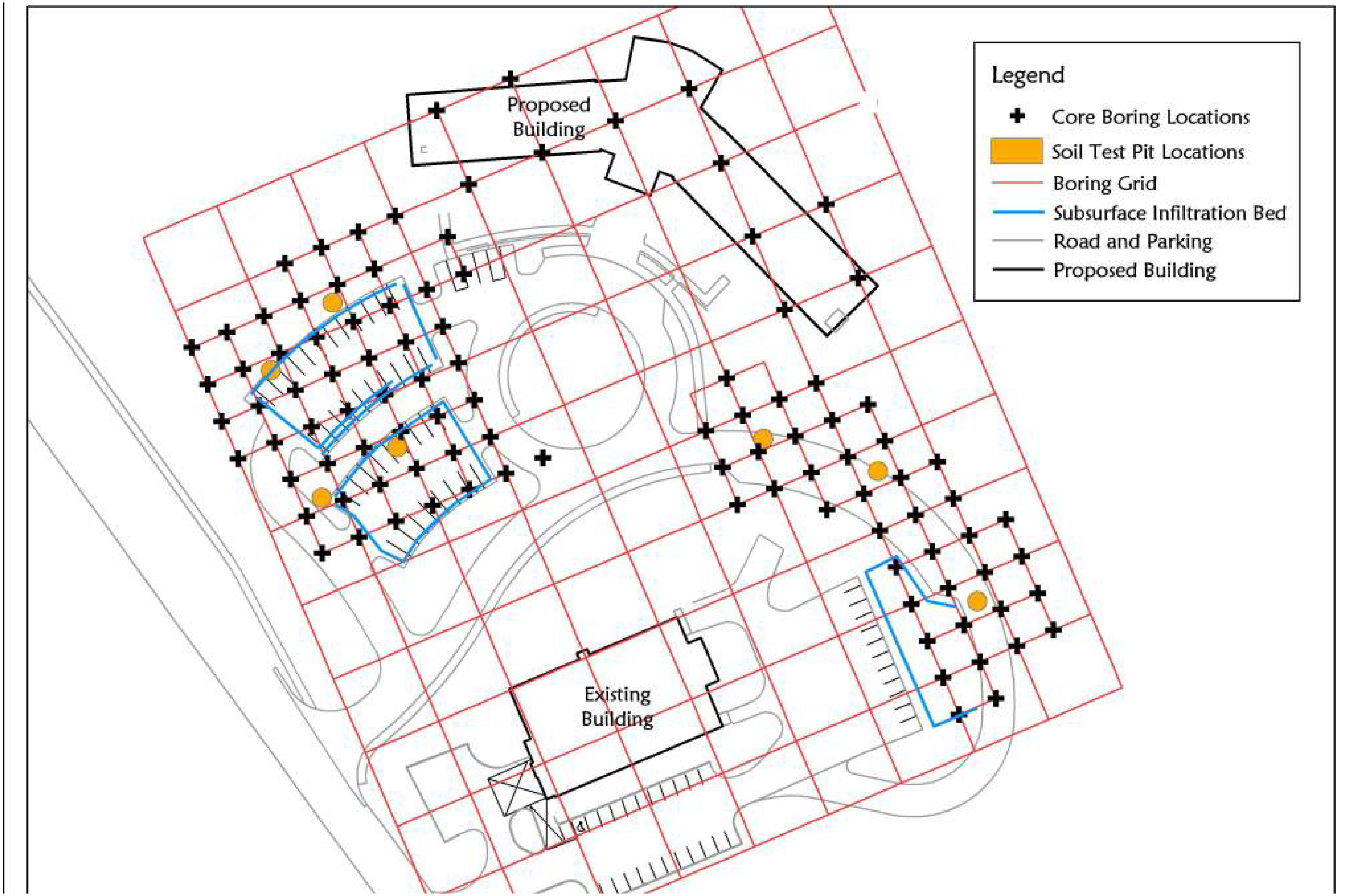
Site Design Considerations

- Karst Topography / Sinkhole Concerns
- Shallow soil mantle
  - Hagerstown HSG “C”
- Downstream Flooding and Water Supply Wells
- Stormwater Management Goals
  - Volume: 2 Year Net Increase
  - Rate: 2-year through 100-year peak
  - Maintain Infiltration and Vegetation

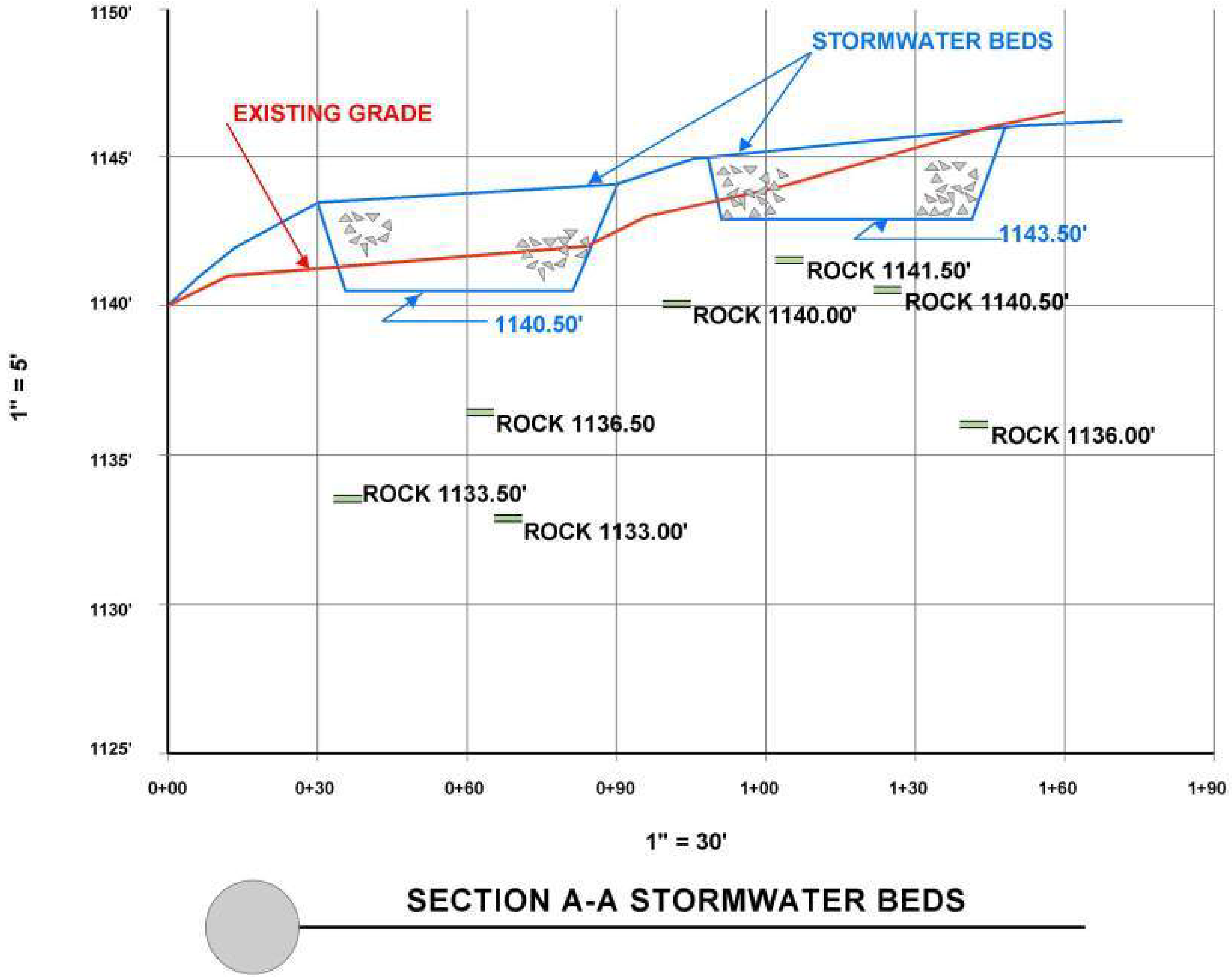
Geology - Karst Area Evaluation

1. Geotechnical Investigation - Borings
   - Depth to rock
   - Pinnacles
   - Sinkhole potential
2. Sinkholes/depressions/other concerns
   - Detailed Geotechnical Evaluation
   - GPR or other techniques
3. Shallow Borings
   - 10 feet deep, 25 feet OC
   - Test Infiltration Areas

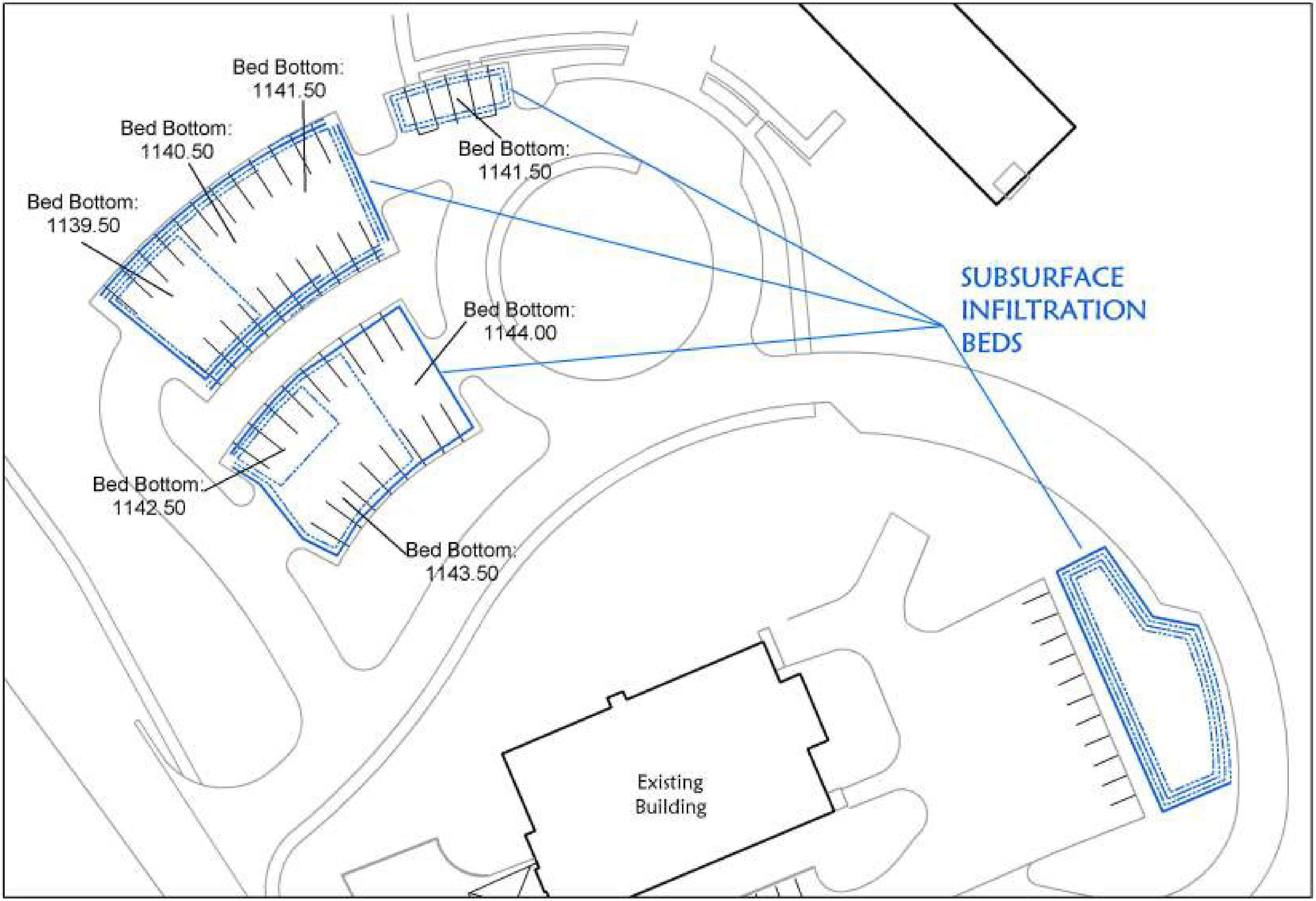
Soil Test Pit and Boring Locations

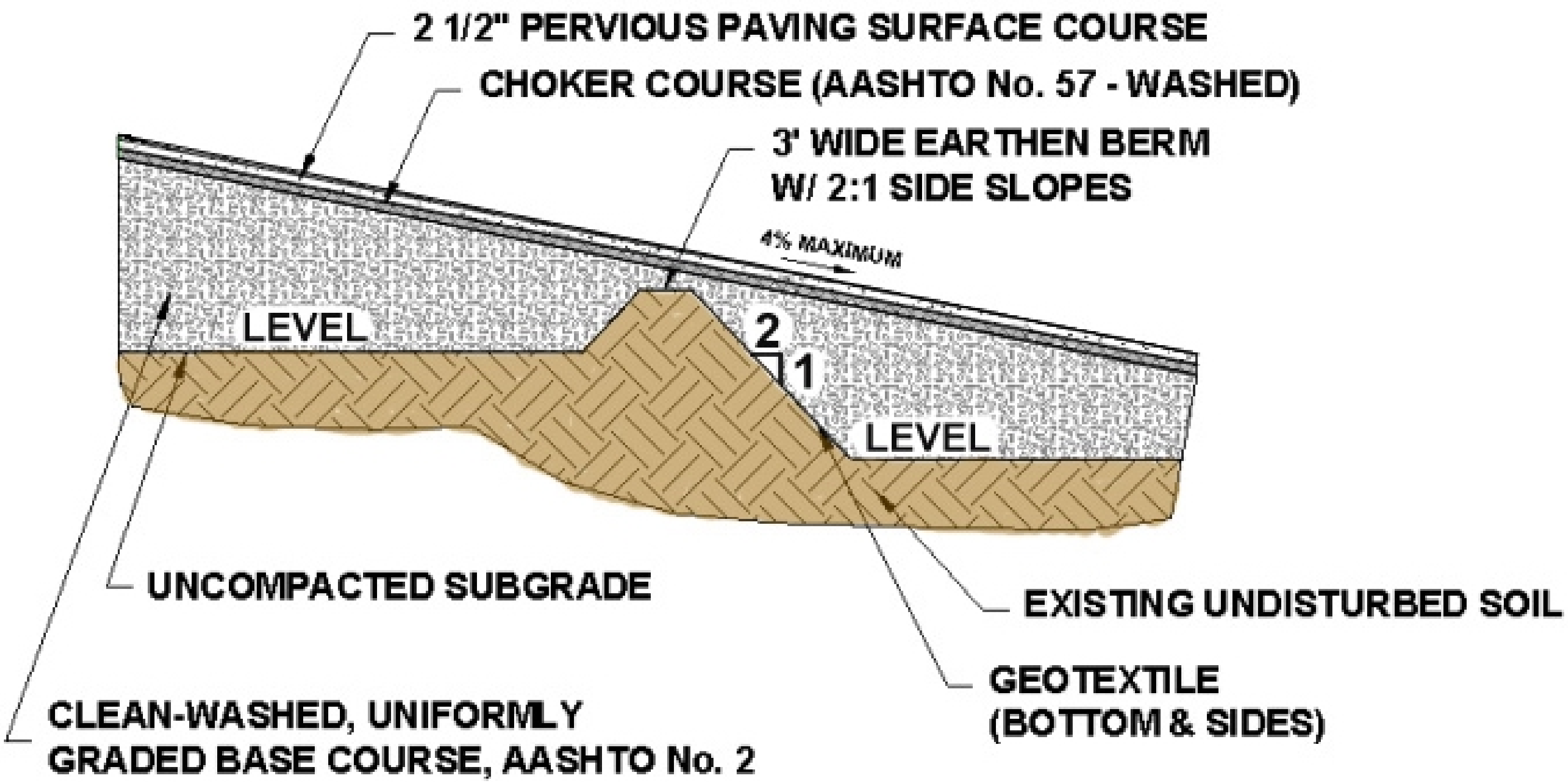


Subsurface Infiltration Bed Cross-Sections and Profiles



Subsurface Infiltration Bed Contours and Grading




2 1/2" PERVIOUS PAVING SURFACE COURSE
CHOKER COURSE (AASHTO No. 57 - WASHED)
3' WIDE EARTHEN BERM
W/ 2:1 SIDE SLOPES
4% MAXIMUM
LEVEL
2
1
LEVEL
UNCOMPACTED SUBGRADE
EXISTING UNDISTURBED SOIL
GEOTEXTILE
(BOTTOM & SIDES)
CLEAN-WASHED, UNIFORMLY
GRADED BASE COURSE, AASHTO No. 2

Stormwater Design

- Manage 2-Year Runoff Volume Increase
- Infiltration – SPREAD IT OUT
  - 5:1 Ratio of Impervious Area to Infiltration Area
  - 3:1 Ratio for Limestone

	Volume of Stone Below Invert (ft^3)	Storage Volume* (ft^3)	Bottom Area (min) (ft^2)
Upper Parking Bay	4,955	1,982	3,750
Lower Parking Bay	11,374	4,550	5,225
Infiltration Bed	3,255	1,302	2,025
Infiltration Trench	1,420	568	450
TOTAL:	**21,004**	**8,402**	**3,361**

* Based on 40% void space in stone bed

2 Year Net Increase: 10,671 ft^3

Impervious Area: 13,818 ft^2

Ratio of Impervious to Infiltration Area:

13,818 ft^2 : 3,361 ft^2 = 4.1 : 1

New Residential: Village at Springbrook

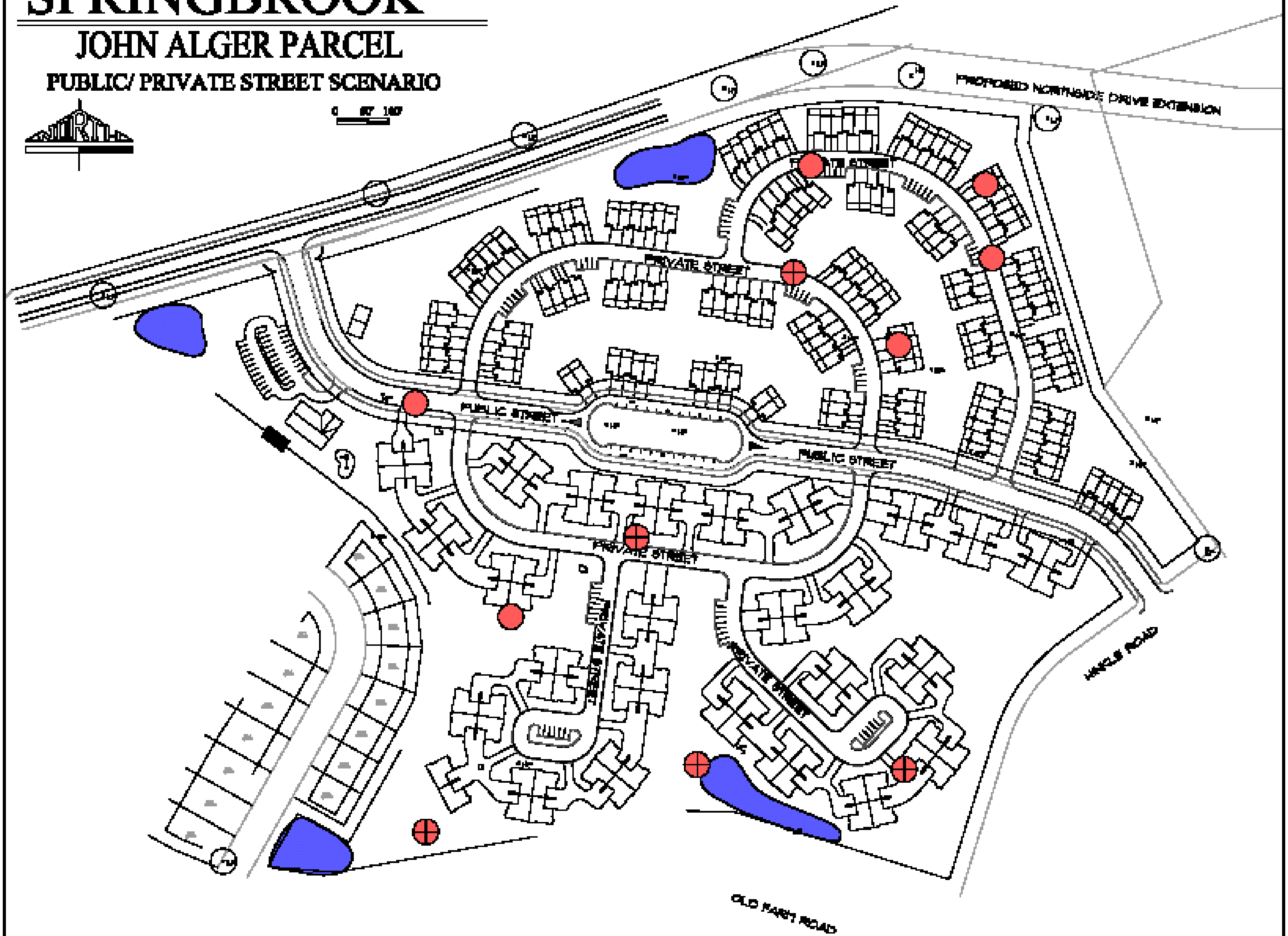
- High Density Residential
- 59 acres
- 269 homes:
- 146 Townhouses
- 96 Quads
- 17 Singles
- Sinkholes and limestone

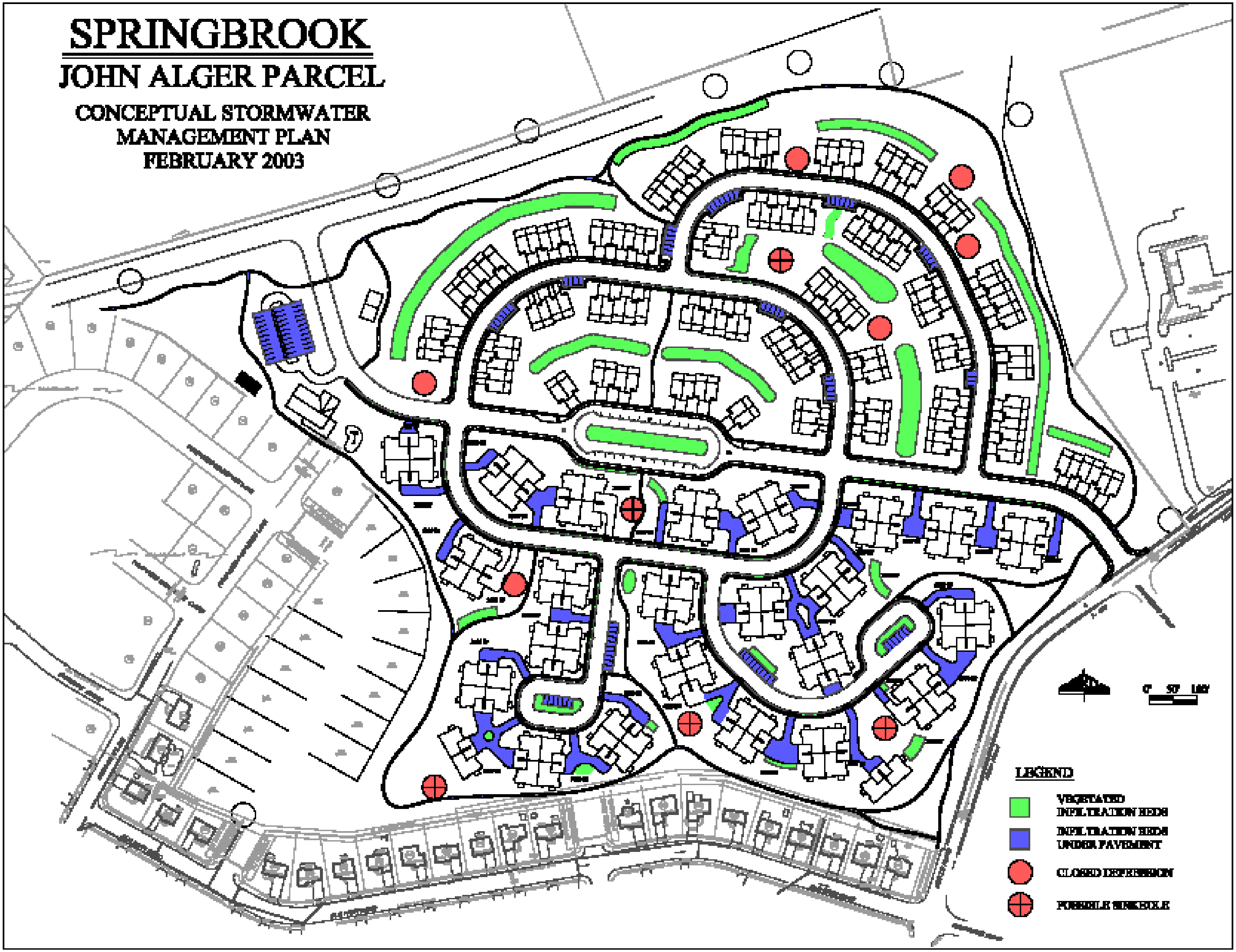
Can Water be Managed within the landscape?127 small measures, no detention basins.


SPRINGBROOK

JOHN ALGER PARCEL

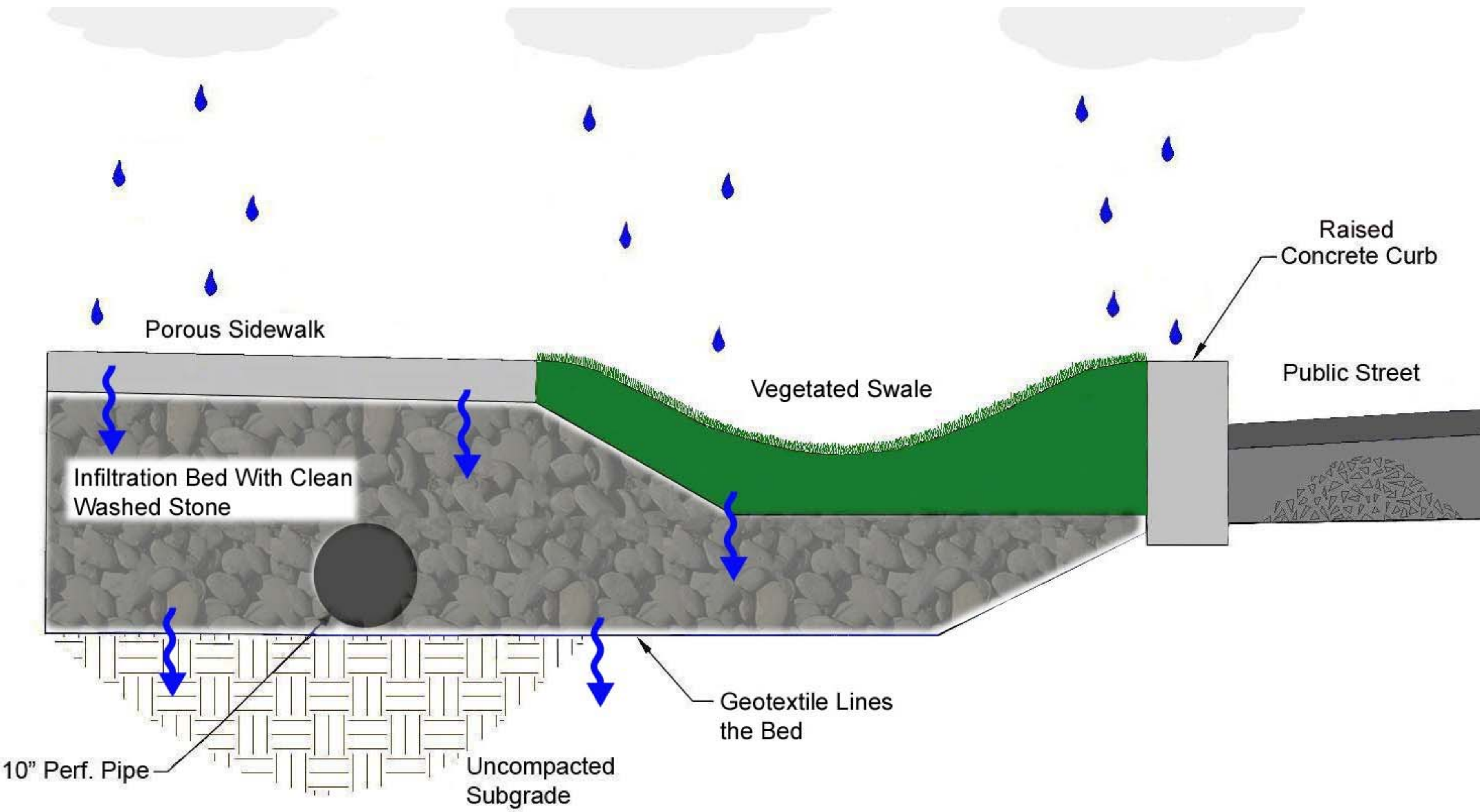
PUBLIC/ PRIVATE STREET SCENARIO




SPRINGBROOK
JOHN ALGER PARCEL
CONCEPTUAL STORMWATER
MANAGEMENT PLAN
FEBRUARY 2003
0' 50' 100'
LEGEND
VEGETATED
INFILTRATION BEDS
INFILTRATION BEDS
UNDER PAVEMENT
CLOSED DEPRESSION
POSSIBLE SINKHOLE

BMPs Integrated into the Site

- Infiltration Beds beneath Driveways
- Porous Concrete Sidewalks
- Porous Asphalt Paths
- Vegetated Swales and Checkdams
- Infiltration Beneath Planting Beds
- Rain Gardens
- Porous Pavement Parking



Integration of Stormwater into Urban Streetscape
Porous Sidewalk and Swale with Raised Curb


TA30


CAT
TA30
312C
CAT

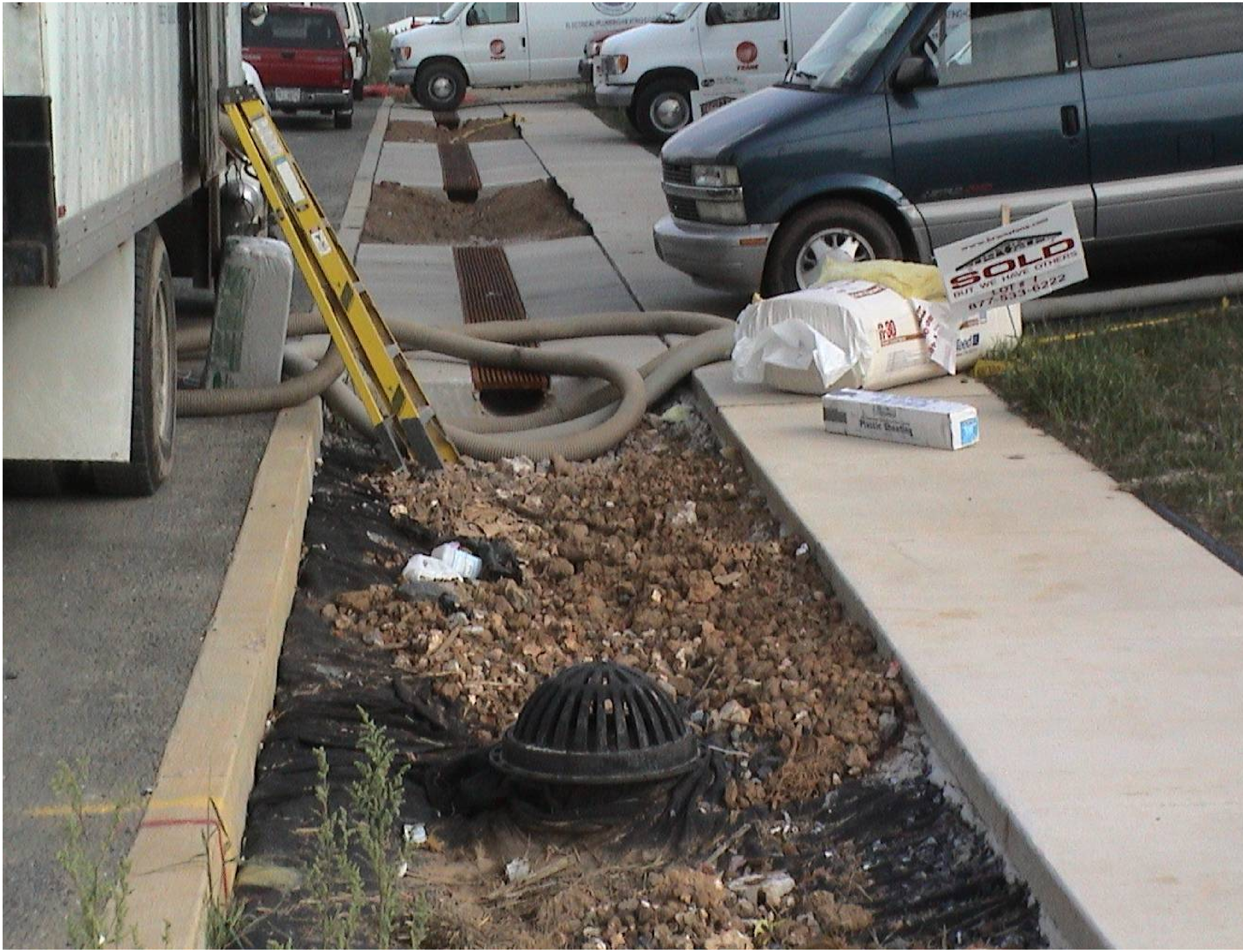

CAT

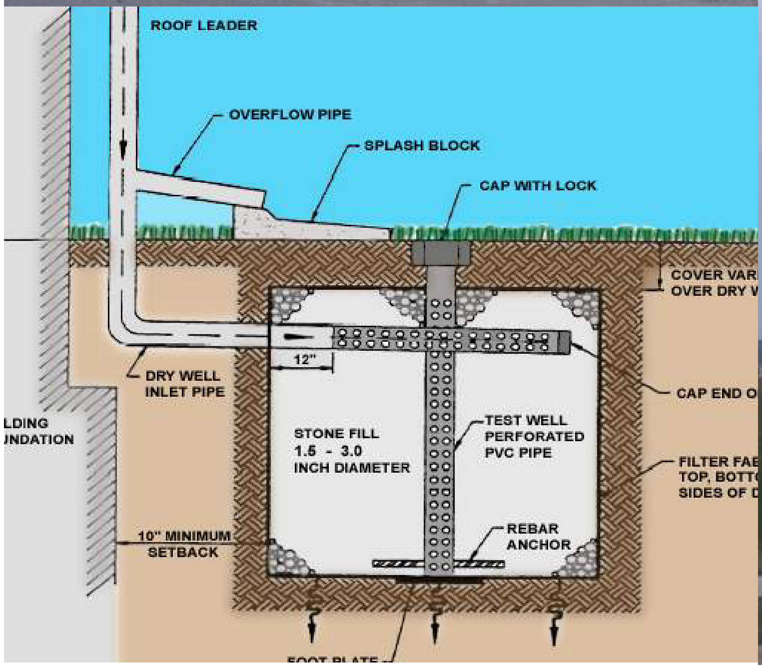

Inlets with Weirs to Control Flow and Water Level

Stormwater beds beneath driveways (standard asphalt).

Overflow to swales along streets

- Quad homes without basements have down spouts connected to infiltration beds beneath impervious driveways.
- Paths made of pervious asphalt.


SOLD
R-30

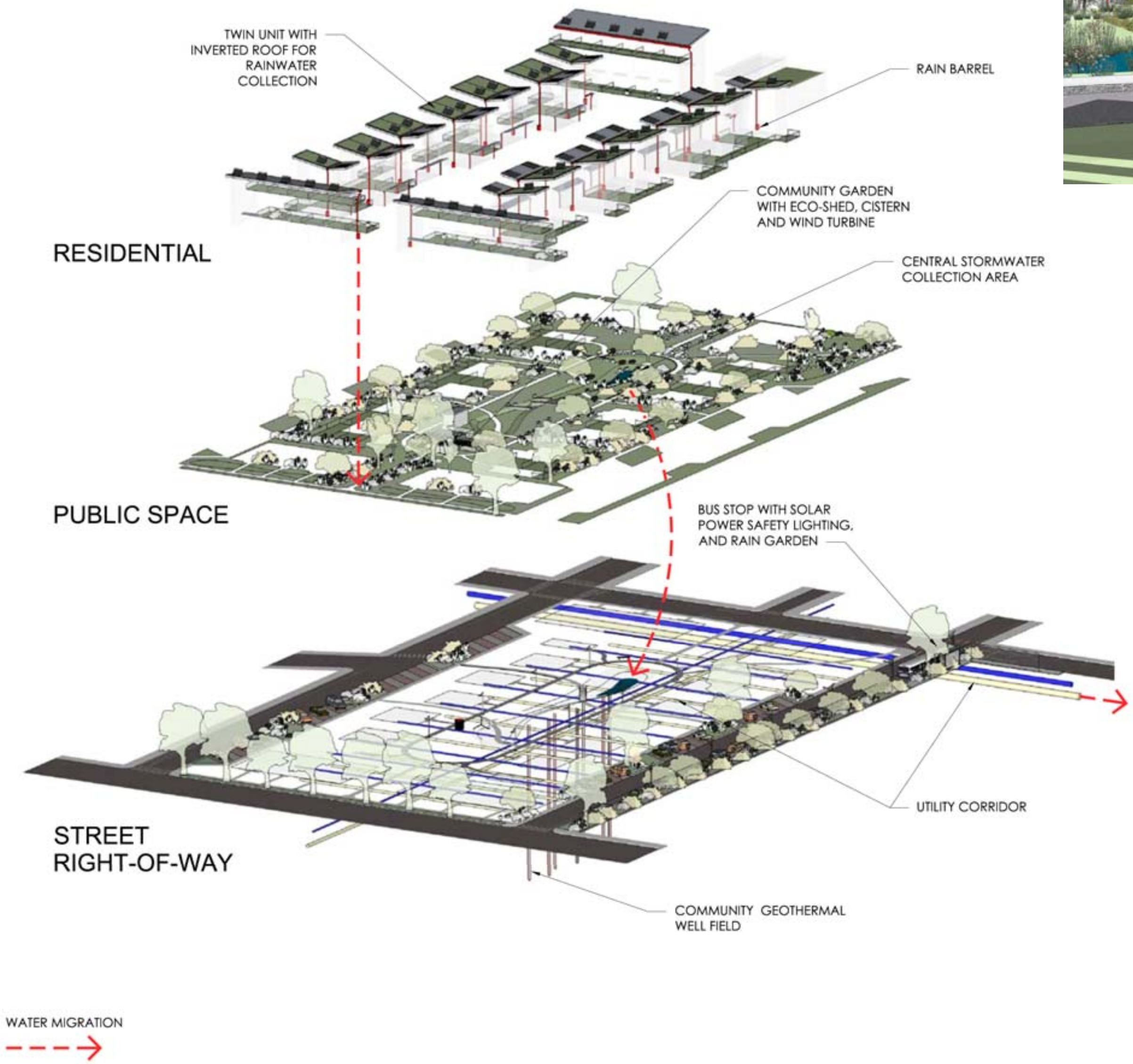


- Each home manages its own runoff in a Rain Garden seepage bed, located in the right-of-way.

Central Park

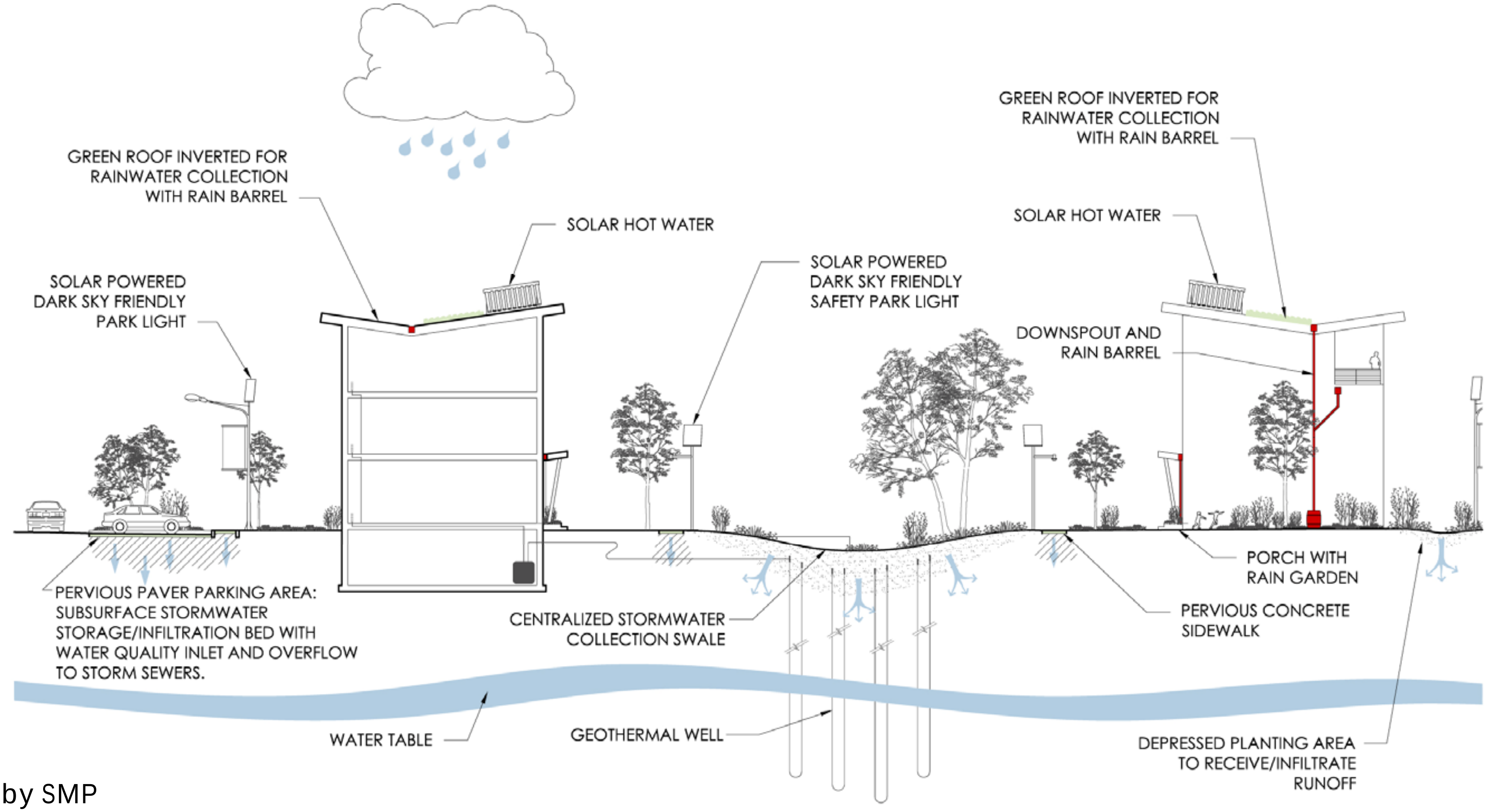
Renderings by SMP Architects

Central Park



Renderings by SMP Architects

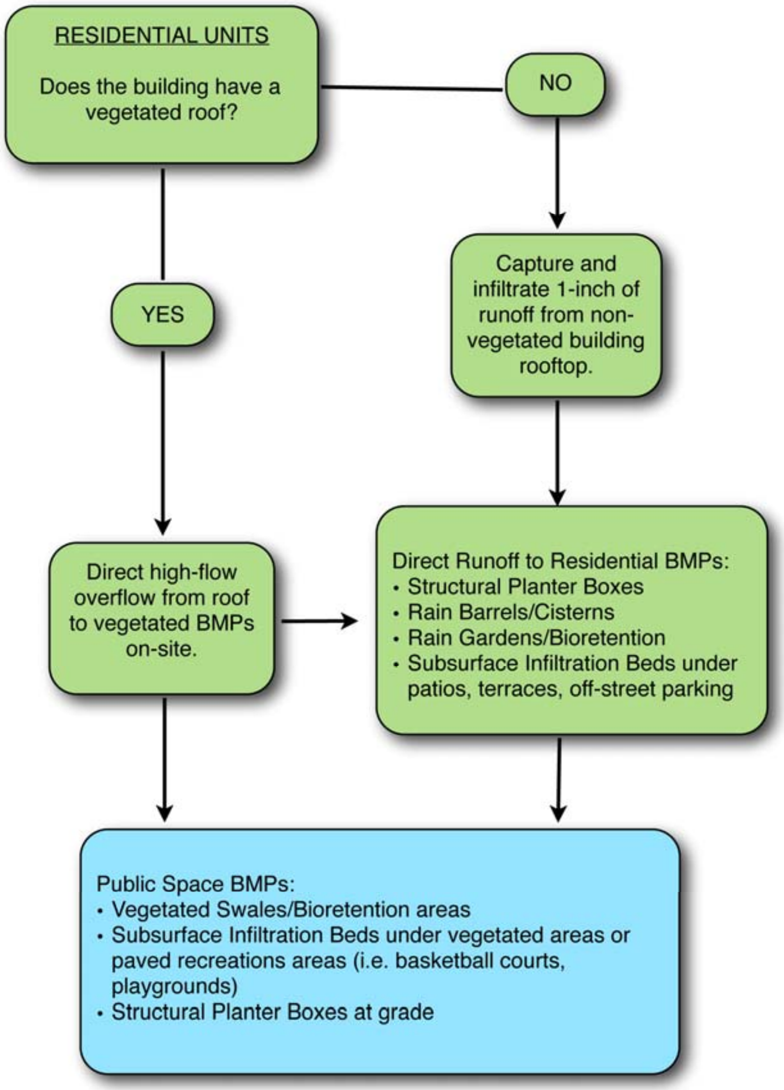
Central Park



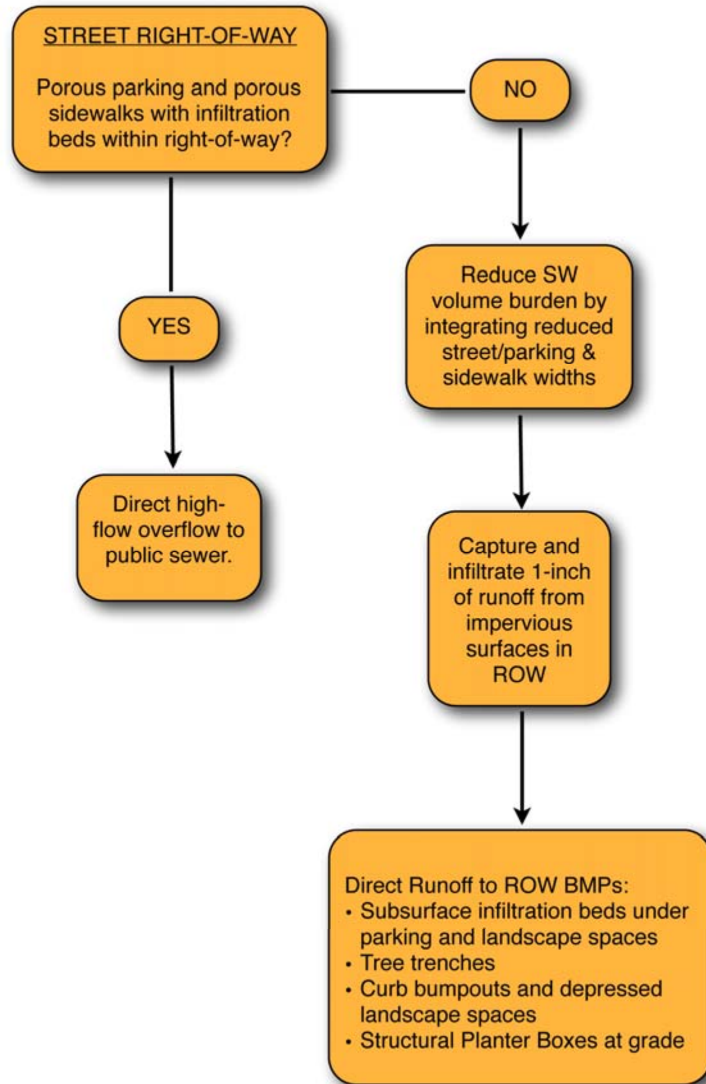
Renderings by SMP Architects

Stormwater Decision Making

Residential



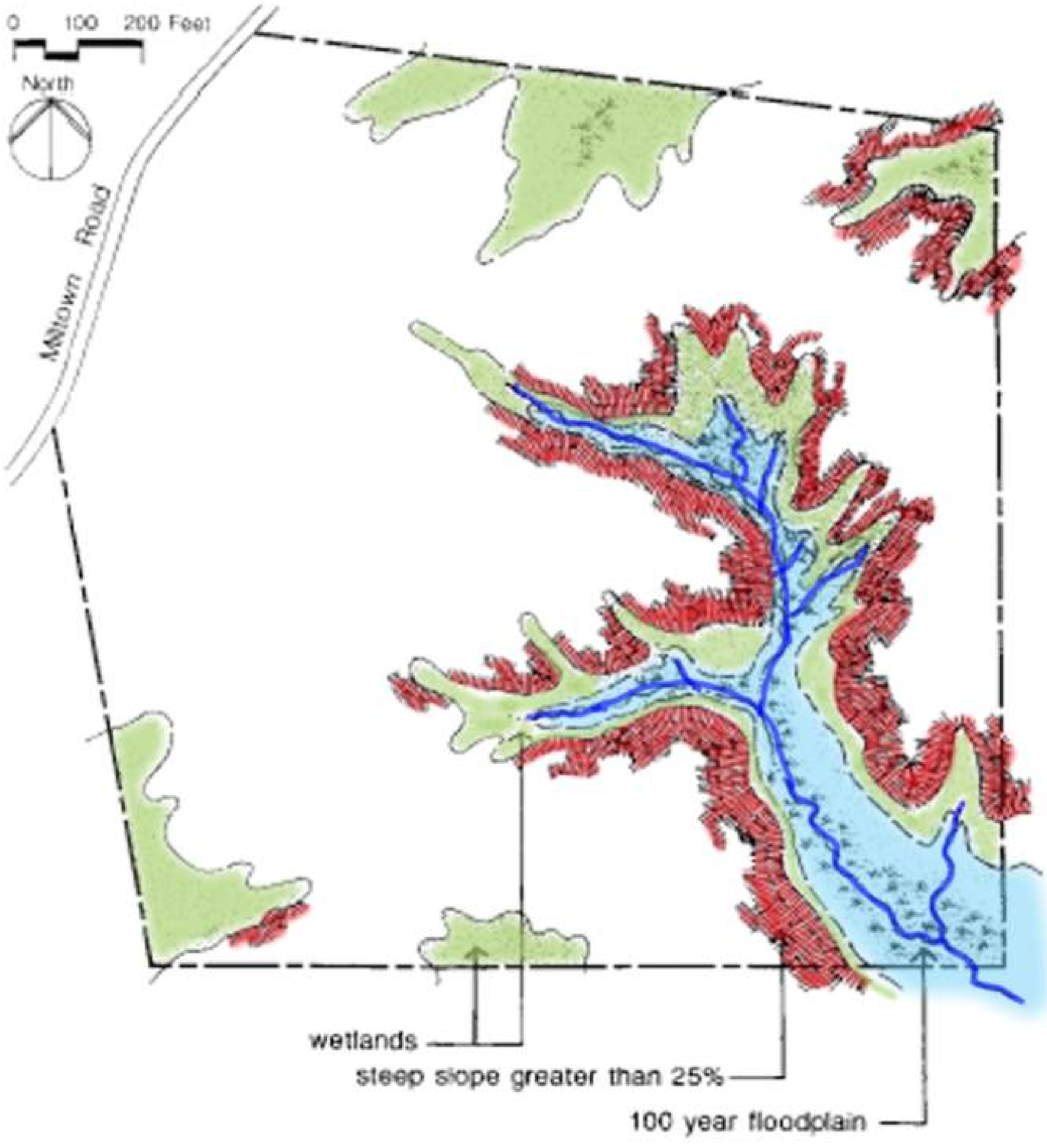
Public Space



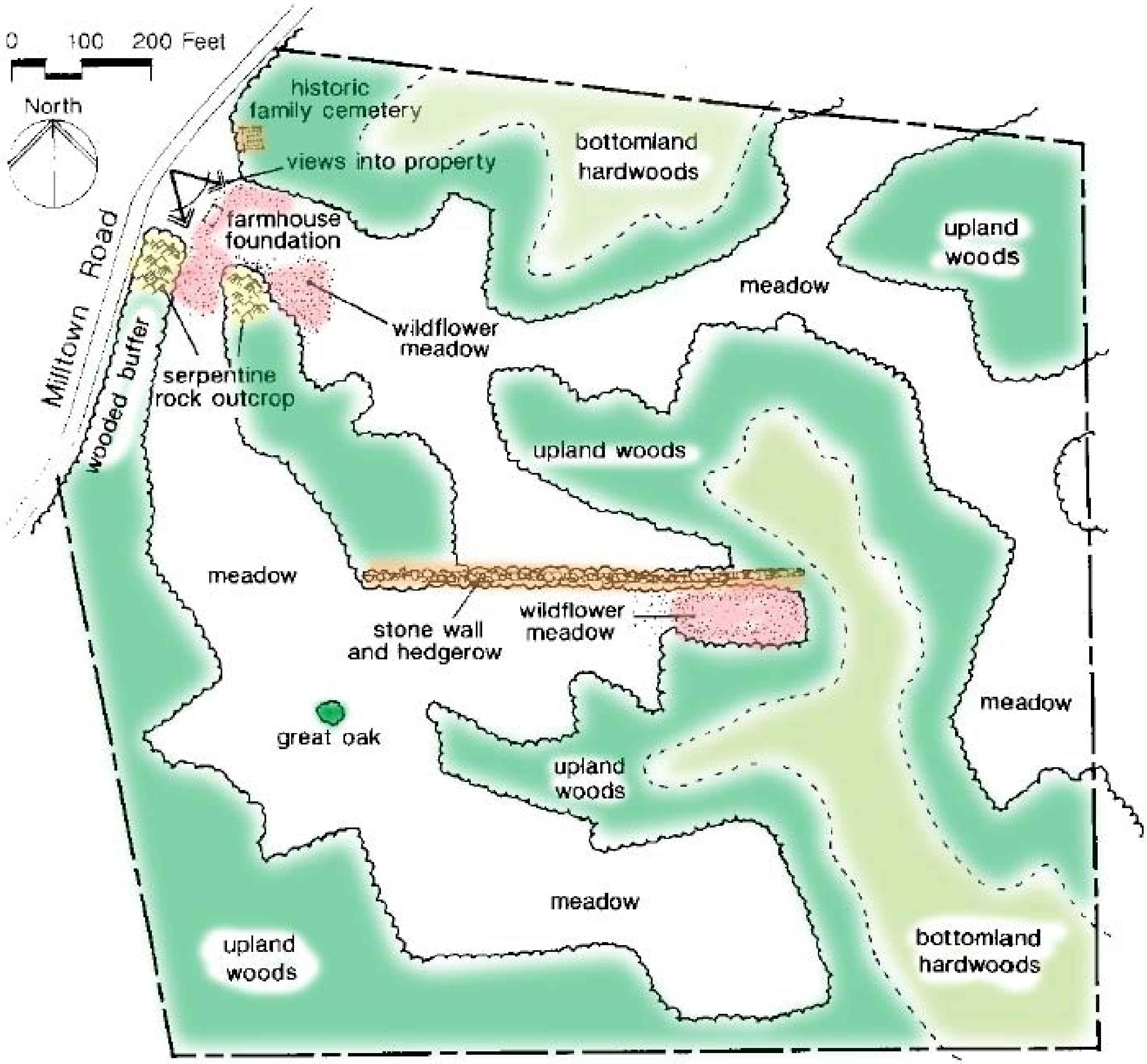
Process for LID

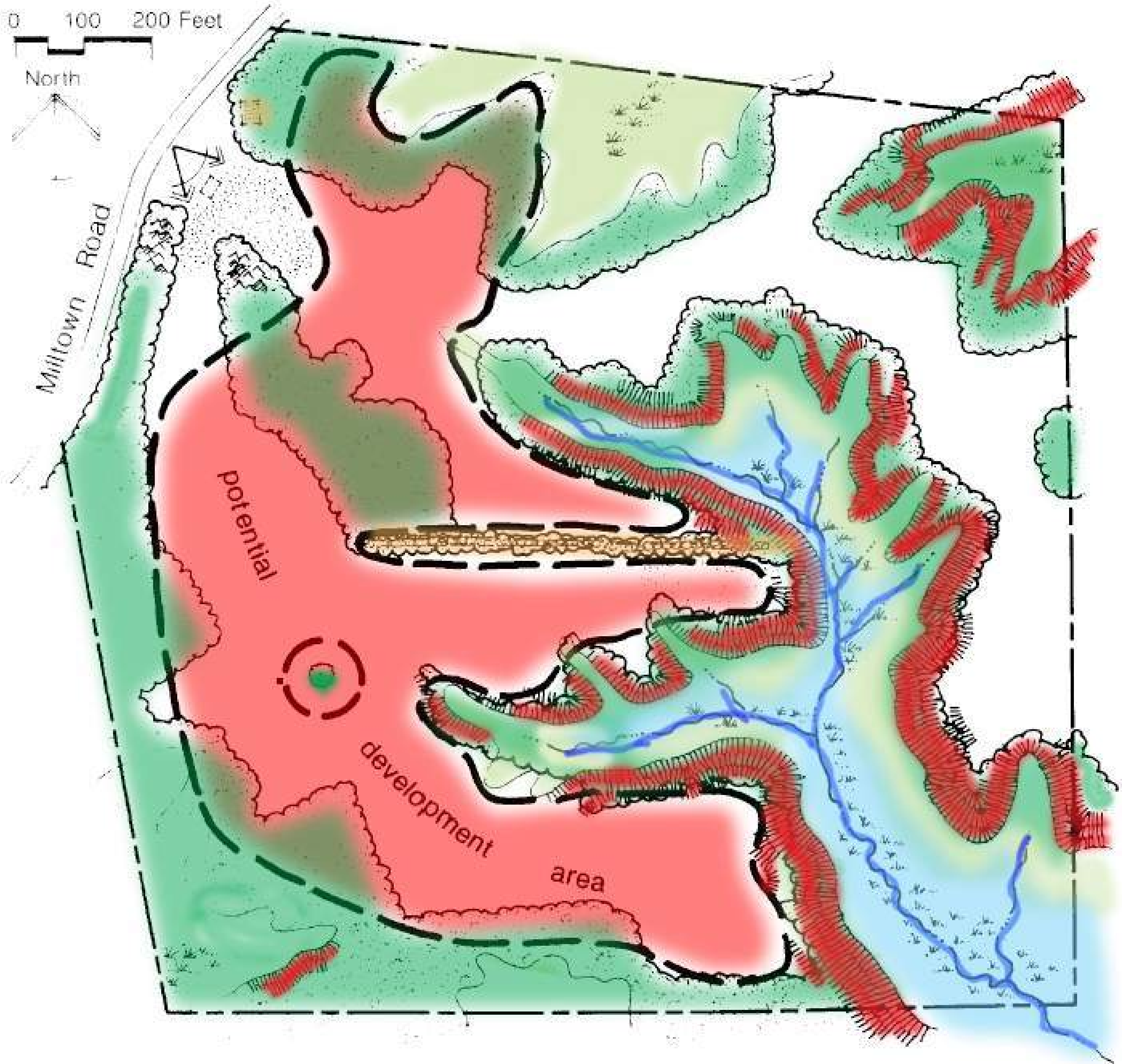
- Understand Existing Site – soils, slopes, vegetation, water levels
- Map Important Natural or Manmade Features

Understand Existing Site – soils, slopes, vegetation, water levels



Map Important Natural or Manmade Features



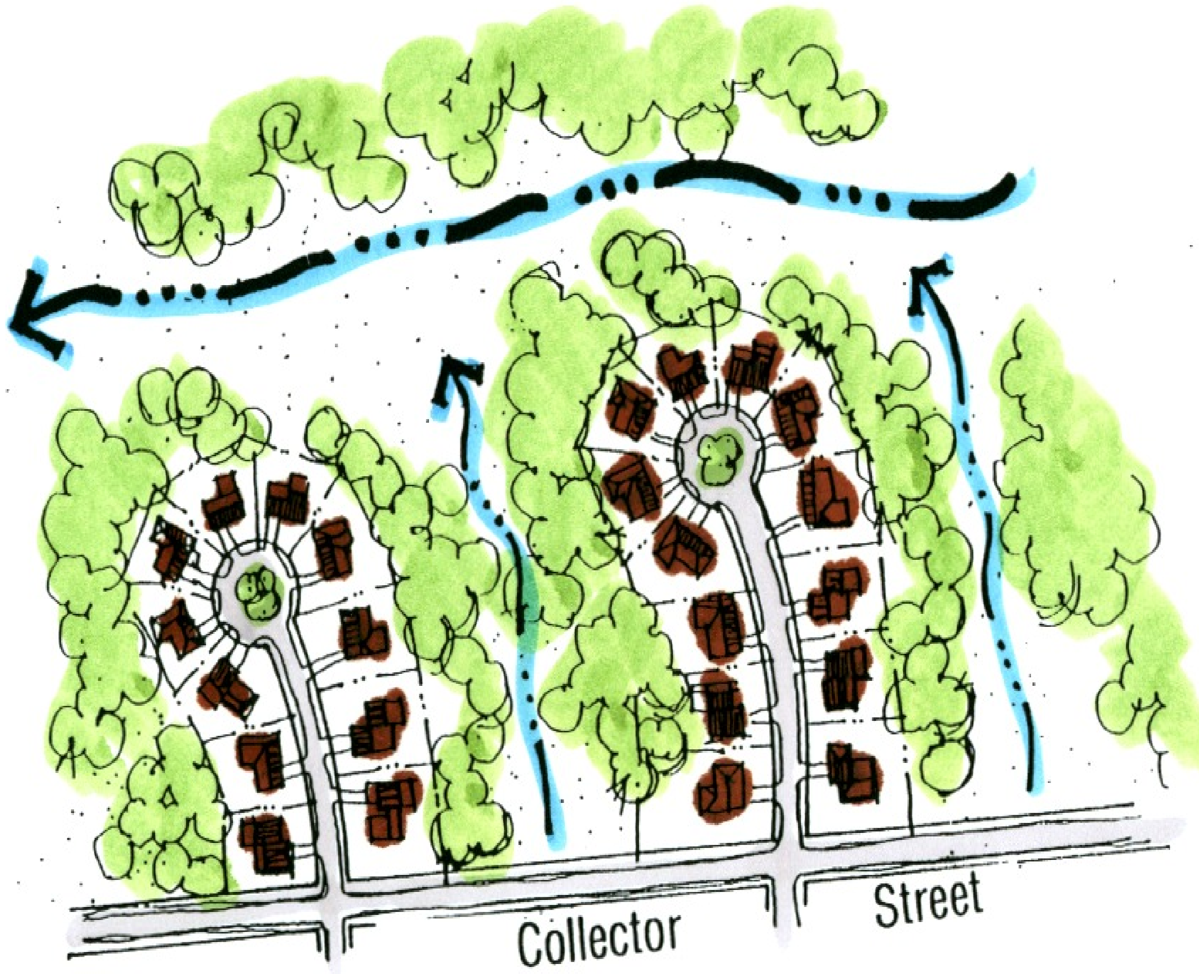

0 100 200 Feet
North
Milltown Road
potential
development
area

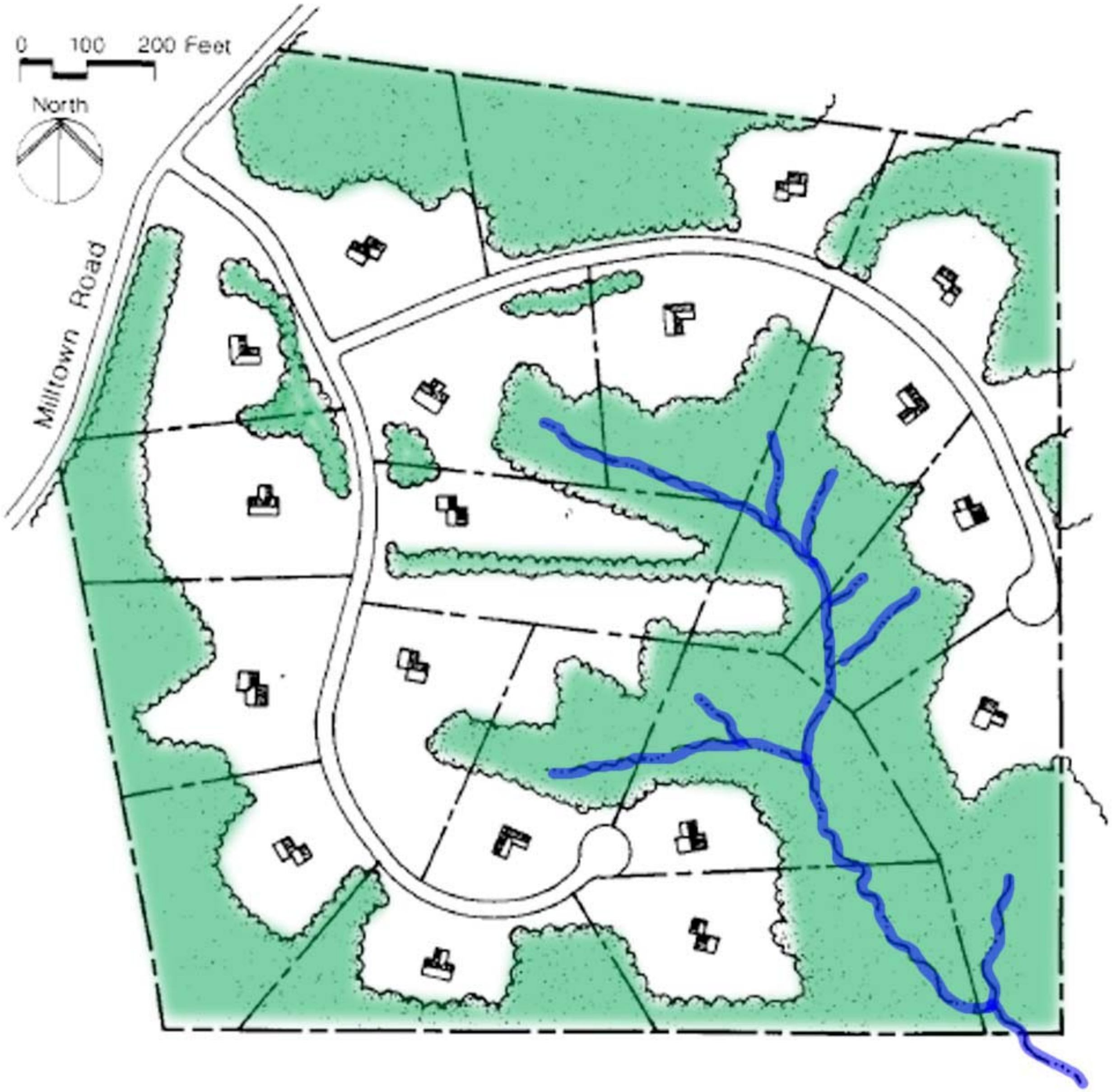
Process for LID

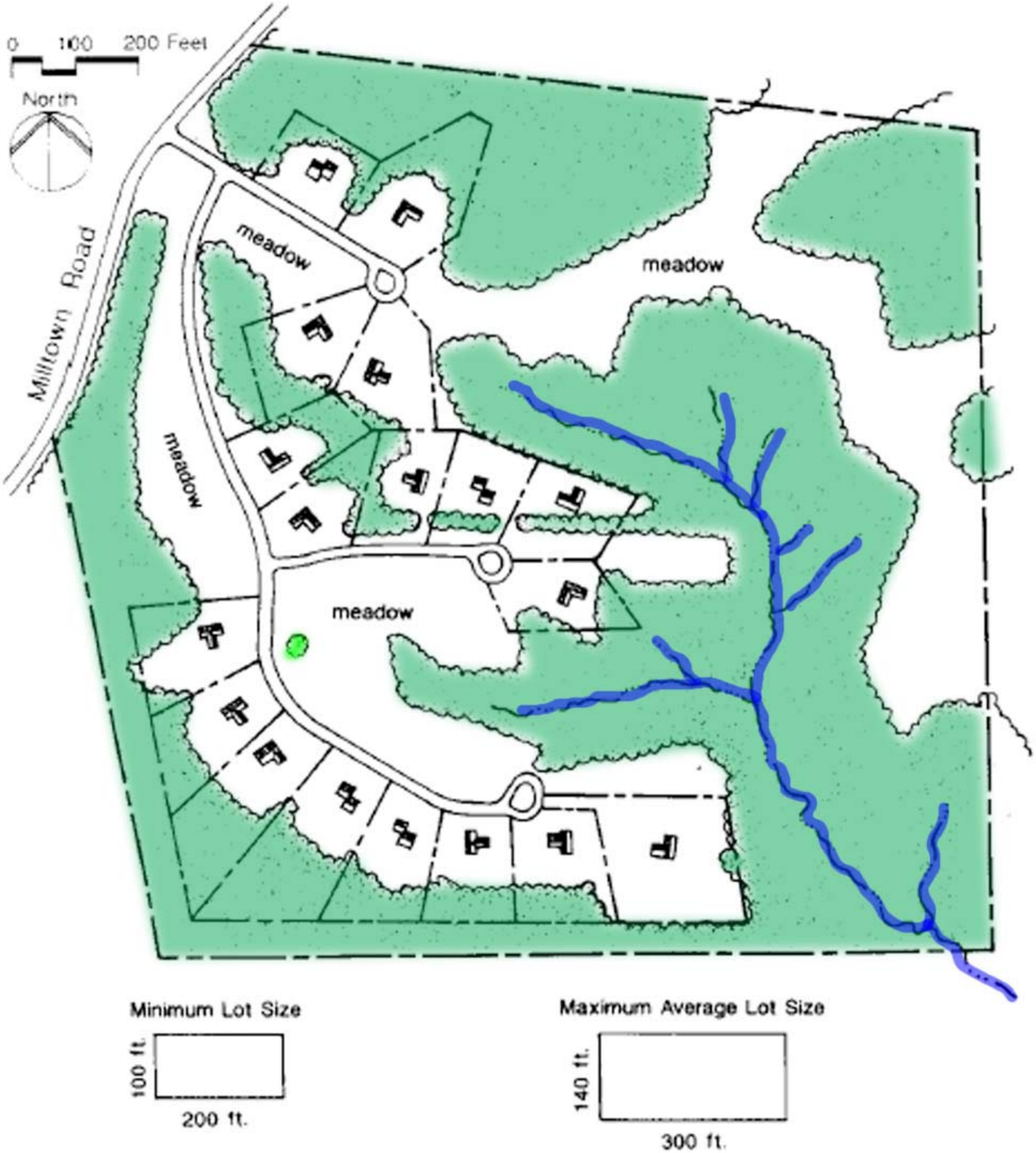
- Understand Existing Site – soils, slopes, vegetation, water levels
- Map Important Natural or Manmade Features
- **Fit Development Program to Site – minimize disturbance and grading**

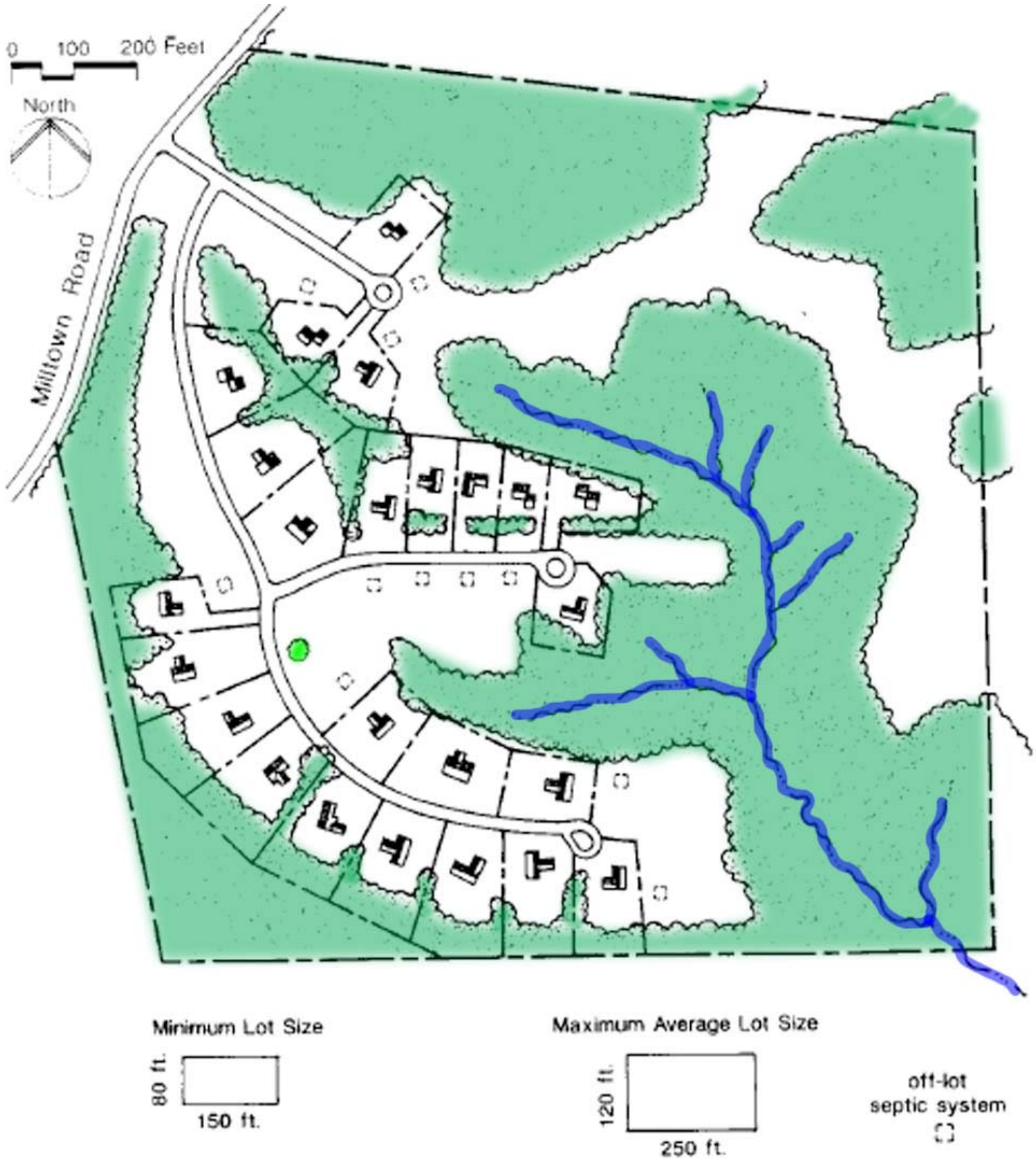
Figure 4.5

Use sensitive areas such as natural drainage areas to form boundaries or buffer zones between clusters of housing.

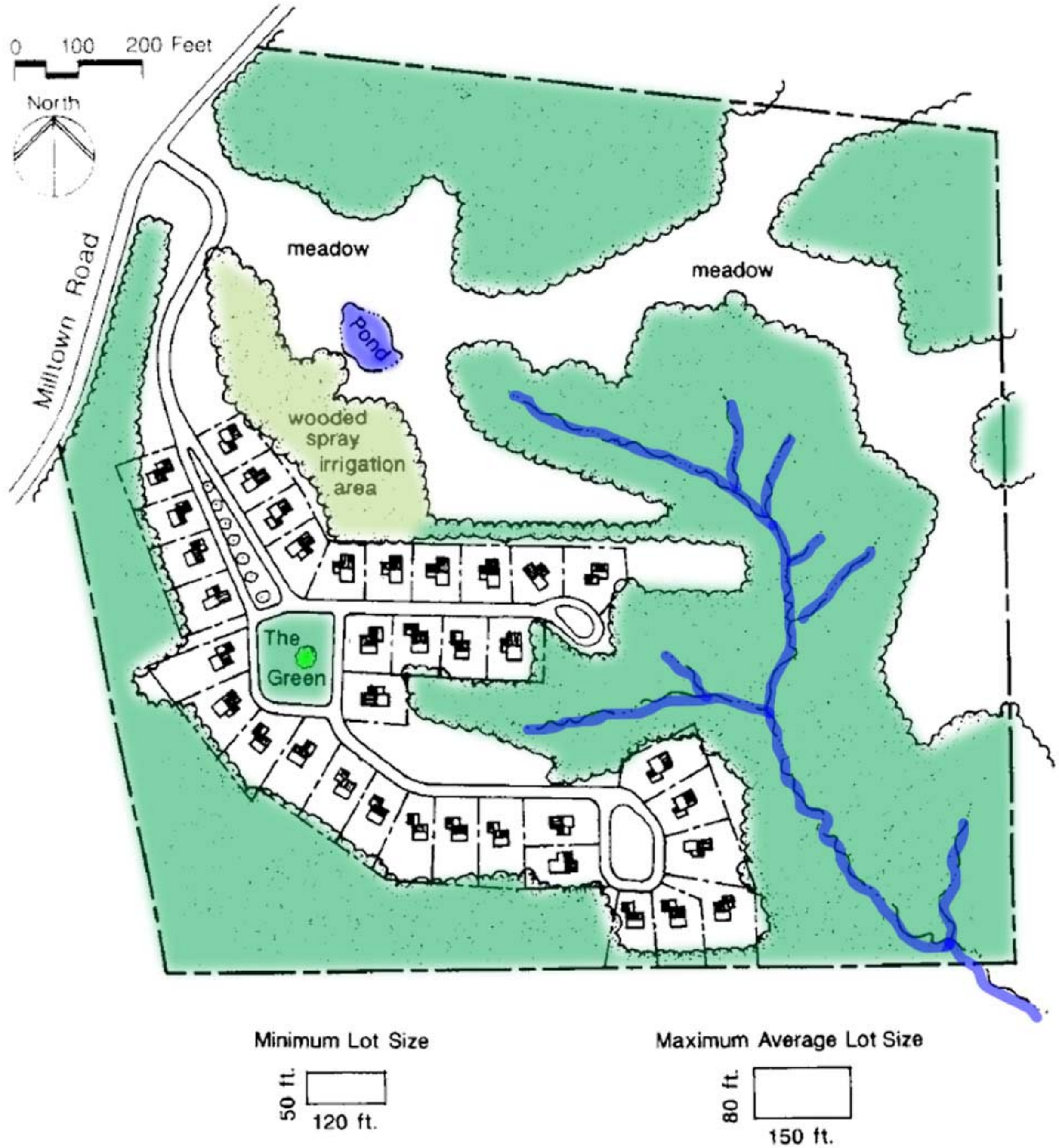


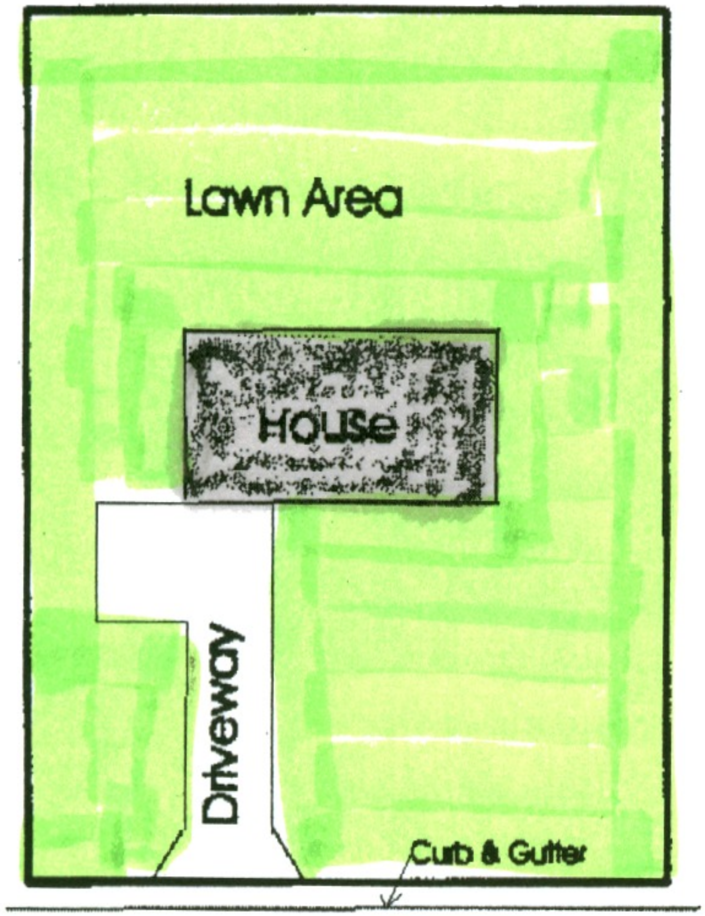

0 100 200 Feet
North
Milltown Road


0 100 200 Feet
North
Milltown Road
meadow
meadow
meadow
meadow
meadow
Minimum Lot Size
100 ft.
200 ft.
Maximum Average Lot Size
140 ft.
300 ft.

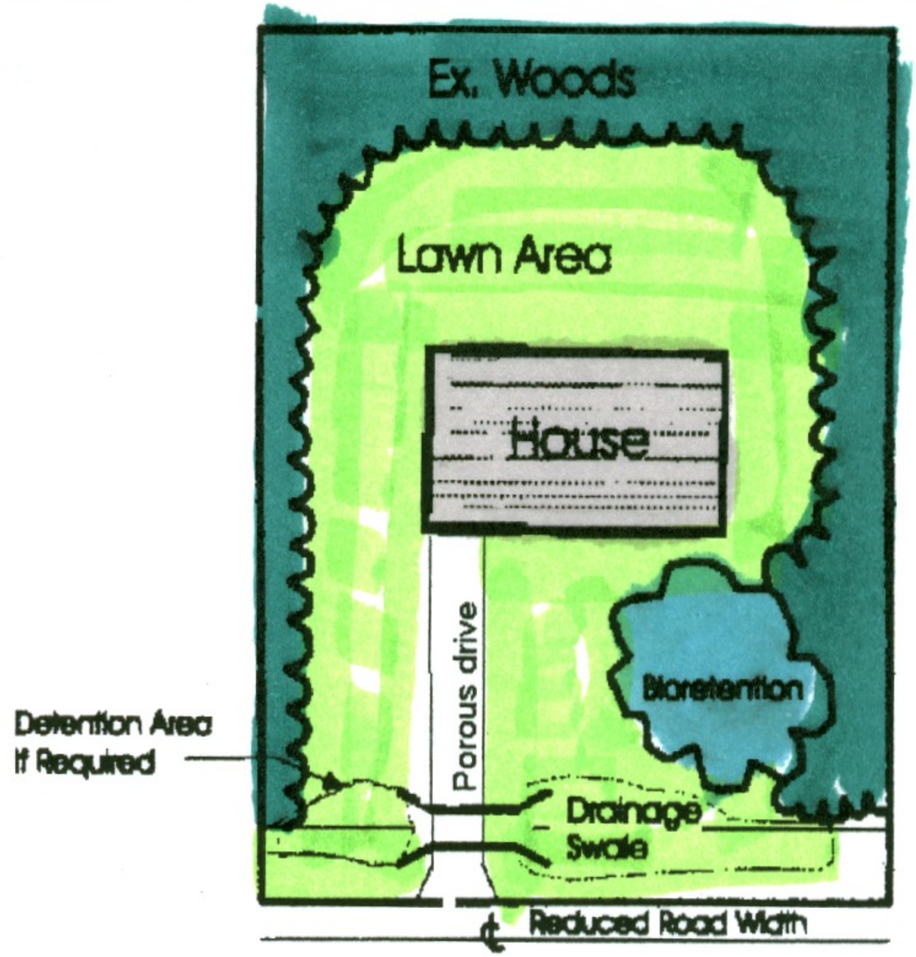


0 100 200 Feet
North
Milltown Road
Minimum Lot Size
80 ft.
150 ft.
Maximum Average Lot Size
120 ft.
250 ft.
off-lot
septic system


0 100 200 Feet
North
Milltown Road
meadow
meadow
Pond
wooded spray irrigation area
The Green
Minimum Lot Size
50 ft.
120 ft.
Maximum Average Lot Size
80 ft.
150 ft.

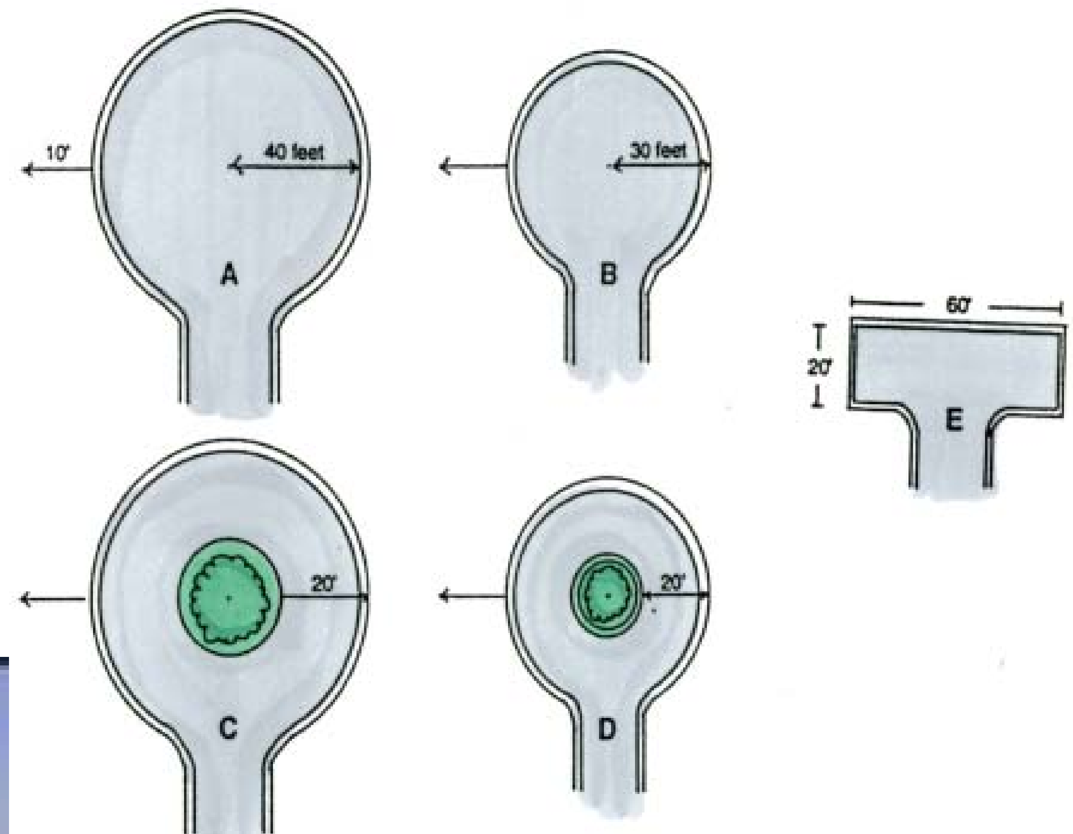


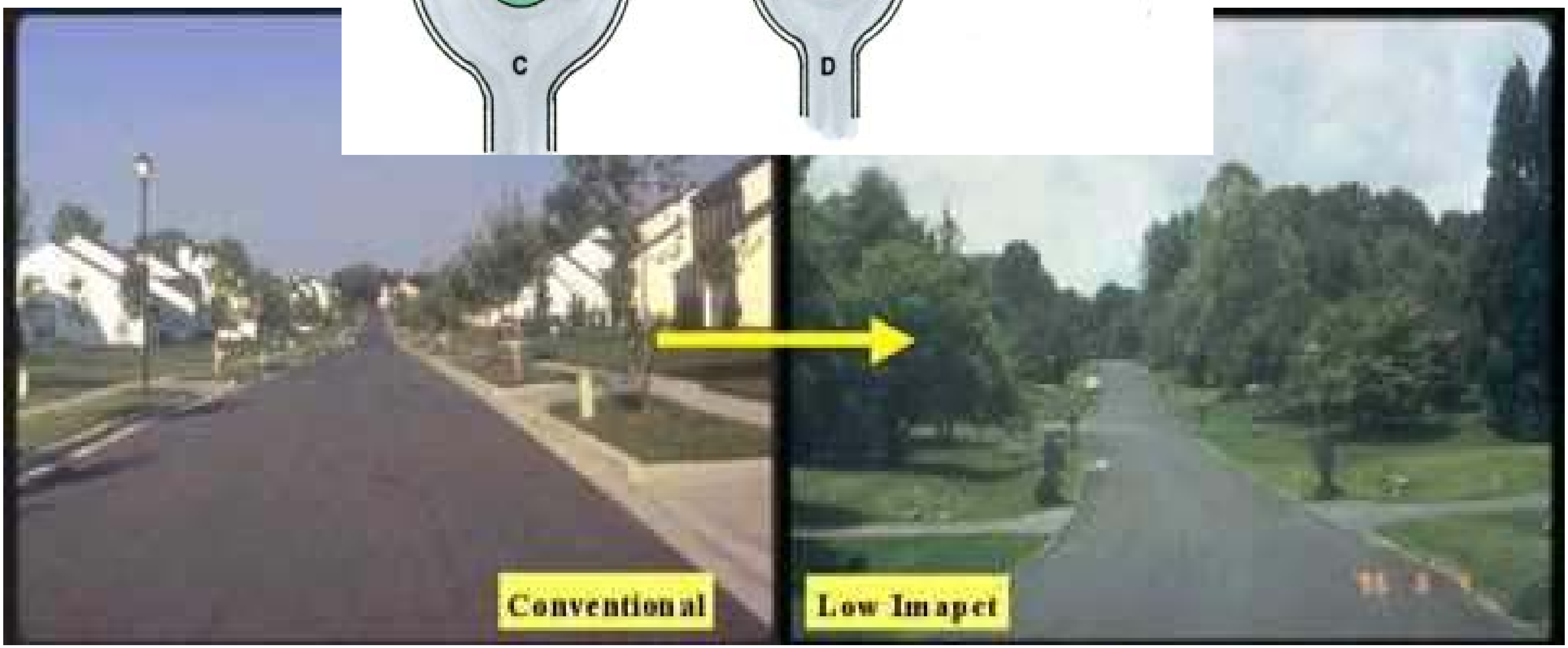
Conventional
1 Acre Lot



Low Impact 1 Acre
Development Lot

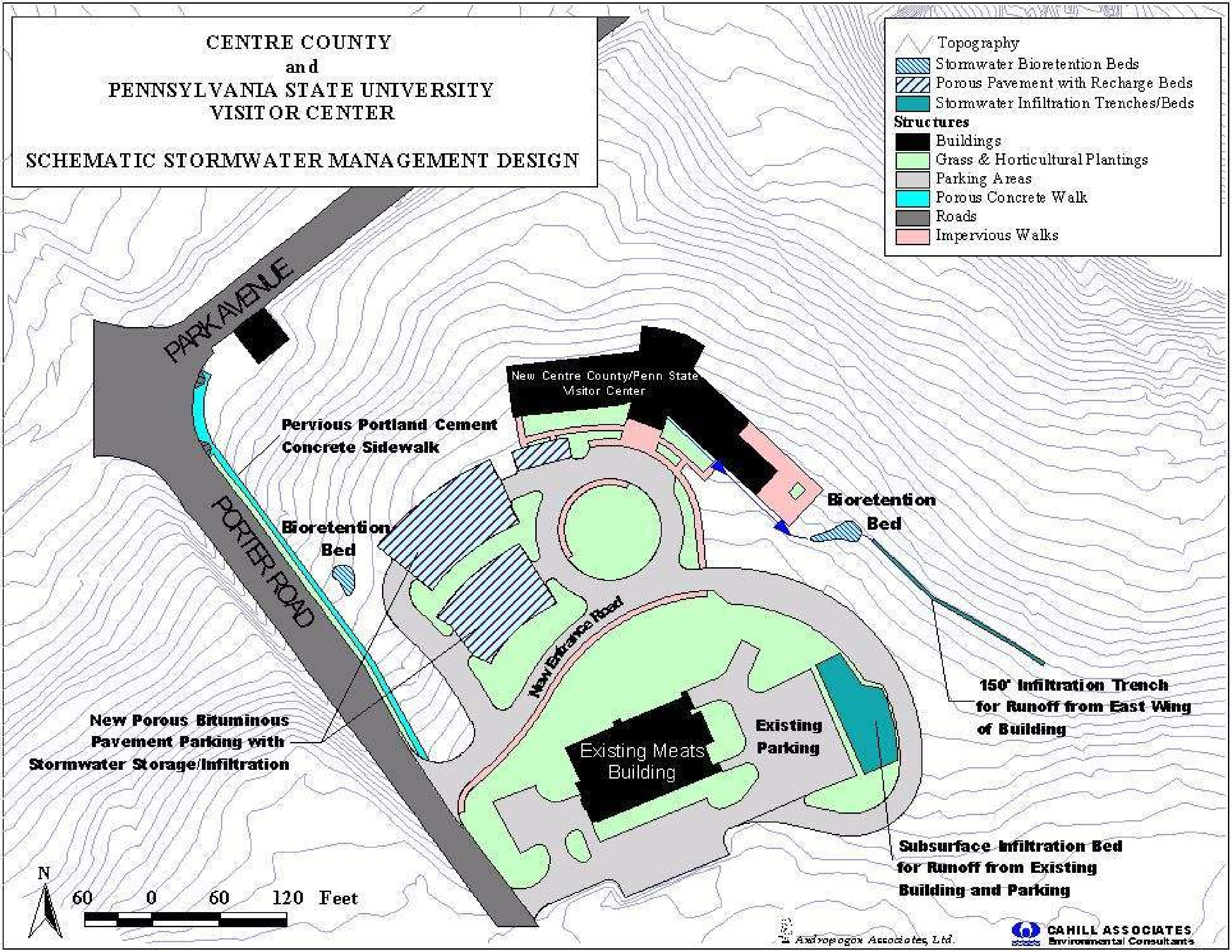

Conventional
Low Imapct


10'
40 feet
A
30 feet
B
60'
20'
E
20'
C
20'
D


Conventional
Low Impact

Process for LID

- Understand Existing Site – soils, slopes, vegetation, water levels
- Map Important Natural or Manmade Features
- Fit Development Program to Site – minimize disturbance and grading
- **Implement Stormwater BMPs Close to Source, within Built Footprint**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Existing Meats Building
Existing Parking
Subsurface Infiltration Bed for Runoff from Existing Building and Parking
N
60 0 60 120 Feet
Andropogon Associates, Ltd.
CAHILL ASSOCIATES
Environmental Consultants

Process for LID

- Understand Existing Site – soils, slopes, vegetation, water levels
- Map Important Natural or Manmade Features
- Fit Development Program to Site – minimize disturbance and grading
- Implement Stormwater Close to Source, within Built Footprint
- **Understand Volume Increase for Site, and for Each BMP Drainage Area**

Office Example

- Pre-development
  - 4.30 acres of Woods (CN=50)
- Post-development
  - 1.08 acres of Woods (CN=50)
  - 1.27 acres of Lawn (CN=61)
  - 1.95 acres of Pavement and Building (CN=98)

How Do Woods Currently Work?

- Before Disturbance, for 3.1” rain
  - Ia = 0.2*S
  - S = 1000/50 – 10 = 2”
  - Ia = 0.2*10” = 2”
- 2” of rainfall <u>before</u> runoff begins!

Current Runoff Volume

$Q = (P - 0.2*S)^2 \ / \ (P+0.8*S)$

$Q = (3.1 - 0.2*10)^2 \ / \ (3.1 + 0.8*10)$

Q = 0.26”

- Even in 3.1” rainfall events, woods generate 0.26” of runoff. Since most storms are small, leave the woods in place as much as possible!
- Net out undisturbed woods, only consider disturbed site

  4.30 ac. – 1.08 ac. = 3.22 ac.

Volume = 3.22 ac. * 0.26” = 3,040 c.f.

Net Increase in Volume

- Post-development
  - For 3.1” storm

	Area (ac)	CN	Ia	Q	Volume (c.f.)
Lawn	1.27	61	1.28"	0.40"	1,859
Impervious	1.95	98	0.04"	2.87"	20,331
					22,190

- Net Increase: 22,190 c.f. - 3,040 c.f. = 19,150 c.f.
- **Goal is to capture 19,150 c.f.**
  - Storage, Infiltration, Reuse

Small Storm Hydrology

Google “Bob Pitt”

Click on “Publications”

“Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices”

Robert Pitt, P.E., Ph.D., DEE
Department of Civil and Environmental Engineering The University of Alabama

Small Storm Hydrology

Design by Land Use and Rainfall Amount

Volume of Runoff = P x R_v x Area

Small Storm Hydrology

Table 2-6. Summary of Volumetric Runoff Coefficients for Urban Runoff Flow Calculations (Pitt 1987).

Rain Depth		Runoff Coefficients for Directly Connected Areas:						
		Flat roofs* (or large unpaved parking areas)	Pitched roofs*	Large impervious areas*	Small impervious areas and streets	Sandy soils	Typical urban soils	Clayey soils
mm	inches							
1	0.04	0.00	0.25	0.93	0.26	0.00	0.00	0.00
3	0.12	0.30	0.75	0.96	0.49	0.00	0.00	0.00
5	0.20	0.54	0.85	0.97	0.55	0.00	0.05	0.10
10	0.39	0.72	0.93	0.97	0.60	0.01	0.08	0.15
15	0.59	0.79	0.95	0.97	0.64	0.02	0.10	0.19
20	0.79	0.83	0.96	0.97	0.67	0.02	0.11	0.20
30	1.2	0.86	0.98	0.98	0.73	0.03	0.13	0.22
50	2.0	0.90	0.99	0.99	0.84	0.07	0.16	0.26
80	3.2	0.94	0.99	0.99	0.90	0.15	0.24	0.33
125	4.9	0.96	0.99	0.99	0.93	0.25	0.35	0.45

*If these "impervious" areas drain for a significant length across sandy soils, the sandy soil runoff coefficients will usually be applied to these areas, however, if these areas drain across typical, or clayey soils, the runoff coefficients will be reduced, depending on the land use and rain depth, according to the following table:

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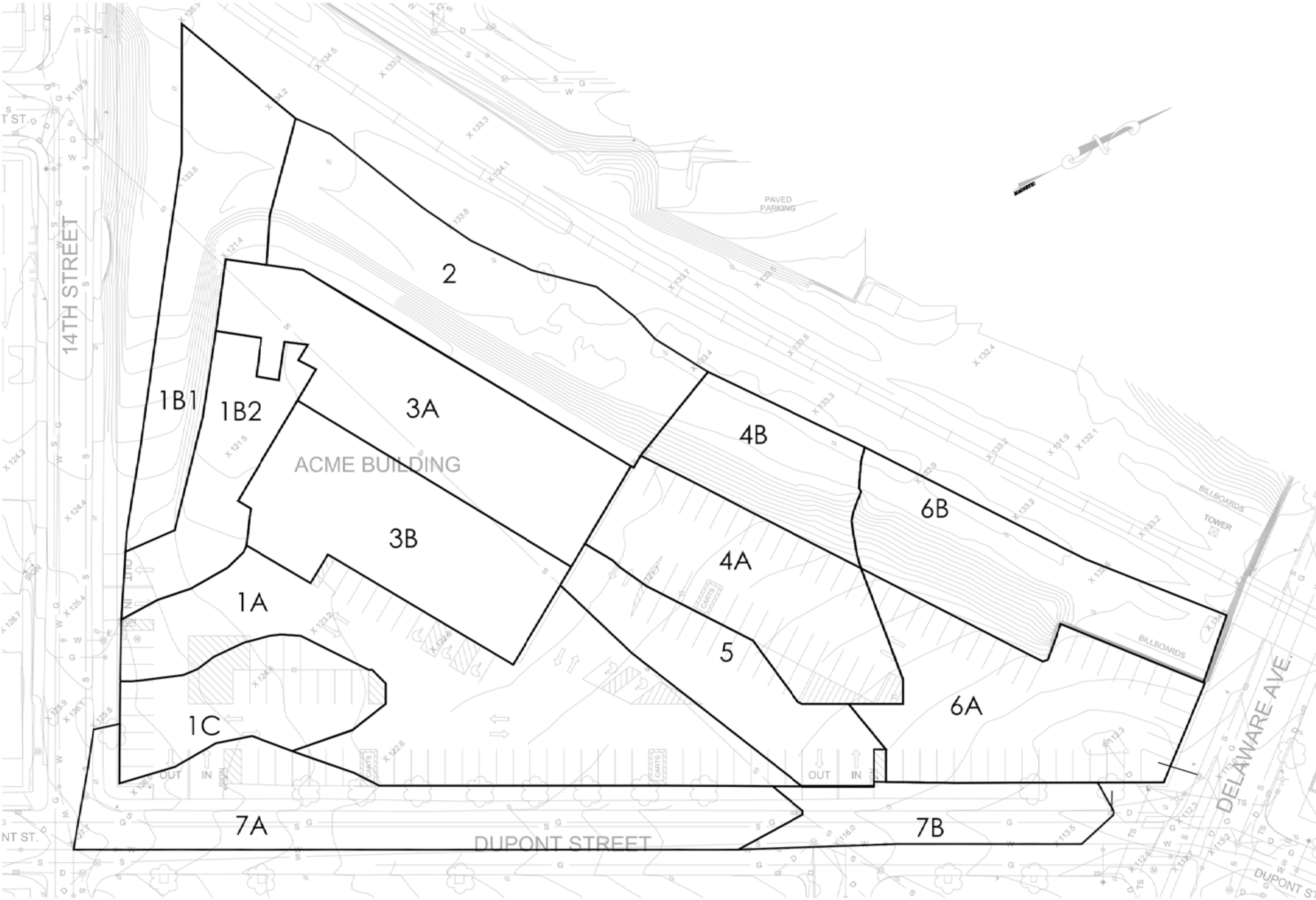

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WILMINGTON ACME STORMWATER CONCEPT PLAN
RUNOFF VOLUMES BY THE SMALL STORM HYDROLOGY METHOD & PEAK RATE CALCULATIONS

Drainage Area	Description	Total Drainage Area	Area	Runoff Coefficient Rv for 1/2" P	1/2" Volume	Runoff Coefficient Rv for 1" P	1" Volume	1.5" Volume	Peak Flow (Q=cia) 1-yr Peak Flow	2-yr Peak Flow	10-yr Peak Flow
		(ft^2)	(ac)		(ft^3)		(ft^3)	(ft^3)	(cfs)	(cfs)	(cfs)
1A	Parking Lot (Large Imp.)	21,216	0.5	0.97	857	0.98	1,733	2,599	1.95	2.32	3.00
$1B_1$	Slope (Urban Soils)	9,992	0.2	0.1	42	0.13	108	162	0.19	0.23	0.30
$1B_2$	Parking Lot (Large Imp.)	5,911	0.1	0.97	239	0.98	483	724	0.54	0.65	0.84
1C	Parking Lot (Large Imp.)	6,632	0.2	0.97	268	0.98	542	812	0.61	0.73	0.94
2	Slope (Urban Soils)	15,758	0.4	0.1	66	0.13	171	256	0.31	0.36	0.47
3A	Building (Flat Roof)	13,220	0.3	0.79	435	0.86	947	1,421	1.22	1.45	1.87
3B	Building (Flat Roof)	11,129	0.3	0.79	366	0.86	798	1,196	1.02	1.22	1.58
4A	Parking Lot (Large Imp.)	10,504	0.2	0.97	425	0.98	858	1,287	0.97	1.15	1.49
4B	Slope (Urban Soils)	6,161	0.1	0.1	26	0.13	67	100	0.12	0.14	0.18
5	Parking Lot (Large Imp.)	7,117	0.2	0.97	288	0.98	581	872	0.66	0.78	1.01
6A	Parking Lot (Large Imp.)	12,586	0.3	0.97	509	0.98	1,028	1,542	1.16	1.38	1.78
6B	Slope (Urban Soils)	10,204	0.2	0.1	43	0.13	111	166	0.20	0.24	0.30
7A	Dupont Street (Large Imp.)	14,955	0.3	0.97	604	0.98	1,221	1,832	1.38	1.64	2.12
7B	Dupont Street (Large Imp.)	5,273	0.1	0.97	213	0.98	431	646	0.49	0.58	0.75
	TOTAL	**150,658**	**1.9**		**4,380**		**9,077**	**13,616**	**11**	**13**	**17**

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WILMINGTON ACME STORMWATER BMP CAPTURE VOLUMES

BMP Type	Area (s.f.)	Depth (ft)	Storage Capacity (%)	Capture Volume (c.f.)	Drainage Area Name	Small Storm 1" Volume (c.f.)	Drainage Area (s.f.)	Drainage Area (ac.)
Rain Garden #1	**1,136**	---	---	---	6A	**1,028**	12,586	0.3
Surface Storage	1,136	0.5	100%	568				
Soil Storage	1,136	2	20%	454.4				
Stone Storage	1,136	0	40%	0				
				1,022				
BioSwale #1	**1,576**	---	---	---	2, 3A	**1,118**	28,978	0.7
Surface Storage	1,576	0.33	100%	520				
Soil Storage	1,576	2	20%	630.4				
Stone Storage	1,576	0	40%	0				
				1,150				
BioSwale #2	**1,195**	---	---	---	4B, 6B	**177**	16,365	0.4
Surface Storage	1,195	0.33	100%	394				
Soil Storage	1,195	2	20%	478				
Stone Storage	1,195	0	40%	0				
				872				
Tree Trench #1	**1,136**	---	---	---	1A, 3B, 5	**3,111**	39,462	0.9
Surface Storage	1,136	0.5	100%	568				
Soil Storage	1,136	3	20%	681.6				
Stone Storage	1,136	2.5	40%	1136				
				2,386				
Infiltration Bed #1	**1,567**	2	40%	1253.6	7A	**1,221**	14,955	0.3
				1,254				
Infiltration Bed #2	**796**	2	40%	636.8	7B	**431**	5,273	0.1
				637				

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WILMINGTON ACME STORMWATER BMP CAPTURE VOLUMES

BMP Type	Area (s.f.)	Depth (ft)	Storage Capacity (%)	Capture Volume (c.f.)	Drainage Area Name	Small Storm 1" Volume (c.f.)	Drainage Area (s.f.)	Drainage Area (ac.)
Rain Garden #1	**1,136**	---	---	---	6A	**1,028**	12,586	0.3
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				1,022				
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Soil Storage	1,576	2	20%	630.4				
Stone Storage	1,576	0	40%	0				
				1,150				


Porous Walkways


Curb Cuts to Meadow


Woodland Berms

Small and Large Measures Built into the Landscape

How we design every site affects our water resources for the future.