Low Impact Development (LID) Hydrology Considerations
What is Bioretention?

“What filtering stormwater runoff through a terrestrial aerobic (upland) plant / soil / microbe complex to remove pollutants through a variety of physical, chemical and biological processes.”

The word “bioretention” was derived from the fact that the biomass of the plant / microbe (flora and fauna) complex retains or uptakes many of the pollutants of concern such as N, P and heavy metals.

It is the optimization and combination of biological chemical and physical processes that makes this system the most efficient of all BMP’s.”
Combination Filtration / Infiltration

2” Mulch

Existing Ground

Sandy Organic Soil

Drain Pipe

Gravel

Moderately Pervious Soils
Bioretention

- Shallow Ponding - 4” to 6”
- Mulch 3”
- Soil Depth 2’ - 2.5’
- Sandy Top Soil
  - 80% Sand
  - 10% Sandy Loam
  - 10% Compost
- Under Drain System
- Plants
Bioretention Design Objectives

• Peak Discharge Control
  – 1-, 2-, 10-, 15-, 100-year storms
  – Bioretention may provide part or all of this control

• Water Quality Control
  – \( \frac{1}{2} \), 1” or 2” rainfall most frequently used
  – Bioretention can provide 100% control

• Ground water recharge
  – Many jurisdictions now require recharge
    ( e.g., MD, PA, NJ, VA)
Pollutant Removal Potential of Aerobic Plant / Microbe / Soil Bioretention Systems

- TSS - 95%
- Heavy Metals - 99%
- Oil and Grease - 95%
- Total Phosphorous - 80%
- Total Nitrogen - 40%
- Coliform - 90%
- Treat over 90% of total volume in less than 1% of the urban landscape.
Pollutant Removal Mechanisms

“Physical / Chemical / Biological”

<table>
<thead>
<tr>
<th>Processes</th>
<th>System Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentation</td>
<td>Mulch</td>
</tr>
<tr>
<td>Filtration</td>
<td>Course Sand</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Pore Space</td>
</tr>
<tr>
<td>Absorption</td>
<td>Surface Area</td>
</tr>
<tr>
<td>Cation Exchange Capacity</td>
<td>Complex Organics</td>
</tr>
<tr>
<td>Polar / Non-polar Sorption</td>
<td></td>
</tr>
<tr>
<td>Microbial Action (aerobic / anaerobic)</td>
<td>Microbes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>decomposition / nitrification / denitrification</td>
<td>Biofilm</td>
</tr>
<tr>
<td>Plant Uptake</td>
<td>Plants</td>
</tr>
<tr>
<td>Cycling Nutrients / Carbon / Metals</td>
<td>“Ecological Structure”</td>
</tr>
<tr>
<td>Biomass Retention (Microbes / Plant)</td>
<td></td>
</tr>
<tr>
<td>Evaporation / Volatilization</td>
<td></td>
</tr>
</tbody>
</table>
Uplands Pollutant Removal

Plants / Soil Flora - Fauna / Soil Chemistry

• Phytoremediation
  – Translocate
  – Accumulate
  – Metabolize
  – Volatilize
  – Detoxify
  – Degrade
  • Exudates

• Bioremediation

• Soils
  – Capture / Immobilize Pollutants
Other Interesting Study Findings

- Mulch and Metals
- Plants and Metals
- Capacity / Longevity of the System
- Time For Reactions (Residence Time)
- 80 to 90% Bacteria Removal
Bioretention Temperature Data

Dr. Davis Inglewood Study - 6/9/99
Swallowtail on Spiked Gayfeather

*Liatris spicata*
How Does LID Maintain or Restore The Hydrologic Regime?

• **Creative ways to:**
  - **Maintain / Restore Storage Volume**
    - interception, depression, channel
  - **Maintain / Restore Infiltration Volume**
  - **Maintain / Restore Evaporation Volume**
  - **Maintain / Restore Runoff Volume**
  - **Maintain Flow Paths**

• **Engineer a site to mimic the natural water cycle functions / relationships**
Key LID Principles “Volume”
“Hydrology as the Organizing Principle”

• Unique Watershed Design
  – Match Initial Abstraction Volume
  – Mimic Water Balance

• Uniform Distribution of Small-scale Controls

• Cumulative Impacts of Multiple Systems
  – filter / detain / retain / use / recharge / evaporate

• Decentralized / Disconnection

• Multifunctional Multipurpose Landscaping & Architecture

• Prevention
Defining LID Technology

Major Components

1. Conservation (Watershed and Site Level)
2. Minimization (Site Level)
3. Strategic Timing (Watershed and Site Level)
4. Integrated Management Practices (Site Level)
   Retain / Detain / Filter / Recharge / Use
5. Pollution Prevention
   Traditional Approaches
LID Practices (No Limit!)

“Creative Techniques to Treat, Use, Store, Retain, Detain and Recharge”

- Bioretention / Rain Gardens
- Strategic Grading
- Site Finger Printing
- Resource Conservation
- Flatter Wider Swales
- Flatter Slopes
- Long Flow Paths
- Tree / Shrub Depression
- Turf Depression
- Landscape Island Storage
- Rooftop Detention / Retention
- Roof Leader Disconnection
- Parking Lot / Street Storage
- Smaller Culverts, Pipes & Inlets
- Alternative Surfaces
- Reduce Impervious Surface
- Surface Roughness Technology
- Rain Barrels / Cisterns / Water Use
- Catch Basins / Seepage Pits
- Sidewalk Storage
- Vegetative Swales, Buffers & Strips
- Infiltration Swales & Trenches
- Eliminate Curb and Gutter
- Shoulder Vegetation
- Maximize Sheet flow
- Maintain Drainage Patterns
- Reforestation
- Pollution Prevention
LID Hydrologic Analysis

Compensate for the loss of rainfall abstraction
Infiltration
Evapotranspiration
Surface storage
Time of travel
LID Design Procedure Highlights

• Site Analysis
• Determine Unique Design Storm
• Maintain Flow Patterns and Tc
• Conservation and Prevention
• Develop LID CN
• Compensatory Techniques. Stress Volume Control then Detention or Hybrid for Peak
Low-Impact Development
Hydrologic Analysis and Design

• Based on NRCS technology, can be applied nationally
• Analysis components use same methods as NRCS
• Designed to meet both storm water quality and quantity requirements
Developed Condition, Conventional CN
(Higher Peak, More Volume, and Earlier Peak Time)

Existing Condition
Detention Peak Shaving

- Developed
- Developed Condition, with Conventional CN and Controls
- Existing Peak Runoff Rate
- Additional Runoff Volume

Q
T

Existing

Developed
Developed Condition, with LID-CN no Controls.

Reduced Runoff Volume

Minimize Change in Curve Number

Developed- No Controls

Reduced Q_p

Existing
Developed, LID-CN no controls

Reduced $Q_p$

Developed, LID-CN no controls same Tc as existing condition.

More Runoff Volume than the existing condition.

Maintain Time of Concentration
Provide Retention storage so that the runoff volume will be the same as Predevelopment.

Retention storage needed to reduce the CN to the existing condition

\[ = A_2 + A_3 \]
Provide additional detention storage to reduce peak discharge to be equal to that of the existing condition.
Comparison of Hydrographs

- Increase Volume with Conventional
- Conventional Controls
- LID Concepts
- Existing
Hydrograph Summary

- **Existing**
- Developed, conventional CN, no control.
- Developed, conventional CN and control.
- Developed, LID-CN, no control.
- Developed, LID-CN, same Tc.
- Developed, LID-CN, same Tc, same CN with retention.
- Same as [6], with additional detention to maintain Q.
Comparison of Conventional and L I D Curve Numbers (CN) for 1- Acre Residential Lots

Conventional CN
20 % Impervious
80 % Grass

Low Impact Development CN
15 % Impervious
25 % Woods
60 % Grass

Curve Number is reduced by using LID Land Uses.

**Disconnectiveness**

\[
CN_C = CN_P + \left[ P_{IMP} \right] (98 - CN_P) \left( 1 - 0.5R \right)
\]

- \( CN_C \) = Composite Curve Number
- \( CN_P \) = Pervious Curve Number
- \( R \) = Ratio Unconnected imp. to total imp
- \( P_{IMP} \) = Percent of imp. site
LID to Maintain the Time of Concentration

“Uniformly Distributed Controls”

* Minimize Disturbance

* Flatten Grades

* Reduce Height of Slopes

* Increase Flow Path

* Increase Roughness “n”
Retention LID Storage Options
(On-Site)

* Infiltration
* Retention
* Roof Top Storage
* Rain Barrels
* Bioretention
* Irrigation Pond
Methods of Detaining Storage to Reduce Peak Runoff Rate

* Larger Swales with less slope
* Swales with check dams
* Smaller or constricted drainage pipes
* Rain barrels
* Rooftop storage
* Diversion structures
# LID Techniques and Objectives

## Low-Impact Development Technique

<table>
<thead>
<tr>
<th>Low Impact Development Objective</th>
<th>Flatten Slope</th>
<th>Increase Flow Path</th>
<th>Increase Sheet Flow</th>
<th>Increase Roughness</th>
<th>Minimize Disturbance</th>
<th>Larger Swales</th>
<th>Flatten Slopes on Swales</th>
<th>Infiltration Swales</th>
<th>Vegetative Filter Strips</th>
<th>Constricted Pipes</th>
<th>Disconnected Impervious Areas</th>
<th>Reduce Curb and Gutter</th>
<th>Rain Barrels</th>
<th>Rooftop Storage</th>
<th>Bioretention</th>
<th>Re-Vegetation</th>
<th>Vegetation Preservation</th>
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</thead>
<tbody>
<tr>
<td>Increase Time of Concentration</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Increase Detention Time</td>
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<td>X</td>
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<tr>
<td>Increase Storage</td>
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<tr>
<td>Lower Post Development CN</td>
<td>X</td>
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<td>X</td>
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</tr>
</tbody>
</table>
## Maintain Time of Concentration (Tc)

### Low-Impact Development Technique

<table>
<thead>
<tr>
<th>Low Impact Development objective to Maintain Time of Concentration (Tc)</th>
<th>Balance cut and fill on lot.</th>
<th>Network Smaller Swales</th>
<th>Clusters of Trees and Shrubs in Flow Path</th>
<th>Provide Tree Conservation on Lots</th>
<th>Eliminate Storm Drain Pipes</th>
<th>Disconnect Impervious Areas</th>
<th>Save Trees in Smaller Clusters</th>
<th>Terrace Yards</th>
<th>Drain from House and then Reduce Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize Disturbance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>Flatten Grades</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Reduce Height of Slopes</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Increase Flow Path (Divert and Redirect)</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Increase Roughness “n”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
</tbody>
</table>
Summary of LID Techniques

(1) Recalculate Postdevelopment CN based on LID land use.

(2) Increase Travel Time (TT) using LID techniques to achieve the same Tc as Existing conditions.

(3) Retention: Provide permanent storage (Infiltration/Retention) using LID techniques to maintain the CN and runoff volume of existing conditions.

(4) Detention: Provide additional detention storage to maintain the same peak discharge as existing conditions.
Physical Processes in LID

- Continuous rainfall
- Interception
- Surface ponding
- Evapotranspiration
- Infiltration
- Soil pore space storage
- Interflow
- Groundwater recharge
- Overland flow
- Channel and pipe flow
- Pollutant generation
- Pollutant removal by physical, chemical, and biological processes
- Runoff temperature moderation
The Ideal LID Model

- Continuous simulation
- Small (lot size) and large (watershed) area
- Suitable for new development and re-development
- Watershed protection criteria
- Models all hydrologic components in catchment
- Models all flow components in BMPs
- Urban conditions (e.g., pipe flow, regulators)
- Detailed land use description
- Many BMP options:
  - Land-use planning
  - Conventional
  - LID
  - Programmatic (e.g., street sweeping)
- Allows for “precision” placement of BMPs
- BMP optimization
The Ideal LID Model (ctd)

- Variety of pollutant generation and removal processes:
  - Physically-based equations
  - Unit processes
  - BMP treatment train
  - Field data probability distributions
- GIS interface
- Various output stats (e.g., duration curves)
- Output to:
  - Instream water quality models
  - Ecosystem models
- Planning and design
- User-friendly
- Well documented
- Interactive
Conventional Hydrologic Models

- Developed for flooding (large storms), suitable mainly for peak flows
- Intended for large drainage areas
- Lumped parameters, do not allow for precise placement of stormwater controls
- Weak infiltration modeling in some models
- Submodels do not represent physical phenomena present in LID
- Complex
Available Models

- TR-20/TR-55, HEC-HMS
- SWMM
- HSPF
- SLAMM
- Prince George’s County’s BMP model for LID
- MUSIC
- LIFE™
- SET
- QUAL2E
- WASP (Water Quality Analysis Simulation Program)
- AGNPS
- STEP-L
TR-20/TR-55, HEC-HMS

- Developed by USDA and USACE respectively
- Intended for large storm events
- Lumped parameters applicable to large drainage areas
- Single event simulation
- Unable to evaluate micro-scale BMPs
- No pollutant generation and removal capabilities
- Not suitable for LID
SWMM

(EPA Stormwater Management Model)

- Wayne Huber, Oregon State U.; & CDM
- Best suited for urban hydrology and water quality simulation
- Robust conveyance modeling
- Wide applicability to large and medium watershed hydrology
- Current version (v. 9 or so) can be “adapted” to simulate LID controls using generic removal functions and simulating some LID BMPs
HSPF

(Hydrologic Simulation Program - FORTRAN)

• EPA program for simulation of watershed hydrology and water quality
• Maintained by AquaTerra as BASINS
• Produces time history of the quantity and quality of runoff from urban or agricultural watersheds
• Best suited for rural hydrology and water quality simulation
• Data intensive, lumped parameter model
• Wide applicability to large watershed hydrology
• Models effects in streams and impoundments
• BMPs simulated as reductions in pollutant load
• Latest beta version (v. 5) capable of simulating some LID BMPs
• Not recommended for LID
SLAMM
(Source Loading and Management Model)

• Dr. Robert Pitt, U. of Alabama, John Voorhees
• Evaluates pollutant loadings in urban areas using small storm hydrology
• Heavy reliance on field data
• 6 land uses (residential, commercial, industrial, highway, ...)
• 14 source area types (sidewalks, roofs, parking, turf, unpaved areas ...)
• 8 BMP types (infiltration, biofiltration, swales, pervious pavement, ponds, ...)
• Calculates runoff, particulate, and pollutant loading for each land use and source area
• Routes particulate loadings through drainage system, to BMPs and outfalls
Prince George’s County BMP Model

- Uses HSPF to derive flow, pollutant loads
- Applies flow and loads to LID BMPs
- Two generic BMPs: storage/detention, channel
- Simulates flow processes in each BMP
- Water quality processes simulated as first-order decay and removal efficiency
MUSIC

- Tony Wang, Monash U., Australia
- Simulates hydrology, water quality (TSS, TN, TP, debris)
- Scale from city blocks to and large catchments
- Aimed and planning and conceptual design of SWM systems
- User-friendly interface
- Event or continuous simulation
- Sources: urban, ag, forest
- BMPs: buffers, wetlands, swales, bioretention, ponds, GPT (gross pollutant traps)
- Pollutant removal by first-order kinetics
- Australia default parameters from worldwide research
- Extensive output statistics
LIFETM
(Low Impact Feasibility Evaluation Model)

- Specifically developed by CH2M HILL to simulate LID microhydrology
- Models water quantity (volume, peak flows) and water quality
- Physically-based, continuous simulation
- New development and redevelopment
- Numerous controls: bioretention, green roofs, rainwater cisterns, pervious pavements, infiltration devices...
- Optimization module balances competing priorities
- Drag-and-drop user friendly interface, GIS linkage
BMP Evaluation Method

HSPF LAND SIMULATION

Existing Flow & Pollutant Loads

– Unit-Area Output by Landuse –

SITE-LEVEL LAND/BMP ROUTING

BMP DESIGN

– Site Level Design –

Simulated Flow/Water Quality Improvement
Cost/Benefit Assessment of LID design

BMP Module

Simulated Surface Runoff

Existing Flow & Pollutant Loads

– Unit-Area Output by Landuse –

Simulated Flow/Water Quality Improvement
Cost/Benefit Assessment of LID design
BMP Class A: Storage/Detention

Inflow:
From Land Surface

Evapotranspiration

Outflow:
Modified Flow & Water Quality
Overflow
Spillway
Bottom Orifice
Underdrain Outflow

Infiltration

Storage
<table>
<thead>
<tr>
<th>BMP</th>
<th>Applicable Zoning Districts(1)</th>
<th>Applicable Performance Criteria (2)</th>
<th>Design Function(3)</th>
<th>Function(4) (WQ, VC, PC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic Clearing &amp; Grading</td>
<td>U, T, R</td>
<td>3(a)</td>
<td></td>
<td>WQ, VC, PC</td>
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<tr>
<td>Reduce Impervious Surfaces</td>
<td>U, T, R</td>
<td>3(a)</td>
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<td>WQ, VC, PC</td>
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<tr>
<td>Bioretention (Rain Garden)</td>
<td>U, T, R</td>
<td>3(a), 3(b)</td>
<td>Section 4.0</td>
<td>WQ, VC, PC</td>
</tr>
<tr>
<td>Infiltration Trench</td>
<td>U, T, R</td>
<td>3(a), 3(b)</td>
<td>Section 8.0</td>
<td>WQ, VC, PC</td>
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<tr>
<td>Infiltration Swale</td>
<td>U, T, R</td>
<td>3(a), 3(b)</td>
<td>Section 8.0</td>
<td>WQ, VC, PC</td>
</tr>
<tr>
<td>Swales</td>
<td>U, T, R</td>
<td>3(a)</td>
<td>Section 5.0</td>
<td>WQ, VC</td>
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<tr>
<td>Swales with Outlet Control</td>
<td>T, R</td>
<td>3(a), 3(a)</td>
<td>Section 5.0</td>
<td>WQ, VC, PC</td>
</tr>
<tr>
<td>Vegetative Filter Strips &amp; Buffers</td>
<td>U, T, R</td>
<td>3(a)</td>
<td>Section 7.0</td>
<td>WQ, PC</td>
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<tr>
<td>Dry Well, Cistern &amp; Rain barrel</td>
<td>U, T, R</td>
<td>3(b)</td>
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<td>WQ, VC, PC</td>
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<tr>
<td>Porous Paving</td>
<td>U, T, R</td>
<td>3(b)</td>
<td></td>
<td>WQ, VC</td>
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<tr>
<td>Curb &amp; Gutter Elimination</td>
<td>R</td>
<td>3(b)</td>
<td></td>
<td>WQ, PC</td>
</tr>
<tr>
<td>Rooftop Storage</td>
<td>U, T, R</td>
<td>3(b)</td>
<td></td>
<td>VC, PC</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>U, T, R</td>
<td>3(b), 3(d)</td>
<td>Section 1.0</td>
<td>WQ, VC, PC</td>
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<tr>
<td>Extended Dry Pond</td>
<td>T, R</td>
<td>3(b), 3(d)</td>
<td>Section 6.0</td>
<td>VC, PC</td>
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<tr>
<td>Storm Water Wetlands</td>
<td>T, R</td>
<td>3(b)</td>
<td>Section 2.0</td>
<td>WQ, VC, PC</td>
</tr>
<tr>
<td>Sand Filter</td>
<td>T, R</td>
<td>3(a)</td>
<td>Section 3.0</td>
<td>WQ, VC, PC</td>
</tr>
</tbody>
</table>

(1) Applicable Zoning Districts: These are the Zoning Districts where the BMP can be used including U = Urban; T = Transitional; R = Rural.
(2) Applicable Performance Criteria: These are the Performance Criteria Section numbers (see Section 3) that the BMP can be used to satisfy.
(3) Design Function: All BMP designs are contained in the N.C. Department of Environment & Natural Resources, Storm Water Best Management Practices, April 1999.
(4) Functions: These are the dominate functions that the BMPs perform including WQ = Water Quality; VC = Volume Control, PC = Peak Control.
DEVELOPMENT PERFORMANCE ANALYSIS

MC Development Co.
Forest Lake Estates
109 Lot LID

Land Use Summary

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Site Area (acres)</td>
<td>36.72</td>
</tr>
<tr>
<td>Pre-development impervious percentage</td>
<td>1.0%</td>
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<tr>
<td>Post-development impervious percentage</td>
<td>33.7%</td>
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</tbody>
</table>

Annual Hydrology Summary

<table>
<thead>
<tr>
<th></th>
<th>Existing Landuse</th>
<th>Design without BMPs</th>
<th>Design with BMPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Surface Runoff (inches/yr)</td>
<td>2.32</td>
<td>13.91</td>
<td>7.43</td>
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<tr>
<td>Annual Infiltration (inches/yr)</td>
<td>12.00</td>
<td>7.08</td>
<td>13.57</td>
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</table>

2-year, 24-hour Storm Event Runoff Volume Summary

<table>
<thead>
<tr>
<th>Storm Event Runoff Volume (acre-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Landuse</td>
</tr>
<tr>
<td>Design without BMPs</td>
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<tr>
<td>2-yr, 24-hr BMP Storage</td>
</tr>
<tr>
<td>Target Storage</td>
</tr>
<tr>
<td>Meets Goal?</td>
</tr>
</tbody>
</table>
Low Impact Development (LID) Hydrology Considerations

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president
scamargo@cdpengines.com
www.cdpengineers.com