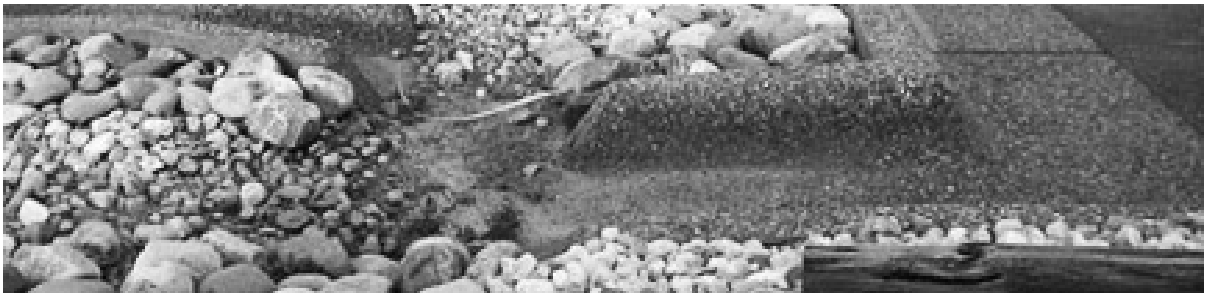




Low Impact Development
A Guidebook for North Carolina

North Carolina State University • June 2009 • Published by North Carolina Cooperative Extension









ACKNOWLEDGMENTS

The core team initiated the document structure, form, and content, and wrote the document. The team consisted of the following key personnel from North Carolina State University and our partner organizations:

Editors:

Christy Perrin, MPA, Watershed Education for Communities and Officials, Department of Agricultural and Resource Economics, North Carolina State University
Lee-Anne Milburn, Ph.D., ASLA, LEED AP, Department of Landscape Architecture and Planning, University of Nevada Las Vegas (formally Department of Landscape Architecture, North Carolina State University)
Laura Szpir, Department of Biological and Agricultural Engineering, North Carolina State University

Contributing Authors:

Christy Perrin, MPA, Watershed Education for Communities and Officials, Department of Agricultural and Resource Economics, North Carolina State University
Lee-Anne Milburn, Ph.D., ASLA, LEED AP, Department of Landscape Architecture and Planning, University of Nevada Las Vegas (formally Department of Landscape Architecture, North Carolina State University)
Laura Szpir, Department of Biological and Agricultural Engineering, North Carolina State University
Bill Hunt, Ph.D., P.E., Department of Biological and Agricultural Engineering, North Carolina State University
Sarah Bruce, MRP, CFM, Upper Neuse River Basin Association
Robert McClendon, MLA, LEED AP, University of North Carolina Coastal Studies Institute
Scott Job, Tetra Tech
Dan Line, P.E., Department of Biological and Agricultural Engineering, North Carolina State University
David Lindbo, Ph.D., Department of Soil Science, North Carolina State University
Steve Smutko, Ph.D., Department of Agricultural and Resource Economics, North Carolina State University
Heather Fisher, AICP, Tetra Tech
Bobby Tucker, E.I., Tetra Tech

Jon Calabria, LA, MLA, Department of Biological and Agricultural Engineering, NC State University
Kathy Debusk, E.I., Department of Biological and Agricultural Engineering, NC State University
Carter Cone, Department of Biological and Agricultural Engineering, North Carolina State University
Miegan Smith Gordon, Co-owner The Captain's Bookshelf, Inc., Asheville, NC
Jean Spooner, Ph.D., Department of Biological and Agricultural Engineering, NC State University
Thomas Blue, P.E., PLS
Nancy Deal, Department of Soil Science, North Carolina State University
Joe Lynn, NCDENR-DEH, OSWP
Diana Rashash, NCDENR, CE Onslow County
Robert Rubin, McKim and Creed
Mark Senior, P.E., City of Raleigh
Nancy White, PhD., University of North Carolina Coastal Studies Institute
Dwane Jones, CPESC, Department of Biological and Agricultural Engineering, NC State University
Bill Eaker, Land of Sky Regional Council

Appendix A was written by Thomas Blue, P.E. PLS, BLUE Land Water Infrastructure

All photographs courtesy of the authors, unless otherwise indicated

Drawings by Darryl Jones, except in Chapter 8 and unless indicated otherwise

Case Study Acknowledgments:

The following partners generously donated their time, drawings, and photographs:

David Tuch, RLA, Equinox Environmental Consultation & Design, Inc. provided details, figures, and photographs about the Drover's Road Preserve development design

Gary McCabe, P.E., Red Line Engineering, P.C. provided details on the Tonbo Meadow development design

Pam Fasse and Brad Karl, JiJi Muge, LLC and Anne & Bradshaw Contractors shared their experience on Tonbo Meadow

Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC provided their original drawings for Tonbo Meadow

Hunter Freeman, P.E., Withers & Ravenel provided details about a development design in Wake County, North Carolina, and CAD files which formed the basis for the figures and designs for the piedmont case study

Jon Calabria, Miegan Smith Gordon, and Carter Cone provided details and photographs for The North Carolina Arboretum case study.

Peer Reviewers Volunteered their time to Review and Edit the Guidebook:

Greg Jennings, Ph.D., P.E., Department of Biological and Agricultural Engineering, North Carolina State University
Dan Hitchcock, Ph.D., P.E., Department of Agricultural and Biological Engineering, Clemson University
Cynthia Van Der Wiele, Ph.D., ASLA, LEED AP, Formally with Department of Forestry and Environmental Resources, North Carolina State University; currently with Chatham County, NC

LID Needs Assessment Respondents:

Several people representing local governments, building, and design responded to a needs assessment survey. We thank all of the participants for their time.

Low Impact Development: A Guidebook for North Carolina **Advisory Committee Members provided ongoing feedback and guidance on guidebook content, structure, and communication through meetings and email. Steering Committee members:**

State and Federal Government:

Boyd Devane, North Carolina Department of Environment and Natural Resources
Bill Diuguid, North Carolina Department of Environment and Natural Resources
Rich Gannon, North Carolina Department of Environment and Natural Resources
Kim Nimmer, North Carolina Department of Environment and Natural Resources
Mike Randall, North Carolina Department of Environment and Natural Resources
Robert Patterson, North Carolina Department of Environment and Natural Resources
Paul Clark, North Carolina Department of Environment and Natural Resources
Mark Recktenwald, North Carolina Ecosystem Enhancement Program
Matt Lauffer, North Carolina Department of Transportation

Local and County Government:

Matt Flynn, Town of Cary
Terry Warren, Town of Cary
D. Will Autry, Town of Carrboro
Fred Royal, Chatham County
James Rhodes, Pitt County
Steve Miller, City of Kinston
Josh Freeman, City of Brevard
Grace Lawrence, North Carolina Cooperative Extension, Wake County Center
Frank Hahne, formally with Mecklenburg County

Academia:

Phil Berke, Ph.D., Department of City and Regional Planning, University of North Carolina
Mark Megalos, Ph.D., Department of Forestry and Environmental Resources, North Carolina State University
Gloria Putnam, North Carolina Sea Grant

Special Interest:

Lauren Kolodij, North Carolina Coastal Federation
Lisa Martin, North Carolina Home Builders Association
Jeff O'Bryant, North Carolina Society of Surveyors
Christine Wunsche, Environment North Carolina

Builders / Developers:

Bill Brewer, Piscerne Military Housing
Keith Britt, Crosland, Inc
Buddy Milliken, The Milliken Company
Chris Wedding, Cherokee Investment Fund
Katherine Henderson, Cherokee Investment Fund

Consultants:

Thomas Blue, P.E., PLS, BLUE Land Water Infrastructure
Stephanie Hall, P.E., Withers & Ravenel
Sam Ravenel, Withers & Ravenel
John Schrum, P.E., Horvath and Associates
Amos Clark, P.E., John R. McAdams
Amy Mackintosh, RLA, Little and Little Landscape Architects
Charlie Musser, Sungate Design
Bill Hamilton, Sungate Design

Funding was provided by a USEPA Clean Water Act Section 319 grant, administered through the North Carolina Division of Water Quality.

Citation for this Guidebook:

Perrin, C., L. Milburn, L. Szpir, W. Hunt, S. Bruce, R. McLendon, S. Job, D. Line, D. Lindbo, S. Smutko, H. Fisher, R. Tucker, J. Calabria, K. Debusk, K.C. Cone, M. Smith-Gordon, J. Spooner, T. Blue, N. Deal, J. Lynn, D. Rashash, R. Rubin, M. Senior, N. White, D. Jones, W. Eaker. 2009. Low Impact Development: A Guidebook for North Carolina (AG-716). NC Cooperative Extension Service, NC State University. *http://www.ncsu.edu/WECO/LID*

Low Impact Development: A Guidebook for North Carolina is available for download from the following websites:
www.ncsu.edu/WECO/LID
www.bae.ncsu.edu/topic/lid

Low Impact Development
A Guidebook for North Carolina

June 2009

TABLE OF CONTENTS

	List of Figures	x
	List of Tables	xvii
	CHAPTER 1: INTRODUCTION TO THE GUIDEBOOK	1-1
1.1	Purpose of the Guidebook	1-2
1.2	Introduction to Low Impact Development	1-3
1.3	Economic and Environmental Benefits of LID	1-5
1.4	Addressing the Hydrologic Cycle through an Alternate Approach to Development	1-8
1.5	Organization of the Guidebook	1-9
1.6	Related Manuals	1-10
	CHAPTER 2: ACHIEVING LID PERFORMANCE GOALS USING A HYDROLOGIC CYCLE APPROACH	2-1
2.1	Introduction to LID Performance Goals	2-1
2.2	Determining Existing (Pre-Development) Hydrology	2-3
2.3	Determining Post-Development Hydrology	2-4
2.4	Stormwater Models	2-13
2.5	Related Stormwater Methodologies	2-14
	2.5.1 Potential Surrogates for Annual Hydrology	2-14
	CHAPTER 3: SITE ASSESSMENT AND DESIGN FOR LOW IMPACT DEVELOPMENT	3-1
3.1	Introduction to Site Assessment and Design	3-1
3.2	Design Goals	3-2
	3.2.1 Starting the Project with a Vision and Values	3-2
	3.2.2 Balancing LID with Other Design Goals	3-3
3.3	Incorporating LID Design Objectives into Design Strategies - Some Examples	3-4
3.4	Design Issues and the Application of LID	3-10

	3.4.1 Circulation Design	3-10
	3.4.2 Sidewalks and Bike Lanes	3-11
	3.4.3 Parking Design	3-12
	3.4.4 Aesthetic Design	3-12
	3.4.5 Addressing Surrounding Land Uses	3-13
3.5	Considerations for Community and Site Design	3-13
	3.5.1 Community Design - Choosing the Right Community for the Site	3-13
	3.5.2 Site Design – Creating the Right Fit	3-14
3.6	The Design Process: How to Do It	3-14
	CHAPTER 4: LID STORMWATER BMPS	4-1
4.1	LID Design Considerations	4-1
	4.1.1 Water Quality Versus Peak Flow Mitigation	4-1
4.2	BMPs Used to Implement LID	4-2
4.3	Thumbnail BMP Selection Guide	4-6
4.4	Considerations for Individual Stormwater BMPs	4-9
4.5	Bioretention	4-9
	4.5.1 Bioretention Design	4-12
	4.5.2 Bioretention Design Models	4-16
	4.5.3 Bioretention Economic Considerations	4-16
	4.5.4 Bioretention Maintenance Considerations	4-19
4.6	Permeable Pavement	4-19
	4.6.1 Types of Permeable Pavements	4-20
	4.6.2 Permeable Pavement Design	4-22
	4.6.3 Permeable Pavement Design Models	4-27
	4.6.4 Permeable Pavement Economic Considerations	4-27
	4.6.5 Permeable Pavement Maintenance Considerations	4-28
4.7	Cisterns and Water Harvesting	4-28
	4.7.1 Water Harvesting Design	4-29
	4.7.2 Water Harvesting Design Models	4-31
	4.7.3 Water Harvesting Economic Considerations	4-31
4.8	Backyard or Pocket Wetlands	4-31
	4.8.1 Pocket Wetland Design	4-31
	4.8.2 Pocket Wetland Economic Considerations	4-35
4.9	Swales	4-35
	4.9.1 Swale Design	4-35

	4.9.2 Swale Economic Considerations	4-36
4.10	Green Roofs	4-36
	4.10.1 Green Roof Design	4-37
	4.10.2 Green Roof Structural Considerations	4-39
	4.10.3 Green Roof Economic Considerations	4-39
4.11	Level Spreaders and Filter Strips	4-39
	4.11.1 Level Spreader Design	4-40
	4.11.2 Level Spreader Economic Considerations	4-44
4.12	Other Tools	4-44
	4.12.1 Infiltration Trenches and Basins	4-44
	4.12.2 Sand Filters	4-44
	4.12.3 Soil Amendments	4-44
4.13	Linking BMPs Together: Treatment Trains	4-45
	CHAPTER 5: LID AND DECENTRALIZED WASTEWATER TECHNOLOGY AND MANAGEMENT	5-1
5.1	Introduction to Decentralized Wastewater Management	5-1
5.2	Decentralized Wastewater and LID	5-2
5.3	Wastewater Characteristics	5-3
5.4	Treatment of Wastewater in a System	5-4
5.5	Types of Wastewater Systems	5-5
5.6	Site Evaluation for Wastewater Systems	5-5
5.7	Wastewater System Selection and Design	5-6
5.8	Wastewater Construction Considerations	5-7
5.9	Permitting	5-8
5.10	Operations and Maintenance	5-8
	CHAPTER 6: LID CONSTRUCTION	6-1
6.1	Introduction to LID Construction	6-1
6.2	LID Construction Planning	6-1
	6.2.1 Topography	6-2
	6.2.2 Drainage	6-2
	6.2.3 Soils	6-3
	6.2.4 Ground Cover	6-4
6.3	Sediment Export Control	6-4
	6.3.1 Minimizing Disturbance	6-6
	6.3.2 Stabilizing Disturbed Soil	6-6

	6.3.3 Controlling Runoff	6-6
	6.3.4 Maintenance	6-7
6.4	Protecting Strategic Areas	6-7
6.5	Communicating with Contractors	6-8
6.6	Maintaining Infiltration	6-8
	CHAPTER 7: LOCAL GOVERNMENT PLANNING AND REGULATORY STRATEGIES	7-1
7.1	Getting Ready for Low Impact Development	7-1
	7.1.1 Protecting Resources for Future Generations	7-1
	7.1.2 Implementing LID Goals Through Changes in Local Policy	7-3
	7.1.3 Understanding How Federal and State Regulations Relate to LID	7-6
	7.1.4 Examples of Local Government Actions to Implement LID	7-8
7.2	Site Plan Review and Approval	7-21
	7.2.1 Site Plan Review and Approval Process	7-22
	7.2.2 Site Plan Evaluation	7-27
7.3	Maintenance and Enforcement: LID Practices During Construction	7-29
7.4	Local Government Maintenance and Enforcement: LID Practices After Construction	7-31
	7.4.1 Assigning Responsibility for Long-Term BMP Upkeep	7-33
	7.4.2 Transitioning from Construction to Post-Construction	7-34
	7.4.3 Long-Term BMP Inspections	7-37
	7.4.4 Maintenance and Enforcement	7-39
	CHAPTER 8: CASE STUDIES	8-1
8.1	Case Study #1 – Drover's Road Preserve	8-1
	8.1.1 Drover's Road Preserve: Introduction	8-1
	8.1.2 Drover's Road Preserve: Background and Project History	8-2
	8.1.3 Drover's Road Preserve: Site Assessment and Design	8-4
	8.1.4 Drover's Road Preserve: Site Stormwater Management	8-8
	8.1.5 Drover's Road Preserve: Construction Phase	8-9
	8.1.6 Drover's Road Preserve: Plan Approval Process	8-10
	8.1.7 Drover's Road Preserve: Lot and Home Site Development	8-10
	8.1.8 Drover's Road Preserve: Cost Considerations	8-11
	8.1.9 Drover's Road Preserve: Long-term Maintenance	8-13
	8.1.10 Drover's Road Preserve: Conclusion	8-13
8.2	Case Study #2 – Tonbo Meadow	8-15

	8.2.1 Tonbo Meadow: Introduction	8-15
	8.2.2 Tonbo Meadow: Background and Project History	8-15
	8.2.3 Tonbo Meadow: Site Assessment and Design	8-19
	8.2.4 Tonbo Meadow: Site Stormwater Management	8-24
	8.2.5 Tonbo Meadow: Construction Phase	8-27
	8.2.6 Tonbo Meadow: Plan Approval Process	8-27
	8.2.7 Tonbo Meadow: Cost Considerations	8-29
	8.2.8 Tonbo Meadow: Long-term Maintenance	8-30
	8.2.9 Tonbo Meadow: Conclusion	8-30
8.3	Case Study #3 – North Carolina Arboretum	8-32
	8.3.1 North Carolina Arboretum: Introduction	8-32
	8.3.2 North Carolina Arboretum: Background and Project History	8-33
	8.3.3 North Carolina Arboretum: Site Assessment and Design	8-33
	8.3.4 North Carolina Arboretum: Site Stormwater Management	8-35
	8.3.5 North Carolina Arboretum: Conclusion	8-37
8.4	Case Study #4 – Conventional Versus LID Design at a Piedmont Site	8-38
	8.4.1 Comparative Case Study: Introduction	8-38
	8.4.2 Comparative Case Study: Conventional Site Design	8-38
	8.4.3 Comparative Case Study: Low Impact Development Site Design	8-45
	8.4.4 Comparative Case Study: Conventional Versus LID Design Pollutant Loading and Cost Comparison	8-57
	BIBLIOGRAPHY	BIB-1
	Helpful LID and Stormwater Web Resources Select LID, Stormwater, and Site Design Printed Resources	BIB-10 BIB 11
	APPENDICES	APP-1
	Appendix A: North Carolina Hydrophysiographic Regions	APP-2
	A.1 Mountain Region	APP-3
	A.2 Piedmont Region	APP-4
	A.3 Coastal Plain Region	APP-5
	Appendix B: Alternative Site-Assessment Hydrologic Metrics for Urban Development	APP-8
	Appendix C: Code and Ordinance Checklist	APP-25
	Appendix D: Glossary of Terms	APP-27

LIST OF FIGURES

Figure 1-1. Low impact development at River Dunes in Pamlico County, North Carolina 1-1

Figure 1-2. Bioretention at Bethel Elementary School in Haywood County, North Carolina (courtesy of David Tuch, Equinox Environmental) 1-2

Figure 1-3. Runoff increases dramatically with percent urbanization 1-6

Figure 1-4. Comparison of pre-development (solid line) and post-development (dotted line) hydrographs 1-8

Figure 1-5. "Good drainage" paradigm 1-9

Figure 2-1. Greenfield commercial development target hydrology 2-8

Figure 2-2. Hypothetical Guilford County, North Carolina development 2-8

Figure 2-3. Post-development hydrologic balance of hypothetical commercial site 2-9

Figure 2-4. Post-development hydrologic balance of commercial site with bioretention 2-10

Figure 2-5. Resulting runoff volume of hypothetical commercial site 2-11

Figure 2-6. Post-development hydrology of hypothetical residential site 2-12

Figure 2-7. Resulting runoff volume from residential site 2-13

Figure 3-1. Reduced impervious areas 3-4

Figure 3-2. Vegetated areas combined with roadways 3-5

Figure 3-3. Non-traditional lot layouts 3-5

Figure 3-4. Reduced sidewalk imperviousness 3-6

Figure 3-5. Pervious surfaces 3-6

Figure 3-6. Rooftop runoff directed to landscape areas 3-6

Figure 3-7. Work with existing topography to limit site disturbance (Seattle, Oregon) 3-7

Figure 3-8. Natural features as stormwater, environmental, and human amenities 3-7

Figure 3-9. People prefer natural areas 3-7

Figure 3-10. Natural waterways manage flow 3-8

Figure 3-11. Disconnected impervious surfaces 3-9

Figure 3-12. Create open space systems 3-10

Figure 3-13. Alternative architectural designs (Prairie Ridge Eco Station, North Carolina Museum of Natural Sciences, Frank Harmon, Architect) 3-10

Figure 3-14. Location of roads (Prince George's County, 2000) 3-11

Figure 3-15. Location of shared-use bike paths 3-12

Figure 3-16. Design of parking 3-12

Figure 3-17a & b. Aesthetic strategies improve LID longevity 3-13

Figure 3-18. Surrounding land uses inform the placement of site features 3-14

Figure 3-19. Identify and map natural features 3-16

Figure 3-20. Site analysis (match the program to the site) 3-16

Figure 3-21. Develop alternative design scenarios 3-17

Figure 3-22. Site design checklist 3-19

Figure 3-23. Site design submission package 3-22

Figure 4-1. Hydrographs associated with various design standards (courtesy of Tom Blue, BLUE Land Water Infrastructure) 4-2

Figure 4-2. An ultra-urban bioretention cell in Charlotte, North Carolina 4-3

Figure 4-3. A grassed cell on the North Carolina State University campus in Raleigh, North Carolina 4-3

Figure 4-4. Pervious concrete in Nashville, North Carolina 4-3

Figure 4-5. Pervious asphalt in Raleigh, North Carolina 4-3

Figure 4-6. Residential cistern in Holly Ridge, Onslow County, North Carolina 4-3

Figure 4-7. Cistern serving institutional water needs in Greensboro, North Carolina 4-3

Figure 4-8. Pocket wetland serving a watershed smaller than one acre 4-4

Figure 4-9. Dry swale in Raleigh, North Carolina 4-4

Figure 4-10. Wet swale along I-40 in eastern North Carolina 4-5

Figure 4-11. Succulent (sedum) vegetated green roof in Kinston, North Carolina 4-5

Figure 4-12. Concrete level spreader in Apex, North Carolina 4-5

Figure 4-13. Metal level spreader in Apex, North Carolina 4-6

Figure 4-14. Sand filter under construction 4-6

Figure 4-15. An upturned underdrain creates a sump in the bottom of the bioretention cell (top); outflow from an upturned underdrain (bottom) 4-11

Figure 4-16. Installing a gravel verge and sod stabilizes the perimeter of bioretention cells and is highly recommended 4-18

Figure 4-17. Typical permeable pavement cross section 4-19

Figure 4-18. Types of permeable pavement 4-21

Figure 4-19. An upturned underdrain elbow creates an internal storage zone for water, adding to the pavement's ability to infiltrate 4-24

Figure 4-20. Water harvesting system 4-29

Figure 4-21. Stormwater wetland in Durham, North Carolina during the drought of 2002 (top); deep pool of stormwater wetland in Craven County, North Carolina during the drought of 2007 (bottom) 4-34

Figure 4-22. Turf reinforcement matting installed in a swale in Durham, North Carolina 4-36

Figure 4-23. Layers of the green roof (courtesy of American Hydrotech, ©1996–2005) 4-37

Figure 4-24. North Carolina Arboretum green roof 4-38

Figure 4-25. Level spreader / filter strip system 4-39

Figure 4-26. Sample cross section of a concrete level spreader 4-41

Figure 4-27. Forebay schematic (top); level spreader with forebay (bottom) 4-42

Figure 4-28. Forebay 4-42

Figure 5-1. Typical components of a conventional septic system 5-2

Figure 5-2. Wastewater production 5-3

Figure 5-3. Nitrogen transformations in a conventional septic system 5-4

Figure 5-4. Advanced treatment system 5-4

Figure 5-5. Off-site systems 5-5

Figure 5-6a & b. Central sewer (top); cluster systems (bottom) 5-5

Figure 5-7. Matching system to site conditions 5-6

Figure 5-8. Low-pressure pipe system 5-7

Figure 6-1. Section showing wooded riparian buffer along the downslope side of the LID project (courtesy of Dan Line) 6-2

Figure 6-2. Temporary level spreader installed downstream of sediment basin in buffer (courtesy of Dan Line) 6-3

Figure 6-3a. Debris and stump grinding at the Pacifica (North Carolina) LID project (courtesy of Dan Line) 6-4

Figure 6-3b. Spreading of stumps ground for mulch (courtesy of Dan Line) 6-4

Figure 6-4. Dredged sediment dumped next to the sediment trap with no vegetation or cover (courtesy of Dan Line) 6-6

Figure 6-5. Level spreader in a preserved wooded buffer downstream of an LID project (courtesy of Dan Line) 6-7

Figure 6-6. Communicating with a contractor during the construction of a bioretention area / rain garden (courtesy of Dan Line) 6-8

Figure 7-1. North Carolina residents and local governments' staff in Haywood County work together to recommend ordinance changes 7-5

Figure 7-2. Voluntary participants in LID redevelopment projects were recognized by the City of Wilmington, North Carolina in a public ceremony 7-10

Figure 7-3. Brunswick County (North Carolina) LID Technical Advisory Committee (courtesy of Lauren Kolodji) 7-11

Figure 7-4. Transylvania County (North Carolina) LID roundtable participants 7-11

Figure 7-5. LID scenario with higher density and increased units depicted in Union County, North Carolina 7-15

Figure 7-6. Conventional development scenario depicted in Union County, North Carolina 7-15

Figure 7-7. Demonstration projects provide powerful educational tools 7-19

Figure 7-8. Sample stormwater operations and maintenance agreement (courtesy of the City of Winston-Salem, North Carolina) 7-24

Figure 7-9. Erosion control fencing protects a creek during construction of a wetland in Wilmington, North Carolina 7-33

Figure 7-10. A well-maintained bioretention cell in Wilmington, North Carolina 7-34

Figure 8-1. Drover's Road Preserve site (North Carolina), with approximate boundaries (courtesy of David Tuch, Equinox Environmental) 8-2

Figure 8-2. Drover's Road Preserve site plan (North Carolina) (courtesy of David Tuch, Equinox Environmental) 8-7

Figure 8-3. Roads have narrow clearing limits and cross slopes no greater than 25 percent (courtesy of David Tuch, Equinox Environmental) 8-7

Figure 8-4. Hiking trails use mulch for cover (courtesy of David Tuch, Equinox Environmental) 8-8

Figure 8-5. Aerial view of the site during summer 2006 (courtesy of David Tuch, Equinox Environmental) 8-8

Figure 8-6. Roadside grass swales (courtesy of David Tuch, Equinox Environmental) 8-9

Figure 8-7. Bioretention during construction (courtesy of David Tuch, Equinox Environmental) 8-9

Figure 8-8. Bioretention cell after construction (courtesy of David Tuch, Equinox Environmental) 8-9

Figure 8-9. Stormwater wetland (courtesy of David Tuch, Equinox Environmental) 8-10

Figure 8-10. Strict clearing limits adjacent to houses maintain more forest cover and enhance natural beauty (courtesy of David Tuch, Equinox Environmental) 8-10

Figure 8-11. Illustration from *Design Guidelines* document showing example setbacks and clearing limits (courtesy of Flying Cloud Properties, Limited, 2004) 8-12

Figure 8-12. Conceptual drawing of future entrance to Tonbo Meadow, North Carolina (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC) 8-15

Figure 8-13. LID site layout for the Tonbo Meadow Development, North Carolina (courtesy of Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC) 8-17

Figure 8-14. Existing site conditions - site boundaries outlined in red (courtesy of Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC) 8-20

Figure 8-15. Existing meadow and woodlands to be preserved as undisturbed open space (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC) 8-21

Figure 8-16. Conceptual drawing of Tonbo Meadow hammerhead turnaround designed to use porous pavement (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC) 8-22
Figure 8-17. Location of rain gardens and stormwater wetland within Tonbo Meadow site design (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC) 8-24
Figure 8-18. On-site stormwater routing schematic for Tonbo Meadow (courtesy of Gary McCabe, P.E., Red Line Engineering) 8-25
Figure 8-19. Conceptual drawing of the Tonbo Meadow development (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC) 8-31
Figure 8-20. North Carolina Arboretum masterplan 8-34
Figure 8-21. Operations Center at the North Carolina Arboretum during the retrofitting process 8-35
Figure 8-22. Green roof at the North Carolina Arboretum Operations Center during routine maintenance 8-35
Figure 8-23. Water discharged from the green roof is released to this linear rain garden at the Operations Center 8-36
Figure 8-24. Wetland pools at the Operations Center shortly after installation 8-36
Figure 8-25. Installing the permeable parking lot at the Operations Center 8-36
Figure 8-26. Level spreader at the Operations Center 8-37
Figure 8-27. Baker Center rain garden at the North Carolina Arboretum just after initial planting 8-37
Figure 8-28. Monoculture events lawn rain garden at the North Carolina Arboretum 8-37
Figure 8-29. Case study site footprint 8-39
Figure 8-30. Conventional subdivision layout 8-42
Figure 8-31. Conventional subdivision stormwater management and infrastructure 8-44
Figure 8-32. Desired areas for protection from development 8-47
Figure 8-33. Final impact footprint 8-49
Figure 8-34. LID subdivision layout and design 8-50
Figure 8-35. LID subdivision stormwater management and infrastructure 8-52
Figure 8-36. Section of typical lot layout showing drainage pattern and LID BMPs 8-54

Figure 8-37. Overhead view of typical lot 8-54

Figure 8-38. Recreation Center and BMPs 8-55

Figure 8-39. Scenario pollutant loads 8-59

Figure A-1. North Carolina hydrophysiographic regions APP-2

Figure B-1. The four primary physiographic regions used for this study were the coastal plain, piedmont, Blue Ridge rain shadow and Blue Ridge rain shed APP-9

Figure B-2. PET in the piedmont region APP-12

Figure B-3. Assigned curve numbers plotted against representative infiltration rates for each land use / soil type grouping with fitted trend line APP-14

LIST OF TABLES

Table 1-1. LID benefits to stakeholders (adapted from US Department of Housing and Urban Development and NAHB Research Center, 2003; with additions from MacMullan and Reich, 2007)	1-7
Table 2-1. A comparison of experimental and research-computed values for two experimental research stations	2-3
Table 2-2. Hydrologic fate of rainfall at Coweeta, North Carolina, Watershed 02 (from Swift et al., 1987)	2-4
Table 2-3. Hydrologic fate of rainfall	2-5
Table 2-4. Annual surface runoff, infiltration, and evapotranspiration percentages for different land surface types	2-6
Table 2-5. Conversion of runoff to infiltration and evapotranspiration for different BMPs	2-6
Table 2-6. Allowable tolerance of hydrologic fates	2-7
Table 4-1. BMP decision factors	4-10
Table 4-2. Bioretention design guidelines for specific pollutants	4-15
Table 4-3. Permeable pavement design guidance summary	4-27
Table 4-4. Recommended vegetation for backyard or pocket stormwater wetlands	4-32
Table 4-5. Level spreader length sizing guidelines	4-41
Table 7-1. Codes and ordinances that affect aspects of low impact development	7-6
Table 7-2. Responses to LID policy implementation survey	7-20
Table 8-1. Annual hydrology for conventional site design	8-43
Table 8-2. Subdivision standards by development type	8-45
Table 8-3. Assumed hydrologic fate values for BMPs	8-56
Table 8-4. Summary of post-treatment annual hydrologic fates for drainage areas (DAs) and for the entire site	8-56
Table 8-5. Example hydrologic fate analysis table for DA 2	8-56
Table 8-6. BMPs and removal efficiencies	8-58
Table 8-7. Scenario pollutant loads	8-59
Table 8-8. Cost estimate for piedmont case study conventional and LID designs (in thousands)	8-61
Table B-1. Vegetative species representing each land cover / region combination	APP-10

Table B-2. A summary of representative infiltration rates and assigned curve numbers for each land use / HSG combination APP-13

Table B-3. Calculated median curve numbers for sandy soils and clay-influenced soils, classified by land use type APP-15

Table B-4. Calculated annual depths for each land use / region category in sandy soils (HSGs A/B) APP-17

Table B-5. Calculated annual depths for each land use / region category in clay-influenced soils (HSGs C/D) APP-17

Table B-6. Summary of the percentage of annual rainfall contributing to each hydrologic component for each land use / region category for sandy soils (HSGs A/B) APP-18

Table B-7. Summary of the percentage of annual rainfall contributing to each hydrologic component for each land use / region category for clay-influenced soils (HSGs C/D) APP-18

Table B-8. Percentage of annual precipitation that leaves a site as infiltration, evapotranspiration and runoff APP-19



CHAPTER 1: INTRODUCTION TO THE GUIDEBOOK

By Christy Perrin and Laura Szpir

This chapter introduces the principles of low impact development and explains the purpose and organization of this guidebook.

Across North Carolina, from the mountains to the coast, communities are finding new ways to reduce the impacts of growth on North Carolina's unique and important natural resources. Projects ranging from the River Dunes development in Pamlico County (Figure 1-1) to Bethel Elementary School in Haywood County (Figure 1-2) are discovering development techniques that protect water resources, which in turn support our lifestyles and local economies. Whether they are called green or blue infrastructure, better site design, sustainable sites, sustainable stormwater, or low impact development (LID), these techniques share common principles: recognizing the value of intact natural resources; and planning, designing, and constructing development in ways that protect and mimic services provided by those resources. In this publication, the term *low impact development* is used to describe an innovative approach to site development and stormwater management that aims to minimize impacts to the land, water, and air, while reducing infrastructure and maintenance costs and increasing marketability.



Figure 1-1. Low impact development at River Dunes in Pamlico County, North Carolina

This guidebook was created out of the recognition that interest in protective development approaches is growing and that more coordinated guidance for North Carolina and southeastern United States communities is needed to apply these approaches. The guidebook provides practical information for professionals, government officials, and others on the approach to land development and stormwater management referred to as low impact development.

1.1 Purpose of the Guidebook

Figure 1-2. Bioretention at Bethel Elementary School in Haywood County, North Carolina



North Carolina government agencies and others support LID to promote public health, safety, and welfare by providing greater protection for and conservation of water resources, ecological processes, environmental quality, and community character. Preserving water resources will help protect quality of life and promote environmentally sustainable economic growth. In particular, the North Carolina Division of Water Quality (NCDWQ) encourages LID and has supported the development of this guidebook to promote its use.

The purpose of this guidebook is to provide technical and policy guidance to local and county government staff, building professionals, and consultants on low impact development principles and practices. In addition, as 50 percent of North Carolina's population relies on septic systems, this guidebook discusses incorporating on-site wastewater treatment into LID designs. *Low Impact Development: A Guidebook for North Carolina* has been developed using lessons learned over the years and current information to provide the most up-to-date design guidance available.

This guidebook provides technical guidance on:

- Designing LID site plans, including site layout, stormwater best management practices (BMPs), and decentralized wastewater technologies;
- Evaluating performance of LID site plans to meet water quality and quantity goals; and,
- Constructing LID sites.

This guidebook provides policy guidance on the following topics:

- Reviewing LID stormwater site plans;
- Local ordinance review procedures for identifying barriers to LID;
- Options for local ordinances and other policies that support LID; and,
- BMP maintenance, inspection, and enforcement.

As low impact development is an evolving field, the electronic version of this document will be updated periodically to reflect current findings and recommendations from ongoing research and on-the-ground experience.

The electronic version will also contain links to additional resources that support the implementation of LID. This guidebook is available in an electronic version as a PDF file from the Watershed Education for Communities and Officials website: www.ncsu.edu/WECO and the North Carolina State University LID Group at: www.bae.ncsu.edu/topic/lid/

1.2 Introduction to Low Impact Development

Under the federal Clean Water Act, one of the major responsibilities of state government is to protect, restore, and sustain the environmental integrity and use of its water resources. Good water quality and thriving fisheries are essential for sustaining the quality of life and continued economic growth of North Carolina communities. As urbanization increases, conventional development and stormwater treatment methods have not prevented the continued degradation of water quality or the adverse impact on the ecological integrity of North Carolina waters. Low impact development provides additional tools to protect water quality by optimizing the urban landscape to reduce and treat stormwater runoff.

Low impact development is a relatively new, comprehensive stormwater management approach. It was first described in 1999 in the Prince Georges County, Maryland, document *Low-Impact Development Design Strategies: An Integrated Design Approach*. Individual LID techniques, however, have been used for many years across the country. The University of Connecticut has studied the Jordan Cove LID development since 1995 (www.jordancove.unconn.edu). Several North Carolina jurisdictions and state agencies have adopted LID principles and practices. Examples are listed in Chapter 7.

The purpose of LID is to maintain and restore a developing watershed's hydrologic regime by creating a landscape that mimics the natural hydrologic functions of infiltration, runoff, and evapotranspiration. This is accomplished through an array of LID site planning practices and stormwater treatment techniques that manage runoff volume and water quality. The more effectively LID is integrated into the landscape, the greater the ability of the site to replicate the natural storage capacity of the land to capture water and capture and cycle pollutants. The decentralized and disconnected distribution (as opposed to the centralized end-of-pipe treatment) of small-scale LID stormwater practices throughout a site slows runoff, allowing for infiltration and reducing site discharge flow. LID includes the following five basic strategies, with multiple techniques for each strategy:

- Conserve resources. At the watershed level, the development tract level, and individual lot levels, try to conserve natural resources

(trees, water, wetlands and special areas), drainage patterns, topography, and soils whenever possible.

- Minimize impact. At all levels, attempt to minimize the impact of construction and development on natural hydrologic cycles and ecological systems by saving existing vegetation and reducing grading, clearing, impervious surfaces, and pipes.
- Optimize water infiltration. To the maximum extent practicable, slow down runoff and encourage more infiltration and contact time with the landscape by saving natural drainage patterns and by maintaining sheet flow using vegetative swales, lengthened flow paths, and flattened slopes.
- Create areas for local storage and treatment. Rather than centralizing stormwater storage, distribute storage across the landscape, adjacent to areas of flow. Use small-scale practices that allow for collection, retention, storage, infiltration, and filtering on site.
- Build capacity for maintenance. Develop reliable, long-term maintenance programs with clear and enforceable guidelines. Educate homeowners, management companies, and local government staff on the operation and maintenance of all practices, and about protecting water quality.

LID is a versatile approach that can be applied to new development, urban retrofits, redevelopment, and revitalization projects, in most soils and hydrologic regimes. The range of options within LID allows flexibility in design and application of techniques so communities from the coast, the sandhills, the piedmont, and all the way to the mountains can adapt it for their needs. All components of the urban environment have the potential to incorporate LID techniques, while selection of the appropriate effective practice or series of practices depends on a variety of site-specific factors. Techniques can be integrated into rooftops, streetscapes, parking lots, driveways, sidewalks, medians, and the open spaces of residential, commercial, industrial, civic, and municipal land uses. Landscaping presents opportunities to direct runoff to these areas for storage, infiltration, and treatment.

The creation of LID's wide array of micro-scale stormwater management principles and practices has led to the creation of new tools to retrofit existing urban development. Newer micro-scale practices that filter, retain, and detain runoff can be easily integrated into existing green space, streetscapes, and parking lots as part of the routine maintenance and repair of urban infrastructure. As North Carolina's urban areas are redeveloped and rebuilt using integrated LID techniques, it may be possible to reduce pollutant loads to receiving waters, increase the availability of local clean water, reduce problems with flooding during peak rain events, and reduce our dependency on expensive centralized stormwater systems.

Land use planning should consider environmental impacts at multiple scales, including the site level, subdivision level, watershed level, and regional level. Local governments can achieve multiple benefits by developing land use, open space, and watershed protection plans to identify both areas for growth and areas for conservation and protection. A LID policy is one tool that should be considered within an overall plan for development, conservation, and restoration of natural areas. Brunswick and New Hanover Counties (North Carolina) serve as examples of local governments incorporating LID as one of many tools within their comprehensive plans.

Directing new growth toward existing development and infrastructure, a concept known as infill development or redevelopment, is a sensible strategy to protect sensitive, undeveloped land in other areas. Development should be considered within the larger context: increased stormwater runoff and reduced infiltration at the site scale may be a trade-off to protect resources that would otherwise be affected by sprawling development patterns. This concept of creating smaller, manageable footprints of concentrated building density within a given area (such as a watershed) has been the fundamental justification for strategies such as "cluster development" or "smart growth."

1.3 Economic and Environmental Benefits of LID

The economic and ecological benefits of LID have been demonstrated and documented through various research projects, case studies, and practical experience (MacMullan and Reich, 2007; France, 2002; Natural Resources Defense Council, 1999; U.S. Department of Housing and Urban Development in partnership with the National Association of Home Builders, 2003; USEPA, 2007; and many others).

The United States Environmental Protection Agency (USEPA) evaluated 17 LID case studies across North America for cost savings over conventional development (USEPA, 2007). In the majority of cases, LID practices were shown to be both economically and environmentally beneficial to communities, with capital cost savings ranging from 15 to 80 percent, due to reduced costs for site grading and preparation, paving and landscaping, and stormwater infrastructure (ponds, pipes, inlet structures, curbs, and gutters). Benefits to environmental goods and services include improved aesthetics, expanded recreational opportunities, increased property values due to desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales.

The effective use of LID site design techniques can significantly reduce the cost of providing stormwater management. Savings are achieved by reducing or eliminating stormwater management ponds; reducing pipes, inlet structures, curbs and gutters; reducing roadway paving; and reducing the amount of land moved during the clearing and grading stages of construction. Where LID techniques are applied, and depending on the type of development and site constraints, stormwater and site development design, construction, and maintenance costs can be reduced by 25 to 30 percent compared to conventional approaches (Clar, 2000).

The growing number of LID evaluations across the U.S. provides strong evidence that the practice of LID is sound and offers many economic and environmental benefits over conventional approaches. Table 1-1 illustrates the potential benefits of LID and shows who receives those benefits.

Economic evaluations of LID often focus on cost comparisons using initial construction costs, as this is the simplest evaluation to perform. However,

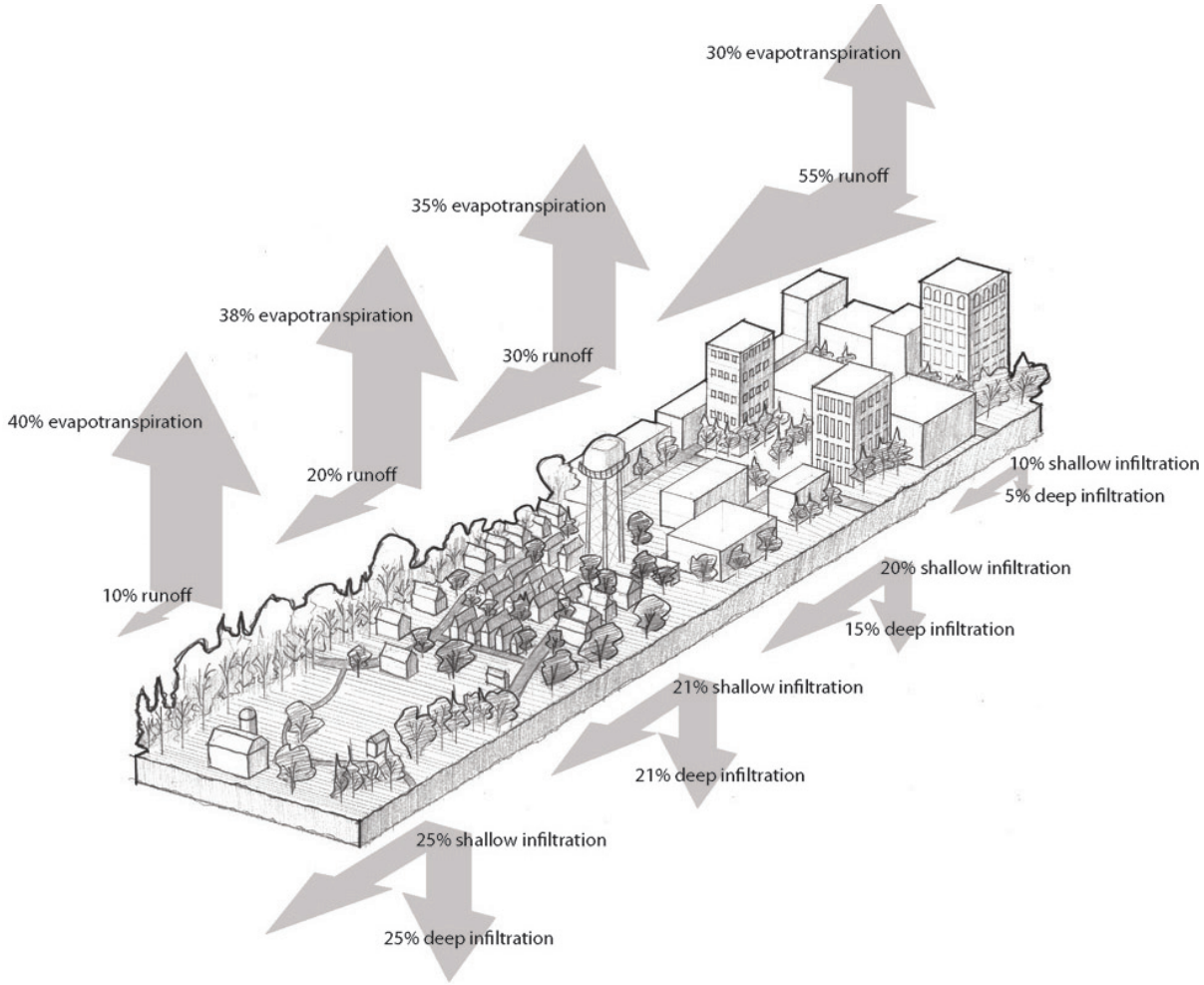


Figure 1-3. Runoff increases dramatically with percent urbanization

Table 1-1. LID benefits to stakeholders (Adapted from US Department of Housing & Urban Development and NAHB Research Center, 2003; with additions from MacMullan and Reich, 2007)

Developers
• Reduces land clearing and grading costs • Reduces infrastructure costs (streets, curbs, gutters, sidewalks) • Reduces stormwater management costs • Increases lot yields and reduces impact fees • Increases lot and community marketability
Municipalities
• Protects regional flora and fauna • Balances growth needs with environmental protection • Reduces municipal infrastructure (streets, curbs, gutters, sidewalks, storm sewers) • Reduces system-wide operations and maintenance costs of infrastructure • Reduces costs of combined sewer overflows (CSOs) • Increases groundwater recharge • Fosters public/private partnerships
Home Buyer
• Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies • Preserves and protects amenities that can translate into more salable homes and increased property values • Provides shading for homes, which decreases monthly energy bills for cooling • Reduces flooding • Saves money through water conservation
Environment
• Preserves integrity of ecological and biological systems • Reduces demands on water supply and encourages natural groundwater recharge • Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies • Reduces impact on local terrestrial and aquatic plants and animals • Preserves trees and natural vegetation

this incomplete assessment neglects operation and maintenance costs, and it does not consider the increased values of environmental goods and services such as healthy fish populations and cleaner drinking water. When discussing the costs of LID, communities should discuss the full range of benefits and costs, including those benefits that are not easily monetized but are important to quality of life. A recent North Carolina Cooperative Extension fact sheet, *Low Impact Development—An Economic Fact Sheet*, provides a framework for discussing economics and includes examples of several economic studies (WECO, 2009).

1.4 Addressing the Hydrologic Cycle through an Alternate Approach to Development

The hydrologic cycle describes the movement of water from the atmosphere to the earth's surface and subsurface layers, and back to the atmosphere again. It includes the ecological processes of rainfall (precipitation), infiltration (shallow subsurface flow and deep seepage), surface runoff, evaporation, and evapotranspiration. With each rainfall event, the water infiltrates into the ground, runs off the surface, evaporates, or is transpired by vegetation back to the atmosphere. With undeveloped conditions, the majority of precipitation either infiltrates or evapotranspires; there is typically very little or no surface runoff (Figure 1-3 and Figure 1-4).

With conventional land development practices, the hydrologic cycle is disturbed as vegetation is removed, soil compacted, ground paved over, and buildings erected, which leads to less infiltration and evapotranspiration and more surface runoff. Conventional development and stormwater management methods—especially the typical stormwater collection and conveyance system—alter the hydrology and, consequently, may affect the physical, chemical, and biological condition of streams and other receiving waters.

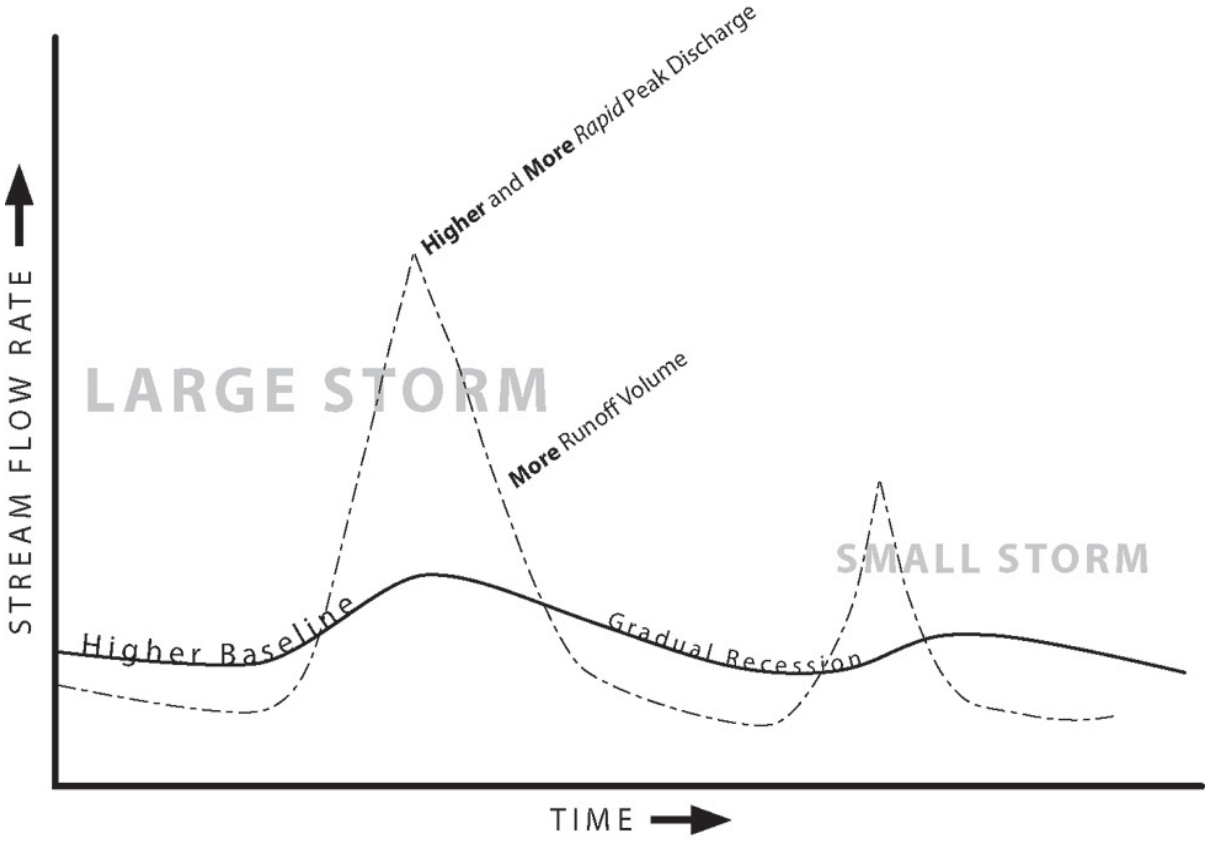


Figure 1-4 Comparison of pre-development (solid line) and post-development (dotted line) hydrographs

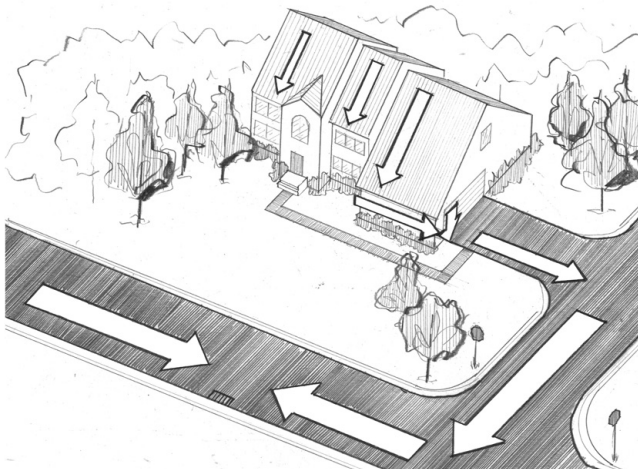


Figure 1-5. Traditional "Good drainage" paradigm which quickly moves stormwater off-site adversely impacts stream hydrology and water quality

Why does this matter? The health of North Carolina's groundwater, streams, and estuaries and the aquatic life they support depend upon the undeveloped hydrologic cycle, where the majority of rainfall infiltrates and evapotranspires with minimal runoff. Continued economic growth and prosperity also depend on promoting a healthy hydrologic cycle, as wells, public drinking water supplies, tourism, recreational and commercial fishing, and shellfish harvesting all require reliable water quantities as well as high-quality water resources and the ability of groundwater to recharge.

The adverse impacts of urbanization are not inevitable but often occur because of the way society chooses to develop land and to collect, convey, concentrate, and treat runoff. This basic "good drainage" paradigm (see Figure 1-5) is the elementary cause of the adverse stormwater quality and quantity impacts of urbanization. The more efficient the drainage system is in moving water away from the site, and the more the hydrology differs from its natural state, the higher the cumulative impacts will be on flooding, erosion, and water quality.

The goal of LID in North Carolina is to use a wide array of site-level planning, design, and control techniques to restore and optimize the land's ability to soak up water and capture and process pollutants in the landscape.

Low impact development is primarily a source reduction approach that uses the native soil and landscaping as strategically protected and distributed features to intercept, store, infiltrate, and use storm flows. Although this new paradigm may seem like a dramatic shift, many southeastern U.S. communities have already begun the work of promoting this change, and federal and state agencies are supporting those efforts, as evidenced in Chapter 7.

1.5 Organization of the Guidebook

This guidebook is organized as follows:

- Chapter 1 explains the purpose and organization of the guidebook and an introduction to LID. Complementary North Carolina stormwater manuals are also listed.

- Chapter 2 outlines LID performance goals for water quantity and water quality and discusses the hydrologic cycle as a central focus of LID. It presents a process with examples for evaluating and comparing pre-development and post-development hydrology to meet LID goals.

- Chapter 3 provides guidance for LID site assessment and design criteria at the development tract scale, including those associated with the master plan-specific characteristics and considerations for surrounding adjacent lands.

- Chapter 4 covers the selection and design of LID stormwater best management practices (BMPs), including pollutant-specific design considerations. Installation, maintenance, and cost issues are also presented for various BMPs.

- Chapter 5 discusses decentralized wastewater treatment system selection, design, permitting, construction, and operation and maintenance.

- Chapter 6 explains how to apply LID principles to the construction phase of development.

- Chapter 7 discusses local government planning and regulatory issues related to designing, implementing, and maintaining LID sites and practices. Local codes, ordinances and policy strategies, site plan and construction review procedures, and enforcement issues are also covered.

- Chapter 8 provides case studies, including examples of current LID sites in North Carolina, and a conventional site design converted to an LID site design following the procedures outlined in this guidebook. Case studies are from the mountains, piedmont, and the coast.

1.6 Related Manuals

This guidebook is intended to complement the manuals listed below. The *North Carolina Erosion and Sediment Control Manual* should be referenced during the construction phase for permitting requirements and guidance on the proper selection and use of erosion and sediment control practices. The *North Carolina Division of Water Quality (NCDWQ) Stormwater Best Management Practices Manual* should be referenced for technical guidance on performance, siting, design, operation, maintenance, and inspection

of structural stormwater control practices and LID practices such as bioretention, wetlands, vegetative swales, permeable pavement, and green roofs. LID guides specific to New Hanover and Brunswick Counties (North Carolina) are also available.

- *NCDWQ Stormwater Best Management Practices Manual* (July, 2007) http://h2o.enr.state.nc.us/su/bmp_updates.htm

- *North Carolina Erosion and Sediment Control Planning and Design Manual* (2006) http://www.dlr.enr.state.nc.us/pages/manualsandvideos.html

- *NCDWQ Stormwater Management Site Planning Handbook* (February, 1998) http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/Site_Planning_Document.pdf

- *New Hanover County-City of Wilmington Joint LID Guidance Manual* www.nhcgov.com

LID and the North Carolina Division of Water Quality *Stormwater BMP Manual*

The *NCDWQ Stormwater Best Management Practices (BMP) Manual* designates the stormwater control requirements that are necessary to meet the conditions of the Environmental Management Commission (EMC) rules. All permits issued by the Division of Water Quality must be consistent with these rules. Some local governments may have approved stormwater-permitting programs, which must also be consistent with the provisions of the DWQ rules. However, some local governments may approve additional requirements or provisions not specifically set forth in the *NCDWQ Stormwater BMP Manual*. If the local government has made the appropriate determination that their program is consistent with the provisions of the *NCDWQ Stormwater BMP Manual* and EMC rules, meeting those local government requirements will be deemed to comply with the provisions of the *NCDWQ Stormwater BMP Manual*. Future versions of the *North Carolina Division of Water Quality's Stormwater BMP Manual* will provide greater guidance regarding LID methodologies. Until then, if a developer is seeking to receive stormwater reduction credits for a NCDWQ stormwater permit, we advise checking first with the state or local government permitting authority ahead of time to ensure that the project meets necessary requirements.

REFERENCES

Beyerlein, D., S. Bolton, D. Booth, et al. 2006, Oct. 26. Partnership recommendations to improve water quality and habitat by managing stormwater runoff; protect ecosystem biodiversity and recover imperiled species; provide water for people, fish and wildlife, and the environment. *Letter to the Puget Sound Partners*. Olympia, WA: Puget Sound Partnership, Puget Sound Water Quality Action Team.

City of Salinas. 2007, July. *Development Standards Plan: Low Impact Development Designs and Practices for Urban Storm Drainage Management*. Salinas, CA: City of Salinas. http://www.swrcb.ca.gov/centralcoast/water_issues/programs/stormwater/muni_phase1/docs/salinas-dsp.pdf

Clar, M. 2000. Applications of Low Impact Development Techniques. Paper presented at the International Symposium on Water Sensitive Ecological Planning and Design (February 25-26, 2000). Cambridge, MA: Harvard Graduate School of Design.

Coffman, L. 2007, Oct. *Low Impact Development Guidance Manual* (Draft). Bolivia, NC: Brunswick County Commissioners.

France, R. L. 2002. *Handbook of Water Sensitive Planning and Design*. Boca Raton, FL: CRC Press.

Hinman, C. 2005, Jan. *Low Impact Development: Technical Guidance Manual for Puget Sound* (Publication no. PSAT 05-30). Olympia, WA: Puget Sound Action Team (with Washington State University, Pierce County Extension). http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

Horner, R, C. May, E. Livingston, et al. 2001. *Structural and Non-Structural BMPs for Protecting Streams*. Crawfordsville, FL: Watershed Management Institute.

Hunt, W. F., C. S. Apperson, S. G. Kennedy, et al. 2006. Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA. *Water Science and Technology* Vol. 52(6-7): 315-321.

Jones, M. P. and W. F. Hunt. 2008. Wet pond and wetland impacts on runoff temperature. *Journal of Biological Engineering* (in review).

Jordan Cove Urban Watershed Project. Website. Waterford, CT: University of Connecticut, College of Agriculture and Natural Resources. www.jordancove.uconn.edu

Lehner, P., G. Aponte-Clark, D. Cameron, et al. 1999, May. Low impact development. In *Stormwater Strategies: Community Responses to Runoff Pollution*. Washington, DC: Natural Resources Defense Council. http://www.nrdc.org/water/pollution/storm/stoinx.asp

MacMullan, E. and S. Reich. 2007. *The Economics of Low-impact Development: A Literature Review*. Eugene, OR: ECONorthwest. http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf

Maxted, J. and E. Shaver. 1997. The use of retention basins to mitigate stormwater impacts on aquatic life. In L. A. Roesner (ed.), *Effects of Watershed Development and Management on Aquatic Ecosystems*. New York, NY: American Society of Civil Engineers.

May, C. W., E. B. Welch, R. R. Horner, et al. 1997. *Quality Indices for Urbanization Effects in Puget Sound Lowland Streams* (Water Resources Series Technical Report No. 154, Publication 98-04). Olympia, WA: Washington Department of Ecology.

McCuen, R. H., G. Moglen, E. Kistler, and P. Simpson. 1979. *Policy Guidelines for Controlling Stream Channel Erosion with Detention Basins*. College Park, MD: Department of Civil Engineering, University of Maryland (prepared for the Water Management Administration, Maryland Department of the Environment, Baltimore, MD).

NAHB Research Center. 2003, July. *The Practice of Low Impact Development*. Washington, DC: U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

Prince George's County. 1999, June. *Low-Impact Development Design Strategies: An Integrated Design Approach*. Largo, MD: Prince George's County Department of Environmental Resources, Programs and Planning Division.

Prince George's County. 1997. *Low-Impact Development Design Manual*. Largo, MD: Prince George's County Department of Environmental Resources (prepared by Tetra Tech, Fairfax, VA).

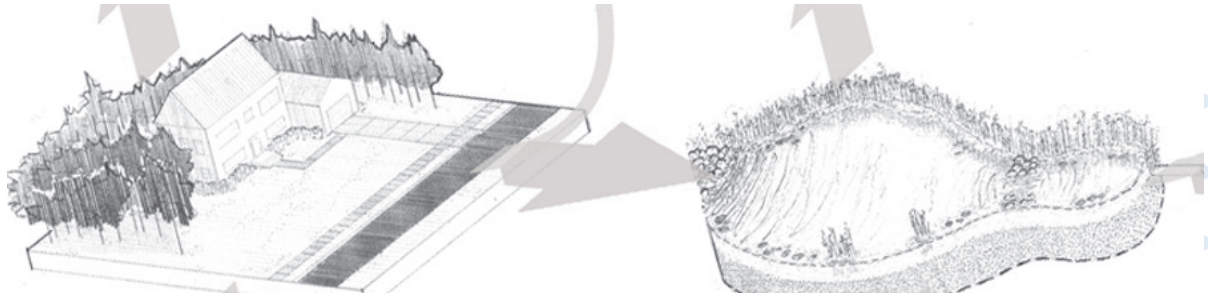
Stribling, J. B. 2001. Relating Instream Biological Condition to BMP Activities in Watersheds. Paper presented at the Conference on Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation (Snowmass, CO). New York, NY: United Engineering Foundation.

U.S. Environmental Protection Agency. 2000, Oct. *Low Impact Development (LID); A Literature Review* (EPA-841-B-00-005). Washington, DC: Office of Water and Low Impact Development Center.

U.S. Environmental Protection Agency. 2007, Dec. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (EPA 841-F-07-006). Washington, DC: U.S. EPA. www.epa.gov/owow/nps/lid/costs07/

U.S. Environmental Protection Agency. 2005, Dec. *Using Smart Growth Techniques as Stormwater Best Management Practices* (EPA 231-B-05-002). Washington, DC: U.S. EPA. www.epa.gov/smartgrowth

Watershed Education for Communities and Officials (WECO). 2009. *Low Impact Development: An Economic Fact Sheet*. Raleigh, NC: Cooperative Extension, North Carolina State University. www.ncsu.edu/WECO/LID



CHAPTER 2: ACHIEVING LID PERFORMANCE GOALS USING A HYDROLOGIC CYCLE APPROACH

By Bill Hunt

This chapter highlights water quantity and water quality goals for low impact development principles and practices and explains how to meet those goals using a hydrologic cycle approach. Following this approach will usually ensure that state and local stormwater regulations are met; however, it remains the responsibility of the developer to ensure fulfillment of all state and local requirements. In areas of the state where the Division of Water Quality (DWQ) has the primary authority to issue individual stormwater control permits, the provisions of the DWQ Stormwater Manual are required. Methods in this chapter that may not be accepted for statewide application by the Division of Water Quality may be approved for use by an individual local government. The purpose of this chapter is to discuss a step-by-step process to evaluate pre-development hydrology and describe how to calculate post-development hydrology to aid in LID design so that the two regimes resemble each other as much as possible.

2.1 Introduction to LID Performance Goals

Water Quantity Performance Goal:
Post-development volumes of runoff, infiltration, and evapotranspiration for each site shall match pre-development[1] volumes of runoff, infiltration, and evapotranspiration for each site, based on an annual budget. If the pre-development volumes of runoff are mimicked, then other water quantity goals such as stream stability outflows and 1-year, 24-hour storm peak mitigation are assumed to be met.[2]

Establishing the target conditions for a site is possible using one of two methodologies: (1) measured volumes obtained from regional research stations, or (2) calculated volumes that are partially derived from USDA-NRCS (1986) methodology. Measured values were obtained from Coweeta Hydrologic Laboratory

[1] Pre-developed can mean before European arrival (pre-Columbian); a common, second undeveloped condition such as a second growth forest; or other target hydrology. For example, an infill development may have a different target hydrology to meet than a wooded property on the periphery of town.

[2] These assumptions will be either proven or disproven by research in the coming years. Most researchers accept, however, that the assumption is reasonable.

in Otto, North Carolina, and Santee Research Laboratory in South Carolina. Research was conducted on hydrologic behaviors for various climatic and soil conditions and was used to compute representative target conditions for different climate/soil/vegetative combinations. The preferred pre-development volumes for a given site may be chosen from either of these settings and should be based on which setting most closely matches actual site conditions. The Santee record, however, is not as complete as Coweeta's, particularly with respect to separating infiltration from evapotranspiration volumes. Factors influencing the feasibility of meeting the performance goal include soil and slope conditions, pre-development land use, and post-development imperviousness, and it is recognized that pre-development hydrology, particularly based on Coweeta values, may not be achievable for all development sites. Therefore, tolerance levels are recommended for various land uses and hydrophysiographic regions later in this chapter (Table 2-6). As additional hydrologic data are collected from other regions of the state, other possible conditions for determining pre-development hydrology may be added.

The research-based values have been cross-referenced with measured site conditions at Coweeta Hydrologic Laboratory and Santee Experimental Forest near Huger, South Carolina. Hydrologic monitoring has been conducted at Coweeta and Santee since 1928 and 1969, respectively. Due to the long time span over which data have been recorded, these two sites provide valuable information regarding evapotranspiration, infiltration, and runoff characteristics of undeveloped forested conditions. These data are assumed to be especially accurate, as both sites have more than 30 years of collected data. To evaluate the accuracy of the research-computed values, the appropriate site conditions for each of the experimental stations were entered into the model and the resulting hydrologic percentages compared to those established by the experimental data. Table 2-1 summarizes the selected site conditions and resulting percentages for each condition. As shown in the table, the research-computed values are very similar to those published by Coweeta and Santee, thereby confirming a reasonable level of accuracy. The similarity of the two sets of values justifies using other pre-developed conditions in other parts of the state based on the research described in Appendix B.

Water Quality Performance Goal:
Design the site and select BMPs that address the removal or sequestration of targeted pollutants in the watershed, as identified by NCDENR (such as TMDLs, Nutrient Sensitive Waters, or Shellfish Waters). Adjust BMP designs to address target pollutants to the maximum extent practicable, or to a non-degradation standard.

Table 2-1. A comparison of experimental and research-computed values for two experimental research stations, Coweeta and Santee, North Carolina

		Evapotranspiration	Infiltration	Runoff
Coweeta	Measured Values	50	45	5
	Research-Computed Values	52.5	41.3	6.2
Santee	Measured Values	77	23*	
	Research-Computed Values	73	27*	

*Reported hydrologic values for Santee combined infiltration and runoff as one value.

A Bit About Coweeta's Data

At lower elevations in Coweeta, an average of 1,770 mm precipitation fell per year with 80 mm running off, 770 mm infiltrating and becoming part of shallow groundwater to replenish streams as base flow, and 890 mm released to the air through evapotranspiration (ET) (Swift et al., 1987). The remaining 30 mm could be assigned to deep seepage, but due to uncertainty in the ET calculation, the actual percentage and fate remain somewhat unknown. The location Watershed 02 was used for runoff and infiltration calculations and Climatic Station 01 was additionally used for evapotranspiration calculations. The elevation of Watershed 02 station is 709 m, and the elevation of Climatic Station 01 is 686 m. At the time of the Swift et al. (1987) study, the duration of the weather records used to determine these values were 37 years for Watershed 02 and 50 years at Climatic Station 01.

2.2 Determining Existing (Pre-Development) Hydrology

In any given area, a certain percentage of rainfall infiltrates, evapotranspires, or runs off. In forested areas of the eastern United States, this breakdown is estimated to be 50 percent infiltration, 40 percent evapotranspiration, and 10 percent runoff on an annual basis. However, the exact percentages will vary both spatially and seasonally. The main variables are amount of precipitation, timing and intensity of precipitation, permeability of soil, slope of terrain, ground cover, antecedent soil moisture conditions, and water table depth. The percentages above were determined based on research conducted by the U.S. Forest Service in Otto, North Carolina, and serve as a possible target condition for developing sites. At the time of writing, this is the only region where there is sufficient data to make a generalization to the rest of the rain shed region (Brevard, Cashiers, and Coweeta). Although precipitation amounts at Coweeta are higher than at any major city in the state, these percentages are still useful as they represent a conservatively high estimate of precipitation to manage in other regions.

For locations that do not closely resemble the rain shed region, or for sites where a conservative estimate is not desired, research-based values were computed based on peer-reviewed infiltration and evapotranspiration research studies. Infiltration percentages were derived using the NRCS curve number method, while evapotranspiration values were determined using measured data from various locations throughout the state. Runoff values

were calculated as the difference in total precipitation (as determined using measured rainfall data from several locations across North Carolina) and the sum of infiltration and evapotranspiration. As hydrologic components depend on a number of external factors such as precipitation, temperature, vegetative characteristics, and soil permeability, percentage values varied based on a site's physiographic region, precipitation, and soil and vegetative characteristics. A full description of the method with which these values were developed may be found in Appendix B. As additional research is conducted and more information is gathered on long-term hydrology across the state, new data will be incorporated into this manual and pre-development hydrology values may be adjusted.

The Coweeta data are summarized in Table 2-2, and research-computed data are summarized in Table 2-3.

Table 2-2. Hydrologic fate of rainfall at Coweeta, North Carolina, Watershed 02 (from Swift et al., 1987)
These values are generalized to the entire state to estimate pre-development hydrology.

Hydrologic Fate	Average Amount [1]	% of Total Precipitation
Precipitation	1770 mm (70 inch)	100%
Runoff	80 mm (3 inch)	5%
Evapotranspiration	890 mm (35 inch)	50%
Infiltration[2]	800 mm (31 inch)	45%
Shallow Interflow	770 mm (30 inch)	44%
Deep Seepage	30 mm (1 inch)	2%

[1] All values rounded to the nearest 10 mm or 1 inch

[2] Infiltration is the sum of Shallow Interflow and Deep Seepage

2.3 Determining Post-Development Hydrology

A development is composed of basic land covers, which can be broadly grouped into four categories: 1) permeable vegetated systems, 2) permeable "hard" systems, 3) impermeable surfaces, and 4) open water. Permeable vegetated systems include vegetated land covers that have been affected by human activities (such as lawns and forests that are harvested for timber) and those that have not (undisturbed forests or grasslands). Permeable "hard" systems are human-built permeable surfaces, such as green roofs and permeable pavement, which tend to be less permeable than natural permeable vegetated systems. Impermeable surfaces include human-built materials such as rooftops, roadways, parking, and other surfaces that entirely prevent precipitation from reaching the soil beneath them. Each surface cover, and underlying soil and slope, has a unique effect on the partitioning of precipitation among long-term infiltration, evapotranspiration (ET), and runoff.

Table 2-3. Hydrologic fate of rainfall, as developed from the compilation and analysis of previous research studies
Values depict the typical hydrologic fate of rainfall in mature forested conditions. See Appendix B for more details regarding the development of these values.

Region:	Coastal Plain	Piedmont	Mountain - Rain Shadow	Mountain - Rain Shed
Hydrologic Fate:				
Evapotranspiration	73%	69%	62%	41%
Infiltration	22%	29%	35%	52%
Runoff	5%	3%	3%	6%

The amount and distribution of these surfaces determine the post-developed site's "untreated" hydrologic profile (that is, the site's hydrology without factoring in the effects of any stormwater management practices). The amount of runoff, infiltration, and evapotranspiration provided by each surface is given in Table 2-4. These data enable infiltration, ET, and runoff to be calculated for the entire site and then compared to that of the pre-development (or target development) hydrologic regime.

Table 2-5 shows ranges for the proposed percentages of runoff that are converted to ET and infiltration for different BMPs.[3] The ranges will vary further according to actual BMP design, underlying soil characteristics, and water tables. Additional data to refine these values is needed.

Data in Table 2-5 for bioretention and permeable pavement is based upon several studies including Hunt et al. (2006), Bean et al. (2007), Sharkey (2006), and Collins et al. (2008a). Data for stormwater wetlands is based upon an internal North Carolina State University Department of Biological and Agricultural Engineering study (Jones, 2008). Standard grassed swale data were obtained from Backstrom (2003) and Backstrom (2002).

[3] More research is needed to either determine or verify these numbers.

Table 2-4. Annual surface runoff, infiltration, and evapotranspiration percentages for different land surface types

Surface Type	Runoff %	Infiltration %	Evapotranspiration %
Undisturbed Woods	5%	45%	50%
Undisturbed Meadow	7%	45%	48%
Disturbed Trees	10%	40%	50%
Disturbed Lawn	15%	40%	45%
Lawn – Amended Soil	7%	45%	48%
Open Water / BMP	100%	0%	0%
Green Roof (4" depth)[1]	40%	0%	60%
Permeable Pavement[2]	15 to 50%	5 to 70%	0 to 15%
Impermeable Surface	70 to 95%	0 to 5%	5 to 30%

[1] Data for green roofs is from Hathaway et al. (2008) and Berghage et al. (2007).

[2] Data for permeable pavements are highly variable, and depend greatly on design and underlying soil conditions.

Table 2-5. Conversion of runoff to infiltration and evapotranspiration for different BMPs

BMP Type	Approximate Infiltration[1]	Approximate ET[1]
Bioretention – shallow media depth (2')	5 to 30% (25%)	15 to 20% (20%)
Bioretention – deep media depth (4')	10 to 40% (35%)	20 to 30% (25%)
Bioretention – IWS layer[2] (4' media depth)	15 to 45% (35%)	20 to 30% (25%)
Permeable pavement – all types except concrete grid pavers filled with sand	10 to 70% (70% sand) (20% TYP piedmont)	0 to 5% (5%)
Permeable pavement – concrete grid pavers filled with sand	15 to 70% (70% sand) (20% TYP piedmont)	5 to 15% (10%)
Permeable pavement – IWS layer	30 to 70%	0 to 15%
Backyard / pocket wetlands	18 to 25% (20%)	10 to 30% (20%)
Swales – standard	5 to 15% (10%)	5 to 10% (5%)
Wet detention swales	5 to 15% (10%)	5 to 15% (10%)
Stormwater wetlands	18 to 25% (20%)	10 to 30% (20%)
Infiltration trench	10 to 40% (35%)	20 to 25% (20%)

[1] Recommended default value in (parentheses)

[2] IWS = Internal Water Storage layer that is incorporated into bioretention and permeable pavement to increase infiltration. Details on the IWS layer are found in Chapter 4.

Ideally, the exact percentages of pre-development annual runoff, infiltration, and evapotranspiration will be achieved in the post-development design by incorporating LID technologies. However, this is probably unreasonable for all site designs, especially those that are infill or redevelopment projects. Factors such as the amount of post-developed imperviousness (such as residential versus commercial), location in the state (sandhills versus Triassic basin), and pre-development condition (greenfield versus grayfield[4]) all affect how closely a designer is able to achieve truly pre-development hydrology. Table 2-6 lists the allowable range of hydrologic fates (e.g., runoff infiltration, and ET) associated with various conditions. These values will be modified as further research is conducted.

Table 2-6. Allowable tolerance of hydrologic fates

	General[1]	**Triassic Basin / Mountains**	**Sandhills / Barrier Islands**
Greenfield – Residential [2]	5%	10%	3%
Greenfield – Commercial [3]	15%	20%	15%
Grayfield – Residential [2]	10%	15%	10%
Grayfield - Commercial [3]	20%	25%	20%

[1] Includes piedmont

[2] 40% impervious or less

[3] 90% impervious or more

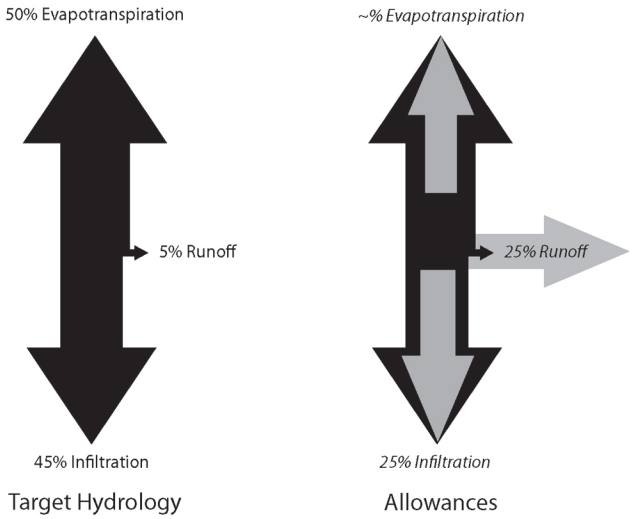
How to use the information in Table 2-6:

As an example, assume a greenfield development is going to be a commercial site (Figure 2-1). The site is located in southwestern Durham County in Triassic basin soils. The target hydrology for the site is 5 percent runoff, 50 percent ET, and 45 percent infiltration. Using Table 2-6, a 20 percent allowance is made for a commercial site's hydrology. This means that up to 25 percent of the water from the site could run off, and as little as 25 percent of the water at the site could infiltrate. Alternatively, some flexibility could be associated with the amount of water that evapotranspires. Using the vernacular, there is 20 percent of the water to "play with."

Table 2-6 includes lower limit and upper limit caps on the tolerances - at or below 40 percent impervious, the tolerances are not lower than those shown for the residential class, while at or above 90 percent impervious, the tolerances are at their maximum values. If a site's impervious area is between 40 percent and 90 percent, then a sliding scale is used to determine the allowable range. For the general and Triassic basin/mountain regions,

[4] "Greenfield" is an area that has previously been undeveloped or in agriculture. "Grayfields" are areas that were developed previously and now are in a state of underutilization.

Figure 2-1. Greenfield commercial development target hydrology



every increase of 5 percent of imperviousness equates to 1 percent more hydrologic "range."[5] So, if the above development is 60 percent impervious, then the allowable range becomes 14 percent. This means a given site could have up to 29 percent runoff and as low as 31 percent infiltration and still be considered a low impact development. An example of the methodology follows.

Example: Matching pre-development and post-development hydrology

A developer is planning to take a wooded tract that is 50 acres and create a mixed-use residential and commercial development (Figure 2-2). Approximately 40 acres will be residential and 10 acres will be commercial. The development will be located in northern Guilford County (in the piedmont), which has a substantial amount of Cecil (Hydrologic Group B) soils.

Using the limited data that are available, the pre-development (or target) annual hydrology is 5 percent runoff, 50 percent evapotranspiration, and 45 percent infiltration (from Table 2-2). On the residential side, the development would be considered LID if the final development is within 5 percent of any of the target amounts (from Table 2-6), so the designer chooses a 10 percent runoff, 45 percent evapotranspiration, and 45 percent infiltration goal. On the commercial portion of the property, the developer's target hydrology has a higher allowable tolerance (15 percent),

[5] For the sandhills and barrier islands, the range is determined by dividing 12 percent by 50 percent, which means every 4.25 percent of imperviousness equates to an increase of 1 percent in the allowable hydrologic range.

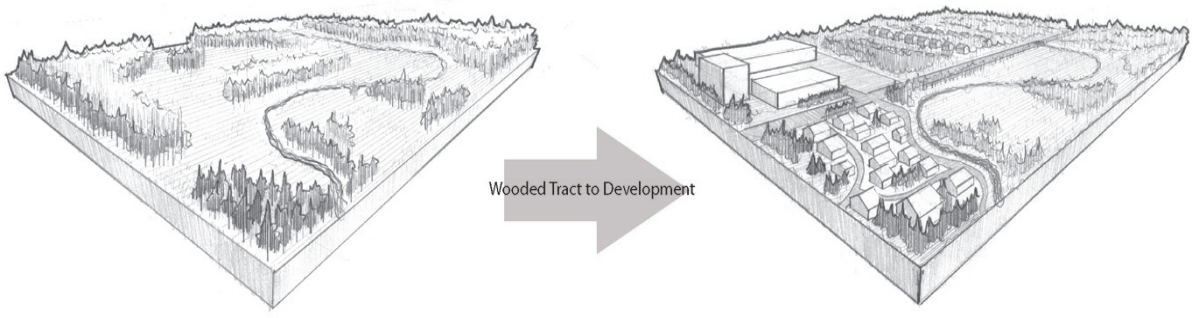


Figure 2-2. Hypothetical Guilford County, North Carolina development

so the designer chooses a 20 percent runoff, 45 percent ET, and 35 percent infiltration goal.

The 10-acre commercial site will be a small shopping center developed in a 100 percent impervious area. The site will employ bioretention, permeable pavement, and green roofs for treatment. Green roofs will account for 2 acres of the surface, permeable pavements 2 acres, and bioretention will treat the remaining 6 acres of impervious surfaces.

The 40-acre residential site will preserve 10 acres of woods, with the remaining development averaging three homes per acre (approximately 25 percent impervious) (Cappiella and Brown, 2001). All the runoff from the developed portion of the residences will drain to bioretention cells initially, and all overflow and bioretention drainage will be treated by a stormwater wetland at the edge of the property.

Commercial Calculation

The post-development hydrologic balance (Figure 2-3) of the surfaces at the commercial site is determined as follows:

2 acres of green roof: 40% Runoff, 60% ET, 0% Infiltration (from Table 2-2)

2 acres of permeable pavement (with IWS layer): 30% Runoff, 5% ET, 65%

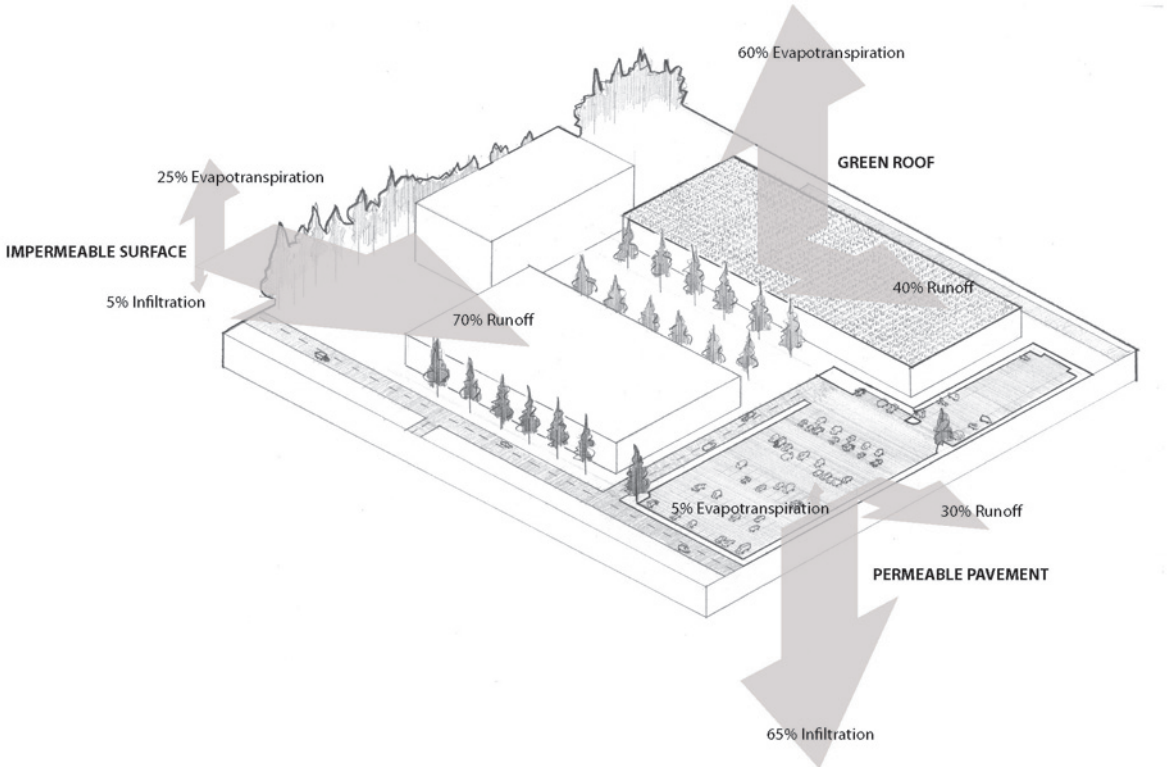


Figure 2-3. Post-development hydrologic balance of hypothetical commercial site

Infiltration (from Table 2-3)
6 acres of impervious surface: 70% Runoff, 25% ET, 5% Infiltration (from Table 2-2)

To estimate the exact percent converted to infiltration or ET (such as with permeable pavement above), either a median value or best professional judgment can be used.

Remember that runoff from the 6 acres of impervious surface is treated by bioretention (Figure 2-4) . To calculate the post-BMP runoff volumes, and assuming that 4 feet of fill media with an IWS layer is used in the bioretention, the runoff that enters the bioretention will be "converted" to 30 percent ET and 30 percent infiltration with only 40 percent of the water entering the bioretention cell, leaving by way of outflow to the storm drainage network.

The calculation of the resulting runoff volume must include the amount that runs off each surface minus the amount treated by a BMP (in this case, bioretention). The calculation of ET percentage is the amount of water to evapotranspire from each surface plus the percentage of ET associated with the BMP. The same is true for infiltration.

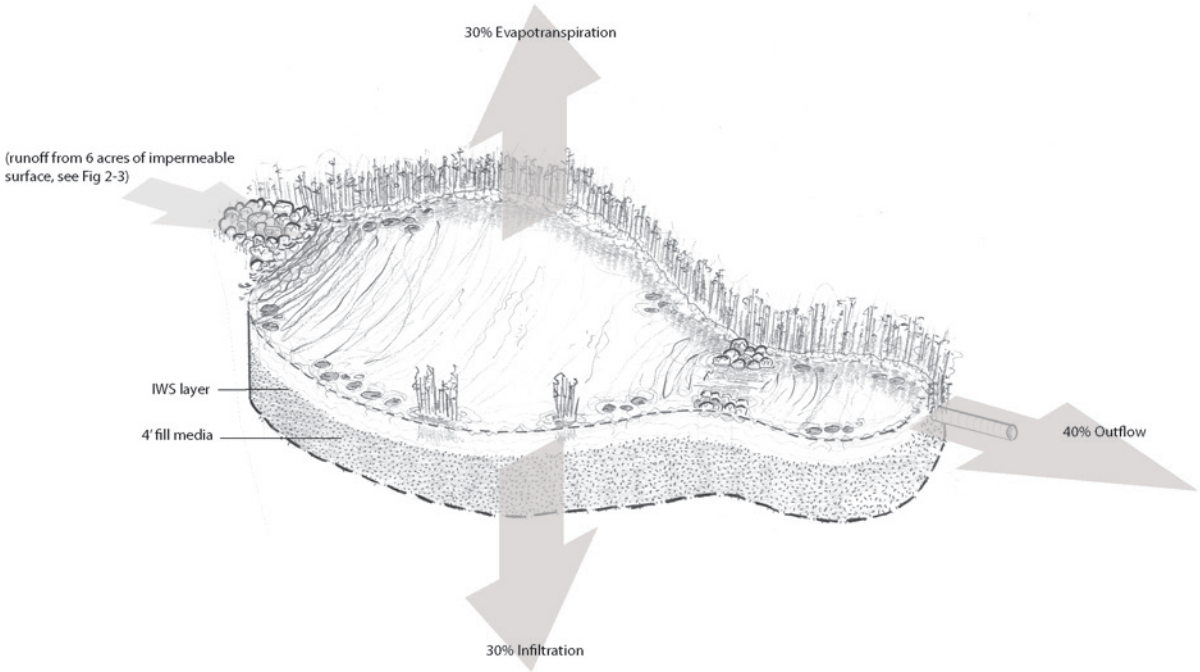


Figure 2-4. Post-development hydrologic balance of commercial site with bioretention

The balance is calculated as follows:
Runoff % = (40% × 2 acres + 30% × 2 acres + 70% × 40% × 6 acres) / 10 acres = 31%
ET % = (60% × 2 ac + 5% × 2 ac + 25% × 6 ac + 30% × 70% × 6 ac) / 10 ac = 41 %
Infiltration % = (0% × 2 ac + 65% × 2 ac + 5% × 6 ac + 30% × 70% × 6 ac) / 10 ac = 29%

Remember that the LID target for the site was 20 percent runoff, 45 percent ET, and 35 percent infiltration. So, while the ET percentage was nearly at the 45 percent goal, the percentage of runoff was too high and the percentage of infiltration was too low (Figure 2-5). Perhaps much of this discrepancy can be accounted for in the residential portion of the development.

Residential Calculation
The post-development hydrologic balance of the surfaces of the residential development is determined as follows:
10 acres of woods: 5% Runoff, 50% ET, 45% Infiltration (Table 2-2)
7.5 acres of impervious surface: 70% Runoff, 25% ET, 5% Infiltration (Table 2-2)
22.5 acres of disturbed lawn: 30% Runoff, 35 % ET, 35% Infiltration (Table 2-2)

The 10 acres of impervious surfaces and 20 acres of disturbed (compacted) lawn drain to bioretention cells first; the treated runoff (and bypassed large storm event volume) is then passed to a stormwater wetland. As a result, a sizeable portion of this runoff can be converted to ET and infiltration.

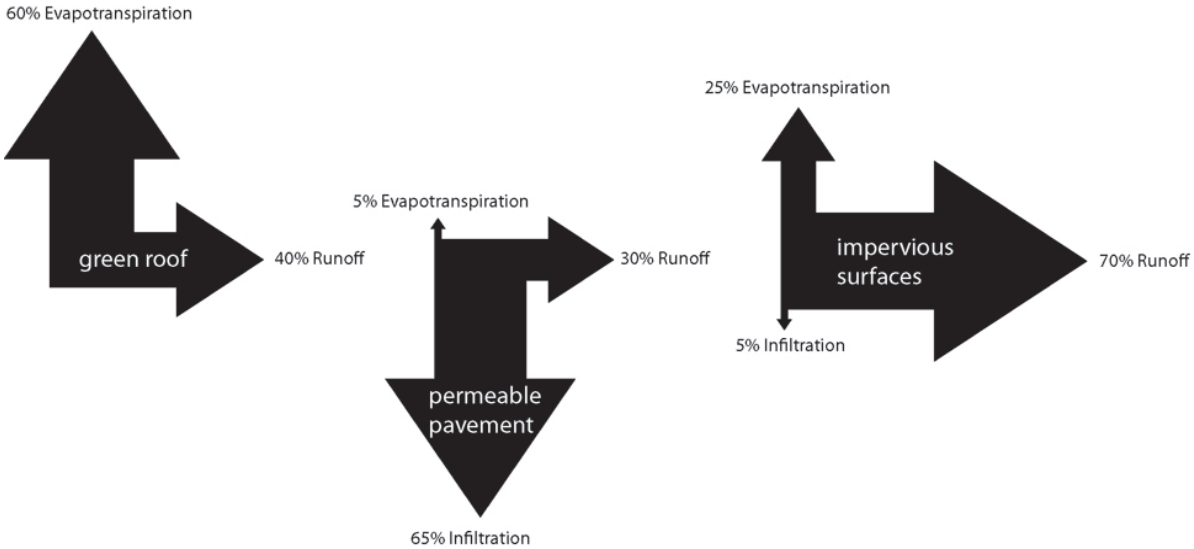


Figure 2-5. Resulting runoff volume of hypothetical commercial site

Bioretention used in the neighborhood is of a typical design. The bioretention cells have 4 feet of media and employ standard underdrains. The amount of ET and infiltration associated with each is 25 percent and 35 percent (Table 2-5). The stormwater wetland has some infiltration at 20 percent and has an ET loss of 20 percent (Table 2-5). Remember that all water that enters the stormwater wetland must overflow or drain from the bioretention cells first. These BMPs, therefore, act in series.

The calculation for each of the hydrologic components for this residential portion is slightly more complicated than was seen for the commercial site. The amount of runoff is determined by knowing what leaves the woods (and goes untreated) and adding to it the water that ran off the impervious surfaces and compacted lawn that does not get converted by either the bioretention cells or the subsequent stormwater wetland. The amount of ET loss is determined by finding the amount of ET associated with each land use, then determining the ET associated with the bioretention cell, ending with the ET that passed through the bioretention into the stormwater wetland. A similar calculation is performed for infiltration loss (Figure 2-6).

The residential hydrologic balance (Figure 2-7) is calculated as follows:
Runoff % = (5% × 10ac + 70% × 40% × 60% × 7.5ac + 30% × 40% × 60% × 22.5ac) / 40 ac = 8.5 %
ET % = (50% × 10ac + 25% × 7.5ac + 35% × 22.5 ac + 25% × 70% × 7.5 ac + 25% × 30% × 22.5ac +20% × 70% ×60% × 7.5ac + 20% × 30% × 60% × 22.5ac) / 40 ac = 46.8 %

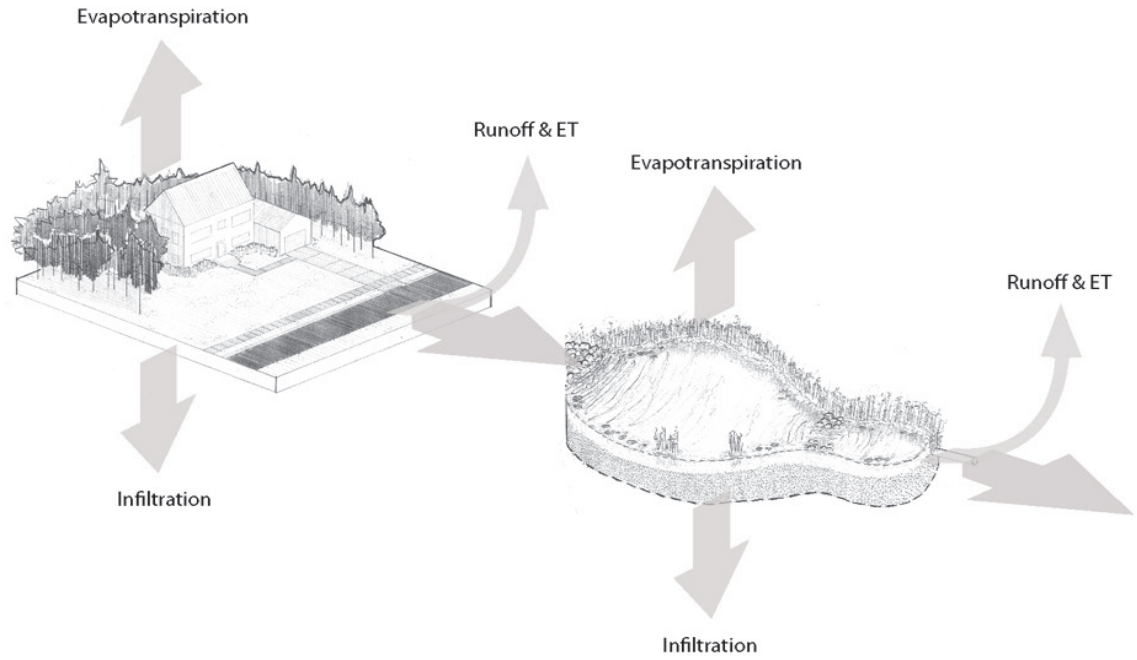
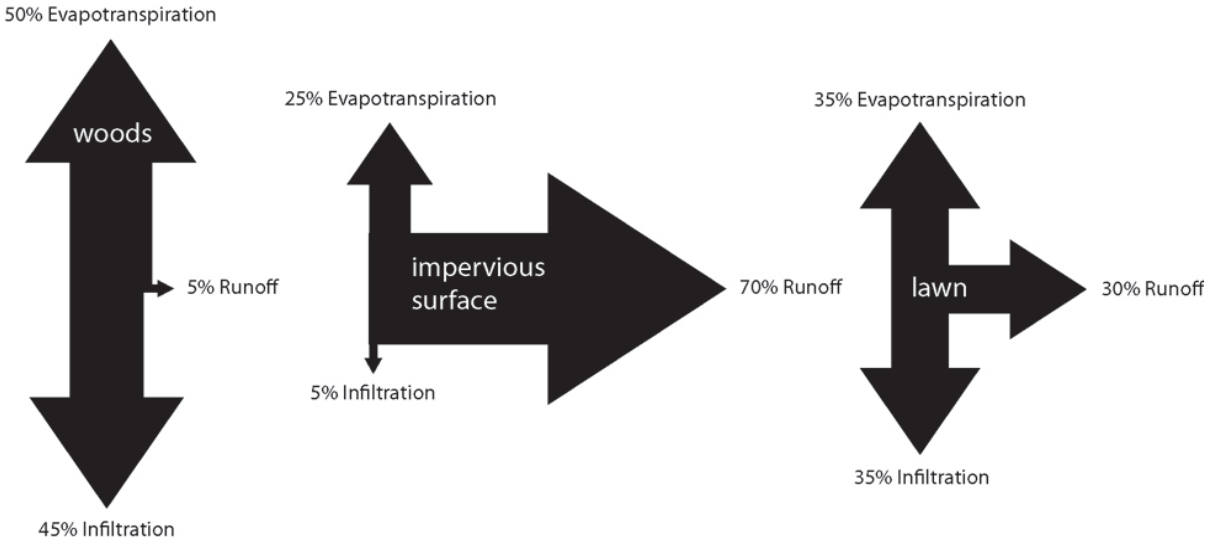


Figure 2-6. Post-development hydrology of hypothetical residential site

Figure 2-7. Resulting runoff volume from residential site



Infiltration % = (45% × 10 ac + 5% × 7.5ac + 35% × 22.5ac + 35% × 70% × 7.5 ac + 35% × 30% × 22.5ac + 5% × 70% × 60% × 7.5 ac + 5% × 30% × 60% × 22.5 ac) / 40 ac = 44.8%

The LID goal of the residential development would be to have no more than 10 percent runoff and be within 5 percent of 50 percent ET, and 45 percent infiltration. In this case the target percentages of runoff, evapotranspiration, and infiltration were all within 5 percent of pre-development conditions. The residential portion of this development met the LID hydrologic criteria.

2.4 Stormwater Models

Various models can be used to determine whether the LID site annual hydrology mimics pre-development (or target) annual hydrology. Several spreadsheet models can accomplish this task, albeit in a somewhat coarse manner similar to that described above. In using a more detailed model such as Storm Water Management Model (SWMM), the amount of infiltration, outflow, and evapotranspiration can be modeled for each individual BMP. It is possible that a simulation model (such as SWMM) will show that more infiltration can be achieved than the amount estimated by the spreadsheet model. It is recommended that some model be used for most of the annual hydrologic calculations. In the future, it is also possible that a national model, such as SWMM or HSPF, will be required for all LID hydrologic analyses.

As a part of this guidebook, a spreadsheet model has been developed to aid in calculating post-development hydrology for a site. The model allows

users to choose their physiographic region and soil type and route runoff through a series of BMPs, then determine the post-development hydrologic percentages. A site may be divided into five land use types, and a portion (or all) of each land use type may be treated with a unique combination of BMPs. This model serves as a tool for the exploration of many different scenarios regarding stormwater routing and treatment and allows for the rapid determination of pre- and post-development hydrology values.

2.5 Related Stormwater Methodologies

The concept of partitioning precipitation to runoff/outflow, infiltration, and evapotranspiration is already being implemented in practice. In 2007, Wake County, North Carolina, adopted a development review process that requires meeting certain curve numbers (USDA-NRCS, 1986) for various land uses (available at www.wakegov.com/departments/erosion.htm). The curve number is a surrogate for the amount of runoff generated annually, but the curve number does not provide a breakdown of infiltration and evapotranspiration.

2.5.1 Potential Surrogates for Annual Hydrology

North Carolina State University is developing a surrogate for annual hydrology using a specified design storm. For example, if an LID site has a hydrograph for a storm (such as a 1-year 24-hour event) that entirely matches that of the pre-developed condition, on an annual basis this development would also have annual hydrology meeting the target amount of runoff, ET, and infiltration. If a relationship like this is shown to exist in the future, determining long-term hydrology may be possible by simply modeling one specific storm event.

Another surrogate for meeting pre-development hydrology may be matching flow duration times associated with a range of storms. That is, if a given storm (such as a 2-year 24-hour event) produced a pre-development base flow discharge time of three days, a low impact development would be designed to release water to the receiving stream network over a similar 3-day period.

REFERENCES

Backstrom, M. 2002. Sediment transport in grassed swales during simulated runoff events. *Water Science and Technology* Vol. 45(7): 41-49.

Backstrom, M. 2003. Grassed swales for stormwater pollution control during rain and snowmelt. *Water Science and Technology* Vol. 48(9): 123-134.

Bean, E. Z., W. F. Hunt, and D. A. Bidelspach. 2007. Evaluation of four permeable pavement sites in Eastern North Carolina for runoff reduction and water quality impacts. *ASCE Journal of Irrigation and Drainage Engineering* Vol. 133(6): 583-592.

Berghage, R. D., D. Beattie, A. R. Jarrett, et al. 2009, Feb. *Green Roofs for Stormwater Runoff Control* (EPA/R/600/R-09/026). Cincinnati, OH: U.S. EPA, National Risk Management Research Laboratory. http://www.epa.gov/nrmrl/pubs/600r09026/600r09026.pdf

Cappiella, K. and K. Brown. 2001. *IC and Land Use in the Chesapeake Bay Watershed*. Ellicott City, MD: Center for Watershed Protection.

Collins, K. A., W. F. Hunt, and J. M. Hathaway. 2008. Hydrologic comparison of four types of permeable pavement and standard asphalt in Eastern North Carolina. *ASCE Journal of Hydrologic Engineering* Vol. 13(12): 1146-1157.

Hathaway, A. M., W. F. Hunt, and G. D. Jennings. 2008. A field study of green roof hydrologic and water quality performance. *Transactions of the ASABE* Vol. 51(1): 37-44.

Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *ASCE Journal of Irrigation and Drainage Engineering* Vol. 132(6): 600-608.

Hunt, W. F., J. T. Smith, S. J. Jadlocki, et al. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *ASCE Journal of Environmental Engineering* (in press).

Jones, M. P. 2008. *Annual Hydrology of a Stormwater Wetland in Eastern and Central North Carolina*. Internal report. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Sharkey, L. J. 2006. *The Performance of Bioretention Areas in North Carolina: A Study of Water Quality, Water Quantity, and Soil Media*. Ph.D. thesis. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Swift, L.W., G. B. Cunningham, and J. E. Douglass. 1987. Climatology and hydrology. In W. T. Swank and D. A. Crossley (eds.), *Forest Hydrology and Ecology at Coweeta* (pp. 35-57). New York, NY: Springer-Verlag.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA–NRCS). 1986. *Urban Hydrology for Small Watersheds* (Technical Release No. 55). Washington, DC: USDA–NRCS.



CHAPTER 3. SITE ASSESSMENT AND DESIGN FOR LOW IMPACT DEVELOPMENT

By Lee-Anne Milburn and Robert McClendon

In contrast to conventional stormwater design, the LID approach emphasizes site design during the planning process. This chapter focuses on site assessment and design for low impact development (LID) and the process recommended for incorporating LID at the master plan and site-level scales. It is divided into four sections: design goals; design objectives; design issues and the application of LID; and the design process. The chapter provides guidance on the design and decision-making processes needed to achieve continuance of the pre-development runoff volume while maximizing appeal to developers, homeowners, and community members.

3.1 Introduction to Site Assessment and Design

The concepts of LID can be applied to design at multiple scales. LID can have a significant impact when implemented on a large scale: it can be integrated into overall regional, municipal, and area planning to identify areas suitable for development and to concentrate appropriate development in those areas. LID is one tool that can help address the impacts of urbanization, sprawl, and development.

LID and comprehensive planning are both integrated and proactive approaches that anticipate a community's future needs. With this guidebook, we intend to help link immediate actions to longer-term community goals. The disciplines of land use planning and design, stormwater design, stormwater management, and LID should be integrated by incorporating LID into local planning and development processes and policies. LID can be integrated into local planning processes at all stages: 1) visioning, 2) goal setting, 3) strategy formation, 4) plan adoption, 5) implementation in terms of regulations and investments, 6) development permit review, and 7) monitoring, evaluation, and adaptation. At each level, communities make choices involving technical activities and community involvement that determine the feasibility and effectiveness of LID activities.

Every site is unique — there is no single LID solution that is appropriate for all sites, terrains, soils, or climates. LID involves an individualized approach to site inventory and analysis that requires assessing all relevant site issues and creating a "site fingerprint," a detailed understanding of how these factors

work together and influence one another. Topography, hydrology, natural features, and other resources all need to be carefully identified and mapped. This is true regardless of the scale at which LID is being implemented in the community, whether it is development of single lots, development of multiple parcels, or community-wide planning. The LID site fingerprint focuses on the environmental conditions, but a comprehensive site assessment would include social, cultural, historical, and economic considerations as well.

The preparation of detailed site assessments, topographic and soil information, and multiple design alternatives with hydrologic analyses is central to the formation of an effective LID strategy. Professionals on the project team should include a landscape architect, a soil scientist, a hydrologist, a civil engineer, and a geotechnical consultant.

The following process is recommended:

1. Project team and local government staff hold pre-consultation meeting
2. Project team and local government staff jointly visit site to identify features that should be included in the site analysis
3. Project team performs site analysis
4. Project team prepares concept plan
5. Local government staff review stormwater concept plan
6. Project team prepares site plan
7. Local government staff review preliminary stormwater site plan
8. Local government staff review final stormwater site plan
9. Project team and local government staff hold pre-construction meeting
10. Local government staff inspect construction
11. Local government staff or other entity inspects site to ensure adequate long-term maintenance of LID features

This review and approvals process for LID is very similar to the process employed for conventional design, but it takes a more proactive approach to review to achieve better development outcomes and more creative solutions while reducing the need for revisions during the approvals process.

3.2 Design Goals

3.2.1 Starting the Project with a Vision and Values

A design goal typically states in one or two sentences the intent, purpose, or overall function of a design. Design goals are conceptual in nature and serve as the "vision statement" for a project. This is an important first step in

the site planning and design process because the design team and developer take the opportunity to express a vision for the project and reach agreement about their goals for the development from the very beginning.

LID-oriented site program goals must consider the hydrologic cycle and the LID practices that best suit the site's natural features while also meeting the client's needs. Goals must be specific to the project, client, context, and site.

Sample goals might include:

- Maximize the number of units per acre while addressing social and environmental concerns;
- Preserve a minimum of 20 percent of wooded areas for stormwater management, air quality, carbon sequestration, and wildlife habitat;
- Create a mixed-use development that balances economic and environmental considerations by incorporating a variety of housing styles and types, commercial development, and recreational amenities such that all are mutually beneficial; or,
- Incorporate open space within a half mile of all residents that also serves for stormwater management, alternative transportation modes, and other uses.

3.2.2 Balancing LID with Other Design Goals

Sustainable community design principles can and should be considered alongside the LID focus on hydrology. This necessitates a consideration of social design issues and human values along with a focus on the natural hydrologic cycle. Although maintaining or improving the hydrologic function of a site is the fundamental theme of LID, other factors are also important to designing a sustainable community.

Sustainability Goal:
Incorporate a balance between LID stormwater management goals and other sustainable design strategies.

LID design can enhance the form and function of stormwater amenities with recreational opportunities. However, it will require consideration of various trade-offs or consequences and the development of innovative solutions. For example, while LID seeks to reduce impervious surfaces as much as possible, eliminating sidewalks negatively affects the livability and social vitality of a neighborhood. Another way of reducing impervious cover is to implement cul-de-sac street configurations, but this design could cut off bicycle routes and isolate neighbors. A balance between LID and other design goals is essential for the creation of livable and sustainable neighborhoods.

It is important to determine goals and objectives for each project and the area's natural resources based on LID principles. These principles provide the most potential for maintaining the environmental quality of the site throughout the development of the project and into occupation.

Base the site design on best practices for hydrology and natural processes for the site. Design the development to suit the site.

3.3 Incorporating LID Design Objectives into Design Strategies - Some Examples

While design goals set the vision for a development (they tell us the outcome we are trying to achieve) specific tools and techniques are needed to translate these ideas into physical reality.

A range of governing principles and suggested strategies relevant to low impact development projects are described in this section. Depending on the site and the project scope, some principles may be more applicable than others. Each project team member or stakeholder should review the LID goals, objectives, and design principles prior to site assessment and determine the vision or values of the project, the motivation for implementation of LID, and the specific issues that should be considered during site assessment and design development. Some generally accepted LID design objectives and strategies for achieving them are provided.

Design impervious areas for the minimum length and width needed to support their intended uses.
This objective can be achieved by matching road widths to traffic volumes and carefully planning emergency and service vehicle access. Reduced road widths will also slow traffic speeds, calming traffic and making streets safer. Narrow roads also reduce the heat-island effects that result from pavement. Adopting alternative street layouts and maximizing the number of homes per unit of impervious cover can reduce pavement lengths. Cul-de-sac designs should be considered to minimize radii and to identify opportunities for alternative layouts, although it is important to consider that such designs may adversely affect accessibility and may increase the need for other connectivity features to maintain accessibility.

Identify opportunities for reduced parking standards (examine for excess parking requirements or possible reductions resulting from mass transit availability or potential shared arrangements). Minimize stall sizes and utilize permeable materials for overflow parking areas when possible.



Figure 3-1. Reduced impervious areas



Figure 3-2. Vegetated areas combined with roadways

Incorporate filter strips, vegetated areas, channels, and curb inlets in roadway rights-of-way, landscaped areas, traffic islands, and islands/roundabouts.

Bioretention areas and other stormwater BMPs are best located in public rights-of-way (Figure 3-2) or commonly held areas to promote long-term maintenance, visibility, and community ownership. This strategy accomplishes both stormwater management and attractive, high-visibility landscape areas. BMPs can be located in almost any area with supportive soils and topography, but consider maintenance and other concerns during the design stage (refer to Chapter 4 for more details).

Modify traditional lot layouts to reduce road frontages and driveway lengths.

Adapting side yard dimensions, modifying architectural designs, and moving buildings closer to the road right-of-way by reducing setbacks can accomplish this objective (Figure 3-3). This technique has the additional benefit of redistributing open space to the rear yard, where open space, natural vegetation, and recreational amenities can be consolidated to maximize community and environmental benefits. For example, common open space can provide community gardens or wildlife habitat for species that would not be able to survive in smaller natural areas.

Carefully locate and design sidewalks to maximize community benefits from impervious surfaces.

Find out the primary destinations of sidewalk users, and identify opportunities to create sidewalks on only one side. For example, if there is a nearby elementary school, a sidewalk can be located on the side of the road most closely associated with the school. Alternatively, a slightly wider sidewalk may allow for multiple uses. Sidewalks adjacent to the road may not always be the most pleasant, safe, and efficient location for pedestrian movement.

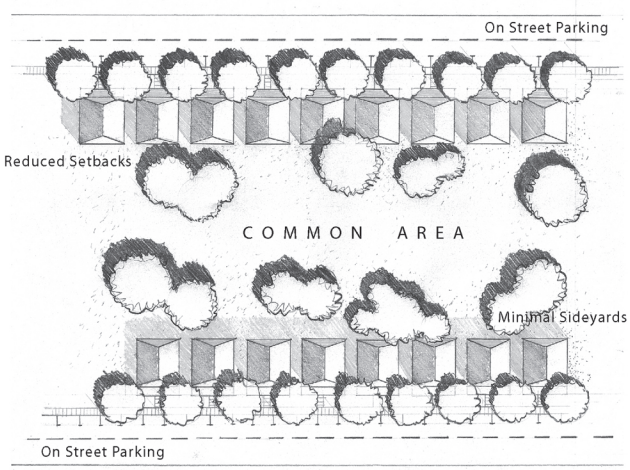


Figure 3-3. Non-traditional lot layouts

Substitute pervious for impervious materials where possible.
Alternative surfaces for parking lanes, overflow parking, driveways, walkways (Figure 3-4), and patios can have significant impact on overall runoff volumes so long as they are protected from sediments in runoff and properly maintained. Pervious variations of asphalt (Figure 3-5) and concrete are available, and brick, stone, granular surfaces, and others are all viable alternatives to be considered based on site and use conditions (refer to Chapter 4 for more details).



Figure 3-4. Reduced sidewalk imperviousness

Direct rooftop runoff onto pervious surface areas, such as turf or vegetated areas, or into cistern systems.
By directing rooftop runoff onto vegetated areas or cisterns, you can direct the water to areas where it will be useful rather than where it may cause harm or overload pipe systems. Gutter systems can collect roof runoff and control flow direction without compromising foundations or other manmade features with directional downspouts (Figure 3-6).



Figure 3-5. Pervious surfaces

Limit site disturbance, clearing, and grading to the smallest areas necessary for that particular phase of development.
This objective offers multiple benefits: it can reduce development costs through use of smaller equipment and less clearing/grubbing/waste; it preserves important vegetation and site features; it prevents erosion, reduces soil compaction, and minimizes habitat loss, resulting in desirable, leafy neighborhoods. Disturbed areas can be reduced in size by strategically planning development to use roadways, future impervious areas, and building footprints for construction access and parking. Where possible, identify areas of past disturbance for these areas, and preserve the best (most intact) soils and most densely vegetated areas for their infiltration abilities. Locate roads and driveways so they follow the



Figure 3-6. Rooftop runoff directed to landscape areas



Figure 3-7. Work with existing topography to limit site disturbance (Seattle, Oregon)



Figure 3-8. Natural features as stormwater, environmental, and human amenities



Figure 3-9. People prefer natural areas

natural contours of the land, reducing cutting and filling (Figure 3-7).

Take advantage of existing waterways, vegetated areas, and amenable soil conditions to direct, absorb, clean, recharge, or store water; reduce air pollution; provide wildlife habitat; and add natural amenity value to a development. Existing amenities such as low areas can provide retention and reduce cut-and-fill costs. Areas of higher elevation can be used to promote infiltration and begin the treatment train process (Figure 3-8). Areas of established high-quality vegetation can prevent erosion, meet aesthetic goals, provide wildlife habitat, and promote evapotranspiration (Figure 3-9).

Use preservation techniques to gain more benefits (both environmental and economic) than are possible from creation or mitigation techniques. Many people prefer communities that are walkable and perceived as "natural." The amenities found on the land in its natural condition are usually those that are the most suitable to that parcel. Rather than trying to create (or re-create) amenities, identify amenities that exist or are compatible with existing conditions through vegetative patterns, topography, or cultural landscapes. Walking is the single most requested amenity in communities—take advantage of preserved vegetated areas, linear stormwater systems, and difficult topographic areas to create human amenity opportunities which reinforce and support open space preservation and maintenance of vegetated areas. A naturally occurring pond is preferred to a big, concrete fountain. Dual value can be received from LID practices, if they are properly located and effectively designed.

Design for ease of maintenance and to minimize maintenance complexity, frequency, and cost.
This requires recognition of homeowner, municipal, county, and state maintenance protocols, and ascertaining the level of maintenance likely to be performed and equipment likely to be available into the future. LID vegetation poses a significant challenge for maintenance. Developing a planting plan for an LID project is similar to other landscape plans—investing in a high-quality planting plan will assure that the designer is mindful of potential maintenance issues such as aggressive or fast-growing plants and nuisance species while judiciously selecting plants for aesthetics, ease of care, and ability to attract birds and butterflies. Native and well-adapted vegetation provide a basis for minimal long-term maintenance, as they require minimal irrigation and no fertilization and perform multiple functions such as aesthetics and evapotranspiration. Note that natives should be carefully used; not all natives are low maintenance or well adapted. Like all plants, native plantings have to be carefully selected to match site conditions. Some online resources for identifying native plants include www.ncsu.edu/goingnative and www.bae.ncsu.edu/stormwater (specifically on plants for bioretention and wetlands).

Design for hydrology.
Designing a site plan to use water as an amenity and a resource is important for long-term sustainability. Attempt to do the following:

- Identify and preserve sensitive areas that contribute to effective hydrologic cycling (such as areas with quality soils or mature vegetation).
- Maintain existing areas of bioretention such as streams and creeks, and preserve paths of flow, such as natural swales or ditches, which direct water to outflows (Figure 3-10).
- Disperse rather than concentrate water to promote infiltration. Where water occurs, design to enhance it so it is a desirable landscape component that landowners will take pride in and preserve. For example, pipes could be replaced with vegetated swales, or decorative scuppers can be placed on downspouts.

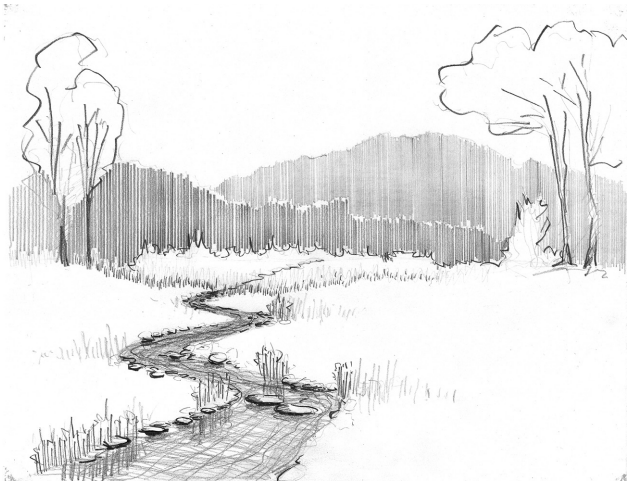


Figure 3-10. Natural waterways manage flow

Design for multiple functions.
Single-function design solutions lead to waste and duplicative investments in our communities. Developing a site requires a significant financial investment. By

purposefully designing areas to serve multiple functions, clients can receive added advantages from their endeavors. Thus, areas designed for environmental benefits, such as meeting stormwater requirements, could also offer aesthetic or community benefits, such as recreation and alternative transportation access. Vegetated areas can be designed for wildlife habitat, infiltration, pollution removal, and stormwater storage. Stormwater management areas can also provide water for irrigation.

Manage development impacts at the source (or as close to it as possible).
Achieving this objective involves a two-step process: first skillfully working with the site's topography to minimize cut and fill; limiting the use of conveyances and minimizing the use of discrete or underground systems; and then integrating solutions on the site. Additionally, revegetating on or near the site is a way to help replicate pre-development vegetation levels.

Disconnect impervious areas.
When impervious areas are connected, water is directed from one impervious area to the next until it reaches a conveyance (pipe) system, which eliminates opportunities for infiltration and evapotranspiration. Impervious areas should instead be disconnected so that flows are redistributed into smaller volumes and directed to a series of pervious areas, which each address a portion of the volume (Figure 3-11).

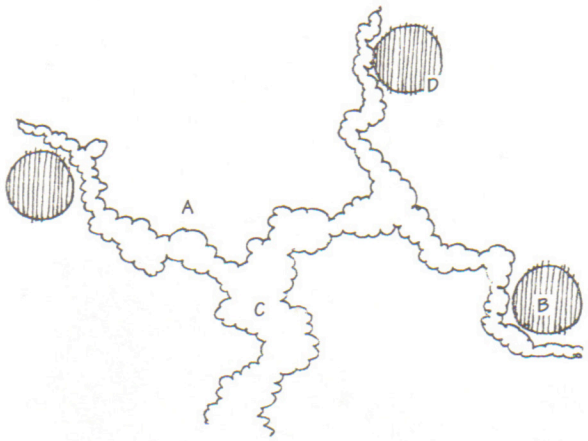
Work with the site's soil conditions strategically.
Limit clearing and grading and impervious areas around permeable soils to prevent compaction and maintain infiltration function. Protect existing undisturbed soil areas as much as feasible. Locate impervious areas in less permeable soil areas so that less infiltration capacity is lost to development. See Chapter 6 for information on repairing soils that have been compacted after construction is completed.



Figure 3-11. Disconnected impervious surfaces

Consolidate natural open space areas whenever possible.
One objective of LID is to disconnect impervious areas, and a related objective is to connect pervious areas. Linking open spaces such as wooded areas allows you to create hydrologic systems that are superior to disconnected best management practices. These linked areas also help preserve existing waterway systems and create safe, aesthetically pleasing recreational amenities. The natural open space systems can include undisturbed or undeveloped natural areas, as well as grassy

Figure 3-12. Create open space systems



sports fields, former pastures, or agricultural fields. These areas also provide habitat for birds and butterflies, movement of seeds from location to location, and support for healthy vegetative communities (Figure 3-12).

Consider alternative architectural designs to reduce building footprints and to adapt layout to site conditions such as topography.
Variable floor elevations, pier construction, walkout basements, or multi-floor buildings are different options to reduce the environmental impact of building construction (Figure 3-13). Take advantage of the opportunities enabled by passive solar orientation. Building footprints and locations are critical; explore opportunities for high floor-area ratios and mixed-use development.

3.4 Design Issues and the Application of LID

Good design and the application of LID can sometimes conflict. This section identifies the common problems with LID design and proposes a range of design alternatives to address them. The following examples are challenges where a balance between environmental, economic, and social considerations was more difficult to achieve. This balance is specific to each site; there is no single correct answer for all site problems. Rather, it is a matter of weighing the relative costs and benefits of a range of alternatives and determining the best possible path for a given situation. For additional information, see USEPA (2005), *Using Smart Growth Techniques as Stormwater Best Management Practices*.

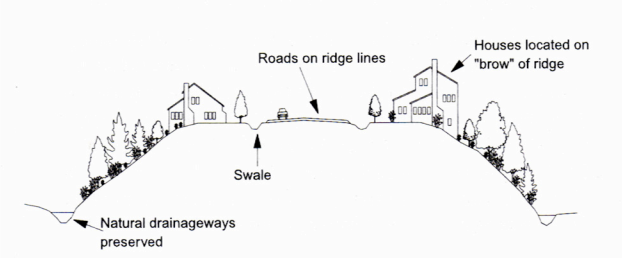
3.4.1 Circulation Design

Certain circulation designs generally have less impervious surface than others. For example, cul-de-sacs often have less pavement than New Urbanist grid patterns (Williams, 2005), and curvilinear patterns can most easily follow topographic changes. However, these types of street designs may lessen connectivity and walkability, and they tend to increase vehicle miles traveled and vehicle emissions.



Figure 3-13. Alternative architectural designs

Figure 3-14. Location of roads (Prince George's County, 2000)



The challenge is to create a sense of community and an efficient transportation network while minimizing impervious surfaces. Some solutions include lengthening street blocks to reduce the number of cross streets, narrowing lot frontages, clustering homes, and replacing conventional intersections with traffic circles and rain gardens. Other solutions include alleys, queuing streets, and open-section streets.

Roads are best placed on ridgelines, stable soils, and areas where large amounts of cut and fill are not necessary because the road can follow the natural topography (Figure 3-14). Entrances to roads should be sited at the high point of ingress to minimize disturbances. Grading should be designed to provide cross-slope drainage which switches sides, or valley drainage (which eliminates the need for pipes, as the road becomes the pipe). Replace curb and gutter with an apron to allow sheet flow. Reduce the road width to the minimum necessary to meet the needs of emergency vehicles, and consider permeable pavements such as porous concrete and asphalt, brick and sand, paving block, cobbles, or gravel for low-traffic areas.

3.4.2 Sidewalks and Bike Lanes

Sidewalks and bike lanes are a significant and sometimes controversial challenge for LID because they can add up to a large amount of impervious cover, but they are important to residents for transportation and play. Sidewalks and bike lanes may be necessary along a street in high-traffic areas. However, sidewalks should be located according to the most efficient pedestrian routes and to ensure the safety of pedestrians, especially children and other vulnerable populations. If sidewalks can be provided on only one side, the project team should place sidewalks on the side that will serve the greatest number of people. Consider proximity to schools and parks to determine the most appropriate side of the street.

Similarly, sidewalk width is an important concern. To reduce excessive impervious cover, design the sidewalk to be the minimum width necessary to provide for multipurpose use.

Locate sidewalks to cluster open space uses such as street trees and stormwater management. Locate and slope sidewalks to direct water to swales. Sidewalks can weave throughout the landscape—they do not have to run strictly parallel to the street. Provide street trees adjacent to sidewalks to

reduce reflected heat and to create a sense of safety for pedestrians.

A range of options for bicycle traffic should be considered, including using bike lanes for traffic calming (as a tool to narrow the road), and on parallel, less heavily trafficked streets, where road widths can more easily accommodate a bike lane without additional paved surfaces. Take advantage of shared-use paths or parking areas to include bike lanes and encourage alternate forms of transportation (Figure 3-15).



Figure 3-15. Location of shared-use bike paths

3.4.3 Parking Design

Traditional parking standards create a significant amount of impervious surface. This surface area can be reduced by the limiting the number of parking spaces, reducing the size of each space, changing the orientation of parking spaces (Figure 3-16), placing parking beneath buildings, and using multistory parking garages. Well-designed parking can perform other functions including overflow parking, stormwater management, and aesthetic benefits by providing vegetation in otherwise built urban landscapes.

Shared parking arrangements can also significantly reduce parking requirements. For example, churches and schools have complementary schedules (daytimes versus evenings and weekends), so one parking lot could meet the needs of both sets of users, reducing the number of parking spaces that are empty at a given time. In residential areas, shared driveways and drive strips can also reduce impervious surface.



Figure 3-16. Design of parking

3.4.4 Aesthetic Design

LID practices are more likely to survive changes in land ownership and be maintained by adjacent homeowners or local governments if they are aesthetically appealing. Appeal can be maximized by using flowering plants, framing views to dwellings or amenities, framing natural plantings by maintaining





Figure 3-17a and b. Aesthetic strategies improve LID longevity

edges, and providing cues to prompt regular care, such as bird houses, fences, or signage. Stormwater areas can become visual amenities with artful rainwater design, attractive furnishings such as scuppers and rain chains, and planting buffers and swales.

3.4.5 Addressing Surrounding Land Uses

Site-specific stormwater management controls must be designed within the context of neighborhood catchment areas or sub-basins. Surrounding land uses inform the placement of site program features. For example:

- Adjacent areas of vegetation and open space should be expanded or connected with those on the site to form larger contiguous areas for habitat and stormwater mitigation.
- Existing roads suitable for site access can reduce the need for additional roads.
- Adjacent neighborhood streets, sidewalks, or paths should be connected to promote pedestrian use and community integration.
- Natural hydrologic flow paths to and from adjacent properties should be maintained in the LID site design.

3.5 Considerations for Community and Site Design

3.5.1 Community Design: Choosing the Right Community for the Site

An urban infill neighborhood or residence will probably have a different style and look than a suburban or rural neighborhood development. A new neighborhood planned for a historic coastal fishing village should have a different character than a golf course community in the piedmont. Determining character of the development by aligning the highest and best economic use within the constraints of the land is a fundamental task when planning an LID community.

The character or style of the area should dictate details such as front yard setbacks, rear service alleys, sidewalks, nature trails, parking, road widths,

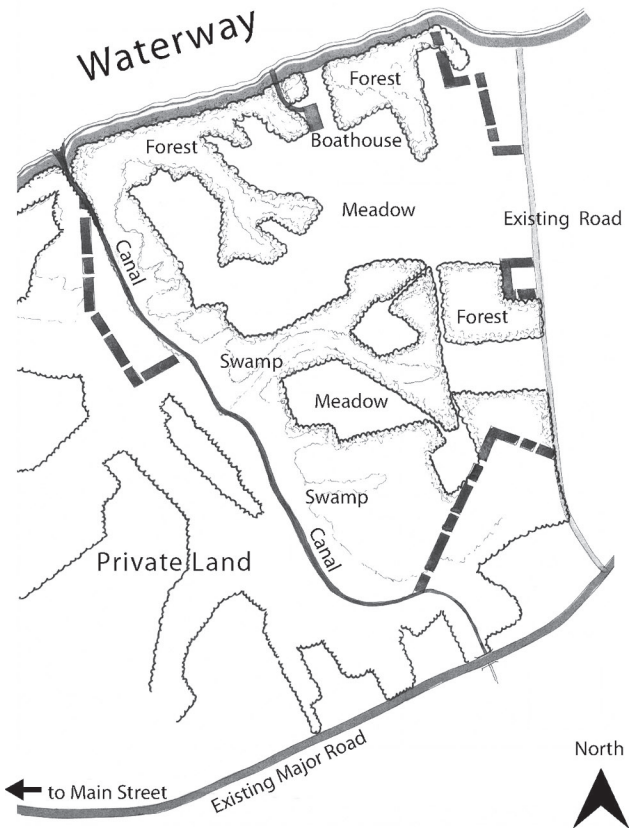
square footage, and lot coverage. LID practices should consider larger design issues. A detailed and consistent vision for the development will make the selection simpler and more self-evident.

The capacity of the land to support infiltration and evapotranspiration is a determining factor in LID. Since the desired character of a development will be the basis for many LID decisions, it is best to understand the site and context and work with the natural processes already in place.

3.5.2 Site Design – Creating the Right Fit

Based on site characteristics such as hydrology, natural vegetation, soils and topography—and of course, context—an appropriate type of development for a particular site should be determined by the project team (Figure 3-18). Any and all opportunities to reduce site impacts and maximize benefits should be identified. These include alternative lot layouts, architectural designs, and relationships between structures and the road. Landscape designs address driveway width and location, pathway and patio design, disconnecting impervious areas, working with stormwater, and highlighting site amenities. The location of stormwater best management practices needs to be carefully considered in order to anticipate and address potential problems with maintenance. Consider rear lot lines, side yards, and front lot lines. Also consider locating BMPs in public rights-of-way such as along property lines, traffic circles, and roadside swales.

Figure 3-18. Surrounding land uses inform the placement of site features



3.6 The Design Process: How to Do It

The LID design process includes the following:

- Set project goals and objectives and identify the program.
- Inventory, assess, and analyze the site.
- Review and revise the program based on site constraints.
- Develop proposals and evaluate.
- Revise and model.

- Revise and remodel.
- Apply regulatory requirements.
- Model stormwater.
- Revise and remodel.

1. Determine preliminary project goals (principles and values) and objectives (set project parameters and program)

Answer the following questions:

- What are the goals of the project, in priority order?
- What is the project program? What do we need to put on the site? What is optional?
- What are the available resources and expertise that can be applied to the project?

The project goals and objectives should consider not only development characteristics and stormwater goals, but also human considerations (what quality does this place need to have?). This should include requirements for built structures and wastewater and stormwater treatment.

2. Perform a site inventory and assessment (look closely at the site)

Identify the key physical and cultural factors that are required by the program. Analyze and map the key factors. These should include:

- topography
- drainage patterns and systems including existing waterways and stormwater facilities
- soils
- ground cover and vegetation
- existing development and land uses, including adjacent areas
- required protection areas such as wells

Natural features, which need to be identified and mapped, include:

- wetlands
- critical habitat areas
- boundaries of wooded areas or areas of sensitive or important vegetation
- floodplain boundaries
- site topography including steep slopes
- required buffers from adjacent or on-site land uses
- stream systems and other water areas

Analyze site features and characteristics in light of the project goals and parameters. These goals will determine what takes precedence in the site assessment. Generally, for LID projects, the priorities are:

1. topography
2. soils
3. hydrology

4. vegetation and habitat
5. surrounding land uses
6. zoning
7. access
8. utility availability

Ensure natural resources are evaluated for rarity and naturalness; diversity and pattern; size and shape; location; and relationship to other resources. Watch for potential problems such as low infiltration soils (clayey), seasonal high water table, and steep slopes.

3. Site analysis (matching the program to the site)

Identify the opportunities and constraints inherent in the natural and cultural characteristics of the site. Match the program to the site assessment: are there better places for some things than others? Are there unique site opportunities that should be maximized or at least considered (such as views or historic structures)? The site analysis should:

- Result in a map that establishes the proposed limits of disturbance and delineates resource protection areas;
- Involve the project team walking the property to ensure that all the key participants agree on project priorities and their implications for development, including site constraints and features to be preserved; and,
- Analyze the site for its capacity to handle the program—can it do what is needed without major reshaping?

4. Reassess project goals and objectives (how should the program change in light of the site constraints and opportunities?)

The site inventory, assessment, and analysis may have identified a development envelope that is too small to support the scope of the program initially proposed because

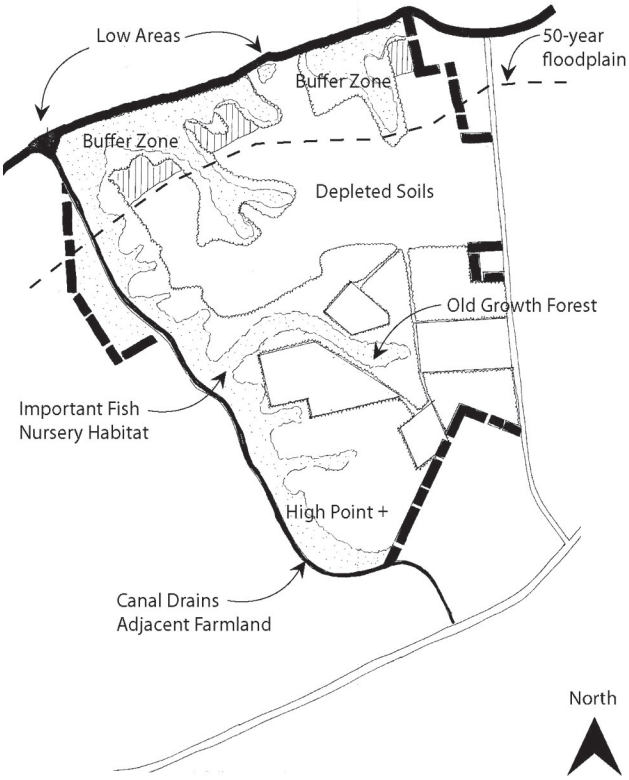


Figure 3-19. Identify and map natural features

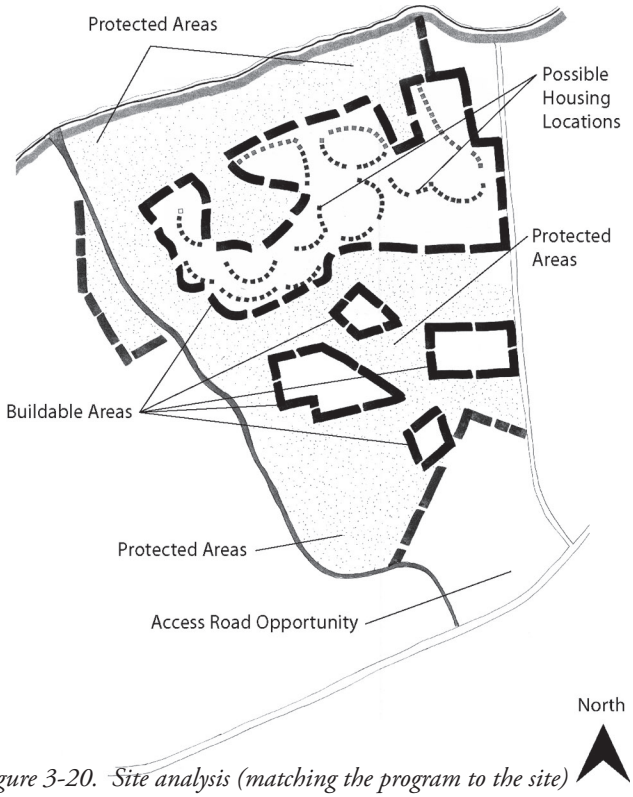


Figure 3-20. Site analysis (matching the program to the site)

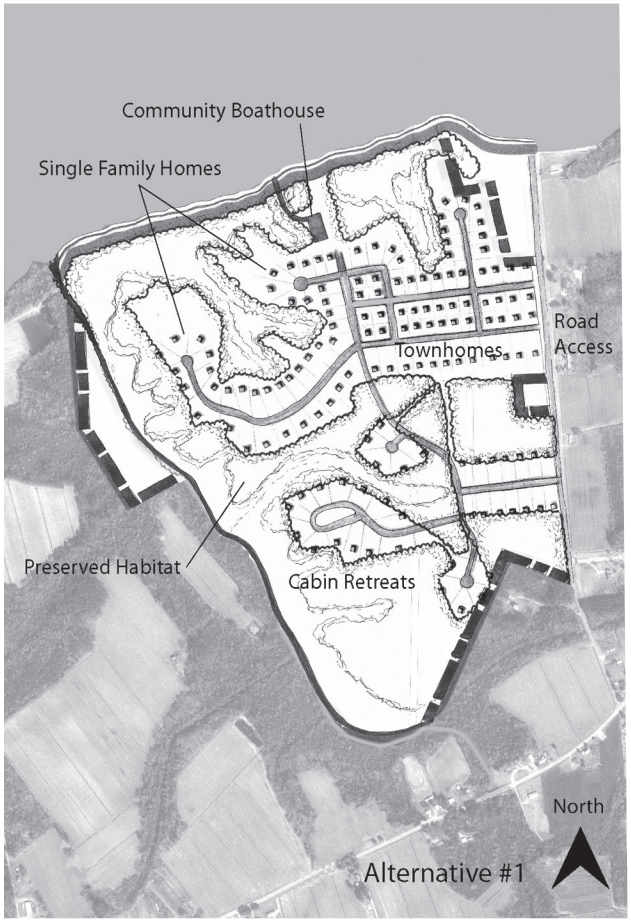


Figure 3-21. Develop alternative design scenarios

of environmental or cultural conditions. Opportunities to support additional density on a site should be explored.

5. Develop alternative design scenarios (schematics)
Multiple design scenarios should be developed to account for the range of factors that can influence LID in a flexible fashion. For example, study different development layouts that emphasize different considerations, such as minimizing impervious areas, preserving existing vegetation, and preserving existing site topography.

6. Evaluate the alternatives based on the site analysis and project goals and objectives
Identify which design best meets the project goals and the design guidelines. This will be a matter of balancing conflicting demands and will require prioritization of some objectives over others. For example, you may be able to reduce impervious surface, but it may require significant cutting and filling, resulting in the loss of more existing vegetation, whereas with a little more impervious surface, you could save the vegetation. Which alternative do you pick? Return to your analysis and program and make the best decision based on long-term implications and community benefits.

7. Apply specific construction and ordinance requirements
Resolve the key details of your design. Match these to regulatory requirements, or identify preferred or recommended characteristics that are worth discussing with state and local approval bodies to identify opportunities for variances. Identify which ordinances to conform to, and which to challenge.

8. Design draft stormwater management practices to treat runoff and maintain the hydrologic regime and model their effectiveness
See Chapter 2 for the process for modeling your design. Have the local government or other permitting agencies review your initial designs for compliance and achievement of best practices.

9. Modify the design to develop final plan

The process of modeling will highlight areas or aspects that are causing problems with stormwater management. Modify the design to address these issues, and perform the modeling process again. When you are getting close to resolving the issues, check with the local government or regional water quality office to review your designs for compliance and achievement of best management practices.

Barriers to LID are likely, but a proactive process with a high level of communication between local government staff and the applicant can often overcome these obstacles. Delays in the plan approval process can be avoided by working proactively with local planners to explain the project goals and objectives early. Local governments are eager to learn more about LID and are usually willing to work with developers to build communities that reduce environmental impacts.

Figure 3-22. Site design checklist

SITE DESIGN CHECKLIST

Start big! Consider the entire site and surroundings and guiding principles, and then work your way down to the lot level. Finish with materials and design specifications.

1. All impervious areas are designed with the minimum required paved area length and width needed to support their intended uses.

- Road widths are matched to traffic volumes.
- Reduced parking standards are adopted if possible.
- Emergency and service vehicle access are designed to reduce duplication.
- Alternative street layouts are used to reduce road length.
- Number of homes per unit of paved area is maximized.
- Parking space size is minimized, including stall sizes.
- Alternative (permeable) materials for overflow parking areas are used where possible.

2. Alternative practices are used where possible to address street, sidewalk, and driveway stormwater.

- Bioretention areas are located in public rights-of-way or immediately adjacent to roadways.
- Bike lanes are made of permeable pavement.
- Vegetated swales replace curb and gutter.

3. Non-traditional lot layouts are used where possible to reduce road frontages and driveway lengths.

4. Sidewalks are located and designed to accrue maximum benefits from the impervious surface.

- Sidewalks are located to address primary destinations.
- Opportunities for single-sided sidewalk provision are identified, supportable, and implemented.
- Permeable pavement is considered.

5. Pervious materials are used where possible.

6. Rooftop runoff is captured and directed away from impervious areas or conveyance systems and onto surface pervious areas such as turf or vegetated areas (including rain gardens) or captured in cisterns or rain barrels for reuse.

7. Site disturbance, clearing, and grading are limited to the smallest areas necessary.

- Development is planned to use roadways, future impervious areas, and building footprints for construction access and parking.
- Best soils and most densely vegetated areas are preserved for infiltration.
- Roads and driveways are sited so they follow the natural contours of the land, reducing the amount of cut and fill required.

8. Natural systems are used to minimize development impacts.

- Existing waterways, vegetated areas, and amenable soils are used to direct, absorb, clean, recharge, or store water.
- Opportunities to reduce air pollution, provide wildlife habitat, and add natural amenity value to a development have been recognized and adopted.
- Low areas are used to provide retention.
- Cut and fill is minimized and opportunities provided by existing topography are maximized.
- Relatively high areas on the site (areas of higher topography such as hills or ridges) are identified. Use them as the starting point for infiltration by locating features relatively high and allowing space for infiltration (both structural and non-structural BMPs) at lower elevations. These areas of higher elevation will promote infiltration and begin the treatment train process.
- Areas of established high-quality vegetation are preserved.

9. Opportunities to preserve site resources are maximized.

- Natural resources such as vegetated areas, waterways, topography, and cultural resources are preserved.
- Opportunities to create areas for recreation and alternative forms of locomotion (such as walking and cycling) are recognized.

10. The design is easy to maintain and minimizes maintenance complexity, frequency, and cost.

- Information on future maintenance responsibilities is provided.
- Information on appropriate maintenance protocols and intervals is provided.
- The level of maintenance and equipment that will be available is accommodated.
- Potential maintenance complications such as invasive or fruiting species are recognized and solutions are provided.
- Plants require minimal pruning, but provide sufficient coverage to reduce weeding needs.
- Native and well-adapted vegetation are used when appropriate.
- Maintenance matches landscape needs.

11. Hydrologic opportunities are maximized.

- Sensitive areas that contribute to effective hydrological cycling (such as areas of quality soils or mature vegetation) are identified and preserved.
- Existing areas of hydrologic function such as local streams, creeks, and wetlands are maintained.
- Paths of flow, such as natural draws, swales, or ditches, which direct water to outflows are preserved.
- Water is dispersed rather than concentrated to promote infiltration.
- The use of water as a desirable landscape component is recognized.
- Impervious surfaces are disconnected by directing runoff to vegetated areas or cisterns.

12. Design features and systems address multiple functions.

- Areas with primary cultural function are maximized for environmental benefit.
- Areas with primary environmental function are maximized for cultural and economic benefits.
- All areas are maximized for recreational benefits, to enhance walkability, and for aesthetic character.
- Vegetated areas address wildlife habitat, infiltration, pollution removal, and stormwater storage.
- Stormwater capture and treatment areas provide sources of water for other purposes when possible.

13. Development impacts are managed at the source (or as close to it as possible).

- The use of engineered conveyance systems is limited.
- Discrete, very large, or underground systems are avoided to the greatest extent possible.
- Cut and fill is limited.
- The site is revegetated to replicate pre-development vegetation levels.

14. Impervious areas are disconnected.

- Rainwater is directed from impervious areas to pervious areas.
- Avoid linking multiple impervious areas together.

15. Site soil conditions are treated as a key factor in design.

- Clearing and grading and impervious areas are located in areas of less permeable soils.
- Areas of permeable soils are preserved from construction and development.

16. Open space areas are consolidated and connected to create open space systems rather than unconnected islands.

17. Alternative architectural designs are used to reduce building footprints or to adapt layout to site conditions such as topography.

Figure 3-23. Site design submission package

SITE DESIGN SUBMISSION PACKAGE

It is recommended that a concept plan be submitted to the local government for review after the site assessment is complete and before submission of the design to get feedback prior to investing in costly detailed modeling.

The following should be included in the package submitted to local government staff for review (partially adapted from the Georgia Stormwater Management Manual (Atlanta Regional Commission, 2001)). The Georgia manual recommends to the local government in Chapter 20 that these components be requested of the developer.

- Preliminary site plan
- Site topography (existing and proposed with minimum two-foot contour interval). In coastal areas, a one-foot contour interval is recommended.
- All perennial and intermittent streams and other surface water features
- Existing stormwater conveyances and structural control facilities
- Direction of flow and exits from the site
- Analysis of runoff provided by off-site areas upstream of the project site
- Site vegetation (existing and proposed), including limits of clearing and grading
- Soils information with sufficient geotechnical information to determine infiltration capacity
- Existing and proposed on-site and adjacent structures
- Existing and proposed on-site and adjacent wells and septic fields
- Floodplains and any existing flooding areas on and adjacent to the site
- Wetlands and sensitive environmental areas
- Existing and proposed drainage areas
- Proposed site plan or lot layout
- Type, size, and location of BMPs
- Type, size, and location of conveyance and conventional stormwater management facilities, outfall location, and others
- Method, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology

In addition, the following are required to document proposed post-development requirements:

- Total area of post-development impervious surfaces and other land cover areas
- Unified stormwater sizing criteria runoff calculations for water quality, channel protection, overbank flooding projection, and extreme flood protection
- Location and boundaries of proposed natural feature protection areas
- Documentation and calculations for any applicable site design credits
- The pre-development (or target) water balance (including annual runoff, infiltration, and evapotranspiration volumes or percentages)

- The post-development water balance (annual runoff, infiltration, and evapotranspiration volumes or percentages)
- The allowable tolerance range for the post-development water balance
- All BMPs listed in the NCDENR manual that meet the "major design elements"

In addition, the following are required to document proposed landscape improvements:

- Arrangement of planted areas, natural areas, and other landscaped features
- Information necessary to construct the landscaping elements shown on the plan drawings
- Descriptions and standards for the methods, materials, and vegetation that are to be used in construction

In addition, the following are required to document maintenance implications:

- Description of maintenance tasks, responsible parties for maintenance, frequency of maintenance, funding, access, and safety issues

Don't forget to review:

- Estimates of stormwater sizing criteria requirements
- Identification and calculation of stormwater site design credits
- Selection and location of structural stormwater controls
- Location of non-structural controls
- Location of existing and proposed conveyance systems
- Flow paths
- Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings
- Existing conditions hydrologic analysis for runoff rates, volumes, and velocities, showing methods used and supporting calculations
- Proposed conditions hydrologic analysis for runoff rates, volumes, and velocities, showing methods used and supporting calculations

The final submission should also include:

- Applicable construction specifications
- Sequence of construction
- Maintenance plan
- Evidence of acquisition of applicable permits
- Evidence of acquisition of necessary legal agreements
- Waiver requests
- Development phasing or implementation sequence

Depending on comments from local government reviewers, the site plan and associated BMPs may need to be revised.

Site Design Evaluation Criteria:

- Where are the resources on the site (waterways, wetlands, drinking water sources, buffers)?
- Is the design laid out to minimize impacts to water resources and buffers?
- Are natural drainage ways preserved as much as possible? Natural drainage ways are often synonymous with groundwater recharge zones.
- Are grading and filling minimized as much as possible?
- Does the design allow impervious surfaces to be minimized or disconnected? (Is runoff from short driveways or other minimized parking areas directed to landscaped areas?)
- Are driveways graded to drain to landscaped areas instead of the street?
- Does the design retain a percentage of high-value undisturbed open space, or is open space confined to non-developable, low-value land (such as steep slopes)?
- Are creeks and waterways buffered (no development within 50 feet of vegetation on either side of the top of bank)?
- Is there a plan for phased development and clearing to minimize soil disturbance?
- Can vegetated or landscaped swales be used instead of curb and gutter?
- Have bioretention or infiltration features (rain gardens) been incorporated into the landscaping plan?
- Are the above features protected from construction sedimentation (through construction sequencing or location of BMPs)?
- Have pervious alternatives been considered for low-traffic paved areas (such as gravel, pavers, porous pavement, grassed parking)?
- Are roof drainage downspouts directed to turf or landscaped areas?

Pavement Evaluation Criteria:

- Is all of the pavement necessary? Can there be fewer sidewalks, sidewalks only on one side of the street, shorter driveways, or narrower streets?
- Can alternative paving materials be used for at least some of the pavement (in parking turnout areas, RV, and overflow parking areas)?
- Has space for infiltration been incorporated into cul-de-sacs and roundabouts? (Can they be graded to drain to a central bioretention feature?)
- Does the parking lot incorporate pervious pavement for rarely used spaces?

Bioretention Evaluation Criteria:

- Can parking lot islands incorporate rainwater infiltration?
- Have overflow structures been included?
- Does home landscaping incorporate buffers at lawn or pavement perimeters?
- Are soil types appropriate to permit infiltration within the design period (NRCS soil types A or B)?

Swale Evaluation Criteria:

- Can swales be used to treat storm water runoff (in parking lots, along roadways, and in parks)?
- Are drainage flow paths as long as possible, to encourage infiltration?
- Does the design provide for an engineered soil matrix that will dewater rapidly?
- Can native vegetation be used instead of turf?
- Who will maintain the swales?

Finally, get agreement from the reviewing entity that the design meets the following requirements, or acquire permission to vary from the following:

1. Minimum standards for stormwater management
2. Design storm frequencies
3. Conveyance design criteria
4. Floodplain criteria
5. Buffer or setback criteria
6. Wetland provisions
7. Any other watershed-based criteria, such as lot densities
8. Erosion and sediment control requirements
9. Maintenance requirements
10. Physical site evaluations such as infiltration tests and geotechnical evaluations

REFERENCES

American Planning Association (APA). 2006, Dec. *Essential PAS Info Packet* (PAS EIP-15). Chicago, IL: American Planning Association.

Atlanta Regional Commission (Facilitator). 2001, August. *Georgia Stormwater Management Manual*. Atlanta, GA: Atlanta Regional Commission. http://www.georgiastormwater.com/

Center for Watershed Protection (CWP), Site Planning Roundtable. 1998, April. *Consensus Agreement on Model Development Principles to Protect our Streams, Lakes and Wetlands*. Ellicott City, MD: CWP.

Center for Watershed Protection, Site Planning Roundtable. 1998, Aug. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Ellicott City, MD: CWP.

Foss, A. 2005, June. *Low Impact Development: An Alternative Approach to Site Design*. PAS Memo. Chicago, IL: American Planning Association.

Hinman, C. 2005, Jan. *Low Impact Development: Technical Guidance Manual for Puget Sound* (Publication no. PSAT 05-30). Olympia, WA: Puget Sound Action Team (with Washington State University, Pierce County Extension). http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

North Carolina Cooperative Extension. *Backyard Rain Gardens*. Website. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering. www.bae.ncsu.edu/topic/raingarden

North Carolina State University. *Going Native: Urban Landscaping for Wildlife with Native Plants*. Website. Raleigh, NC: North Carolina State University. www.ncsu.edu/goingnative.

Plant Conservation Alliance, Alien Plants Working Group (PCA–APWG). *Weeds Gone Wild*. Website. Washington, DC: Bureau of Land Management. http://www.nps.gov/plants/alien/

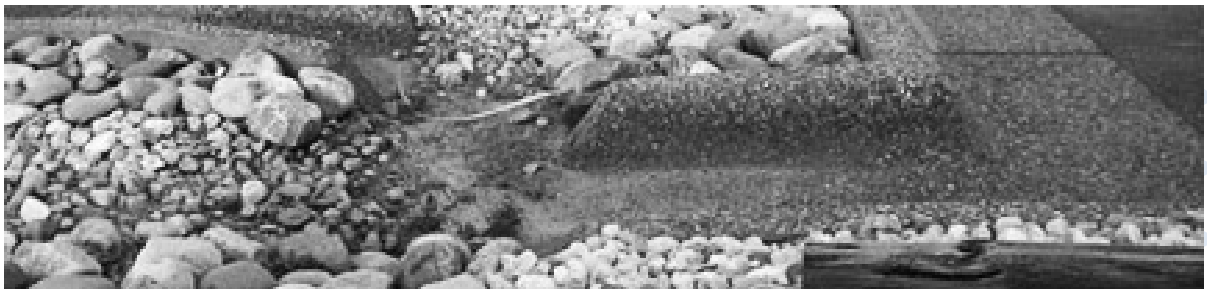
Prince George's County. 2000, January. *Low Impact Development: An Integrated Design Approach*. Largo, MD: Prince Georges County, Department of Environmental Resources.

Randall, J. and J. Marinelli. 1996. *Invasive Plants: Weeds of the Global Garden* (Handbook No. 149). New York, NY: Brooklyn Botanic Garden Club, Inc.

Shaver, E. 2000, April. *Low Impact Design Manual for the Auckland Region* (Technical Publication 124). Auckland, New Zealand: Auckland Regional Council.

Stafford County. 2003, March. *Stormwater Management Design Manual*. Stafford, VA: Stafford County Commissioners. http://co.stafford.va.us/Homepage/Planning_&_Zoning_Applications_&_Information.shtml

Town of Warsaw, Virginia. Date unknown. *Town of Warsaw Low Impact Development Stormwater Management Policy*. Warsaw, VA: Town Office.



CHAPTER 4: LID STORMWATER BMPs

By Bill Hunt

This chapter explains how LID integrated management practices are selected and designed. Pollutant-specific practice design is highlighted. Examples focus on first flush capture, but also account for larger events (such as the 2- and 10-year storms) and the annual hydrologic cycle (such as groundwater recharge).

4.1 LID Design Considerations

As discussed in Chapter 2, best management practices (BMPs) help an LID project meet its annual pre-development hydrologic budget ("pre-development target"). That is, as water enters into a given BMP as runoff, it is converted and discharged as outflow, evapotranspiration, or infiltration (for values to use in calculations for these assumptions, see Chapter 2).

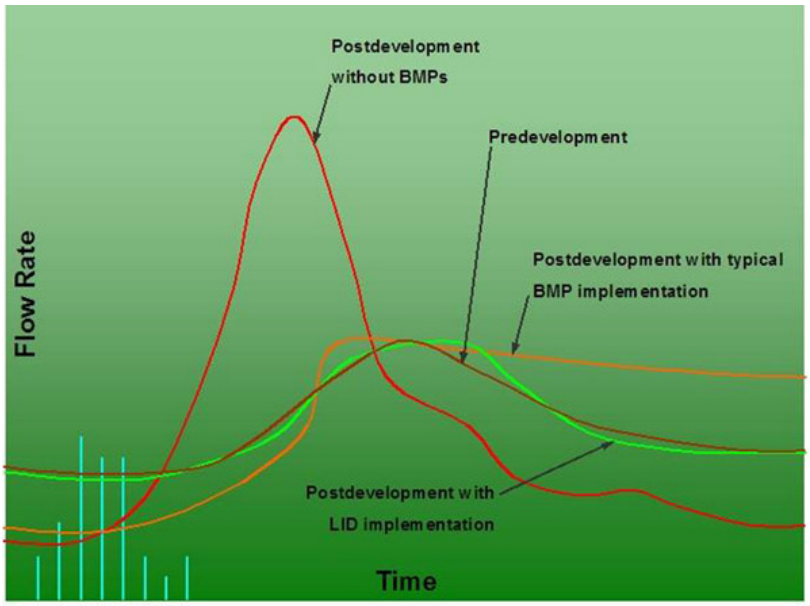
4.1.1 Water Quality Versus Peak Flow Mitigation

With LID, stormwater BMPs are specifically designed to improve water quality as well as address peak flows. On an annual basis, as much as 90 percent of all runoff pollution can be treated (not necessarily removed entirely) when a relatively small storm is reliably captured by stormwater BMPs. The precipitation associated with this storm is termed the water quality volume for the particular storm. In North Carolina, the water quality volume is that produced by either a 35.7 mm (1.5 in.) event in the 20 coastal counties (including those on the Albemarle and Pamlico sounds) and 25 mm (1.0 in.) event for the rest of the state.[6]

Most conventional BMPs are sized by examining pre-development flow peaks for relatively large storm events such as a 1- or 2-year, 24-hr storm, or possibly larger storms (such as 10- or 100-year, 24-hr events). Figure 4-1 shows an example of this examination.

[6] For up-to-date values and water quality requirements, please consult NCDENR or your local municipality or county.

Figure 4-1. Hydrographs associated with various design standards (courtesy of Tom Blue, BLUE Land Water Infrastructure)



The brown hydrograph is the pre-development (or target) hydrograph, with the red hydrograph resulting from development without any special design or stormwater treatment or control. The hydrograph for LID is represented by the light green curve shown above. Older peak flow design standards employing conventional BMPs would have resulted in the orange hydrograph. The green hydrograph shows that pre-development and post-development hydrology match much more closely with LID implementation.

A conventional BMP such as a storm water detention pond can release flow at rates that do not exceed the maximum rate of the 1- to 2-year storm event (also shown in Figure 4-1).

To meet both a water quality and a peak flow mitigation goal, a substantial amount of infiltration will probably be required. It needs to be stressed that implementing stormwater BMPs such as those discussed in this chapter is the final piece of meeting system design requirements. Often, structural practices alone are not sufficient. Reducing impacts before breaking ground is more cost efficient and usually provides other benefits resulting from protected habitat, forest canopy, and other land features (see Chapter 3 for more information).

4.2 BMPs Used to Implement LID

The following major engineered, structural BMPs will be discussed:

- bioretention;
- permeable pavement;
- cisterns / water harvesting;
- backyard or pocket wetlands;
- swales;
- green roofs;
- level spreaders / filter strips;
- infiltration trenches;
- basins;
- wells;



Figure 4-2. An ultra-urban bioretention cell in Charlotte, North Carolina



Figure 4-3. A grassed cell on the North Carolina State University campus in Raleigh, North Carolina



Figure 4-4. Pervious concrete in Nashville, North Carolina



Figure 4-5. Pervious asphalt in Raleigh, North Carolina



Figure 4-6. Residential cistern in Holly Ridge, Onslow County, North Carolina



Figure 4-7. Cistern serving institutional water needs in Greensboro, North Carolina

- sand filters; and,
- soil amendments.

An overview of each BMP will first be presented in this section, followed by more detailed information.



Figure 4-8. Pocket wetland serving a watershed smaller than one acre

Bioretention
Commonly called a "rain garden," bioretention is a filtration and infiltration BMP and landscaping feature that is partly based on sand filter design. The typical bioretention practice is an excavated basin underdrained by a perforated pipe envelope. Specialized soil overlies the drainage envelope and provides a "media" in which to plant vegetation. Mulch is often added (Figure 4-2).

Permeable Pavement
Permeable pavement has openings that allow water to pass through it rather than forcing runoff to shed off of it. Examples include permeable asphalt, concrete, or open-celled pavers. Under the top level is a gravel storage layer ranging in depth from 4 to 12 inches and, in some cases, an underdrainage system. Rainfall passes through the pavement and partially fills the gravel storage layer, where it infiltrates over an extended period of time. Examples of two permeable pavement applications are shown in Figure 4-4.

Cisterns and Water Harvesting
Cisterns and water harvesting systems capture rainfall (usually from rooftops) in a large sealed container and store it for later use. Cisterns can be either above or below ground (Figures 4-6 and 4-7).

Pocket (or "Backyard") Wetlands
Pocket wetlands are small wetlands integrated into the landscape, which are usually shallow and constructed in lower-lying, wet-tending areas. Examples of pocket wetlands are shown in Figure 4-8.



Figure 4-9. Dry swale in Raleigh, North Carolina



Figure 4-10. Wet swale along I-40 in eastern North Carolina



Figure 4-11. Succulent (sedum) vegetated green roof in Kinston, North Carolina



Figure 4-12. Concrete level spreader in Apex, North Carolina

Swales

Swales are depressions in the landscape that collect water from surrounding areas. They are an inexpensive way to convey water from a source to a treatment practice or an exit from the property. They are usually turf (Figure 4-9), but can sometimes be allowed to grow wetland vegetation (Figure 4-10).

Green Roofs

Green roofs feature a prepared base that is covered in planting media and vegetation in place of traditional shingles, asphalt, or tile. Green roofs employ specialized media that allows water to be partially captured and is lightweight, stable, and supports vegetation. Examples of green roofs are found in Figure 4-11.

Level Spreaders and Vegetated Filter Strips

Level spreaders are concrete curbs that spread flow evenly over the same grade before entering a riparian buffer or other downslope vegetated filter strip. This allows infiltration and some eventual evapotranspiration. In certain river basins, such as the Neuse and Catawba, level spreaders are required to prevent direct discharge to streams shown on USGS 1:24,000 topographic quads and on USDA soil survey maps. The most current level spreader designs call for them to be made of hardened material such as concrete (Figure 4-12) or metal (Figure 4-13).

Infiltration Devices

Infiltration trenches, wells, and basins are a group of related practices similar to bioretention that convey water in shallow cells. They are specifically intended to infiltrate water into shallow groundwater. Infiltration systems are typically filled with riprap or another very porous media. Bioinfiltration (mentioned with bioretention) is also considered an infiltration device.

Sand Filters and Soil Amendments
Sand filters involve a drainage pipe under a sand-filtering media (Figure 4-14). The traditional, concrete-lined sand filter provides little to no infiltration and only a small amount of ET.

4.3 Thumbnail BMP Selection Guide

There are several factors to consider when deciding which practice(s) to implement for a given development. They are:

- Watershed size;
- Existing (or "in situ") soils;
- Site stability;
- Seasonally high water table (SHWT);
- Seasonally low water table (SLWT);
- Topography (slope) of the potential BMP site;
- The amount of credit NCDENR and the local government gives a practice (or specific design of the practice);
- Costs (including land requirements, design and construction, and long-term maintenance); and,
- Other project goals and needs, such as parking, aesthetics, and water harvesting.

Watershed Size
The allowable watershed treatment size for green roofs and, in North Carolina, permeable pavement, is the size of the practice itself.[7] Other practices, such as aboveground cisterns and infiltration wells, are best designed for small catchments (less than ¼ acre). Most LID technologies are appropriate for watersheds approximately one acre or less (bioretention, below-ground cisterns, infiltration trenches, and sand filters). Finally, a few practices can

[7] As of January 12, 2008. There is a precedent in other states to allow permeable pavement to have contributing run-on.



Figure 4-13. Metal level spreader in Apex, North Carolina





Figure 4-14a & b. Sand filter under construction
A drainage pipe underlies a sand-filtering media. Most sand filters do not allow for infiltration.

treat watersheds up to 5 acres and greater (wetlands, level spreaders, infiltration basins, and swales).

In-situ Soils
The ecoregions of North Carolina can be characterized by their soil types. For example, the sandhills and barrier islands have primarily deep, relatively sandy soil, while the Triassic basin in the piedmont is noted for its extremely tight clayey soil. The underlying soil on a site affects the type of practice selected. Sandier soil locations are able to infiltrate more water and are therefore more suitable for practices like bioretention, infiltration wells, and permeable pavement. A few practices perform better in tighter soils, notably stormwater wetlands. Finally, some practices function well regardless of in-situ soil type, such as cisterns and water harvesting systems, sand filters, and swales.

Near Site Stability
Most LID practices are susceptible to clogging, so it is important to locate these practices in areas with stable uplands (see Chapter 6, LID Construction). However, cistern and water harvesting systems and, to a lesser extent, stormwater wetlands, can still perform if the surrounding area is somewhat unstable for short periods. If practice sequencing is needed, these two practices can precede most others.

Seasonally High and Seasonally Low Water Tables (SHWT and SLWT)
For practices that rely on infiltration, SHWT should not encroach upon the bottom of the practice. SHWTs that are too high would adversely affect bioretention practices, permeable pavement, and infiltration wells, trenches, and basins. A typical "safe" separation between the bottom of an infiltration-based BMP and the SHWT is 2 feet. For stormwater wetlands, an SLWT that is too low (too far from the surface) reduces its viability, as this practice depends on being wet for much of the year.

Topography and Slope
Sites with steep slopes make larger-scale practices difficult to construct without great expense. However, all the BMPs listed in this chapter can be designed to be reasonably small, including stormwater wetlands, provided other factors are suitable (such as SLWT). Some slopes, however, are too steep for some BMPs, from a construction cost standpoint. Steep slopes are most problematic for level spreader and vegetated filter strip systems, which rely on a downslope condition of less than 15 percent for up to 50 feet. There are cases, too, where a site can actually be too flat for some practices, such as bioretention cells with underdrains.

NCDENR Credits for BMPs
In select watersheds of North Carolina, BMPs are assigned removal credit

for total nitrogen (TN) and total phosphorus (TP). Across the state, BMPs are assigned removal credit for total suspended solids (TSS). In the future, the state may mandate that other pollutants be removed in certain regions (such as pathogenic bacteria in coastal waters). Because different BMPs remove different pollutants at different rates, some BMPs will be favored, depending on the amount of credit they are given by the state. In some cases, stormwater practices may be used in series to obtain the required pollutant reduction "credit" specified by NCDENR or a local government.

For example, a stormwater wetland currently receives a 40 percent TN removal credit, whereas a wet pond receives 25 percent TN removal credit. Therefore, in some parts of North Carolina such as in the Greenville area, stormwater wetlands are installed in favor of wet ponds. Similarly, as discussed in Chapter 2 (Achieving LID Performance Goals Using a Hydrologic Cycle Approach), certain BMPs will convert more inflow to ET and infiltration than others, which may make them more appealing to designers for whom these goals are paramount.

Some local governments may provide credit for non-structural BMPs for meeting local watershed protection goals. For example, Wake County provides credit for reforestation to meet required stormwater curve numbers.

Costs—Land, Construction, and Maintenance

Stormwater practices have different relative costs. Some practices are more land intensive, but cost less to construct and maintain. Because costs vary depending on context, no one BMP is inherently superior. For example, in ultra urban areas where only rooftop space is available for treatment, a green roof may be the most cost-effective option because of the high opportunity cost of land.

Typically, on a per-square-foot of watershed treated basis, green roofs and permeable pavement[8] take up the most space, followed by stormwater wetlands and bioretention. Infiltration basins, wells, and trenches are still less land intensive, followed by swales and level spreader or vegetated filter strips. Sand filters and cisterns or water harvesting can actually take up no usable land if they are buried underground.

From the perspective of construction cost, for the cost per unit area of watershed treated, level spreaders and vegetated filter systems and stormwater wetlands are the least expensive, followed by bioretention and the infiltration devices. At the opposite end of the spectrum are green roofs and permeable pavement, which incur higher costs per unit area.

[8] Rooftops and parking lots are "necessary" spaces that might go otherwise unused for BMP treatment. There is a cost benefit associated with this.

Maintenance costs are still relatively unknown and, in great part, depend upon the required aesthetic appeal associated with the property.[9] All things being equal, green roofs seem to have the cheapest maintenance per square foot of practice, while sand filters are among the most expensive.

Other Design Goals and Considerations

BMPs are constructed to satisfy goals and needs in addition to mitigating hydrologic changes and improving water quality. For example, in limited land space situations the ability to drive or park on a BMP may be an important factor. In this example, permeable pavement or a sand filter would clearly be strong options. In other locations where landscape codes require portions of a commercial development be set aside for vegetation, bioretention may meet both landscaping and water quantity/quality requirements. As water shortages become an increasing trend, having a BMP that allows water to be reused for irrigation or washing may be important; cisterns and water harvesting systems would be most beneficial in this case. Finally, green roofs enable increased living space, insulation, and reduction of the heat island effect. Table 4-1 summarizes the decision factors and gives basic selection guidance.

4.4 Considerations for Individual Stormwater BMPs

Design standards for each of the BMPs will NOT be thoroughly reviewed in this chapter. The recent *North Carolina Stormwater BMP Design Manual*, which includes detailed design standards for each of the practices discussed in this chapter, is available at: http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

The discussion below highlights parts of the State of North Carolina's BMP design manual or provides design guidance not included in the NCDENR BMP design manual.

4.5 Bioretention

Bioretention can be designed for hydrology and for pollutant removal. Hydrology will be discussed first.

As NCDENR (2007) clearly states, bioretention cells are designed to capture runoff, filter through a special media, and then inflow the runoff partition to outflow, infiltrate, and evapotranspire. There are methods of reducing the amount of outflow (and thereby increasing infiltration and ET), one of which includes a change in the drainage configuration. In lieu of underdrain flow directly downhill, it is possible to include an upturn in the underdrain, effectively creating a sump. An example of this is shown in

[9] Much of maintenance is driven by the look of the site, which is aesthetic in nature.

Table 4-1. BMP decision factors

BMP Type	Watershed Size (ac)[1]	In – Situ Soils[2]	Importance of Stability[3]	Water Table	NC DENR Credits	Costs[4]	Other
Bioretention	Small -Medium	All	Very	SHWT > 2' from bottom of cell	Very High	Medium	Meets aesthetic needs
Permeable Pavement	Small - Large	Sand better; clay can be OK	Very	SHWT > 2' from bottom of pavement "cut"	High[5]	High	Can park on
Cisterns / Water Harvesting	Small	All	Not	SHWT low enough so that partially buried cistern will not float	Medium[6]	High	Provides water for other uses
Wetlands	Medium – Large	Clay better[7]	Somewhat	SLWT near surface (type 2-3')	Very High	Low	Can meet aesthetics
Swales	Medium – Large	All	Somewhat	Any WT acceptable	Low	Low	Conveys water
Green Roofs	N / A	N / A	Not	N / A	Medium[8]	Very High	Prolong roof life, provide cooling effect
Level Spreaders	Medium – Large	All	Very	SHWT > 1' from bottom of level spreader	High	Low	Locate in riparian buffers
Infiltration Devices	Medium	Sand	Very	SHWT > 2' from bottom of cell	Medium[9]	Medium	
Sand Filters	Small – Medium	All	Somewhat	Any WT OK but no submerging	High	High	Can park on
Amended Soils	Small - Large	All	Very	Any WT OK but no inundation	Not Assigned[4]	Medium	

[1] Small (less than ¼ acre), medium (~1 acre), large (~5 acre)

[2] The continuum of sandy to clayey

[3] Importance of watershed stability for the "well being" of BMP - a very important stability BMP would fail / clog if surrounded by a substantial amount of disturbed soil

[4] Relative to unit area of watershed treated

[5] NCDWQ credit only provided based on site soil conditions

[6] NCDWQ provides credit for volume and peak flow reduction if harvested water has a dedicated use

[7] SLWT near surface allows wetlands in all soil types

[8] NCDWQ allows reduction in peak flow and volume calculations

[9] NCDWQ does not provide infiltration credit in poor soils

Figure 4-15a & b. An upturned underdrain creates a sump in the bottom of the bioretention cell (top); outflow from an upturned underdrain (bottom)





Figure 4-15. This theoretically will force more water to infiltrate between storm events. It has been shown to work in several research studies (Dietz and Clausen, 2006; North Carolina State University unpublished data), even in somewhat clayey locations. In some cases where the receiving drainage network is at an elevation above that of the underdrain, it may be necessary to raise the underdrains to tie into the site's drainage system. When trying to meet a target hydrologic condition that requires substantial amounts of infiltration and evapotranspiration (as explained in Chapter 2), creating a sump provides more infiltration.

In Situ Soil

The in situ soil has a tremendous impact on the amount of infiltration that occurs from the sump. In Rocky Mount, storms up to 1.70 inches have been completely captured in a 2-foot-deep sump, while in Greensboro many storms less than 1 inch produced some outflow from the drainage system (Hunt et al., 2006). The Greensboro bioretention cell also had a nominal 2-foot depth sump. The reason for this difference is attributed to the underlying soils at both sites. In Rocky Mount, the soils are quite sandy (reflective of the upper coastal plain), and in Greensboro they are clayey (typical of the piedmont).

Basin Geometry

Adjusting the bioretention basin's geometry theoretically should have an impact on the amount of water that laterally infiltrates (leaves the side walls). Increasing the perimeter-to-surface-area ratio of the cell should have a subsequent increase in the amount of infiltration. To date, no work has verified this and in the future, it is expected that basin geometry will be a part of bioretention design.

Depth to Water Table

It is essential that the SHWT be determined prior to constructing a bioretention cell. A SHWT that intersects the bottom of a bioretention

cell will serve to dewater the shallow groundwater. At a study in Wilson (Hunt, 2003), this occurred and more pollution (Kg's of TN and TP) exited the bioretention cells than entered them as part of influent stormwater. Employing a soil scientist to verify the SHWT or even monitoring the water table through a series of wells (especially in the winter) is extremely important in sites that might have a restrictive water table, such as those in the coastal plain. If the SHWT is within 1 to 2 feet of the bottom of the bioretention cell, a bioretention cell should either be redesigned, located somewhere else on the property, or another practice should be used. In some cases, the Division of Water Quality requires a two-foot separation.

Fill Media

The NCDENR (2007) manual stresses the importance of fill media selection, but it bears further repeating. The type of fill soil that is used will dictate how much water is temporarily captured by the cell and later released to the atmosphere by ET. If the media contains a substantial amount of organics, TN and TP losses from the cell to the receiving waters can be high as well.

Media Depth and Volume

When designing bioretention for pollutant removal (from a concentration perspective), the required depth of the cell may vary. It should be noted that shallower media depths will retain much less inflow and therefore have lower values of ET and infiltration. From a pollutant load[10] perspective, deeper cells and oversized cells will (all things being equal) have lower effluent pollutant loads than shallower and undersized cells. A recent study completed by engineers at North Carolina State University and the University of Maryland at College Park found that increasing the ratio of media volume to drainage area does substantially impact the amount of outflow from a bioretention cell (Jones and Hunt, 2009, Li et al., 2009). While design guidance is not yet available, it is highly likely that future "oversizing" of bioretention cells will allow more water to infiltrate and evapotranspire. This will become an important design standard.

4.5.1 Bioretention Design

In current bioretention design standards, one general guideline is used to locate, size, and design bioretention cells. This design guideline gives no regard to target pollutants. However, the research conducted at North Carolina State University, the University of Maryland, Pennsylvania State University, and Villanova University allows more refined design guidelines to be developed. These pollutant-specific guidelines are summarized in Table 4-2.

[10] Pollutant load is volume of water multiplied by the concentration of the pollutant. Pollutant load is measured in pounds or kilograms.

Total Suspended Solids (TSS)
The trapping mechanism for most TSS is sedimentation. This occurs in the bioretention cell's depression storage volume (referred to as the "bowl"), which temporarily stores runoff. Some fine suspended particles are removed by filtration through the very top portion of the media and mulch layer. No specific fill soil depth is required, because nearly all TSS removal occurs prior to water infiltrating the cell. Higher infiltration rates (exceeding 2 inches per hour) for the fill media work best. When located in drainage areas with high TSS loads, however, higher maintenance is required to prevent clogging.

Metals
A study conducted by researchers at the University of Maryland showed that more than 95 percent of metal removal occurred in the top 8 inches (20 cm) of bioretention fill soil. Metal accumulation rates in Maryland and North Carolina are not high enough to retard plant growth or pose a disposal problem in most applications. Fill-soil depth in bioretention cells does not need to exceed 18 inches to effectively remove metals from stormwater runoff. The infiltration rate of the media can vary. It is best that the cell's top layer remain unsaturated, so infiltration rates exceeding 2 inches per hour may be most appropriate.

Pathogens / Bacteria
Initial study results for bioretention removal of pathogens show excellent rates (Hunt et al., 2008). Most scientists and engineers agree that bacteria die-off occurs at the surface where stormwater is exposed to sunlight and the soil can dry out. While no minimum soil depth is required to remove pathogens, it is best for these bioretention cells to not be densely vegetated. Minimal plant coverage allows for greater exposure to sunlight and consequent die-off of bacteria.

Temperature
Increased water temperature is a form of pollution important to western North Carolina's trout fisheries. Information collected on bioretention's ability to reduce outflow temperature at four cells (Jones and Hunt, 2009) showed that some bioretention cells were able to reduce peak temperatures by as much as 10°C (16°F). It is recognized that deeper soil media and ample shade can reduce the temperature of effluent. Bioretention cells with large media volume to drainage area ratios outperformed standard-sized bioretention cells. Research suggests that a 3-foot minimum media depth is acceptable, although a 4-foot depth is preferred. An Internal Water Storage (IWS) volume at the bottom (and cooler area) of the fill media may reduce temperature as well.

Total Nitrogen (TN)

Research conducted at Penn State University (Hunt, 2003) and the University of Maryland (Hsieh and Davis, 2005) found that nitrogen removal can be improved by retaining water in the bioretention cell for a longer period of time. Soil media infiltration rates of 1 inch per hour are preferable to higher infiltration rates. Tests examining the effectiveness of introducing an internal storage zone (shown in Figure 4-16) have not yielded any statistically significant results; however, it does appear that the introduction of the internal storage layer may reduce the outflow concentration of NO_3-N and, consequently, TN. A minimum fill media depth of 30 inches is recommended for TN removal; 36 inches is preferred. If an internal storage layer is used for TN removal, it is important to keep the "top" of this zone at least 18 inches below the surface of the bioretention cell, so that the portion of the soil column where phosphorus is captured (the top) does not risk saturation.

Total Phosphorus (TP)

Lower P-Index soils reduce phosphorus loads leaving the bioretention cell. If phosphorus is a target pollutant, it is imperative that the fill soil be tested to verify that it has a relatively low P-Index, ranging between 15 and 30. P-Indices lower than 15 either retard or do not support plant growth. Infiltration rates greater than 1 inch per hour are likely best for effective TP removal. As with metals, it is important that the zone where phosphorus is collected, the surface layer, does not saturate, which would cause some of the trapped phosphorus to go into solution and leave the bioretention cell. A minimum fill soil depth of 24 inches is recommended.

Conflicting Design Standards

What if a bioretention cell is supposed to treat both nitrogen and pathogens? Pathogen removal does not require the bioretention media to be as deep nor infiltration to be as restrictive as does TN removal. In these cases, the more restrictive design parameters should be used. For example, the recommended design for this cell would be 36 inches of media depth at an infiltration rate of 1 to 2 inches per hour (deeper and slower than what is needed for pathogen removal but just right for TN removal).

Specifying Fill Soil Media

Fill soil selection is a crucial component of bioretention design, particularly in tighter clay soil regions of North Carolina's piedmont and Triassic basin.[11] Fill media should:

(1) provide adequate drainage,
(2) reduce pollutant levels, and
(3) support plant growth.

[11] Including the Triassic Basin.

Table 4-2. Bioretention design guidelines for specific pollutants

Target Pollutant	Minimum Fill Media Depth	Target Infiltration Rate	Other Design Guidance
TSS	No minimum fill depth required	Any rate is sufficient. 2 to 6 inches per hour recommended.	If high TSS influent, frequent maintenance required.
Pathogens	No minimum fill depth required	Any rate is sufficient. 2 to 6 inches per hour recommended.	Limiting plant coverage allows more direct sunlight to kill pathogens.
Metals	18 inches	Any rate is sufficient. 2 to 6 inches per hour recommended.	Must keep top layer of cell from saturating for extended periods of time.
Temperature	At least 36 inches (48 inches preferred)	To be determined. Slower rates may be preferable (less than 2 inches per hour).	Introduction of IWS volume at the bottom of the cell may reduce effluent temperature.
Total Nitrogen (TN)	At least 30 inches (36 inches preferred)	1-2 inches per hour. Slower rates are better.	Introduction of IWS volume may reduce TN concentrations.
Total Phosphorus (TP)	24 inches	2 inches per hour.	A low P-Index is essential. Recommended P-Index should range from 15 to 30.

It is recommended that a bioretention soil media, or fill soil, mix has the following recipe:

(1) 85 to 88 percent sand. A washed medium sand is sufficient. A USGA greens mix is not necessary and can be costly.

(2) 8 to 12 percent fines. Fines include both clay and silt.

(3) 3 to 5 percent organic matter. Studies in Maryland have shown newspaper mulch to be an ideal source of organics. In North Carolina, peat moss has been successfully used.

When mixing soil components to create the engineered media, it is essential the components are well mixed and consistent.

The 3 to 5 percent organic matter does not change based upon target pollutant. However, the percentage of fines does. Incorporating a higher percentage of fine soil particles will reduce infiltration rate. To obtain a 1-inch per hour infiltration rate recommended for nitrogen removal, roughly 12 percent of the fill soil should be composed of fines. The 2-inch per hour infiltration rate recommended for phosphorus, metals, and other pollutants should contain approximately 8 to 10 percent fines.

The organics are included to "kick-start" nitrogen removal and plant growth while the bioretention cell matures. When the introduced organic matter is finally depleted by microbial activity, the bioretention system is expected to provide some organic content to the fill through mulch decomposition, grass clippings, and root infiltration.

To support plant growth, while removing phosphorus from runoff, the fill soil must have a P-Index between 15 and 30. If the bioretention area is not designed to reduce phosphorus in runoff, a P-Index for the fill soil of 30 to 50 is recommended. In addition to having a low P-Index, it is best for fill media to have a relatively high cation exchange capacity (CEC). Higher CEC's indicate soils that have a greater ability to capture and retain phosphorus. Some "designer" soils with low P-Indices and higher infiltration rates have been tested to have CEC's exceeding 20. Although a minimum CEC has yet to be established, CEC's exceeding 10 are expected to work relatively well at removing target pollutants in bioretention systems.

The types of vegetation expected to grow in the bioretention cell also affects the depth of media selected. Grassed covers do not need more than 15 to 18 inches of media to survive, while certain small trees specified to grow in bioretention require a minimum of 36 inches. Most bioretention shrubs can survive and even flourish with a minimum of 24 inches of fill media.

4.5.2 Bioretention Design Models

There are a few models available for bioretention design. Perhaps the most-used model currently is RECARGA from the University of Wisconsin. It can be found at http://dnr.wi.gov/runoff/stormwater/technote.htm

North Carolina State University Department of Biological and Agricultural Engineering has developed a simple bioretention model to show how a designed cell performs for a select precipitation event (such as the 2-year, 24-hour storm) for several cities across North Carolina. It is available at www.bae.ncsu.edu/stormwater/downloads.htm

Lastly, work is beginning on using DRAINMOD, an intensive drainage model created by Dr. R. Wayne Skaggs of North Carolina State University and used worldwide for agricultural and wetland hydrologic problems, for bioretention design. Guidance on applying DRAINMOD to bioretention design may be available by the end of 2009.

4.5.3 Bioretention Economic Considerations

Bioretention is a fragile stormwater practice. Across the state, thousands of dollars have been wasted because measures were not taken to prevent bioretention cells from clogging with sediment during construction. Much of this cost could have been avoided if simple precautions were taken. Discussion of preventing sedimentation during construction is found in Chapter 6, LID Construction.

Bioretention Placement

Avoid locating bioretention cells near disturbed areas. Excessive sedimentation ruins bioretention. During construction of bioretention cells, take protective measures such as lining the perimeter of the bioretention cell with either straw bales or a silt fence.

Construction phasing of a bioretention cell is critical and must be well planned and executed, as it can be complicated. The principal excavation of the cell can occur any time during the construction process. Often, sediment traps or basins are transformed into bioretention cells. This is an excellent use, provided the sediment trap is excavated prior to its conversion to a bioretention cell. If the bioretention facility is constructed as a median in a parking lot, it is best to wait until the parking lot's base gravel course is placed before installing the underdrains, gravel layer, or fill media of the bioretention cell. Ideally, the initial asphalt layer is placed before bioretention construction (post-excavation) starts. Once the fill soils are brought on site, paving of the parking lot can be completed. When the parking lot and surrounding landscape are stable, vegetation can be planted and mulch spread.

Be wary of out-parcel development (future development occurring up slope). Even if the bioretention cell immediately treats a stable parking lot, a subsequently developed out parcel, such as a bank or fast-food establishment constructed after the main portion of the shopping center is built, can add sediment to the bioretention cell, causing it to clog.

Pre-Treatment

To prevent premature clogging of bioretention cells, designers are strongly encouraged to specify pre-treatment devices. The most commonly used in North Carolina in descending order are: (1) gravel verge (thin strip) with sod surrounding the perimeter, (2) grass swale, and (3) forebays. A level gravel verge between the pavement edge and vegetation helps disperse flow entering the bioretention area. The gravel strip should be garden-rake width (approximately 8 inches). Immediately installing sod downslope of the verge provides a layer of pre-treatment before runoff enters the bioretention cell proper. The sod serves as a grassed filter strip (Figure 4-16). The minimum width required for the sod filter strip is 3 feet, with 4 to 5 feet recommended. In addition to trapping pollutants before they reach the bioretention cell, the sod immediately stabilizes the perimeter of the bioretention cell, preventing internal erosion. Centipede grass has been successfully used as a sod verge in central and eastern North Carolina. Fescue and bluegrass are best suited for western North Carolina.

A simple grassed swale is another pre-treatment option. A minimum length is not specified, but most suspended sediment has been observed to fall

out in the first 10 to 15 feet of the swale. The exact minimum length would depend upon drainage area size and composition, and the swale's slope, width, and cover.

Occasionally, large bioretention areas will utilize a forebay for pretreatment. The forebay should be sized so that it slows runoff water entering the bioretention cell, allowing some sediment to settle. Forebay depth ranges between 18 and 30 inches. Bioretention applications utilizing forebays are limited to locations where standing water is not considered a hazard and there is not enough room to incorporate either a sod/gravel verge or a grassed swale (Figure 4-17). Forebays must be hydraulically isolated from the underdrains so that runoff does not short circuit the bioretention media. Forebays can be lined to prevent direct flow into the underdrains.



Figure 4-16. Installing a gravel verge and sod stabilizes the perimeter of bioretention cells and is highly recommended. The resulting filter strip shown here is nominally 5 feet wide.

The following are factors unique to bioretention costs:

1. Amount of land required in addition to that mandated by landscape ordinances to construct the bioretention cell. Sometimes a bioretention cell can be sited wholly within areas that are required to be "green" by local codes.
2. The amount and depth of fill media. Deeper and more fill media outperform shallower systems with respect to pollutant load reduction, but such systems are more expensive to construct. However, the depth required of the bioretention media does vary by target pollutant.
3. Location of fill media vendor. Bioretention fill media is freight sensitive, so longer hauls will cost the developer more money.
4. Available space for and type of pre-treatment. A grassed swale is the cheapest pre-treatment technique, but is often unavailable due to spatial constraints.
5. Plant density. Some codes require a minimum number of plant stems per acre.
6. Type of vegetative cover. Grass systems tend to be cheaper to establish and maintain than tree/shrub/mulch systems, but the grassed bioretention cell's performance has yet to be fully established.
7. Several other costs are not unique to bioretention, such as surface area of the practice, impact of utility lines, and the ability to keep the bioretention free of off-site fine sediment.

4.5.4 Bioretention Maintenance Considerations

To preserve bioretention performance, the cells must be maintained. Like any landscape feature, bioretention areas must be pruned, mulched, and initially watered and fertilized. Grassed bioretention cells are usually mowed.

Because plants are an important monetary investment in bioretention and are essential to the aesthetic appeal of bioretention systems, they need to be established as quickly as possible. The need for rapid establishment requires bioretention cells to be limed (if indicated by a soil test). Additionally, plants may need to be spot-fertilized to ensure growth and survival in low P soils. Watering the plants every 2 to 3 days for 1 to 2 months helps ensure vegetation survival. The frequency of these tasks varies seasonally, with more frequent maintenance required in summer than in winter.

Maintenance tasks unique to bioretention include occasional removal of mulch and the top layer of fill soil. Give special consideration to preserving healthy vegetation during this removal. Consequently, not all the top layer of fill media is removed during this maintenance task. Because clogging occurs most frequently at the top of the soil column, the bioretention basin rarely needs to be completely excavated. However, this has been necessary when the bioretention cell was located in an unstable drainage area.

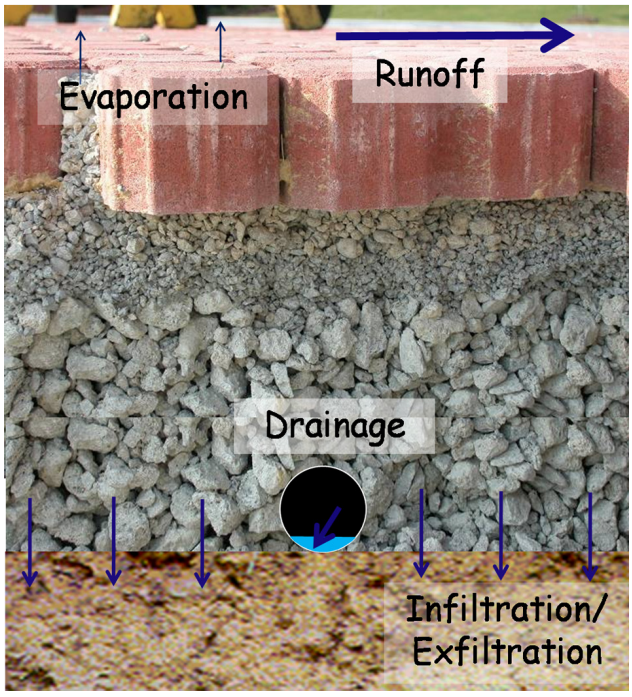


Figure 4-17. Typical permeable pavement cross section Water that collects in the drainage layer will infiltrate and potentially outflow (if underdrains are used). A very small amount of water will be evapotranspired. The gravel storage layer shown in this picture can hold up to 5 inches of rainfall.

4.6 Permeable Pavement

Unlike traditional surfaces, permeable pavement allows water to pass through its surface. All permeable pavement types essentially operate the same way. After water migrates through the surface, it temporarily collects in the gravel storage layer (Figure 4-17). Depending upon the rainfall intensity, rainfall volume, and existing soil infiltration rate, water then either exits the bottom of the permeable paver via soil infiltration or underdrain pipe, or water inside the pavement will build up until runoff occurs. Intense rainfall rates can produce runoff from

permeable pavement, particularly on concrete grid paver systems filled with sand. Many pollutants can be trapped inside water that passes through the pavement or removed as the water passes out of the pavement into the surrounding soil.

4.6.1 Types of Permeable Pavements

There are five types of permeable pavements: Permeable Asphalt (PC), Permeable Concrete (PC), Permeable Interlocking Concrete Pavers (PICP), Concrete Grid Pavers (CGP), and Plastic Grid Pavers (PG). Pictures of each are shown in Figure 4-18. General structural design considerations are discussed for each of the pavements below. Additional references are provided throughout for those who wish to investigate this pavement design further.

Permeable concrete (PC) is a mixture of Portland cement, fly ash, washed gravel, and water. The water to cementitious material ratio is typically 0.35 to 0.45. Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space. An admixture improves the bonding and strength of the pavements. These pavements are typically laid with a 10 to 20 cm (4 to 8 in) thickness and may contain a gravel base course for additional storage or infiltration. Compressive strength can range from 2.8 to 28 MPa (400 to 4000 psi).

Permeable asphalt (PA) consists of fine and course aggregate stone bound by a bituminous-based binder. The amount of fine aggregate is reduced to allow for a larger void space of typically 15 to 20 percent. Thickness of the asphalt depends on the traffic load, but usually ranges from 7.5 to 18 cm (3 to 7 in). A required underlying base course increases storage and adds strength (Ferguson, 2005). Minimal amounts of permeable asphalt have been used in North Carolina.

Permeable interlocking concrete pavements (PICP) are available in many different shapes and sizes. When lain, the blocks form patterns that create openings through which rainfall can infiltrate. These openings, generally 8 to 20 percent of the surface area, are typically filled with pea gravel aggregate, but can also contain topsoil and grass. ASTM C936 specifications state that the pavers be at least 60 mm (2.36 in) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and gravel fill, a 38 to 76 mm (1.5 to 3.0 inch) fine gravel bedding layer, and a gravel base course storage layer (ICPI, 2004).

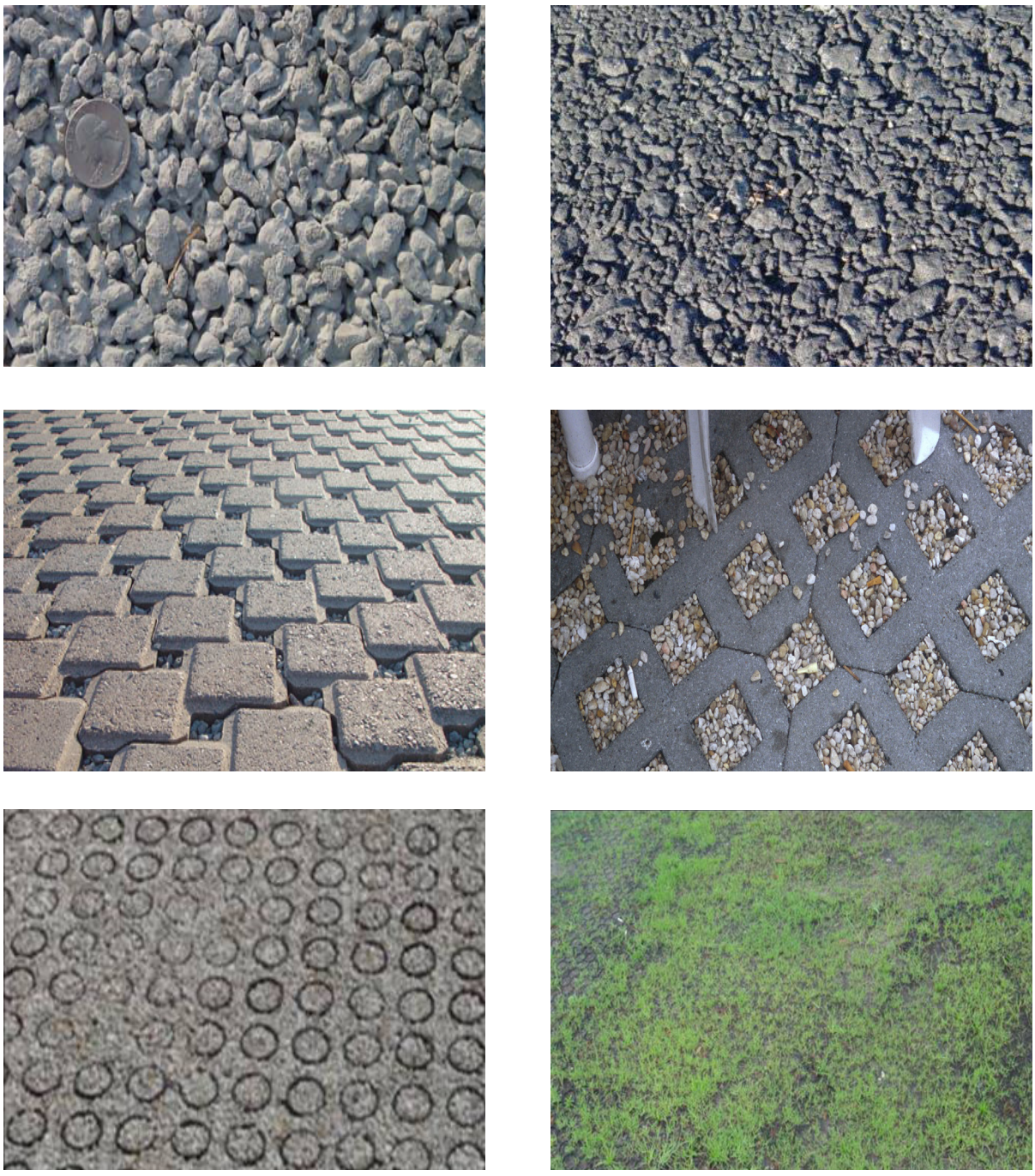


Figure 4-18. Types of permeable pavement
Top left to right: Permeable concrete (PC), permeable asphalt (PA), Middle left to right: permeable interlocking concrete pavers (PICP), concrete grid pavers (CGP). Bottom left to right: plastic reinforcing grids (PG) filled with gravel, and PG with grass.

Concrete grid pavers (CGP) are specified by ASTM C 1319, Standard Specification for Concrete Grid Paving Units (2001a) that describes properties and specifications for concrete grid pavers. CGP are typically 90 mm (3.5 inch) thick with a maximum 60 × 60 cm (24 × 24 inches) dimension. The percent open area ranges from 20 percent to 50 percent and can contain topsoil and grass, sand, or aggregate in the void space. The minimum average compressive strength of CGP can be no less than 35 MPa (5,000 psi). A typical installation consists of grid pavers with fill media, 25 to 38 mm (1 to 1.5 inches) of bedding sand, gravel base course, and a compacted soil subgrade (ICPI, 2004).

Plastic reinforcement grid pavers (PG), also called geocells, consist of flexible plastic interlocking units that allow infiltration through large gaps filled with gravel or topsoil planted with turf grass. A sand bedding layer and gravel base course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space is dependent on the fill media (Ferguson, 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa (2000 psi). This value increases up to 38 MPa (5500 psi) when filled with various materials.

4.6.2 Permeable Pavement Design

Permeable Pavement as a BMP Versus Surface Cover

Permeable pavements, like green roofs, are both treatment practices and a surface cover or land use. That is, rain that falls directly on the pavement either runs off, infiltrates, or evapotranspires. Water that runs off permeable pavement could be treated by another BMP (such as bioretention). In determining the amount of runoff generated from a surface cover, curve numbers (USDA-SCS, 1986) are utilized. Curve numbers were calculated for several permeable pavements in eastern North Carolina by Bean et al. (2007b), who have shown the average curve number of permeable pavements to range from a low of 45 to a high of 89. The curve number for standard impermeable pavement is 98. The reason for the variation in the North Carolina study was due to two factors: base (or storage) depth and underlying soil composition. The less the water storage and the more clayey the underlying soil, the higher the curve number.

Design Considerations for Infiltration

Permeable pavements can be specifically designed to optimize infiltration. Designers can adjust the following parameters:

1. Depth of storage layer
2. Surface infiltration
3. Underdrain need
4. Underdrain configuration
5. Location of pavement for best in situ soil (to a lesser extent)

Depth of Storage Layer

On average, each inch of gravel in the base can store ⅓ inch of rainfall. So, a 9-inch gravel storage layer holds 3 inches of rainfall at a given moment, assuming the drainage layer is flat. For structural reasons, described in Guidelines for 1993 American Association of State Highway and Transportation Officials Pavement Design (VDOT, 2003), a gravel storage layer is needed for most permeable pavement types (with the notable exception of pervious concrete). Provided the underlying (or in situ) soils allow some infiltration to occur, deeper storage layers allow more water to infiltrate during large storm events.

Surface Infiltration

The type of pavement used has a minor effect on surface infiltration, with pavements employing a sand or sandy soil fill having lower surface infiltration rates than pavements designed with pea gravel fill or pervious concrete or pervious asphalt. The long-term difference, however, among pavement types is not significant (Bean et al., 2007a). Rainfall intensities of 1 to 2 inches per hour may cause runoff from CGP filled with sand and PG filled with sand. Rainfall intensities of 4 inches per hour may cause runoff from the other permeable pavement types, per Bean et al.'s study.

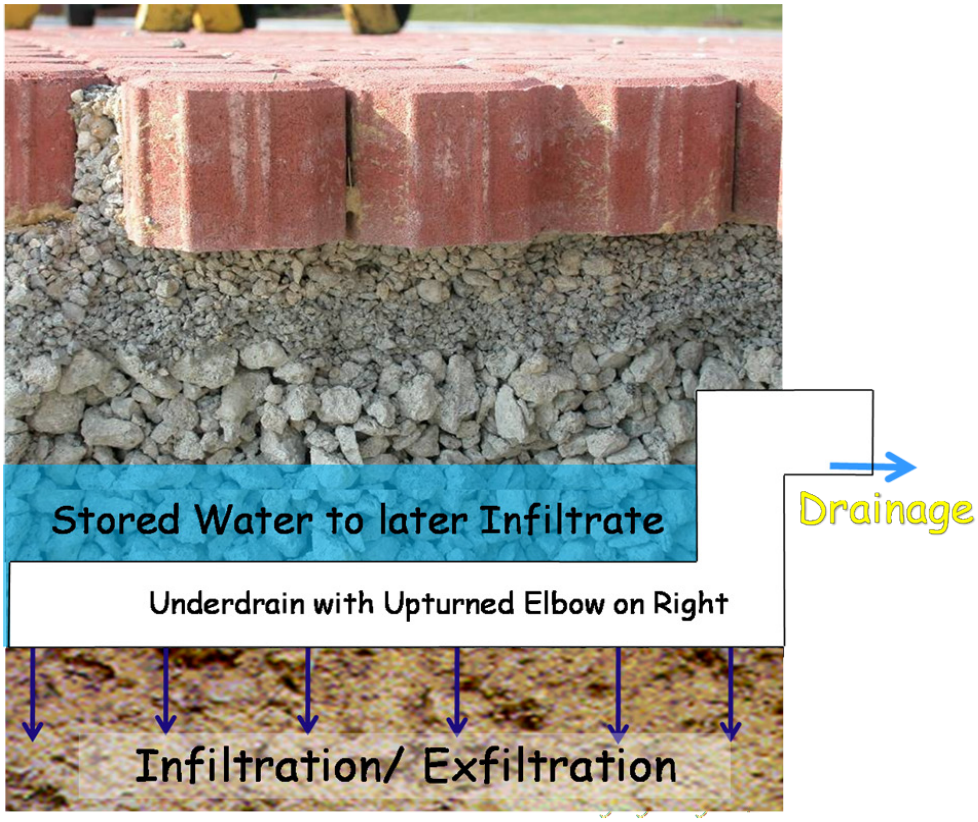
Underdrain Need

This need depends upon the in situ soil. If the soil infiltration rate is sufficiently reduced, an underdrain is required. It is reasonable to expect the preconstruction infiltration rate to be decreased by a factor of 10 to 20 following construction due to soil compaction by heavy equipment. For example, a sandy clay loam may have an infiltration rate of 0.5 inches per hour prior to permeable pavement construction. After construction, this rate may range from 0.025 to 0.05 inches per hour. For given design needs, this rate may be too low and underdrains will need to be used (Bean et al., 2007b).

Underdrain Configuration

Research (Collins et al., 2008a) indicates that an upturned underdrain—one that creates a storage zone in the bottom of the pavement base layer—can reduce outflow volumes (see Figure 4-19). A specific study, however, has yet to be conducted on this design feature. Water that initially pools internally in the pavement (1) does not drain, and (2) can slowly infiltrate the subbase, increasing times to peak, reducing runoff volumes, and lowering peak outflow rates. Another option with the underdrains is to size them for limited outflow rates. That is, use underdrains with a small diameter. Another option is to cap the underdrains with a restrictive orifice, or hole. While this might not substantially reduce outflow volumes, it would dramatically reduce peak flows and increase times to peak for a given storm event. Doing this is akin to using a small orifice to dewater a pond or wetland over a 2- to 3-day period.

Figure 4-19. An upturned underdrain elbow creates an internal storage zone for water, adding to the pavement's ability to infiltrate



Pavement Location in "Best" In-situ Soil

A developed site may have surprisingly varied underlying soils, some of which will be borderline impermeable while others will have some permeability. If the designer is able to identify locations with somewhat permeable underlying soils, the permeable pavements will potentially infiltrate a substantial amount. It is typically much easier to find permeable in situ soils on the barrier islands, the coastal plain, and sandhills.

Optimizing Evapotranspiration

While permeable pavements typically do not have a substantial amount of ET loss, there are a few pavement types that may hold water near the surface long enough for minor ET losses to occur. A system that captures and stores water near the surface of the pavement, such as CGP and PG filled with sand, has been estimated to temporarily store at least 6 mm of most storms and presumably "release" this water to the atmosphere by ET (Collins et al., 2008a). On an annual basis, up to 33 percent of all precipitation events would be "captured" in this way by these pavements. A similar effect was not found for other types of permeable pavements (PC or PICP filled with gravel).

Design Considerations for Water Quality

Permeable pavements improve stormwater runoff quality often, but not always. Many states, including North Carolina, do not assign pollutant removal credit to these systems (NCDENR, 2007). Research has investigated how well permeable pavements remove metals, sediment, motor oil, and nutrients and their impact on pH and temperature.

Pollutant Loads

Because most permeable pavements substantially reduce the volume of runoff or outflow, it stands to reason that they will also reduce pollutant loads. Several studies confirm that permeable pavements demonstrate lower total pollution loadings than standard pavements (Bean et al., 2007b).

Thermal Pollution (Temperature)

Permeable pavements can reduce thermal pollution (Karasawa et al., 2006) compared to conventional asphalt. The decrease was between 10°F and 25°F. This is in great part due to the color of the pavement. Only results for PICP have been published in a peer-reviewed format, so it is possible that not all permeable pavement types, such as PA, will have such an impact.

Pavements Buffer pH

Permeable pavements can buffer acidic rainfall pH (Dierkes et al., 2002; Collins et al., 2008b) likely due to the presence of calcium carbonate and magnesium carbonate in the pavement and aggregate materials. They provide a greater buffering capacity than asphalt, due to the greater surface area provided by contours in the pavement geometry and the additional coarse aggregate layer through which the water migrates. Of all pavement types, PC provided the most buffering capacity because it provided influent water the greatest contact time with cementitious materials (Collins et al., 2008b).

Nutrient Removal

Several studies have suggested that aerobic conditions, which result as permeable pavement drain, can result in nitrification of ammonia-nitrogen (NH_4-N) to nitrate-nitrogen (NO_3-N). This can lead to increased levels of nitrate-nitrogen leaving the permeable pavement. Compared to asphalt, substantially lower NH_4-N and total Kjeldhal nitrogen (TKN) concentrations and higher NO_3-N concentrations in permeable pavement drainage have been measured in multiple experiments (Bean et al., 2007b; Collins et al., 2008b). It also appears that CGP and PG filled with sand are better able to reduce TN. This makes sense, because CGP filled with sand very much resembles a low head (ponded water), limited media depth sand filter. Sand filters have repeatedly been shown to reduce TN concentrations (Barrett, 2003). This is an important finding, as it means that one type of

pavement (CGP with sand) appears to be preferable to other pavement types with respect to nitrogen removal. More research probably needs to be conducted to verify this finding but, if verified, perhaps this type of permeable pavement could receive TN removal allowances.

Metals

Most heavy metals are captured in the top layers (1 to 2 inches) of material in permeable pavement void space (Dierkes et al., 2002). For PICP, CGP, and PG that are filled with sand, this implies that standard street sweeping will probably remove the majority of heavy metals collected in the pavement fill material. Exact recommendations for disposal have yet to be made.

Hydrology at the Bottom of the Cell

If we are concentrating "all this pollution" in a permeable pavement cell, will these pollutants not affect groundwater? This is possibly the greatest concern regarding long-term pollutant control. Long-term studies and simulations of permeable pavement pollutant distributions have revealed low risks of subsoil pollutant accumulation and groundwater contamination (Dierkes et al., 2002; Kwiatkowski et al., 2007; Dietz, 2007). It is important, however, that seasonally high water tables do not encroach upon the interface of the base and the subbase, as a high water table will saturate soil that would collect pollutants and eventually leach them into the groundwater. SHWT should be at least 1-foot, and preferably 2 feet from the bottom of the pavement base. As with bioretention, if the SHWT is within 1-foot of the permeable pavement base, the permeable pavement should either be located somewhere else on the site where the SHWT is not restrictive or the practice should be eliminated from consideration. This will be particularly appropriate in portions of the coastal plain. In some cases, the Division of Water Quality requires a two-foot separation.

A summary of permeable pavement design guidance is found in Table 4-3.

Table 4-3. Permeable pavement design guidance summary

Design Parameter	Guidance	Rationale
Optimal Pavement Types for Runoff Reduction	All are excellent. PC, PICP, and CGP filled with gravel are best.	Research shows that all types of pavement types reduce runoff substantially. CGP and PG filled with sand have slightly higher runoff rates.
Design Surface Infiltration Rate	1 to 3 in/hr	Studies show that 90% of all study sites had at least 1 in/hr surface infiltration rates, with 2 to 3 in/hr being a median range for partially clogged permeable pavement.
Design Base Exfiltration Rate	0.01 to 1 in/hr. 0.10 in/hr is default for loamy sand.	Even in somewhat sandy soils, exfiltration rates from the base were affected by compaction that occurred during construction.
Curve Number	45 to mid 80s, depending upon site. 75 to 80 is recommended.	If the site is free from clogging, extremely low CN's are possible. With moderate clogging, CN's tend to be in the mid-70s. If the pavement is clogged with clay, the CN may exceed 90.
Underdrain Flow Rate	Release water so that a 2-year event is emptied in 2-4 days.	Allows a mimicking of pre-development hydrology stream recharge post event. Mitigates peak flow.
Increasing Infiltration to Subbase	Create a sump in base of pavement.	A sump allows water to pool and slowly infiltrate the subbase. Even at low infiltration rates of 1-2" per day, many storms are fully captured in the sump.
Optimal Pavement Types for Metal Removal	All are excellent. CGP and PG filled with sand are easiest to maintain.	It is easier for street sweepers to remove the smützdecke (or clogged layer) from the top of the sand column associated with CGP and PG.
Optimal Pavement Types for Nutrient Removal	CGP and PG filled with sand.	These pavements act as if they are low head, shallow depth sand filters. More research is needed to confirm this interim finding.
Seasonally High Water Table (SHWT)	1 foot, preferably 2 feet from the bottom of the pavement base.	SHWT closer to the base will (1) impede exfiltration from the pavement, and (2) lead to pollutant leaching from the pavement.

4.6.3 Permeable Pavement Design Models

There is a permeable pavement model available from North Carolina State University's Department of Biological and Agricultural Engineering. It was created through a grant from NCDENR. There are other proprietary models available to designers as well. The BAE model is accessed at the following website:
www.bae.ncsu.edu/stormwater/downloads.htm

4.6.4 Permeable Pavement Economic Considerations

Cost factors unique to permeable pavement include the following:

1. The type of pavement used. Not all permeable pavement types cost the same. In general, the permeable version of a pavement (pervious

concrete as compared to standard concrete) is approximately 15 percent more expensive than the standard, impermeable version.
2. The depth of the gravel-bedding layer. A deeper gravel base costs more, but does allow for more infiltration from the system.
3. The gravel-bedding layer needs to be washed. This increases the cost over a standard crusher run, which contains fines.
4. Slope of the lot. A flat lot is easier to construct. Pavement applications built on a slope will need internal berms to create an underground ponding zone. The berm cost will add up.
5. Other costs not unique to permeable pavements include surface area of the practice, impact of utility lines, and the ability to keep the permeable pavement free of off-site fine sediment.

4.6.5 Permeable Pavement Maintenance Considerations

Permeable pavements will function for up to 20 years if they are constructed in areas that are free of disturbed soil and are regularly maintained. A survey of 48 permeable pavement sites in North Carolina and other mid-Atlantic states verified that standard maintenance, such as street sweeping, increased infiltration rates of the permeable pavements tested.

4.7 Cisterns and Water Harvesting

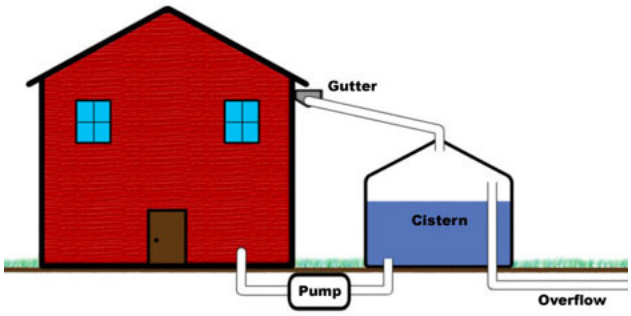
Cisterns harvest rainwater from rooftops and temporarily store water for uses such as irrigation, washing vehicles, washing laundry, and flushing toilets. Cistern water is most easily used for non-potable (non-drinkable) purposes; however, with special treatment, it can also be consumed.

The water harvesting system consists not only of a cistern, but also a pipe network diverting rooftop runoff to the cistern, an overflow bypass for when the cistern is full, and a pump and distribution network to deliver water to its intended use (Figure 4-20). Tanks, or cisterns, can hold from less than 100 gallons to more than 100,000 gallons for a small commercial site. The cisterns may rest on the surface or be located entirely below ground. Tanks are made of plastic, metal, or concrete, depending upon the cistern's size and location.

One typical small-scale cistern is the rain barrel. Rain barrels are typically less than 100 gallons in size and can be used for limited water needs, such as in a garden. Although rain barrels serve an excellent demonstration and awareness purpose, they rarely contribute a significant amount to runoff reduction due to their small size.

Pumps used to distribute water from cisterns tend to be low head, high flow pumps, like centrifugal pumps. The entire system cost for installation ranges

Figure 4-20. Water harvesting system
A water harvesting system consists of a cistern, which collects runoff from an adjoining rooftop, a gutter system to get the water to the cistern, and a pump to distribute captured rainfall to use in the home or on the landscape.



from $0.75 per gallon for larger cisterns to nearly $2 per gallon for smaller cisterns. Economies of scale certainly exist. Modeling has shown that in certain instances, the payback period for cistern systems is less than 10 years.

Benefits of harvesting rainwater include a minor reduction in flooding and associated reduction of channel erosion, the capture of rain-borne nutrients and other atmospherically-deposited pollutants, a free water supply for which the owner does not need to pay potable water fees, and the chance to use nutrient-rich stormwater for irrigation.

Large-scale water harvesting is practiced frequently in Florida and in parts of North Carolina. Golf course ponds have been used to capture stormwater runoff and reuse the runoff for green and other course irrigation.

4.7.1 Water Harvesting Design

Water harvesting systems are best sized by running a model that simulates long-term precipitation and water demands. Factors that are a part of the model are described below.

Supply
Water supplied by an individual precipitation event is calculated by the equation below.
$S_i = RF_i \times A \times CF$

S_i = Water supplied by an individual event (volume)
RF_i = Individual event rainfall (depth)
A = Surface area of roof (area)
CF = Capture factor

The capture factor (often set to 0.9) reflects the fact that not all the rain that falls on the roof finds its way into the cistern. Some water splashes off the roof during the rain and other water may overflow a gutter.

Demands
The most common demands for cistern-captured water are irrigation, vehicle (outdoor) washing, toilet flushing, and laundry. If the water is treated to high extent, it could be consumed (or be potable).

Irrigation rates are based upon required water for vegetative growth. Traditionally, water is applied at a rate so that just enough reaches vegetation. This is based on water conservation. However, for stormwater management, it has been suggested that water be over-applied so that the cistern has more space in it prior to the next storm event. The frequency of washing, the type of equipment used, and the length of washing time determine the amount of water dedicated to vehicle washing. Water used to supply toilet flushing is a function of the number of users and the volume of each flush.

A good starting rule for estimating the size of cistern is to try 1 gallon per square foot of rooftop.

Sizing Tanks to Optimize Solutions
A cistern is sized to optimize a balance of water demand met, the frequency of a dry cistern, the amount of water (and nutrients) captured, and cost (payback period). Various solutions might capture the majority of runoff but be quite expensive. In other cases, it is important for the cistern to rarely go dry, so an otherwise over-sized cistern might be most appropriate. For a residence, the size of a cistern to have any impact on runoff reduction probably needs to exceed 500 gallons.

Potential for Evapotranspiration and Infiltration
Remembering that the goal of LID is to meet a target hydrology, it is important to know how much rainfall a cistern water harvesting system can "convert" to ET and infiltration. Clearly, all water that bypasses the cistern is counted as outflow, but what about water used to irrigate landscapes, flush toilets, or wash vehicles? It is assumed that cistern water harvested for irrigation will be applied so that it infiltrates the ground. A subsequent portion of that is retained by the vegetation and eventually evapotranspires. In light of the *Low Impact Development: A Guidebook for North Carolina* being a "living document," at this point it is recommended to divide the volume of water used to irrigate a landscape evenly between irrigation and ET. Water that is used for toilet flushing neither infiltrates nor evapotranspires, but it also clearly does not run off. Because captured water used for toilet flushing does eventually return to the stream, albeit after the storm event has passed, it is recommended that this water be treated as if it were shallow interflow. Shallow interflow is part of the "infiltration" volume. Vehicle washing can either be treated like toilet-flushed water or irrigated water, depending upon where the washing occurs. Vehicle washing

that flows onto the permeable landscape (grass) resembles irrigation and is most apt to occur on residential property. Vehicle washing that occurs at a car washing facility will connect to the sanitary sewer network and therefore resembles toilet flushing.

4.7.2 Water Harvesting Design Models

A water-harvesting model is available from North Carolina State University's Department of Biological and Agricultural Engineering at the following website: www.bae.ncsu.edu/topic/waterharvesting

4.7.3 Water Harvesting Economic Considerations

Cost factors unique to cisterns and water harvesting systems include the following:

1. Whether or not the cistern is above ground or below ground. Above-ground cisterns are substantially cheaper but do occupy space that could otherwise be dedicated to another use.
2. Pumping: Pump costs may not be insignificant, especially if water is to be delivered to several areas and several uses.

4.8 Backyard or Pocket Wetlands

The most common reason a backyard, or pocket, stormwater wetland is used on an LID site is the presence of high water tables in places where stormwater is most ably treated. Very few LID practices function appropriately when there is a SHWT. In these situations, a shallow backyard wetland is often the most appropriate BMP.

The stormwater wetland should be designed so that it intersects the SHWT and possibly also the SLWT. If the difference between the SHWT and the SLWT is substantial, then a drier stormwater wetland will be created, which is reasonable as long as plant selection reflects the hydrology.

4.8.1 Pocket Wetland Design

Plant Selection
Plants for backyard wetlands usually need to be aesthetically appealing and mosquito resistant. It is also recommended that these plants be native to North Carolina. Fortunately, the majority of plants listed in Table 4-4 satisfy both counts.

Cattails (Typha spp.) are conspicuously absent from the list. Although native, cattails are well adapted to develop monocultures that shelter

mosquitoes from their predators. In short, if a stormwater wetland is to be located near a population center, such as a commercial center parking lot or a residential neighborhood, it is advised to keep cattail populations under control. If more than 15 percent of a stormwater wetland (that is located near people) is populated by cattails, it is recommended to remove the majority—if not all—of the cattails present. However, if stormwater wetlands are to be constructed in rural areas, such as along highways in eastern North Carolina, it is reasonable to allow cattail growth, as these plants are tolerant of relatively high pollutant loads and propagate easily.

Mosquito Resistant Design

A study was conducted in the mid-2000s in North Carolina showing that typically, mosquitoes were not present in high numbers at the majority of stormwater wetlands and wet ponds (Hunt et al., 2006b). However, it was found that mosquitoes can survive and thrive in wetlands with certain characteristics, namely: overgrown by monocultures of cattails, heavily

Table 4-4. Recommended vegetation for backyard or pocket stormwater wetlands

Common Name	Scientific Name	Normal Water Depths[1]	Comments
Spatterdock	Nuphar lutea	> 6”	Yellow flower most of summer
Softstem Bulrush	Schoenoplectus tabernaemontani	0–6”	Former scientific name: Scirpus validus
Pickerelweed	Pontedaria cordata	0–6”	Bright and showy purple / blue flower
Broadleaf Arrowhead	Sagittaria latifolia	0–3”	Broad leaves, white flowers in summer
Bulltongue Arrowhead	Sagittaria lancifolia	0–3”	White flowers in summer
Burreed	Sparganium americanum	0–6”	Tolerates flowing water zones near inlets and outlets
Lizard’s Tail	Saururus cernuus	2” – emergent 2”	Can dominate in drier years, distinctive thin white flower
Woolgrass	Scirpus cyperinus	2” – emergent 2”	Tall, brown seed head in late summer; makes tall border
Common Rush	Juncus spp.	2” – emergent 2”	Grows best at the water’s edge; near evergreen
Blue Flag Iris	Iris virginica	2” – emergent 2”	Showy blue flower in late spring; grows at water’s edge
Cardinal Flower	Lobelia cardinalis	0” – emergent 6”	Red flowers in late summer
Hibiscus (Rose Mallow)	Hibiscus moscheutos & H. grandiflorus	0” – emergent 6”	Beautiful, showy white and red flowers mid-late summer
Joe Pye Weed	Eupatorium purpureum	0” – emergent 6”	Purple bloom summer and fall

[1] At normal pool

wooded, algal mats, and floatage or debris. It was found that by providing habitat for predators and keeping mosquito habitat to a minimum, mosquito populations can be mitigated. One major conclusion of the study was to design several small deep pools throughout a stormwater wetland. These pools are refuges for mosquito predators like *Gambusia affinis* (mosquito fish). If a stormwater wetland is quite small (as many will be in LID applications), then either one deeper pool (18 inches of water) or none will be used. A second design recommendation was to include flowering species of vegetation that attract other mosquito predators such as dragonflies. The list presented in Table 4-4 contains many flowering species that are specifically inviting to mosquito predators. Mosquito resistant design is detailed in the following factsheet:

Hunt, W.F., C. S. Apperson, S. G. Kennedy, W. G. Lord. 2005. *Mosquito Control for Stormwater Facilities.* North Carolina Cooperative Extension Publication # AG-588-4, Raleigh, NC. Available at: www.bae.ncsu.edu/stormwater/PublicationFiles/Mosquitoes2005.pdf.

Mosquito Resistant Maintenance

In addition to design, stormwater wetlands must be maintained to keep mosquitoes from becoming a problem. Some common mosquito maintenance requirements include:

1. Removing unwanted trees and shrubs. Table 4-4 did not include any woody species because an abundance of woody species was found to provide a safe harbor for mosquitoes. It is reasonable to have a limited number of woody species (one recommendation is 1 tree per 3,000 square feet of wetland), but others will volunteer.
2. Removing cattails. Cattails, as discussed earlier, are very aggressive and can outcompete other vegetation if given enough time. Removing cattails as they arrive in the wetland is an annual to semi-annual process that need not be time consuming.
3. Removing trash and other floatables. Pocket wetlands, like all BMPs, receive water from a larger watershed, meaning that water not only comes to the wetland, but everything in or carried by the water does as well. Trash will necessarily collect in a wetland if there is a human population in or adjacent to the wetland's drainage catchment. Floating trash provides mosquitoes an area free of many predators.
4. Trash removal from outlet. In addition to being unsightly, trash can also clog a wetland's outlet.[12] A clogged outlet will necessarily raise the elevation of the water inside the wetland, which may cause desirable vegetation from Table 4-4 to die (that is, they would

[12] If the stormwater wetland treats a large enough watershed, there will be a rigorously designed outlet structure. Many small watershed wetlands (those treating less than 1 acre, for example) will not have an intensively designed outlet.

drown). Into these voids of dead vegetation the hardier species (like cattails) will come.

Drought Tolerance

One common concern among designers is the ability of shallow water plants to survive during a drought. As Figure 4-21 shows, once established, shallow water plants can tolerate being dry (not inundated) during drought periods. Remember that naturally occurring wetlands also become dry occasionally. In fact, wetting and drying cycles are key to the wetland's ability to treat many pollutants effectively. Even during droughts, soils within the wetland remain moist within a foot of the surface. As long as wetland plant roots are able to reach these moist soils, the wetland plants can survive during droughts.





Figure 4-21. Stormwater wetland in Durham during the drought of 2002 (top); deep pool of stormwater wetland in Craven County, North Carolina during the drought of 2007 (bottom). Note the pickerelweed (a plant that usually flourishes in 3 to 6 inches of water) that is "high and dry" (bottom)

Potential for Evapotranspiration and Infiltration

Stormwater wetlands do have ET and infiltration losses. The exact amount of each has not been well quantified. As water ponds in a stormwater wetland immediately following a storm, the level of water is usually above that of the surrounding groundwater table. Along the perimeter of a stormwater wetland, some post-storm infiltration loss would be expected. The volume of water lost from a given storm event would be the result of the height above the water table of the water ponded inside the wetland, the residence time of water inside the wetland, and the surrounding soil's permeability.

There are ET losses from the stormwater wetland between rainfall events. This amount varies by vegetation type and time of year. A preliminary study revealed that the amount of infiltration loss and ET loss annually may range from 22 to 26 percent and 11 to 26 percent, respectively (Jones, 2008).

4.8.2 Pocket Wetland Economic Considerations

Stormwater wetlands can be relatively inexpensive to construct, provided a SHWT is intercepted. Some cost considerations somewhat unique to these small wetlands include:

1. Excavation. If the water table to intersect is near the surface, then very little excavation is required. If the water table to intersect is, for example, 4 feet from the surface, then excavation costs will substantially rise.
2. Plant spacing. Most herbaceous species cost approximately $1 to purchase and install. Many designers desire the minimum spacing of 36-inch centers. However, this spacing (1) will leave the wetland with a barren look for at least a year, and (2) opens the door to cattail infestation. A more densely planted wetland (one plant on 24 inch centers) results in a better looking wetland in the short term, but is more expensive—although the expense is usually offset somewhat by lower maintenance costs, as fewer unwanted species need to be removed.
3. Outlet Construction. Outlets can become expensive to construct, especially for wetlands treating large watersheds. However, the small backyard wetlands discussed herein usually have simple outlets such as pre-treated lumber.
4. Required Aesthetics. If the wetland is "front and center" it needs to be more attractive, so specific planting plans must be followed and maintenance becomes more important.
5. Stormwater wetlands are more tolerant of excessive off-site sediment loads because they are not predicated on infiltration to function. This does not absolve the contractor from verifying that the upslope is stable or at least protected. Moreover, a stormwater wetland can eventually fill with sediment, inhibiting plant growth, if sediment is not carefully controlled.

4.9 Swales

4.9.1 Swale Design

Swale design is well reviewed in the NCDENR (2007) stormwater manual. One notable concept covered is turf reinforcement matting. Swales are typically designed to tolerate up to 4 feet per second (fps) velocities. Higher velocities cause erosion inside the swale. To combat this, a turf reinforcement mat can be employed that anchors grass to the earth. Figure 4-22 shows an example of turf reinforcement mat installation.

Turf reinforcement mats allow grass to tolerate substantially higher velocities (10 fps). This enables swales to be used for many more applications.

In cases where the swale intersects the SHWT, it can go "wet." If vegetation is allowed to follow its natural course, then this swale will eventually become a "wetland swale." Little research has been done on this type of swale's effectiveness; however, a wetland swale would presumably have better nutrient (particularly nitrogen) removal rates than standard swales. Velocities in wetland swales will tend to be quite low, so turf reinforcement matting is not necessary. Wetland swales do have a higher roughness coefficient (used to calculate swale geometry). Exact roughness coefficients have not been measured, but a Manning's n of 0.030 may be assumed to approximate a fully grown wetland swale. A second impact of wetland swales is that vegetation will cover much of the swale's cross section. In a standard low-cut grass swale, nearly all of the swale's cross section is open space. In a wetland swale, when vegetation overgrows the bottom, an estimated 10 percent of the cross-sectional area is taken up by plant mass. The higher roughness coefficient and the decreased amount of free space will lead a wetland swale's cross section to be larger than an equivalent dry swale.





Figure 4-22. Turf reinforcement matting installed in a swale in Durham, North Carolina

4.9.2 Swale Economic Considerations

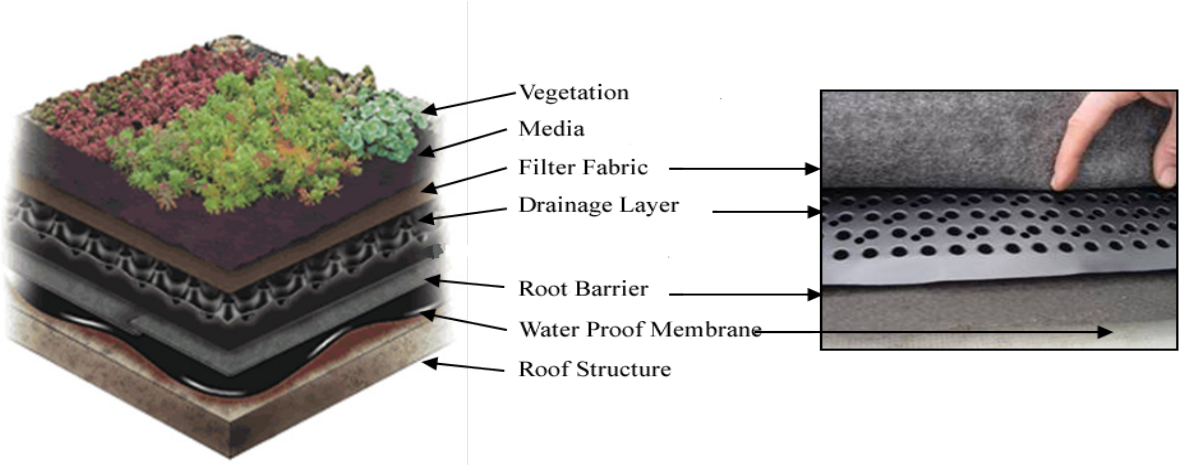
Costs unique to swales are:

1. Turf reinforcement matting. Turf reinforcement matting can increase the total swale construction cost by more than 50 percent. However, turf reinforced swales are still less expensive than the riprap swales they usually replace.
2. Maintenance. Swale maintenance will vary from simply mowing to occasional wetland plant harvesting or thinning. Swale maintenance is relatively simple.
3. Grass swales are often used for water quality benifits in liue of, or in addition to, curb and gutter.

4.10 Green Roofs

Green roofs are categorized as either extensive or intensive. Extensive green roofs, the type most often used in North Carolina, involve shallow media systems with low-lying vegetation. Extensive green roofs require little maintenance and are relatively inexpensive compared to intensive green

Figure 4-23. Layers of the green roof (courtesy of American Hydrotech, ©1996-2005)



roofs. Intensive roofs are designed for heavy loads, whether people or dead weight (soil and plants). Intensive green roofs may have more than 12 inches of media and trees or shrubs growing on them. The restaurant chain Carrabas™ uses intensive green roofs on many of its stores.

4.10.1 Green Roof Design

Media Selection

A green roof consists of many layers including those highlighted in Figure 4-23. The most costly design consideration is the media. Ideally, use the minimum amount of media that will (1) support the desired aesthetic, and (2) maintain needed hydrologic function. In North Carolina, the optimum green roof media depth is 3 to 4 inches. These roofs are deep enough to support vegetation and also meet hydrologic goals such as runoff reduction. A shallower roof is acceptable in climates that are colder than the humid and warm Southeast.

The type of media used on a green roof is critical to its performance. Although more research is needed on this issue, early indications are that the basic media (an expanded slate or expanded clay) with a marginal amount of compost (5 to 10 percent) is sufficient for reasonable plant growth. Avoid using compost such as animal waste, which readily leaches nitrogen and phosphorus (Hathaway et al., 2008).

Green roofs will support a roof pitch up to 8 percent. Steeper roofs require a containerized system (media is loaded in small boxes that are stacked "up the roof") (Figure 4-24).

Potential for Evapotranspiration

Studies show that green roofs mitigate small to medium-sized storm events throughout North America, including in North Carolina (Hathaway et al.,

2008; Berghage et al., 2007). In nearly every study, green roofs retained and sent back to the atmosphere, via ET, between 50 and 60 percent of all rainfall.



Figure 4-24. North Carolina Arboretum green roof

Because green roofs, like permeable pavement, are considered a surface that either generates runoff or produces ET, a curve number can be assigned to them. Research at North Carolina State has shown that a 4-inch media depth green roof should have a curve number between 80 and 88, which is substantially lower than that of a standard flat roof (98). Runoff peak coefficients (better known as Rational Coefficients) have also been calculated for green roofs, with the median Rational C being 0.65 for storms of intensities exceeding 2 inches per hour. Again, this is favorable to typical roof Rational Coefficients of 0.95 to 1.00. The media on the roof is able to slow down and retain water even in the largest events.

A study at Penn State (Berghage and Beattie, 2004) showed that a completely dry green roof could retain up to 0.4 inches of water per 1.0 inch of media depth. Field experiments in North Carolina suggested this number ranges from 0.2 inches to 0.4 inches of water per inch of media.

Hydrologic Model

A green roof model has been created at Penn State University with some North Carolina-specific features (Jarrett et al., 2008). The model is available on the North Carolina State University Department of Biological and Agricultural Engineering stormwater website: http://www.bae.ncsu.edu/stormwater/downloads.htm.

Vegetation Selection

Green roofs are a harsh environment, alternating between very wet and very dry. The roofs remain hot (but not extremely hot) in spring, summer, and fall. Essentially no native vegetation would be able to survive this desert-like environment. The types of plants that survive on green roofs are succulents, notably sedum and delosperma species on shallow media depth green roofs. Designers should contact a green roof plant vendor before selecting plants. One available website is www.greenroofplants.com

4.10.2 Green Roof Structural Considerations

Extensive green roofs, also referred to as "Landscape Roofs" in the North Carolina building code, need to be designed for a live load of 20 psf and a dead load of the saturated media. A 4-inch media depth green roof fully vegetated with sedum will require a dead load range of between 25 and 35 psf. An intensive green roof must withstand a live load of 100 psf. If a green roof is part of a new design and no structural retrofitting is required, then the extra cost of a green roof may be as little as $1 per square foot of roof. However, if a green roof is to be retrofitted onto an existing roof, the cost could be much more substantial. If an existing roof is to be retrofitted with a green roof, it is essential that a structural engineer be consulted to make sure the existing roof has excess capacity to handle the weight of the new green roof.

4.10.3 Green Roof Economic Considerations

Green roofs are undoubtedly the most expensive BMP per watershed unit area treated. However, they probably offer the most additional benefits of any BMP as well. Green roofs have been shown to increase roof life (by limiting ultra-violet penetration to the roof membrane), provide some insulation, reduce the heat island effect, and provide additional living space. What will typically trigger the use of a green roof is an ultra-urban BMP requirement. In locations where land costs are extremely high and there is no space available to dedicate to another practice, green roofs can be an attractive alternative.

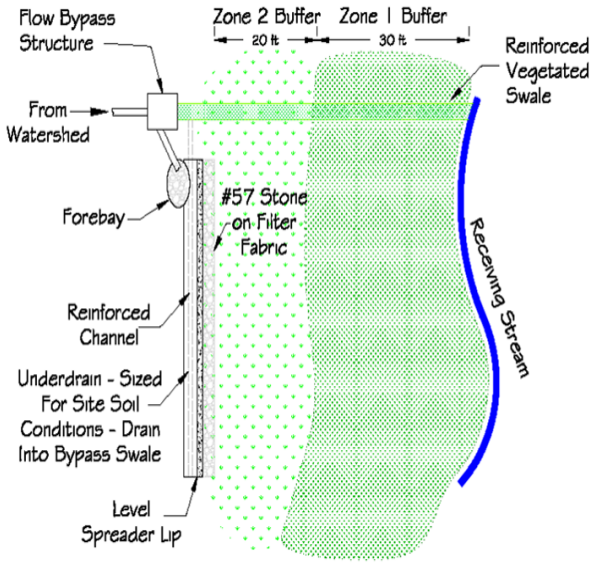


Figure 4-25. Level spreader / filter strip system

4.11 Level Spreaders and Filter Strips

Level spreaders and graded grass filter strips may often be the most appropriate BMP in locations with a SHWT near the surface (as might be expected in portions of the coastal plain). Their use, conversely, will be more limited in steep slope applications typically found in the mountains. Level spreader systems consist of three parts: the forebay, the channel, and the riparian buffer (or vegetated filter strip) (Figure 4-25).

Forebay
The first part of the system is the forebay, which is used for the preliminary treatment of stormwater. It is an excavated, bowl-shaped feature that slows the influent stormwater and allows heavy sediment and debris to settle. Forebays may be lined with riprap to reduce erosion within them. The uneven riprap surfaces function as small sedimentation basins. When a level spreader is used to disperse outflow from a detention pond, a forebay may be necessary to reduce runoff velocity before the outflow reaches the level spreader.

Channel
After the stormwater passes though the forebay, it enters a concrete, rock, or grassed channel—the main body of the level spreader. This is a dead-end channel because it does not directly connect the watershed to the stream. Instead, the channel is a long, shallow impoundment that fills to the level of its lower side. The lower side (the downslope side) of the channel is constructed so that it is level along its full length. This lower side, or level spreader lip, is often constructed of concrete or metal so that it resists erosion. As stormwater enters the channel, it rises until it fills the channel and exits evenly over the lip. The downslope side of the system functions as a long, broad-crested weir.

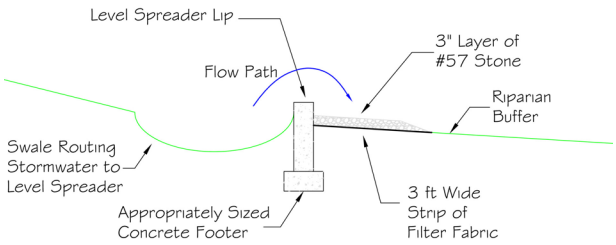
Riparian Buffer
After the stormwater passes over the level spreader lip, it enters the riparian buffer, often simply called the buffer. As the stormwater passes through the buffer vegetation, some of the water infiltrates. Ideally, the buffer will remove sediment and nutrients from runoff before it reaches the stream.

4.11.1 Level Spreader Design

Level Spreader Lip
A level spreader system obviously needs a stable lip that will not erode. Concrete level spreaders can be built with minimal slope along the length of the channel's downslope side. Concrete level spreaders resist erosion better than level spreaders made of earth, gravel, or both. If a flow greater than the design flow is routed over a concrete level spreader, it will not be damaged. Level spreaders made of earth, ABC stone, or both should not be used in any urban applications because they routinely fail. Another stable material is a metal gutter. Like concrete level spreaders, prefabricated metal level spreaders can be expected to remain level with minimal maintenance.

Ideally, the lip of the concrete level spreader should be higher than the existing ground by 3 to 6 inches. This allows water to pass over the lip without interference from buffer vegetation. To limit any erosion that could occur as water falls from the top of the level spreader to the existing

Figure 4-26. Sample cross section of a concrete level spreader



soil, a layer of filter fabric should be extended a distance of 3 feet from the level spreader lip towards the buffer. Stone, such as No. 57 aggregate, should be placed on top of the filter fabric (3 to 4 inches deep) to reduce erosion just downslope of the level spreader (Figure 4-26). A 3-foot wide strip of erosion control matting can be used in place of the filter fabric and No. 57 stone combination. However, such an area must be stable and have adequate vegetation before receiving stormwater.

Level Spreader Dimensions

Level spreader dimensions span a broad range, and no combination seems to be superior. The width of a level spreader, however, should be three times wider than the diameter of the pipe feeding the system. The design depth, or depth between the invert of the level spreader channel and the level spreader lip, is currently recommended to be no less than either 9 inches or half of the inlet culvert diameter, whichever is greater.

Discharging into a buffer with thick ground cover requires 13 feet of level spreader for every 1 cubic foot per second (cfs) of flow. This design specification is based on maximum flow velocities to limit erosion in the buffer. Grass, for example, is more resistant to erosion than mulch and detritus in woods. Therefore, a shorter length of level spreader is needed upslope of grass than upslope of mature woods. In forested buffers, this number varies based on the width of the riparian buffer. The wider the riparian buffer, particularly wooded buffers, the more stormwater will infiltrate the buffer. When infiltration within the buffer is taken into account, the length of level spreader per unit of flow can be reduced:

- A level spreader discharging onto a 50-foot wide wooded riparian buffer should be sized at 65 feet per 1 cfs of flow.

Table 4-5. Level spreader length sizing guidelines

Filter Strip Vegetation	Riparian Buffer Width (ft)	Length of Level Spreader (ft per 1 cfs of flow)
Thick ground cover	Any width	13
Forested	Any width	65
"Neuse"	30' wooded + 20' grass	45

- Discharging onto a 100-foot wide wooded buffer requires 50 feet of level spreader per 1 cfs of flow.
- Discharging onto a 150-foot wide wooded buffer requires 40 feet of level spreader per 1 cfs of flow.

The minimum length of any level spreader should be 13 feet, and the maximum allowable length by Department of Water Quality (DWQ) standards is 130 feet. A summary of the sizing guidelines for level spreader lip length is shown in Table 4-5.

Forebay Inclusion

Forebays should be used in level spreader systems to dissipate energy and reduce the sediment that accumulates behind the level spreader lip (Figure 4-27). The forebay is essentially a bowl-shaped depression lined on the bottom and sides with Class B riprap. The forebay should be sized so that it is 0.2 percent of the contributing catchment's impervious or paved surface area.

The depth of the forebay where the stormwater initially enters should be 3 feet. The forebay should then taper upward to a depth of 1-foot prior to discharging into the level spreader (Figure 4-28).

Flow Bypass

If runoff from large storms (those that deliver more than 1 inch of rain per hour) is allowed to flow through a level spreader or riparian buffer system that is not designed to handle such storms, erosion can occur within the buffer. Thus, during heavy rain storms that produce more runoff than can be infiltrated by the buffer, excess stormwater should bypass the buffer and be sent through a protected channel to a predetermined protected stream entry point. This is achieved by allowing the runoff produced by a rainfall intensity of 1 inch per hour to enter the

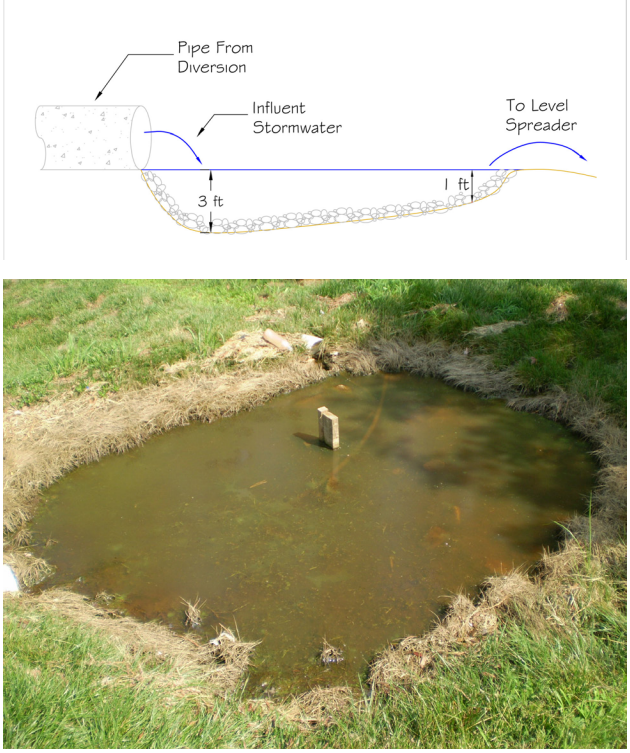


Figure 4-27. Forebay schematic (top); level spreader with forebay (bottom)



Figure 4-28. Forebay

level spreader while diverting runoff from heavier rainfalls to the stream. The bypass channel, or swale, should employ turf reinforcement matting or riprap.

Maximum Slope
The first 10 feet of riparian buffer downslope of the level spreader should have a slope less than or equal to 4 percent.

The overall slope of the buffer should not exceed 6 percent for wooded buffers and 8 percent for buffers containing thick ground cover (such as grass). When slopes are greater than this, other practices, such as bioretention, stormwater wetlands, and ponds can be used to reduce peak flows and provide water quality improvements. However, on a case-by-case basis, the DWQ may approve a series of level spreaders for riparian buffer slopes of 12 to 15 percent. This approval is contingent on a site visit and the professional judgment of the DWQ individual permitting the project.

Potential for Evapotranspiration and Infiltration
Vegetated filter strips, including riparian buffers, are able to infiltrate a substantial amount of water. Much of this water can be captured by vegetation and potentially evapotranspired. North Carolina State researchers are conducting research in 2009 at two level spreader sites in the piedmont of North Carolina to determine the volume of water the level spreader system removes from outflow. The level spreaders were designed following the guidance presented here. The amount of infiltration is expected to vary by downslope cover and width of the filter strip.

Advantage of Designed Vegetated Filter Strips over Naturally-occurring Riparian Buffers
Studies show that designed filter strips will infiltrate substantial quantities of runoff when used in conjunction with level spreaders (Hathaway and Hunt, 2007). The reason for this is that vegetated filter strips are graded according to design, ensuring their "levelness" and downward slope. Water will remain in sheet flow for much longer periods than those associated with a naturally occurring riparian buffer. An extensive study by Hathaway and Hunt (2008) showed that level spreaders upslope of riparian buffers did not provide diffuse flow in any of the 24 level spreader and riparian buffer systems examined. In many cases the topography of the riparian buffer forced water to re-concentrate, effectively bypassing most of the riparian buffer's hydrologic benefits. Grassed filter strips that are evenly graded perpendicularly from the level spreader tend to keep flow from concentrating, thus allowing for increased infiltration. In the study by Hathaway and Hunt (2007), of the 29 storm events that occurred in a residential neighborhood in Charlotte, North Carolina, only three produced any outflow at the far edge of the filter strip. While this is one unique case,

the runoff reduction implications are positive for the use of this BMP, particularly in areas such as the coastal plain, where SHWTs are too high for bioretention, permeable pavement, and other infiltration-based practices.

4.11.2 Level Spreader Economic Considerations

1. Level spreaders are one of the least expensive BMPs to construct. However, their cost has increased due to the material requirement (concrete or other hardened structure in lieu of wood, earth, or gravel). Access to the level spreader site by a concrete truck is often an issue.
2. The level spreader itself does not occupy a substantial amount of room, but the vegetated filter strip does. If the vegetated filter strip is a riparian buffer, regulations may require this land to be set aside, making the level spreader–filter strip system even more affordable.
3. Perhaps more than any other BMP, however, prospective level spreader–vegetated filter sites must be visited by the designer prior to design, if existing topography is to be used. Especially in riparian buffers, draws will form over time, which will prematurely collect sheet flow and convey it to the stream. Level spreaders must be located above filter strips void of existing draws.

4.12 Other Tools

4.12.1 Infiltration Trenches and Basins

For a thorough review of infiltration wells, trenches, and basins, please see the *Stormwater BMP Manual* (NCDENR, 2007). Many of the concepts discussed in the bioretention section of this chapter also apply to infiltration trenches and basins, particularly that deeper and oversized basins will convert a much higher fraction of inflow to infiltration. Also, infiltration trench and basin hydrology is affected by the geometry of the practice. Maximizing the perimeter-to-surface area ratio of the practice will improve the infiltration basin's performance.

4.12.2 Sand Filters

NCDENR (2007) provides a thorough design review of sand filters in the *Stormwater BMP Design Manual* (NCDENR, 2007).

4.12.3 Soil Amendments

Amending soil during and immediately after construction can help make BMPs more permeable. Ripping and subsoiling soils previously compacted during construction, followed by planting and mulching

with organic matter, can keep the soil from crusting over. This leads to increased infiltration in soils that are moderately permeable in pre-disturbed conditions. A study was conducted at the University of Tennessee- Knoxville (Tyner, 2009) showing that ripping the soil base beneath permeable pavements significantly improved infiltration.

4.13 Linking BMPs Together: Treatment Trains

One of the hallmarks of LID is linking practices into "treatment trains." Having a green roof lead to a cistern or water harvesting system, or permeable pavement outflow draining to a bioretention cell, or a series of smaller practices eventually draining to a large stormwater wetland are all examples of treatment trains. In this manner, the treatment effects provided by each practice compound each other. In fact, some newer design guidance suggests treating each practice as a series of unit processes, such as infiltration, evapotranspiration, filtration, sedimentation, and detention. Some practices consist of one unit process, while others contain multiple unit processes. The eventual goal would be to employ as many unit processes in a treatment train as possible. Chapter 2, Achieving LID Performance Goals Using a Hydrologic Cycle Approach, provides a framework for BMPs and the unit processes of infiltration and evapotranspiration to be combined.

ADDITIONAL RESOURCES

North Carolina Department of Environment and Natural Resources (NCDENR). 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

REFERENCES

Barrett, M. E. 2003. Performance, cost, and maintenance requirements of Austin sand filters. *Journal of Water Resources Planning and Management* Vol. 129(3): 234-242.

Bean, E. Z., W. F. Hunt, and D. A. Bidelspach. 2007a. Field survey of permeable pavement surface infiltration rates. *Journal of Irrigation and Drainage Engineering* Vol. 133(3): 247-255.

Bean, E. Z., W. F. Hunt and D. A. Bidelspach. 2007b. Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. *Journal of Irrigation and Drainage Engineering* Vol. 133(6): 583-592.

Beattie, D. and R. Berghage. 2004. Green roof media characteristics: The basics. In *Proceedings of the 2nd International Conference on Greening Rooftops for Sustainable Communities* (Portland, OR, June 2-4, 2004). Toronto, Ontario: Green Roofs for Healthy Cities–North America.

Berghage, R. D., D. Beattie, A. R. Jarrett, et al. 2009, Feb. *Green Roofs for Stormwater Runoff Control* (EPA/R/600/R-09/026). Cincinnati, OH: U.S. EPA, National Risk Management Research Laboratory. http://www.epa.gov/nrmrl/pubs/600r09026/600r09026.pdf

Collins, K. A., W. F. Hunt, and J. M. Hathaway. 2008a. Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering* Vol. 13(12): 1146-1157.

Collins, K. A., W. F. Hunt, and J. M. Hathaway. 2008b. Nutrient and TSS removal comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering* (submitted).

Deal, N. E. J. Buchanan, K. Farrell-Poe, M. Gross, D. Gustafson, D. Kalen, B. Lesikar, D. Lindbo, G. Loomis, R. Miles and C. O'Neill. 2007. Speaking the same language: a glossary for the decentralized wastewater treatment field. In K. Mancl (ed.) *On-Site Wastewater Treatment. Proceedings of the Eleventh National Symposium on Individual and Small Community Sewage Systems*. ASABE, St. Joseph, MI.

Dierkes, C., L. Kuhlmann, J. Kandasamy, and G. Angelis. 2002. Pollution retention capability and maintenance of permeable pavements. In *Proceedings of the 9th International Conference on Urban Drainage, Global Solutions for Urban Drainage* (Portland, OR). Reston, VA: ASCE.

Dietz, M. E. and J. C. Clausen. 2006. Saturation to improve pollutant retention in a rain garden. *Environmental Science and Technology* Vol. 40(4): 1335-1340.

Dietz, M. E. 2007. Low impact development practices: A review of current research and recommendations for future directions. *Water, Air and Soil Pollution* Vol. 186: 351-363

Ferguson, B. K. 2005. *Porous Pavements*. Boca Raton, FL: CRC Press.

Hathaway, A. M., W. F. Hunt, and G. D. Jennings. 2008. A field study of green roof hydrologic and water quality performance. *Transactions of the ASABE* Vol. 51(1): 37-44.

Hathaway, J. M. and W. F. Hunt. 2006. *Level Spreaders: Design, Construction, and Maintenance* (AG-588-9). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf

Hathaway, J. M. and W. F. Hunt. 2007. *Little Sugar Creek -Westfield Level Spreader: Final Monitoring Report*. Charlotte, NC: City of Charlotte.

Hathaway, J. M. and W. F. Hunt. 2008. Field evaluation of level spreaders in the piedmont of North Carolina. *Journal of Irrigation and Drainage Engineering* Vol. 134(4): 538-542.

Hsieh, C-H. and A. P. Davis. 2005. Evaluation and optimization of bioretention media for treatment of urban storm water runoff. *Journal of Environmental Engineering* Vol. 131(11): 1521-1530.

Hunt, W. F. 2003. *Pollutant Removal Evaluation and Hydraulic Characterization for Bioretention Stormwater Treatment Devices*. Ph.D. Dissertation. University Park, PA: Pennsylvania State University.

Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006a. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* Vol. 132(6): 600-608.

Hunt, W. F., C. S. Apperson, S. G. Kennedy, et al. 2006b. Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA. *Water Science and Technology* Vol. 52(6-7): 315-321.

Hunt, W. F., J. T. Smith, S. J. Jadlocki, et al. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *Journal of Environmental Engineering* Vol. 134(5): 403-408.

Hunt, W. F., C. S. Apperson, S. G. Kennedy, and W. G. Lord. 2005. *Mosquito Control for Stormwater Facilities* (AG-588-4). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Mosquitoes2005.pdf

Hunt, W. F. and W. G. Lord. 2006a. *Bioretention Performance, Design, Construction, and Maintenance* (AG-588-5). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Biorention2006.pdf

Hunt, W. F. and W. G. Lord. 2006b. *Stormwater Wetland and Wet Pond Maintenance* (AG-588-7). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/WetlandMaintenance2006.pdf

Hunt, W. F, M. R. Burchell, J. D. Wright and K. L. Bass. 2007. *Stormwater Wetland Design Update* (AG-588-12). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/WetlandDesignUpdate2007.pdf

Hunt, W. F. and K. A. Collins. 2008. *Permeable Pavement Research and Design Implications* (AG-588-14). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/PermeablePavement2008.pdf

Interlocking Concrete Pavement Institute (ICPI). 2004. *Concrete Grid Pavements* (Tech Spec 8). Washington, DC: ICPI.

Jarrett, A. R., W. F. Hunt and R. D. Berghage. 2008. Evaluating a Spreadsheet Model to Predict Green Roof Stormwater Management. In *Proceedings of the 2nd National Low Impact Development Conference*. Reston, VA: ASCE.

Jones, M. P. 2008. *Annual Hydrology of a Stormwater Wetland in Eastern and Central North Carolina*. Internal report. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Jones, M. P. and W. F. Hunt. 2006. *Choosing a Pump for Rainwater Harvesting* (AG-588-8). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Pumps4Cisterns2006.pdf

Jones, M. P. and W. F. Hunt. 2007. *Designing Urban Stormwater BMPs for Trout Waters* (AG-588-10). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/BMPsColdTemps2007.pdf

Jones, M. P. and W. F. Hunt. 2009. Bioretention impact on runoff temperature in trout-sensitive waters. *Journal of Environmental Engineering* (in press).

Karasawa, A., K. Toriiminami, N. Ezumi and K. Kamaya. 2006. Evaluation of performance of water-retentive concrete block pavements. In *Proceedings of the 8th International Conference on Concrete Block Paving, Sustainable Paving for Our Future* (San Francisco, CA). Herndon, VA: ICPI.

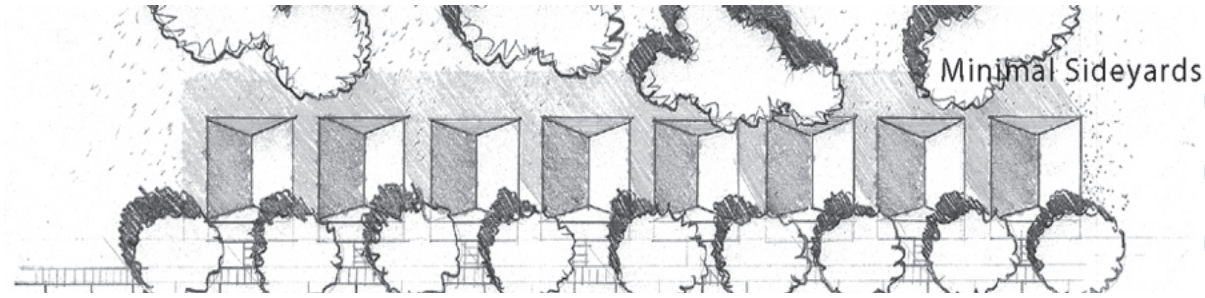
Kwiatkowski, M., A. L. Welker, R. G. Traver, et al. 2007. Evaluation of an infiltration best management practice utilizing pervious concrete. *Journal of the American Water Resources Association* Vol. 43(5): 1-15.

Li, H., L. J. Sharkey, W. F. Hunt and A. P. Davis. 2008. Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland. *Journal of Hydrologic Engineering* Vol. 13(4) (in press).

North Carolina Department of Environment and Natural Resources (NCDENR). 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

Tyner, J. S., W. C. Wright and P. A. Dobbs. 2009. Increasing exfiltration from pervious concrete and temperature monitoring. *Journal of Environmental Management* doi:10.1016/2009.02.007(in press).

Virginia Department of Transportation (VDOT). *Guidelines for 1993 AASHTO Pavement Design*. Richmond, VA: Virginia Department of Transportation – Materials Division, Pavement Design and Evaluation Section. http://www.virginiadot.org/business/resources/bu-mat-pde-AASHTOForConsultants0503.pdf



CHAPTER 5: LID AND DECENTRALIZED WASTEWATER TECHNOLOGY AND MANAGEMENT

By David Lindbo, Nancy Deal, Joe Lynn, Diana Rashash, and Robert Rubin

This chapter explores how the wide range of on-site wastewater treatment and dispersal systems (also called decentralized wastewater technologies and management) offer viable options and benefit low impact development and related goals.

5.1 Introduction to Decentralized Wastewater Management

North Carolina relies upon on-site systems to treat and disperse wastewater for more than 50 percent of its population. This number is likely to increase with development. The conventional approach to on-site wastewater treatment and dispersal may have limitations (requiring large lots for treatment, dispersal of wastewater, and repair), but it does have some benefits when used in an overall low impact development plan that incorporates all aspects of the natural as well as social environment.

The concept of decentralized wastewater technology and management refers to wastewater treatment and dispersal systems ranging from the individual on-site treatment system (commonly known as the septic system) to small community collection and treatment systems. Site location, design, installation, operation, and maintenance are considered. Decentralized systems typically rely on land application (via either surface or subsurface dispersal) of wastewater. They allow the treated wastewater to reenter the hydrologic cycle close to where the water was removed, often, as in the case of an individual system, less than a few hundred feet. They are considered to be non-point source discharges. This is in contrast to centralized wastewater technology and management where wastewater is collected and treated at a large municipal treatment plant. The treated wastewater is then dispersed to the environment as point source discharge, effectively removing the water from the area in which it was utilized. The U.S. Environmental Protection Agency (EPA) has recommended decentralized wastewater management as a preferred choice in rural areas across the U.S. (EPA, 2003; 2005).

5.2 Decentralized Wastewater and LID

Clustering multiple facilities into one large drain field offers advantages. For example, a drain field can become an amenity as open space for walking trails or other activities. No permanent structures should be located on the drain field, and no livestock should be allowed in the area. It can be planted and managed as a piedmont prairie or other type of non-wooded habitat. Grass, low-growing plants and other vegetation can be grown, so long as they do not interfere with the operation and maintenance of the system. Irrigation systems should not be installed.

All septic systems recycle water indirectly as it enters the house from the well, is used by the residents, and then is flushed into the septic system as wastewater (Figure 5-1). The wastewater does not remain in the septic system, but is slowly dispersed into the soil, where it is treated naturally and allowed to percolate into the groundwater. This process keeps the water taken into the house in the same watershed, as opposed to centralized sewer and collection systems that may transport or dispose of wastewater in a different basin, potentially depleting local aquifers and waterways.

Septic systems can treat nutrients on site. A typical household with four people will produce approximately 40 pounds of nitrogen (N) and 5 pounds of phosphorous (P) annually, and grasses or other vegetation can utilize some of the N over the drainfield. The remaining N will likely move off-site in groundwater as nitrate, or it may naturally be denitrified in the soil. Phosphorus will likely be adsorbed onto soil particles. As long as no erosion occurs, the soil provides a large sink for P from wastewater.

Pathogens or germs common in wastewater are effectively treated on site by the soil. Once effluent flows into the soil, most of the pathogenic bacteria and viruses are filtered out or die off.

Wastewater can be treated to allow for reuse. It is possible to remove the majority of pathogens and nutrients using more advanced technologies. Treated water can be disinfected by either chlorine or ultraviolet light and can be used for toilet flushing or landscape watering. Reusing wastewater in this fashion reduces dependence upon our limited water resources. An added benefit from using reclaimed water for irrigation is that the plants, reducing the need for chemical fertilizers, can assimilate some

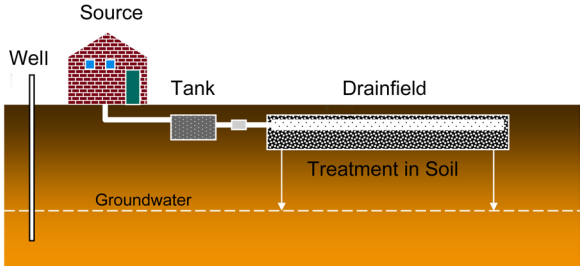


Figure 5-1. Typical components of a conventional septic system

of the nutrients. Reuse of treated wastewater is practiced throughout the world.

Decentralized systems can allow for best use of the soil and site. Drain fields for a development can be located to take advantage of areas of suitable soil, resulting in either on- or off-site (remote) systems. Wastewater may also be collected in cluster systems: it is collected for several houses or buildings and dispersed in a large communal drain field or surface application area.

5.3 Wastewater Characteristics

Wastewater is a mixture of organic and inorganic constituents that are transported in water. This chapter will consider only the nutrient and biological (pathogenic) components. Other constituents include fats, oils, and greases (FOGs), and inorganic material such as soil particles, pharmaceuticals, and personal health care products. Although these must be considered and effectively treated, their discussion is beyond the scope of this document.

The majority of wastewater is not produced from the toilet or commode (Figure 5-2); only about 25 percent is produced as toilet waste (also known as black water). An additional 25 percent is from bathing, and laundry wastewater accounts for another 25 percent. The final 25 percent is composed of kitchen wastewater and miscellaneous use. Bath, laundry, and kitchen wastewaters are often termed gray water, but they too may contain bacteria and nutrients and are treated as black water.

Since wastewater flowing to a decentralized treatment component contains human wastes, it will contain bacteria, some of which may be pathogenic. The list of these organisms is long and can vary greatly from one wastewater source to another. Typically, the bacteriological strength of the wastewater is characterized by the fecal coliform content expressed as colony forming units (CFU) per 100 milliliters. Along with bacteria and biochemical oxygen demand (BOD), wastewater contains nutrients such as N and P. Both of these nutrients can have significant negative ecological implications. Both N and P can be effectively treated by conventional as well as advanced decentralized wastewater treatment systems.

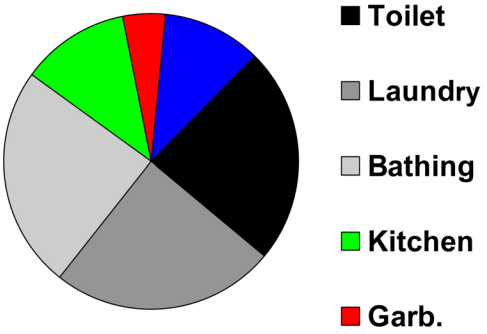


Figure 5-2. Wastewater production

One final aspect of wastewater characteristics is flow. By rule, flow from a residence is determined by the number of bedrooms. It is generally assumed that an individual produces 60 gallons per day of flow and

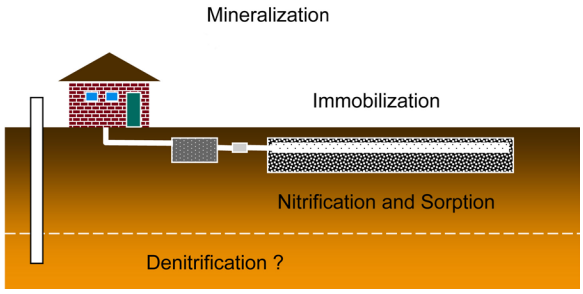
that there are potentially two people per bedroom, making the estimated flow 120 gallons per day per bedroom. In designing a system, the number of bedrooms for the residence is multiplied by 120 to get "design flow." Design flow is then used in conjunction with soil and site factors (long-term acceptance rate or LTAR) to determine the size of the system. A problem arises when a residence uses 70 percent or more of its design maximum. This can reduce treatment efficiency and may lead to premature failure.

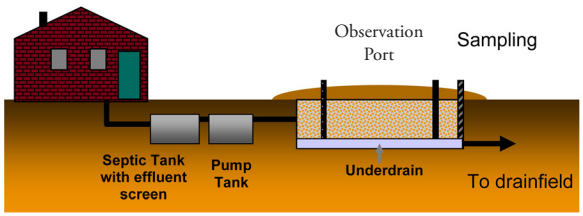
5.4 Treatment of Wastewater in a System

Once the wastewater is generated in the house, it flows into the septic tank. The septic tank is a large, watertight, reinforced concrete box that is buried underground adjacent to the house. The primary purpose of the septic tank is to act as a settling basin for solids and a holding tank for the wastewater. In this environment, wastewater treatment is limited due to the lack of oxygen. Nevertheless, there is a reduction in BOD and total suspended solids (TSS), as well as slight reductions in some nutrients due primarily to retention in either the scum layer, sludge layer, or both.

As the wastewater flows out of the septic tank into the drain field and soil beneath it, the majority of treatment occurs. Within the drainfield, the effluent flows out of holes in the drainpipes and slowly trickles through the gravel down to the soil. Once wastewater flows into the soil, many of the pathogenic bacteria and smaller organisms such as viruses are filtered out or die. Nutrients such as phosphorus and some forms of nitrogen may be adsorbed in the soil, thus reducing nutrient additions to the environment (Figure 5-3). In a properly functioning drainfield, the soil beneath the trenches is aerobic (contains oxygen). The aerobic

Figure 5-3. Nitrogen transformations in a conventional septic system





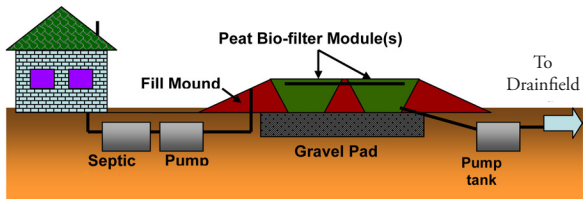


Figure 5-4. Advanced treatment system

Figure 5-5. Off-site systems

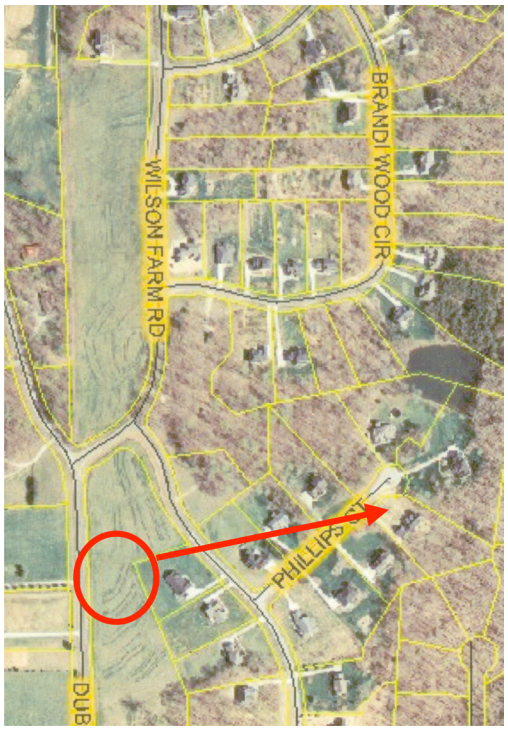
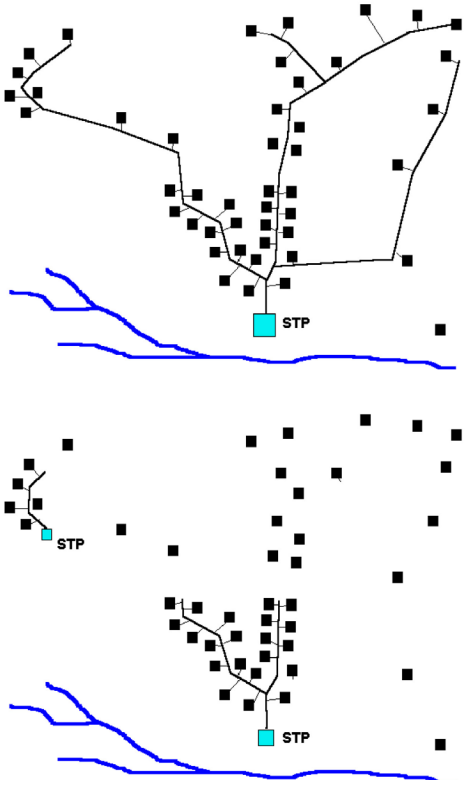


Figure 5-6a & b. Central sewer (top); cluster systems (bottom) (EPA, 2003; 2005)



conditions are needed to assure proper treatment of the pathogenic bacteria found in the effluent (Figure 5-1). Advanced treatment systems can achieve high levels of treatment with routine and predictable denitrification of aerobically treated wastewater (Figure 5-4).

5.5 Types of Wastewater Systems

On-site systems come in a vast array of types, sizes, and shapes too numerous to detail in this publication, but they all contain several common features. Typically, a system consists of four basic parts: the source (building), the septic tank, the drainfield, and the soil beneath the drain field (Figure 5-1). We consider "the system" to be a treatment train where wastewater flows from one component to the next. Decentralized wastewater treatment systems can be divided into three broad groups: individual systems, off-site systems (Figure 5-5), and cluster systems (Figure 5-6). Within each of these broad groups a wide array of treatment trains and components are possible.

5.6 Site Evaluation for Wastewater Systems

In general, soils that are relatively deep and well drained are best suited for wastewater systems. A deep, well-drained soil is likely to be aerobic and treat the wastewater more effectively than a shallow soil that is wet or poorly drained. Also, sites that have a gentle slope (5 to 15 percent is ideal) allow better water management. Landscape position is also important. Systems located at the base of slopes tend to be more problematic than those in a higher landscape position. Any landscape position that would allow water to pond (such as a depression) is considered to be unsuitable.

North Carolina uses a soil morphologic and site evaluation approach as a basis for determining long-term acceptance rates for onsite wastewater systems. Based on the 2005 North Carolina General Assembly rules, soil texture is used to determine the LTAR range for a given location. The LTAR is then adjusted based on other morphologic factors. The LTAR determination method follows a step-by-step approach. In the end the

system is a custom design for each house, lot, subdivision, or community. Advance treatment and effective management can reduce LTAR, resulting in a more efficient use of land resources and lessening the overall risk to the environment.

5.7 Wastewater System Selection and Design

Once the site has been evaluated, the system type can be selected. System selection is first based on soil depth and available space (Figure 5-7). If conventional systems cannot be used, a system is selected based on other factors such as risk, costs, and permitting issues.

One advantage of LID is that the site is assessed in a holistic fashion. In some cases, the system choice may be based more on environmental risk than on expediency and cost.

Development of any sort should consider wastewater needs. If wastewater cannot be treated and dispersed (either by central collection and treatment or decentralized treatment and dispersal) then there is no development. Decentralized wastewater treatment and management has some specific advantages when considering a greener (lower impact) development. First, the entire site is evaluated to determine where the soils are best for different types of systems. At this stage the soil and site can help determine the best areas for stormwater BMPs and identify areas that warrant special attention (springs, seeps, unique vegetation, and others). Second, these systems allow for local aquifer recharge. Potable water is removed via drinking water wells, utilized in the residence or business, and then treated in the soil or dispersed to the aquifer close to where it was removed. This process maintains local base flow more effectively than if the wastewater were collected, treated, and discharged by a central treatment plant far from its source. Third, smaller decentralized systems minimize the effect of catastrophic events such as hurricanes. In other words, smaller systems are more resilient. Next, these systems often reduce overall density, as the land area must be set aside for wastewater treatment and dispersal. This space can be designated as open and protected. Fifth, planning and using the land resource effectively, including a decentralized system approach, costs less than a central sewer. The decentralized approach can save up to 50 percent in initial development costs and 80 percent in long-term costs. In the end, an assessment of the area is needed to choose the best technologies for the site based on soil and site conditions. All BMPs (wastewater, construction, storm water, and

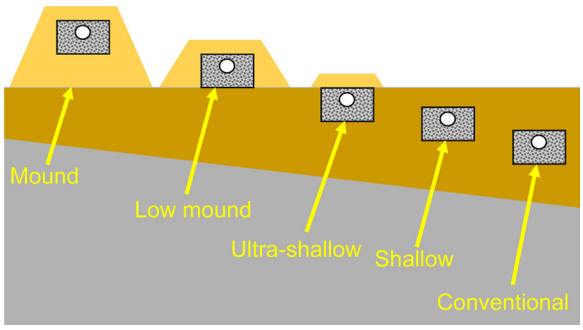


Figure 5-7. Matching system to site conditions

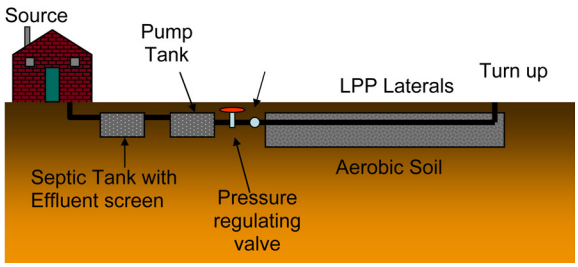


Figure 5-8. Low-pressure pipe system

others) should be considered at the outset so that the design of each BMP is compatible with the others.

System design and selection must consider the expected daily flow, expected wastewater characteristics, and soil and site conditions. The applicant or owner's preferred building location, building footprint, driveway location, and location of other structures must be considered whenever applicable. Site preparation and landscaping plans must be considered in designing the system. Applicable rules and regulations must be considered. For example, the North Carolina building code requires foundation drains in some situations, and surface water must be diverted away from manufactured homes. North Carolina water supply watershed rules may require additional setbacks from surface waters.

The LTAR chosen is determined by the soil and site conditions and by the type of system under consideration. For example, a clay soil would have an LTAR between 0.4 and 0.1 gpd/ft^2 for a conventional system, but it would be 0.2 to 0.05 gpd/ft^2 for a low-pressure pipe system (Figure 5-8). Also, saprolite systems and drip systems have different LTARs. The site evaluator should work closely with the designer to determine the appropriate LTAR for the given site, system, and regulation as applicable.

The system option(s) will be determined by the depth of usable soil or saprolite to an unsuitable horizon; expansive mineralogy, restrictive horizon, soil wetness; rock, parent material, or unsuitable saprolite; and the steepness of the slope.

An on-site system that is a good match with the soil and site conditions should function properly for a long time, provided it is properly used and maintained. No system will function as designed if daily flows are consistently exceeded, the characteristics of the effluent changes adversely, no maintenance activities are performed, or components are damaged.

5.8 Wastewater Construction Considerations

Sequencing and Site Protection

The system, other LID BMPs, and construction need to be installed in such a way as to not interfere with each other. This requires coordination with all contractors. It must be understood that if the wastewater system (including the reserve area) is damaged during construction to the point where it cannot be used, the certificate of occupancy may not be issued.

Compaction
If the system area is compacted, it can cause premature system failure. Ideally, once the system is installed, the area (including repair) will be flagged and no other traffic will go over it.

Site Clearing
Site clearing should be done with minimal disturbance and compaction.

Final Grading
Final grading over the system should be the last step. It should be done with the smallest, lightest equipment possible. Final grading over the system must comply with the system permit and allow for appropriate cover such as turf or low-maintenance plantings.

Landscaping
Post-construction landscaping can benefit or destroy an on-site wastewater treatment system. Good landscape ensures that surface flow (including roof runoff) is diverted from the entire system. Poor landscaping allows surface flow to go over the system or for other stormwater BMPs to be installed over the system or repair area, which should be avoided. Low ground covers, native grasses, and perennial plantings are encouraged to minimize root invasions, maintenance, and site disturbance. Installing an irrigation system over a wastewater treatment system is always discouraged.

5.9 Permitting

Various agencies oversee decentralized wastewater system permitting in North Carolina. All subsurface systems are under the Onsite Water Protection Section (OWPS) of NCDENR-DEH, with local health departments acting as authorized agents of the state. All systems that apply to land or discharge to surface water fall under NCDENR Division of Water Quality (DWQ) oversight. Each has a slightly different set of rules governing system classification, permitting, responsibilities and enforcement. Any person owning or controlling a residence, business, or place of public assembly that is not served by a public sewer must obtain a septic permit prior to obtaining any building permits or initiating construction.

5.10 Operations and Maintenance

Operation and maintenance (O&M) are essential to successful long-term performance of wastewater treatment technologies, thus are part of the system's life cycle. Operational inspections detect problems that can cause malfunctions of the system. Elements of system management may be relatively simple for conventional gravity systems, but increase in complexity

A wide range of technologies are available for using in onsite wastewater systems, including:

Aerobic treatment units
Aerobic media filters
Anaerobic upflow filter
Anion exchange
Cation exchange
Chlorination
Constructed wetland
Effluent filters
Grease trap
Infiltration by soil and other media
Lagoons
Mechanical skimmer
Media filters
Recirculating processes
Septic tank
Single pass aerobic processes
Soil infiltration
Ultraviolet

as advanced treatment technologies are added to the treatment train.

Frequency of systems monitoring and inspections is related to the complexity of the treatment system, wastewater loading to the system, and the human and environmental risks that would be associated with system failure. Monitoring frequency is often mandated by code or regulation. In many cases, codes and regulations require a system operating permit, which may require the homeowner to maintain a maintenance contract with a local service provider. For some systems, a state-licensed operator in responsible charge (ORC) is required.

Counties that have adopted local rules may have additional management parameters. Some counties make homeowners associations responsible for system maintenance, while some may choose to establish a public entity to oversee onsite wastewater system O&M. Such programs have been successful in reducing system failure rates (Lindbo et al., 1998).

ADDITIONAL RESOURCES

Vast resources are available regarding all aspects of decentralized wastewater technology and management. As a starting point, county Cooperative Extension offices offer free fact sheets from North Carolina State University about septic systems. These publications give landowners basic, practical information about their systems, appropriate operation and maintenance activities, and environmental risks associated with poor operation and maintenance (O&M) practices.

North Carolina State University Department of Soil Science
http://www.soil.ncsu.edu/programs/septicsystem/

REFERENCES

Consortium of Institutes for Decentralized Wastewater Treatment (CIDWT). 2007. *Decentralized Wastewater Treatment Glossary*. Knoxville, TN: University of Tennessee. http://www.onsiteconsortium.org (verified April, 2008).

Deal, N. E., J. Buchanan, K. Farrell-Poe, et al. 2007. Speaking the same language: a glossary for the decentralized wastewater treatment field. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Greene, R. S., B. H. Ward and D. L. Lindbo. 2007. Remote wastewater nitrification fields. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Joubert, L., P. Flinker, G. Loomis, D. Dow, A. Gold, D. Brennan, and J. Jobin. 2004. *Creative Community Design and Wastewater Management*. Project No. WU-HT-00-30. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by University of Rhode Island Cooperative Extension, Kingston, RI.

Lindbo, D. L., J. Lynn, K. Neal, G. Young and A. Amoozega. 2007. Applying soil morphology to long term acceptance rate determination. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Lindbo, D. L., T. M. Campbell, N. Deal, and R. Hollowell. 1998. Performance of sand-lined trench and conventional systems within a management entity. In D. M. Sievers (ed.), *On-Site Wastewater Treatment, Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems* (March 8-10, 1989, Orlando, FL). St. Joseph, MI: ASABE. pp. 177-85.

North Carolina General Assembly. 2005. Laws and Rules for Sewage Treatment and Disposal Systems, North Carolina Gen. Stat. 130A-333, 4, Rule 1900, Title 15A, Subchapter 18A. *North Carolina Administrative Code*. Raleigh, NC: State of North Carolina.

U.S. Environmental Protection Agency (US EPA). 2003. *Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (EPA 832-B-03-001). Washington, DC: Office of Water, U.S. EPA.

U.S. Environmental Protection Agency. 2005. *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems: An Introduction to Management Tools and Information for Implementing EPA's Management Guidelines* (EPA-832-B-05-001). Washington, DC: Office of Water, U.S. EPA.



CHAPTER 6: LID CONSTRUCTION

By Dan Line

This chapter describes the issues related to planning the construction of an LID project, such as topography, drainage, soils, and ground covers. It identifies strategies for construction that will maximize the long-term success of the project and reduce maintenance requirements, such as sediment control, protecting key areas, and effective communication with the construction team.

6.1 Introduction to LID Construction

The application of LID principles and concepts to the construction phase of the development, in general, should cause only subtle changes to conventional construction. Principles such as preserving hydrologically strategic areas, reducing compaction on disturbed areas, and maintaining vegetation during construction are keys to controlling sediment export during construction and for continued stormwater management following the construction phase.

Elements that guide the design and implementation of LID during construction include: construction planning, sediment export control, strategic area protection, effective communication with contractors, maintenance of infiltration potential, and consideration of physiographic region. LID construction differs slightly from conventional construction in its emphasis on certain elements such as phased clearing and grading, which benefit and protect the stormwater management measures involved in LID. Because the LID project must adhere to the same set of rules and regulations regarding erosion and sediment control as those of conventional development, most of the differences are subtle.

6.2 LID Construction Planning

The first element in the construction of an LID project is planning the construction activities with regard to site characteristics such as topography, soils, drainage, and vegetation. The LID site design (Chapter 3) should have considered these characteristics; thus, the construction planning simply complements the site design. The degree to which the site design and construction plan incorporate the following considerations and principles will determine the LID project's effectiveness. Development and construction timelines and constraints also affect the ability to integrate these considerations into the construction process.

6.2.1 Topography

The primary considerations related to topography are slope steepness and length as these directly affect erosion, and to some extent runoff, potential. The combination of longer and steeper slopes increases erosion potential, therefore, construction planners should pay special attention to cleared areas having the following combinations of slope steepness and length:

0% - 7% steepness	>300 ft length
7% - 15% steepness	>150 ft length
15+% steepness	>75 ft length

Because of the high erosion potential of these areas, erosion and sediment control practices should be emphasized. Also, if possible, leaving vegetation on part of the slope permanently or at least until another part is stabilized (phased grading) or minimizing the length of time the slope is denuded may help reduce erosion potential. When these measures are not possible, installing diversions along the slope to prevent runoff from flowing down the entire length of the slope is recommended. These and other erosion and sediment control practices are outlined in the *North Carolina Erosion and Sediment Control Planning and Design Manual*.

6.2.2 Drainage

An ideal LID drainage system will be incorporated into the future stormwater treatment system and will not be simply a means of transporting runoff on and from the site. Hence, natural drainage patterns should be identified to plan construction activities around them and utilize them for treating runoff and conveying it from the site. If runoff volume and peak rates are expected to increase significantly during or after construction, natural drainage features may need to be stabilized. Leaving a vegetated buffer along the drainage feature can often provide the necessary stabilization and help mitigate the effects of incoming runoff and sediment (Figure 6-1). The vegetated buffer has many desirable functions including infiltration and temporary storage of runoff, filtration of surface flow, reduction of runoff velocity, shade, and potential greenway or nature trail, and such buffers are often required under state and



Figure 6-1. Section showing wooded riparian buffer along the downslope side of the LID project



Figure 6-2. Temporary level spreader installed downstream of sediment basin in buffer

local regulations. If construction equipment must cross the drainage feature, stabilization practices should be put in place as outlined in the *North Carolina Erosion and Sediment Control Planning and Design Manual*.

Temporary and permanent manmade ditches, storm drains, and channels constructed on the site should also be stabilized. If they convey water to the natural drainage feature, they should also, when possible, end at a stable, low-energy outlet at the periphery of the vegetated buffer. This will force runoff through the buffer, which will help mitigate any adverse effects of construction and future stormwater runoff. Dispersing runoff within the buffer via a level spreader can further enhance the effectiveness of the buffer (Figure 6-2). Similar to other sediment control BMPs, the level spreader, if properly maintained or modified, may become part of the permanent LID stormwater management practices system.

6.2.3 Soils

Major soil considerations for LID construction include erodibility, permeability, and depth to bedrock and water table. Other site-specific considerations include shrink-swell capacity and slippage tendencies. Erodibility is particularly important for erosion and sediment control as it is a measure of how easily a soil is eroded by raindrop impact and runoff. Erodibility is a function of soil texture (distribution of sand-, silt-, and clay-sized particles), organic matter content, and soil structure. The most erodible soils generally contain relatively high proportions of silt and very fine sand and a low proportion of organic matter. Most clays and organic matter tend to bind individual soil particles together, thereby creating clumps or aggregates of soil particles, which are harder to dislodge (erode) and transport with the runoff.

The permeability of soil is the rate at which water moves through it. Highly permeable soils generally have little runoff, and thus the erosion potential is less because there is little runoff available to transport sediment. In addition, runoff from the completed development may be less, so smaller or fewer practices are needed to treat it. However, clearing and grading may significantly reduce the permeability of the soil due to loss of structure and compaction; therefore, the construction plan must reflect this. Some of this reduced permeability may be reversed immediately by subsoiling

to mechanically loosen compacted soil prior to final grading and, over time, by deep-rooted vegetation such as certain types of trees. Depth to water table and bedrock often determines if a stormwater or sediment control practice can be implemented and could determine if additional drainage is needed or if construction is possible during wet weather. Hence, these conditions must be factored into construction planning.

6.2.4 Ground Cover

In most situations, ground cover is the most important factor in soil erosion prevention; therefore, vegetation that provides this cover should be preserved. This vegetation is characterized by both a relatively high leaf area, which reduces the impact of raindrops, and dense roots and stems, which both hold soil in place and slow runoff flow over the soil. Further, vegetation that has dense stems or leaves near the ground surface can be very effective at filtering sediment or other pollutants from runoff.



Figure 6-3a and b. Debris and stump grinding at the Pacifica (North Carolina) LID project (top); spreading of stumps ground for mulch (bottom)

Native trees, shrubs, and other vegetation that are well adapted to the area provide natural beauty to an LID project while protecting the soil from erosion and providing opportunities for mitigating runoff. Thus, the LID construction plan should, where at all possible, preserve the native vegetation. Where existing vegetation cannot be saved, the plan should include seeding for establishing temporary vegetation, applying mulch, and staging construction. Mulch can take many different forms, but one approach is to grind tree stumps from the site and use them as mulch (Figure 6-3) to stabilize bare soil areas until native vegetation can be established.

6.3 Sediment Export Control

The second element in LID construction is controlling sediment export, which is accomplished best by minimizing soil erosion followed by installing sediment control practices. Any land-disturbing activity increases the potential for soil erosion. The *North Carolina Erosion and Sediment Control*

Design Manual outlines many ways to minimize this potential. From an LID as well as other standpoints, the most effective sediment export control starts by controlling erosion at the source where raindrop impact and scouring by runoff dislodge soil particles or small clumps of soil particles from the soil matrix and begin the process of transporting sediment. Because soils vary in how easily their particles are dislodged, erodibility varies by soil type, so erosion control measure efficiencies will also vary by soil type.

Some of the erosion control measures most closely aligned with LID include minimizing disturbance, stabilizing disturbed soil, and controlling runoff. These practices must not only be designed and installed properly, but must also be maintained to provide maximum sediment retention throughout the project.

Through careful planning, sometimes sediment control devices can later be converted into LID stormwater management measures. For example, at the Pacifica development in Carrboro, North Carolina, two sediment basins were converted to a bioretention area and a detention pond after major construction was completed. Such conversions may require additional up-front investments, but may save time, costs, and effort overall.

Physiographic Considerations

Physiographic conditions vary considerably across North Carolina, necessitating changes in construction practices. Soils range in texture from predominantly sand to clay and in extent from deep to shallow, while climate and vegetation vary from coastal to mountainous. Although construction practices will be site-specific, there are general concepts to remember. For example, infiltration is much easier to maintain during construction on the sandy, deep soils of the sandhills and coastal plain regions and much more difficult in the more silty and clayey soils of the piedmont. The steep slope of the mountains combined with the shorter growing season require more attention to runoff control and temporary vegetation than the flatter slope and the longer growing season of the coastal plain. The proposed revisions to the *North Carolina Erosion and Sediment Control Design Manual* contain guidance on selecting appropriate plants for various regions of the state.

6.3.1 Minimizing Disturbance

Obviously, minimizing the area of soil disturbance reduces erosion potential on the construction site; however, disturbance is inevitable. Breaking up large disturbed areas into smaller, more manageable areas helps reduce erosion potential. Minimizing disturbance also helps maintain the infiltration capacity of the soil, which is a basic principle of LID.

6.3.2 Stabilizing Disturbed Soil

Stabilizing disturbed soil involves various ways of preventing soil detachment, or the breakdown of clumps or aggregates of soil particles, which makes transport by runoff off-site much less likely. One of the ways to prevent soil detachment is to establish vegetation with roots that hold the soil in place. Vegetation also provides ground cover that shields the soil surface from the impact of raindrops and the shearing action of runoff and wind. Various mulches can also be used to shield the soil surface from raindrop impact and runoff shear, at least temporarily. The combination of using mulch for immediate protection and seeding vegetation for long-term protection can provide good soil stabilization on construction sites. Chemical stabilizers such as polyacrylamide (PAM) and other compounds can be effective at stabilizing soil under some conditions, but as yet have not had widespread use. Recommended soil stabilization practices are included in the *North Carolina Erosion and Sediment Control Design Manual* under Section 6.10.

6.3.3 Controlling Runoff

Controlling runoff involves minimizing its volume, velocity, and contact with erodible soil surfaces. Runoff volume may be minimized in a number of ways: protecting as much vegetation as possible, leaving the soil surface of disturbed areas rough for as long as possible, using chemical soil stabilizers (which help maintain infiltration), and reducing compaction. In general, practices that help minimize runoff during construction also facilitate runoff abatement from the LID project following construction.

When runoff does occur, diversions should be used to prevent runoff from flowing over long lengths of exposed soil. Diversions should then empty into stabilized runoff conveyance channels. These and other recommended runoff control measures are described in



Figure 6-4. Dredged sediment dumped next to the sediment trap with no vegetation or cover





Figure 6-5. Level spreader in a preserved wooded buffer downstream of an LID project

the *North Carolina Erosion and Sediment Control Design Manual* under Sections 6.2 through 6.4.

6.3.4 Maintenance

Erosion and sediment control practices must be properly maintained to ensure effectiveness. Sediment-retaining practices are designed to fill up with sediment. Once they have reached capacity, they cannot perform their intended functions and can even contribute sediment. Hence, periodic inspections and maintenance are vitally important and often required by regulations.

Maintenance activities should be conducted in a manner that does not lead to sediment export. This is particularly important when retained sediment in sediment-trapping devices is removed as part of a maintenance operation. If it is simply piled up somewhere, it can easily be washed away (Figure 6-4). If extracted sediment cannot be hauled to a containment area, it must be stabilized with mulch and temporary vegetation.

Inspections are also important to identify current and potential problems that may be created by intense storms and construction activity. For example, at one construction site after storm drain installation, a diversion berm that extended around the site to funnel runoff to a sediment trap (which was in a natural drainage way) was removed. The berm was removed right up to the edge of the sediment trap, allowing runoff water to go around the trap. As this example illustrates, proper water handling practices are crucial, especially larger ones. If they fail, not only do they fail to trap sediment, they can also become net contributors of sediment.

6.4 Protecting Strategic Areas

Strategic areas should have been identified and preserved in the site design, but restrictions to strategic areas must carry through during construction. Strategic areas include lands that provide beneficial hydrologic functions, such as a groundwater recharge area, or that are positioned on the landscape to facilitate post-construction stormwater treatment (Figure 6-1). These areas should not be used to park equipment, store heavy building materials,

or to conduct any other construction activities that disturb or compact soil. Strategic areas can be excellent locations for post-construction infiltration measures such as level spreaders (Figure 6-5).

Strategic areas may also include post-construction LID measures such as bioretention cells. Although most stormwater BMPs should not be installed until construction is complete and the site is completely stable, it is sometimes necessary to install certain BMPs during the latter stages of construction. In this case, the BMP must be protected and sediment-laden stormwater diverted around the practice to prevent damage to the BMP, which, if severe, could render it completely ineffective and necessitate its replacement. It is particularly important to protect bioretention areas and sand filters, as these are highly susceptible to clogging.



Figure 6-6. Communicating with a contractor during the construction of a bioretention area / rain garden

6.5 Communicating with Contractors

Communication with contractors is more critical during LID construction because traditional practices and methods may not be appropriate. Additional time and effort may be needed to explain the importance of design details so that they are installed properly. For example, in one case, a contractor installed an overflow outlet for a bioretention area at ground level, even though the plans called for it to be raised, because the contractor did not understand the operation of the practice. Also, it is a good idea to discuss with contractors the importance of leaving designated areas undisturbed, using appropriate soils or soil mixtures, and minimizing disturbance and compaction (Figure 6-6).

6.6 Maintaining Infiltration

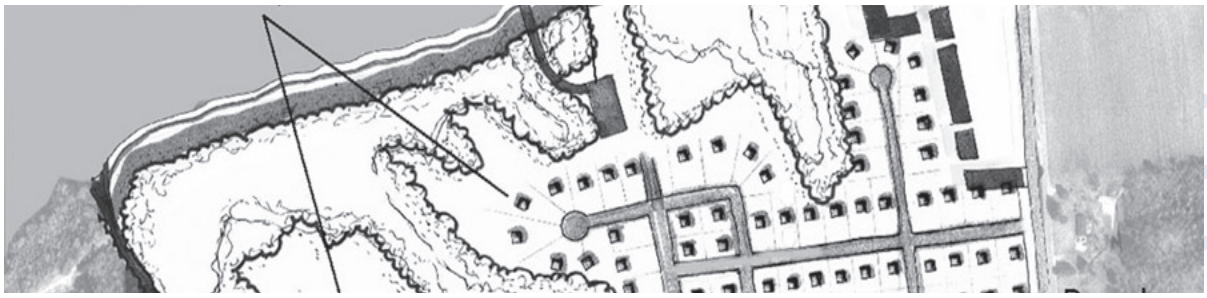
One of the goals of LID is to minimize runoff from developed sites by maintaining the soil's infiltration capacity. For this goal to be achieved, it must be factored into the site plan through minimizing impervious surfaces, preserving soil structure and surface vegetation, and storing and treating on-site runoff. These techniques must be implemented from construction all the way to completion of the development.

Areas that must be cleared and graded will lose infiltration capacity due to

the loss of soil structure. This is often compounded by compaction caused by heavy earth-moving equipment. Compaction has been shown to reduce the infiltration rate of newly established lawns to less than 1 centimeter per hour (Hamilton and Waddington, 1999). Sometimes compaction may be reduced by using lighter equipment (especially on future pervious areas such as lawns) and confining heavy equipment to areas such as roads, which will be impervious anyway. Another way to reduce the effects of compaction is to rip or subsoil pervious areas when construction is almost complete to help restore and improve the infiltration capacity of the soil.

REFERENCES

Hamilton, G. W., and D. V. Waddington. 1999. Infiltration rates on residential lawns in central Pennsylvania. *Journal of Soil and Water Conservation* Vol. 54(3): 564-568.



CHAPTER 7: LOCAL GOVERNMENT PLANNING AND REGULATORY STRATEGIES

By Christy Perrin, Steve Smutko, and Sarah Bruce

The purpose of this chapter is to guide local governments, building professionals, and consultants on the local government planning and regulatory issues related to designing, implementing, and maintaining low impact development strategies. Specific guidance is offered in three stages of regulatory review: (1) preparing for low impact development by drafting and redrafting local codes, ordinances and policies; (2) ensuring proper planning and construction of LID management practices through site plan and construction review procedures; and (3) ensuring long-term function and performance of low impact design practices.

7.1 Getting Ready for Low Impact Development

7.1.1 Protecting Resources for Future Generations

Protecting and improving a community's natural resources begins with planning—involving the community to develop a vision for its natural resources, identifying existing natural resources that are protected or in need of protection, and then developing plans to guide policy and projects. Regional green infrastructure, open space, and watershed planning provide a necessary practical view of the landscape, since our natural resources (water, air, wildlife) overlap jurisdictional boundaries.

Your Comprehensive Plan Should be the Starting Point for LID

Principle: The Town of Cary will be distinguished by a high-quality physical environment that is achieved through strong design appearance requirements; time-honored town-making principles; protection of natural areas, air, and water quality through use of innovative techniques; carefully managed infrastructure improvements; and sound fiscal practices.

Source: *Town of Cary Comprehensive Plan, 2004.*

County and municipal planning provide some of the local tools for implementing the broader vision that is necessary for protecting and restoring natural resources. Although this guidebook is not intended to provide instruction on planning processes, low impact development (LID) is one set of tools for natural resource protection that should be part of a comprehensive plan that identifies natural resources and outlines measures to protect or restore those resources. LID is a tool for minimizing impacts to water quality on sites that have been deemed appropriate for development by a community.

City of Greenville Environmental Quality Goals

- *To protect, preserve, and enhance the quality of the City's water resources.*
- *To manage the discharge of storm water in an environmentally sound and economically feasible manner.*
- *To preserve and enhance wetlands and floodplain areas.*

Compare LID Principles with Community Goals

To help you incorporate LID principles and practices into your local policies, consider the following questions:

- How does LID fit into your community's comprehensive plan? How can LID help meet your community's goals for natural resource protection, livability, and sustainability?
- How much does the community recognize the need for natural resource protection? If community support is not already apparent, significant public education and involvement may be prudent before embarking on policy changes.
- Does your community support LID throughout the entire jurisdiction, or does it want to focus LID efforts in specific areas, such as watershed overlay districts, to protect particular high-value natural resources?
- Do your urban infill or redevelopment goals align with LID principles? Urban infill may require more flexible LID standards due to limited land space.
- How much time and effort can you afford to give your community in LID planning and decision making? LID is a new concept, and change can be challenging. Alleviating fears may require a public dialogue that takes time, money, and some power-sharing in making decisions about LID. If conducted with care, a public dialogue can result in greater support for LID, an educated and empowered citizenry, and broader, more successful LID implementation.
- Who are the local champions who can help? Local government staff may feel intimidated at the prospect of taking on LID. Tap into local expertise and assistance from community groups, environmental organizations, agencies such as North Carolina Cooperative Extension and Soil and Water Conservation districts, and businesses.
- What other resources are available? For example, the U.S. Environmental Protection Agency has developed guidance on using LID to manage stormwater, and several North Carolina agencies offer grants that may help with pilot programs and demonstration projects.

7.1.2 Implementing LID Goals through Changes in Local Policy

Local governments across the country are employing a range of methods for enabling, encouraging, or requiring low impact development in their jurisdictions. How successfully a community is able to implement LID will depend on its natural resource protection goals and local and state support for LID techniques. In the Pacific Northwest, LID is seriously and widely employed as a method for mitigating impacts to salmon habitat. Phase II Stormwater Communities in Washington have been required to allow for LID within their ordinances, with several LID projects found in every Puget Sound, Washington, locality. A 2008 ruling requires Washington permittees to use LID methods for parcel and subdivisions after recognizing that typical stormwater detention is not protecting salmon resources. The District of Columbia has one of the most advanced USEPA stormwater permits and aggressively promotes and enforces LID, while nearby the State of Maryland enacted a law in 2007 requiring LID to the maximum extent practicable.

The main starting point for codifying LID principles and practices is generally the municipal or county stormwater ordinance. In North Carolina, the state encourages the use of LID in the *NCDWQ Stormwater BMP Manual*, and many municipalities and counties are adding provisions for implementing LID through their stormwater ordinances. Other codes and ordinances also play an important role in getting LID in the ground.

The Stormwater Ordinance

The goal of LID is to reduce impacts from stormwater runoff to water bodies; therefore, creating or amending the local stormwater ordinance

What do we Mean by LID?

A definition of the required thresholds and performance criteria for LID projects should be included in a jurisdiction's code. The Town of Huntersville LID performance criteria include these measures:

1. 85% TSS removal.
2. Using LID to treat the runoff from the first 1 inch of rainfall. Use LID alone or with conventional practices to treat the difference in runoff from pre- versus post-conditions for the 2-year 24-hour storm in the Rural and Transitional Zoning Districts. Elsewhere use the 1-year 24-hour storm.
3. Any temporary water quality storage pools must drawdown in 48 to 120 hours.
4. Peak storm water runoff rates shall be controlled for development above 12% impervious (1 dwelling per acre).
5. No one BMP shall receive runoff from an area greater than 5 acres.

is a key link between the community's watershed protection goals and stormwater management performance criteria. The stormwater ordinance provides the guidance necessary for implementing these goals. If the jurisdiction does not already have a stormwater ordinance, developing one is an ideal opportunity to involve the community and incorporate LID into the community's development management policies.

Ideally, the stormwater ordinance is where information on performance criteria and evaluation; design standards; and references to design manuals, maintenance requirements, and enforcement procedures are specified. A number of resources can assist communities with development or revision of stormwater ordinance provisions. Chapter 2 of this guidebook (Achieving LID Performance Goals Using a Hydrologic Cycle Approach), discusses stormwater management performance criteria for LID and how to select performance criteria. University of North Carolina-Chapel Hill's School of Government has recently developed a model stormwater ordinance (School of Government, 2007), and the Center for Watershed Protection provides a post-construction stormwater model ordinance (CWP, 2008). Finally, references to several jurisdictions' stormwater ordinances are included within the "Examples of Local Government Actions to Implement LID" section of this chapter.

Other Codes and Ordinances

Other ordinances are important to enabling LID. Many codes and ordinances were developed long before we understood the negative impacts of impervious surface, altered hydrologic regimes, and reduced tree canopy on water resources and wildlife habitat. Moreover, any number of provisions may complicate the use of LID, for example, by requiring special permits or variances, mandating the use of curb and gutter, or large lots. The Center for Watershed Protection notes that the mix of "subdivision codes, zoning regulations, parking and street standards, and other local ordinances that collectively shape how development happens…create the wide streets, expansive parking lots, and large-lot subdivisions that crowd out natural areas and open space" (Center for Watershed Protection, 1998).

The aspects of managing development that should be examined for LID implementation can be divided into the following five categories:

- Clearing and grading: Land-disturbing activities undertaken to prepare a site for development. Such activities may increase erosion, contribute to runoff and flooding, change drainage patterns, and reduce flood storage capacity.
- Dimension and density: Placement of structures and runoff conveyances on the developed property.
- Natural systems: Areas not developed that provide beneficial

ecological functions. Open spaces, landscaped areas, riparian buffers, tree preservation areas, and steep slopes are all part of the site's natural system.

- Parking: As parking is a significant source of impervious surface, addressing the amount, location, and design of parking area can provide significant benefits.
- Streets: Streets also contribute a large amount of impervious surface, so it is important to consider the area, location, and design of streets and other transportation corridors.

Local governments address these five development themes in any number of codes and ordinances. To encourage LID, governments should identify and address language in these codes and ordinances that is inconsistent with LID principles and practices and change this language so that LID is easier to implement than conventional development.

Review Local Codes and Ordinances

Implementing LID requires a comprehensive examination of the community's development management policies. Because such an examination is inherently multidisciplinary, the best way to ensure a successful review is through a collaborative effort that involves representation from all relevant boards and departments, elected officials, emergency response officials, watershed advocates, developers, and the public at large. This effort will take time and some staff support.

To facilitate this review, the matrix in Table 7-1 shows which codes and ordinances typically address which development theme. For example, LID principles related to dimension and density can be found in building codes, the comprehensive plan, the on-site wastewater ordinance, and so on. A checklist of suggested revisions for these codes and ordinances is included in this guidebook as Appendix C. This checklist is based on the Better Site Design Manual from the Center for Watershed Protection (CWP, 1998). The CWP provides a *Codes and Ordinance Worksheet* (available within their 1998 manual and separately on their website) as a benchmarking tool for local governments to



Figure 7-1. North Carolina residents and local governments' staff in Haywood County work together to recommend ordinance changes

use as a comparison. Several communities throughout the southeast have employed CWP's resources for this purpose.

Table 7-1. Codes and ordinances that affect aspects of low impact development

Code/Ordinance	Clearing & grading	Dimension & density	Natural systems	Parking requirements	Street standards
Building codes	X	X			
Comprehensive plan	X	X	X	X	X
Environmental impact ordinance	X		X		
Floodplain ordinance			X		
Hazard mitigation plan	X		X		
Landscaping ordinance			X		
On-site wastewater	X	X	X		
Parks, recreation, and/or open space plans			X		
Planned unit / residential development plans	X	X	X	X	X
Public works standards			X		X
Riparian buffer ordinance	X	X	X		
Sedimentation and erosion control	X		X		
Steep slope ordinance	X	X	X		X
Stormwater ordinance	X		X		
Subdivision regulations	X	X	X	X	X
Tree preservation ordinance	X		X		
Unified development ordinance	X	X	X	X	X
Zoning ordinance	X	X	X	X	X

7.1.3 Understanding How Federal and State Regulations Relate to LID

The federal Clean Water Act (CWA) is the basis for most water quality programs. In North Carolina, federal CWA programs are delegated to the state. The North Carolina Division of Water Quality (NCDWQ) is the primary division of the North Carolina Department of Environment and Natural Resources that implements stormwater management. Other divisions, including Division of Land Resources, also have stormwater-related programs. The *NCDWQ Stormwater BMP Manual* guides design and maintenance of stormwater BMPs—all BMPs that are used in an LID project to meet state post-construction stormwater regulatory requirements must conform to the Manual's minimal requirements.

Various water quality regulations may apply, depending upon location in the state (an interactive map is available online to determine regulations that apply at http://h2o.enr.state.nc.us/su/msi_maps.htm). Local governments that have been delegated the authority to implement state regulations will review site plans locally, whereas those that have not been delegated authority rely upon regional NCDWQ and Division of Land Resources staff to review plans for compliance with state water quality and erosion control regulations. LID can be used to help meet these regulations. NCDWQ staff work continually to update the BMP manual and to improve the ease of permitting and maintaining LID sites.

Local governments should communicate with their regional NCDWQ office to ensure that their stormwater management program meets state regulations in their jurisdiction, especially when considering policy changes to implement LID or other local approaches.

State regulations that may apply to jurisdictions and to development activities are listed below. These were current as of 2008. Visit NCDENR's website for current rules and regulations at www.enr.state.nc.us/html/rules.html. They include the following:

- NPDES Stormwater Permitting Program
- Municipal Stormwater Permits (Phase I and Phase II)
- Industrial Stormwater Permits
- Water Supply Watershed Protection Rules
- Coastal, Outstanding Resource, and High Quality Stormwater Rules
- Nutrient-Sensitive Waters Rules (such as Randleman Reservoir Rules, Neuse and Tar-Pamlico River Basin Rules, Catawba River Basin Buffer Rules, and Jordan Reservoir Water Supply Nutrient Management Strategy)
- Section 401 and 404 Permits
- Option for a Universal Stormwater Management Program
- Sedimentation Pollution Control Act

Note that this list does not include regulations applied to non-development land uses, such as forestry and other agricultural activities.

With the exception of the Sedimentation Pollution Control Act, all of these regulations address stormwater in the post-construction context. Among the post-construction regulations, the operative pollutant removal performance criteria include 85 percent removal of total suspended solids as well as nutrient export rate targets. A given LID practice may address one or both of these criteria. Those that do are included in the *NCDWQ Stormwater BMP Manual* with associated design specifications to satisfy the presumptive treatment efficiencies. The water quality regulation(s) to which a given

development project is subject can and should influence the selection of LID practices.

With regard to water quantity, some of the above post-construction regulations require matching the post-development peak rate to the pre-development peak rate, or require a match to a blended water quality–water quantity requirement. If a specific LID practice is not included as a BMP in the *NCDWQ Stormwater BMP Manual*, the extent to which the specific LID practice design can meet state post-construction requirements for water quantity must be determined on a case-specific basis. The estimates of runoff conversion to infiltration and evapotranspiration given in Table 2-3 assume that the proposed BMPs comply with the *NCDWQ Stormwater BMP Manual* for water quality purposes, regardless of the water quantity requirements that may also apply in a given circumstance.

NCDENR has a voluntary Express Permitting Program that offers a more timely review of certain environmental permits than the traditional permit review process, faster permit decisions, and faster project certification, as well as consultation to identify necessary environmental requirements. To encourage LID, NCDENR allows applications for LID projects to be processed under this Express Permitting Program at a reduced permit fee (currently, the same fee charged for "low-density" projects applying through the Express Permitting Program). The Express Permitting Program review team can review multiple permit applications that may be required for a project concurrently. Contact your regional NCDWQ office with questions about the Express Permitting Program. The one-stop NCDENR permit handbook is at http://portal.ncdenr.org/web/csc/start/overview.

7.1.4 Examples of Local Government Actions to Implement LID

Communities in North Carolina, in the Southeast, and across the country have employed a mix of approaches in their strategies to implement LID. The local government may choose to:

Building Support for LID

In 2007, Haywood Waterways Association invited towns, the county, citizens, conservation groups, realtors and developers to participate in a roundtable discussion about development in Haywood County. In a facilitated process, participants learned about land use impacts on natural resources and discussed how to better protect those resources while accommodating rapid growth. Jurisdictions reviewed their ordinances using the Center for Watershed Protection's Better Site Design Guidebook, and participants recommended ways to improve local policy and increase low impact development in the County.

- Create a new or amend the existing stormwater ordinance. Performance standards should allow integrated and innovative BMPs, and include post-construction maintenance requirements. We recommend providing links to other codes that also affect stormwater infiltration, such as landscape, open space, and tree and forest preservation.
- Alter or adopt other individual ordinances (such as a riparian buffer, landscaping, or steep slope ordinance).
- Create a Unified Development Ordinance (UDO) that incorporates and promotes LID principles and techniques.
- Create an LID ordinance.
- Cite LID and BMP design manuals within ordinances. We recommend that ordinances not include details about BMP design specifications or performance criteria, since the science of stormwater management is rapidly evolving. Instead, incorporate the applicable BMP design manual(s) by reference.
- Adopt overlay districts on existing zoning districts for LID developments (incentives are likely needed if districts are for voluntary use).
- Implement LID through the Planned Unit (or Residential) Development (PUD) process. PUDs allow a large site to be developed with a mix of land uses according to an overall plan. Better coordination of site elements reduces infrastructure and impervious surfaces, protects more natural resources, and maximizes the beneficial uses of common areas.
- Implement LID through conditional use permits, which enable local governments to require higher standards of development.

Many communities throughout North Carolina and the South are providing leadership in LID. Sometimes change is stewarded by elected and appointed officials such as the Town of Huntersville, while in some instances developers or other organizations have led the charge (Milliken Company's Woodsong Development pioneered LID in Brunswick County). Some communities, including the Town of Cary, prefer to provide LID as a choice for managing stormwater. Others, including Stafford County, Virginia, the Town of Huntersville, North Carolina, and the Town of Hickory, North Carolina, require LID for meeting stormwater requirements. Governments have applied incentives and requirements jurisdiction-wide or to protect priority natural resources, such as a particular watershed.

The following is a sampling of LID implementation initiatives being applied by local governments in North Carolina, the Southeast, and the United States. As your community considers which options may best meet local goals, remember that public involvement and education are key to implementing most approaches. As the likelihood for controversy increases,

so does the need for an early and intensive public education and involvement process. Consider how you can involve your advisory boards, commissions, and committees to study the best means of implementing techniques locally.



Figure 7-2. Voluntary participants in LID redevelopment projects were recognized by the City of Wilmington, North Carolina in a public ceremony

PLANNING AND PUBLIC INVOLVEMENT

Review codes, ordinances, and policies to identify and reduce impediments

Process: Use Center for Watershed Protection (CWP) *Better Site Design Principles and Codes and Ordinance Worksheet* as starting point to compare, while also considering locally specific interests such as steep slopes (www.cwp.org/PublicationStore/bsd.htm).
Opportunities: Identify areas where codes and ordinances can be improved, through either incremental or comprehensive revisions.
Issues: Allow some staff time to conduct review and to submit changes. Public involvement needed for more controversial items.
Example: Brunswick and New Hanover Counties involved committees to review and recommend changes to local codes. Haywood County local governments participated in a public roundtable for this purpose.

Collaborate with neighboring jurisdictions on LID policy

Process: Work on a regional or watershed basis to ensure adequate protection of natural resources and consistency of policies, and to leverage resources for implementation.
Opportunities: Pooling resources for ordinance reviews and studies stretches taxpayer dollars, especially if any LID-related ordinances or programs are shared, and enables projects that small towns may not be able to implement on their own. Developers appreciate consistency with policies among local governments. Collaboration also ensures that development does not simply follow the path of least resistance and get pushed to the least-regulated areas.
Issues: Jurisdictions may perceive a loss of autonomy, but this concern may be alleviated if voluntary implementation is stressed and jurisdictions benefit equally from pooled resources.
Example: Towns in the North Carolina Outer Banks participated in the



Figure 7-3. Brunswick County (North Carolina) LID Technical Advisory Committee (courtesy of Lauren Kolodji)



Figure 7-4. Transylvania County (North Carolina) LID roundtable participants

How will Reducing Street Widths Affect Emergency Access?

Emergency officials and citizens may express concern that reducing road widths and removing cul-de-sacs could impede fire truck access. Involving emergency officials in ordinance review can yield innovative solutions. For example, a community could purchase fire trucks sized to access narrower streets, or consider sprinkler systems in homes. In Tumwater, Washington, to compensate for narrower roads and reduced access for emergency vehicles in LID projects, structures are required to meet more rigorous fire standards.

Outer Banks Hydrology Committee, where they studied and recommended methods for reducing the harmful impacts of stormwater runoff. All are actively promoting LID. A model ordinance was developed for implementing LID and is available from the University of North Carolina Coastal Studies Institute at http://csi.northcarolina.edu/content/education/lidassessment.htm
Example: The Mountain Landscapes Initiative (MLI) is a long-range program by the Community Foundation of Western North Carolina in partnership with the Southwestern Commission, the regional Council of Governments organization serving county and town governments in the seven westernmost counties. The project engaged over 400 citizens in developing a toolbox with community-determined standards for planning and development in North Carolina's mountains. www.mountainlandscapesnc.org

Sponsor public dialogue

Process: Create a public mechanism to discuss concerns, educate each other, and create recommendations for projects and policies.
Opportunities: A less contentious development process may result; a more informed citizenry can participate more effectively and meaningfully in local planning processes and development decisions.
Issues: Time and funds may be needed to conduct an in-depth public process. Expertise in conflict management may be needed.
Examples: Haywood County Growth Readiness Roundtable (www.ncsu.edu/WECO/haywood), Transylvania LID Roundtable (www.ncsu.edu/WECO/transylvania), Wilmington, North Carolina Roundtable (www.wilmingtonnc.gov/Portals/0/stormwater/watershed_roundtable.pdf) and Brunswick County LID Technical Advisory Committee (http://www.nccoast.org/LID/lfstrategies)

POLICY INITIATIVES

Reduce street width and length, parking stall, and parking ratio requirements

Process: Compare to CWP Better Site Design Principles (1998) or other guidance and determine standards that minimize impervious surfaces.
Opportunities: Reduces infrastructure costs, reduces stormwater treatment requirements.
Issues: Requires collaboration with emergency services, developers, others, as well as staff time.
Example: Seattle Street Edge Alternative Program www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems

Reduce setbacks and frontages and aim for higher floor-to-area ratios to reduce building footprints

Process: Compare to CWP Better Site Design Principles or other guidance and determine standards that minimize impervious surfaces.
Opportunities: Provides flexibility with overall design, enables greater accessibility and alternative transportation options, creates a safer and more interesting streetscape.
Issues: May be inconsistent with existing development and design standards. This may necessitate a discussion of desired community character to address perceived drawbacks of density. Form-based codes may become more critical.
Example: City of Olympia, Washington, changed its municipal code to mandate smaller footprints to better protect critical natural resources. www.psat.wa.gov/Publications/LID_studies/ordinances_regulations.htm#ord4

Require LID for managing stormwater

Process: Require LID to meet stormwater management requirements, such as those set forth under a locality's Phase II permit.
Opportunities: Reduces paving and infrastructure costs. Reduces needs for expensive restoration and retrofit projects in the watershed and the stream corridor.
Issues: If surrounding communities do not encourage or require LID, higher standards could simply push development and its impacts elsewhere. Coordination with neighboring jurisdictions is important.
Example: Town of Huntersville, North Carolina (www.charmeck.org/Departments/StormWater/Contractors/Huntersville+LID.htm)
City of Hickory, North Carolina, requires LID in overlay district (www.hickorygov.com). Search for: Land Development Code Article 5 for information on the Henry River Conservation Overlay District)

Stafford County, Virginia, requires the stormwater management to utilize LID site planning to the maximum extent practicable. In addition, stormwater runoff from parking lots is required to be treated by infiltration or bioretention filtering systems.

Require identification and protection of critical natural areas

Process: Require site inventory and percentage of open space to be protected.
Opportunities: Helps protect critical natural resources.
Issues: Extra costs to inventory site, opportunity costs of lost development (can be offset with density increases in suitable areas).
Examples: Town of Mineral Springs, North Carolina, mandates 50 percent open space protection in required conservation subdivisions www.mineralspringsnc.com
Charlotte-Mecklenburg Post-Construction Stormwater Ordinance requires undisturbed open space to be set aside. The minimum amount depends on the development's built-upon area. www.charmeck.org/Departments/StormWater/Contractors/Post+Construction+Storm+Water+Programs.htm

Require parking spaces above maximum allowed to be pervious

Process: Set maximum instead of minimum number of spaces; allow extra parking only if it is permeable.
Opportunities: Allows activities that require parking while encouraging a compact development pattern and more efficient use of land, cost savings from parking lot construction, reduced stormwater treatment infrastructure costs.
Issues: An experienced contractor is needed for constructing permeable parking. As with many new practices, implementing grant-funded demonstration projects may be necessary to first build local capacity. Parking lots in clay soils can pose special clogging concerns; innovative designs and additional oversight may be necessary in clay soil regions.
Examples: New Hanover County, North Carolina (www.nhcgov.com); Town of Huntersville, North Carolina (www.huntersville.org), requires parking spaces above a set amount to be provided as pervious. The Town of Bluffton, South Carolina established parking maxima and requires that 50 percent of commercial parking and residential driveways, sidewalks, and patios be permeable pavement where soil conditions permit (www.townofbluffton.com/sdm/swordinance.pdf)

Remove curb and gutter requirement and allow or require vegetated swales

Process: Determine standards that minimize connections between impervious surfaces, increase opportunities for infiltration, and provide guidance for swale design.
Opportunities: Reduced infrastructure cost, improved water quality, decreased need for expensive stream restoration and watershed retrofit projects.
Issues: Public may perceive lack of curb and gutter as lower-quality development until they see it implemented successfully. Street aprons and sidewalks may help address these concerns. Vegetated swales need maintenance to function properly.
Examples: City of Conover, North Carolina, created an alternate street design with flat curbs to allow sheet flow into vegetative conveyances (www.municode.com). The Town of Bluffton, South Carolina, requires vegetated conveyances to promote infiltration (www.townofbluffton.com/sdm/swordinance.pdf).

Require minimum tree densities or percent forest cover

Process: Establish goals for different types and scales of development for protection of tree cover and specimen trees. Communicate these goals to developers and plan reviewers.
Opportunities: Encourages forest and tree protection, which have many other environmental and community benefits. Grants and subsidized resources may be available for reforestation.
Issues: Focusing on forested resources to provide stormwater reduction is a new concept and details around implementation of the credit need to be worked out, such as how to ensure that the forested area is maintained in perpetuity. Also, forested areas are not necessarily viewed as an amenity. Public education about the importance of forests for protecting water resources may be needed.
Example: City of Olympia, Washington, requires a minimum tree density of 220 trees per acre (approximately 55 percent tree cover in any given development), to protect salmon habitat (www.psat.wa.gov/Publications/LID_studies/ordinances_regulations.htm#ord2)

Allow LID projects in areas deemed highly suitable for development to have higher built-upon ratios

Process: Allow more units or built square footage on the lot in exchange for implementation of LID techniques as appropriate, such as additional undisturbed natural space, wider riparian buffers, or superior stormwater management. Figures 7-5 and 7-6 illustrate increased density and units in



Figure 7-5. LID scenario with higher density and increased units depicted in Union County, North Carolina



Figure 7-6. Conventional development scenario depicted in Union County, North Carolina

exchange for undisturbed natural space.
Opportunities: LID focuses development impacts on the lands most suited for dealing with them, and by placing additional units on these lands, may reduce development pressure on less appropriate lands. Additional units may also enable economies of scale with regard to amenities and infrastructure, and the developer's profit margin could be higher.
Issues: Potentially greater or more complex development impacts needing mitigation. Also, public perception of higher densities is often negative, so education and involvement may be needed to explain how net impacts are actually lower.
Example: The Town of Cary, North Carolina, allows higher densities in a southeast overlay district. Carteret and Henderson counties, North Carolina, provide density bonuses up to 20 percent of normal density (dwelling units) when certain criteria, including protection of a minimum percent of open space, are met (www.carteretcountygov.org and www.henderson.lib.nc.us/county/).
City of Wilmington, North Carolina, provides development bonuses when a threshold number of points is earned through adding more environmentally protective features, including the use of LID (www.ci.wilmington.nc.us/).
Local governments in the Puget Sound, Washington area provide a density bonus for Planned Low Impact Developments (PLIDs) (www.psp.wa.gov/).

Allow trails through green spaces instead of sidewalks

Process: Reduce sidewalk requirements when pedestrian greenway corridors are provided.
Opportunities: Reduces impervious surfaces, reduces developer's infrastructure costs.
Issues: May reduce pedestrian accessibility, especially at night.
Example: Stafford County, Virginia (http://co.stafford.va.us/code/Stormwater_Management/)

Reduce stormwater retention requirements

Process: If the reduced stormwater management needs are not already accounted for, reduce stormwater retention requirements when LID is used.
Opportunities: Reduces costs for ponds and other devices for developers, lowers service requirements from lower environmental impacts for the local government.
Issues: Mitigation of smaller storms may result in more downstream nuisance flooding.
Example: The Town of Black Mountain, North Carolina allows LID designs to capture and retain the first inch of runoff, whereas conventional developments must be designed to capture and retain the 2-year/24-hour storm (www.townofblackmountain.org).

Credit reforestation toward stormwater requirements

Process: Provide credits for additional protection of forested open space and reforestation towards meeting required stormwater performance goals.
Opportunities: Encourages forest and tree protection, which have many other environmental and community benefits. Grants and subsidized resources may be available for reforestation.
Issues: Focusing on forested resources to provide stormwater reduction is a new concept and details about implementation of the credit need to be worked out, such as how to ensure that the forested area is maintained in perpetuity. Also, forested areas are not necessarily viewed as an amenity. Public education about the importance of forests for protecting water resources may be needed.
Example: Wake County, North Carolina, allows reforestation to contribute to meeting a required stormwater performance goal (which is a curve number they require to be met) www.wakegov.com/water/watershed/default.htm

ADMINISTRATIVE PRACTICES

Provide guidance, including a basic stormwater model, for applicants to use on their proposals

Process: Provide a basic model for calculating volume reductions and water quality benefits from utilizing LID. Allow or require applicants to run the model on their early plans and submit the results with their proposals. Adopt and provide a manual.
Opportunities: May enable faster local government review of the proposal. Forces developers to think through stormwater impacts in a methodical and applied fashion, which will result in more consistency with development reviews and better development outcomes.

Issues: Models may not exist for all areas. Applicants must learn how to use the model, and staff must learn how to check and interpret results.
Examples: With assistance from the North Carolina Coastal Federation, New Hanover County, North Carolina and City of Wilmington, North Carolina developed a joint LID manual and an accompanying spreadsheet model called LID-EZ (www.nhcgov.com).
Wake County created a manual (www.wakegov.com/water/watershed/default.htm) with scoping-level site evaluation tools for both the Upper Neuse River Basin watershed (www.unrba.org/set) and Huntersville, North Carolina.

Provide expedited review

Process: Assign priority status to LID projects and establish a maximum time between receipt and review that is less than that of conventional developments.
Opportunities: Provides an important incentive to implement LID: time savings. Guaranteeing decisions in a certain time frame reduces risks from delays.
Issues: Impacts staff resources and other project review schedules. Supplemental support may be necessary, for example, from Soil and Water Conservation staff (who may be able to supplement site visit efforts) or outside consultants.
Example: NCDWQ allows their Express Review permitting process to be used for LID developments (http://h2o.enr.state.nc.us/ncwetlands/express_review.htm).
The Puget Sound Partnership in Washington also cites this technique as a possibility, although a specific local government application has not yet been identified.

Approve administratively rather than with hearing

Process: Allow LID developments of a predetermined size or number of units to be reviewed and approved internally by multi-disciplinary teams.
Opportunities: May enable faster review.
Issues: Reduces opportunities for public involvement.
Example: the Puget Sound Partnership in Washington cites this technique as a possibility, although a specific application has not yet been identified.

Reduce development fees for LID projects

Process: Establish criteria for LID projects. Waive all or a portion of application, review, and inspection fees for projects meeting LID criteria.
Opportunities: Provides incentive to applicant to implement LID. Development community may favor.

Issues: Lost revenue may exceed cost savings and may need to be offset by other means.
Example: the Puget Sound Partnership in Washington cites this technique as a possibility, although a specific application has not yet been identified. North Carolina General Assembly passed a law (SL 2007-381) allowing municipalities to reduce building permit fees for energy efficient projects. Leadership in Energy and Environmental Design (LEED) and similarly certified developments qualify. Potential exists for fee reduction for LID projects.

Lower stormwater fees for low impact developments

Process: Establish criteria for LID and reduce stormwater charges assessed, or provide a fee credit for properties that meet LID criteria.
Opportunities: Lower fees for stormwater ratepayers. Reduced capital and environmental mitigation needs for the local government.
Issues: Not all municipalities have a stormwater utility for charging fees. For those that do, stormwater fees fund a number of public needs related to stormwater such as education—costs that are not reduced by use of LID. Reduced revenues may need to be offset. Ratepayers often have little to do with the design of the structure they occupy, so the incentive for LID design may not be high. Also, it is critical to properly maintain any practices associated with a credit or reduced fee over the long term.
Example: The City of Monroe, North Carolina provides stormwater fee credits for stormwater facilities that go beyond base standards, and education (www.cityofmonroe.org). The City of Durham, North Carolina includes provisions for reduction of fees for BMP retrofit projects (www.durhamnc.gov). Fee credit for LID techniques is used by the City of Issaquah, Washington (www.psparchives.com/our_work/stormwater/lid/lid_regs.htm).

Reduce property taxes on properties meeting LID criteria

Process: Establish criteria for LID. Reduce or waive property taxes on an LID project for a given number of years.
Opportunities: Cost savings from reduced impacts to community resources.
Issues: Reduced revenues, but these may be offset by lower service requirements.
Example: the Puget Sound Partnership in Washington cites this technique as a possibility. Washington, DC, is working on providing property tax credits for green roofs on nongovernmental buildings.

RECOGNITION AND AWARENESS INITIATIVES

Implement capital and private demonstration projects

Process: Partner with other organizations to create LID developments.
Opportunities: Grants may be available to fund demonstration and pilot projects, especially for projects that have exemplary environmental benefits.
Issues: Private partnerships require a developer willing to think outside the box. Costs may be higher.
Example: Town of Cary, North Carolina, residential LID project (www.townofcary.org/depts/planning/lidp.htm), Bethel Elementary School, Bethel, North Carolina (www.ncsu.edu/WECO/haywood/Bethel_school.pdf).
Washington, DC is implementing a massive LID project including building and monitoring 17 LID projects by August 2009, setting a tree canopy goal and planting 13,500 trees, installing 50 rain gardens and 125 rain barrels, and requiring all of the jurisdiction's new and renovated buildings to include green roofs where feasible.

Recognize projects that go above and beyond local requirements by implementing LID

Process: Develop criteria for recognition and provide recognition through a public award, websites, meetings, utility mailers, media, and others.
Opportunities: Increases public awareness of LID, helps developer with marketing development, stimulates market demand for green development.
Issues: Staff resources would be needed to develop and implement a partnership to conduct the recognition program if one is not already available.
Examples: Lower Cape Fear Stewardship Development Award (www.stewardshipdev.com), Raleigh, North Carolina, environmental awards (http://raleighnc.gov/environmentalawards).



Figure 7-7. Demonstration projects provide powerful educational tools

Obtain or provide grants for LID projects

Process: Research outside funding sources or set aside local funds for grants to encourage engineers and developers to implement innovative LID designs.
Opportunities: Outside funding is often available for projects with exceptional benefits and potential to generate capacity for future projects.

Issues: A funding source and grant administration needed. Applying for a grant can be a lengthy and involved process, probably not suitable for a time-critical need.
Example: Chesterfield County, VA provides grants for LID projects (www.co.chesterfield.va.us/communitydevelopment/engineering/lidgrant.asp). The Towns of Pittsboro and Cary, North Carolina both used US EPA Clean Water Act section 319 grants to partner with developers on implementing demonstration LID projects. Haywood Waterways Association received a North Carolina Clean Water Management Trust Fund grant to help with LID design and construction at Bethel Elementary School.

This sampling of LID policy implementation efforts shows that many local governments are taking steps to provide for LID in their jurisdictions. A wide range of techniques are being applied; however, one commonality between them is apparent—communities are taking the first step toward promoting a development that does a better job of protecting water quality. A first effort may or may not show immediate changes in LID submissions and implementation, but it will help build the momentum for positive change to occur and begin the important conversations in the community.

Table 7-2. Responses to LID policy implementation survey

What has your jurisdiction done or is doing to increase the number of low impact development projects submitted and built? (choose all that apply)		
Answer Options	*Response Percent*	*Response Count*
Educated the public about LID	53%	17
Engaged the public in discussions about LID	69%	22
Reviewed our codes and ordinances to identify impediments to LID	63%	20
Amended our codes or ordinances to remove impediments to LID	22%	7
Amended our codes or ordinances to add incentives for LID	25%	8
Amended our codes or ordinances to require LID	16%	5
Enacted other incentives to encourage LID	19%	6
Adopted an ordinance specifically related to LID	16%	5
Used LID in municipal or county capital projects	30%	7
Publicly recognized developers who use LID	19%	6
Other (please specify)	28%	9

In an effort to gauge how local governments are trying to encourage LID, in late 2007, WECO (www.ncsu.edu/WECO) conducted a survey of local government planners and stormwater managers in North Carolina and the Southeast. Thirty-two participants answered the question, "What has your jurisdiction done or what is it doing to increase the number of LID developments submitted and built?" Many respondents were educating others about LID, engaging the public in dialogue about LID, and

reviewing their ordinances (Table 7-2). These baseline activities are key to furthering LID implementation, showing that these local governments are likely on their way.

7.2 Site Plan Review and Approval

Moving a low impact development strategy from design concept to functional, enduring, on-the-ground development requires a well-designed review and approval process. The purpose of a review and approval process is to ensure quality design and construction through the planning, design, construction, and post-construction phases.

Site plan review is a process whereby construction documents, designs, and drawings are reviewed to ensure that a development proposal complies with local, state, and federal regulations. The site plan is drawn to scale, showing the layout of proposed uses and structures. Unlike a plat—which depicts only the subdivision of a parcel into smaller lots along with necessary roads and easements—the site plan includes lot lines, streets, building sites, existing structures, open spaces, landscaping, utilities, and other information.

Site plan review for a specified development and uses is typically performed by the local planning commission and governing boards. Site plans typically are reviewed to assure that:

- The design will comply with local, state, and federal requirements;
- Public facilities and infrastructure are adequate to serve future residents;
- The development will not adversely impact the environment or adjacent neighborhoods;
- Landscaping and screening are appropriate; and,
- Structures and their locations are compatible with surrounding uses.

The State of North Carolina requires a stormwater management permit for projects greater than one acre in areas draining to Outstanding Resource Waters (ORW) or High Quality Waters (HQW), those requiring a Coastal Area Management Act (CAMA) major permit, and unincorporated areas within the extra-territorial jurisdiction (ETJ) of a designated Phase II municipality. In many cases, local jurisdictions with stormwater programs conduct site plan reviews consistent with state standards. In localities without a state-approved stormwater management program, staff of the Division of Water Quality conducts these reviews.

We will focus on site plan review and approval of LID features by local government entities. The review requirements recommended in this document satisfy the state's stormwater review requirements. However, in

jurisdictions without local stormwater management programs, DWQ staff following DWQ procedures will conduct site plan reviews.

Review of stormwater BMPs is conducted to assure that final engineering design and construction drawings for the stormwater aspects of proposed development meet the requirements of the associated land use and local ordinance standards. The goal of the review is to facilitate the construction of facilities that protect the public health and safety and that will be durable and maintainable with lasting quality.

7.2.1 Site Plan Review and Approval Process

The site plan review and approval process should involve continuous interaction between the developer and local planning staff from concept planning to final inspection. In a community that has a strong stormwater ordinance in place, site plan review and approval typically will involve the following steps:

1. Concept plan submittal and meeting between developer and local government staff
2. Preliminary site plan and stormwater plan submittal, review, and approval
3. Submittal of operations and maintenance agreements and performance guarantees for stormwater BMPs
4. Submittal of as-built documentation for stormwater BMPs
5. Final inspection
6. Issuance of certificate of occupancy

An example of a comprehensive pre- and post-construction review and approval process for LID and other stormwater applications from Winston-Salem, North Carolina, is shown in Figure 7-8. The details of review and approval for LID components of a site plan (steps 1 and 2, above) are discussed in this section. Steps 3, 4 and 5 are discussed in sections 7.3 and 7.4.

Concept Plan

At the early stages of site planning, the developer should prepare an LID management system concept plan and, together with his or her designer, meet with the planning staff. The purpose of this concept plan meeting is to familiarize the applicant and the planning staff with the applicable provisions of the local land development and stormwater control ordinances that are required to permit the proposed development before the developer has invested significant resources into the site plan. This conference should be held prior to drafting a site plan or subdivision plan to ensure that the plan will address all applicable requirements of the ordinance.

A primary goal of the concept plan from the standpoint of stormwater management is to identify potential sources of stormwater runoff associated with the development and ensure that the design standards for LID management practices are sufficient to control it. The concept plan should provide a description of existing conditions (such as natural features, drainage features, site contours, soil types) and proposed conditions (drainage features, building areas, infrastructure). It is critical that the local government check the concept plan to make sure that critical natural features will be off-limits to construction traffic and development. For example, in the Neuse River Basin, all intermittent and perennial streams shown on either the USDA Soil Survey or USGS 1:24,000 maps must have a 50-foot riparian buffer.

Preliminary Site Plan Review and Stormwater Permit Review

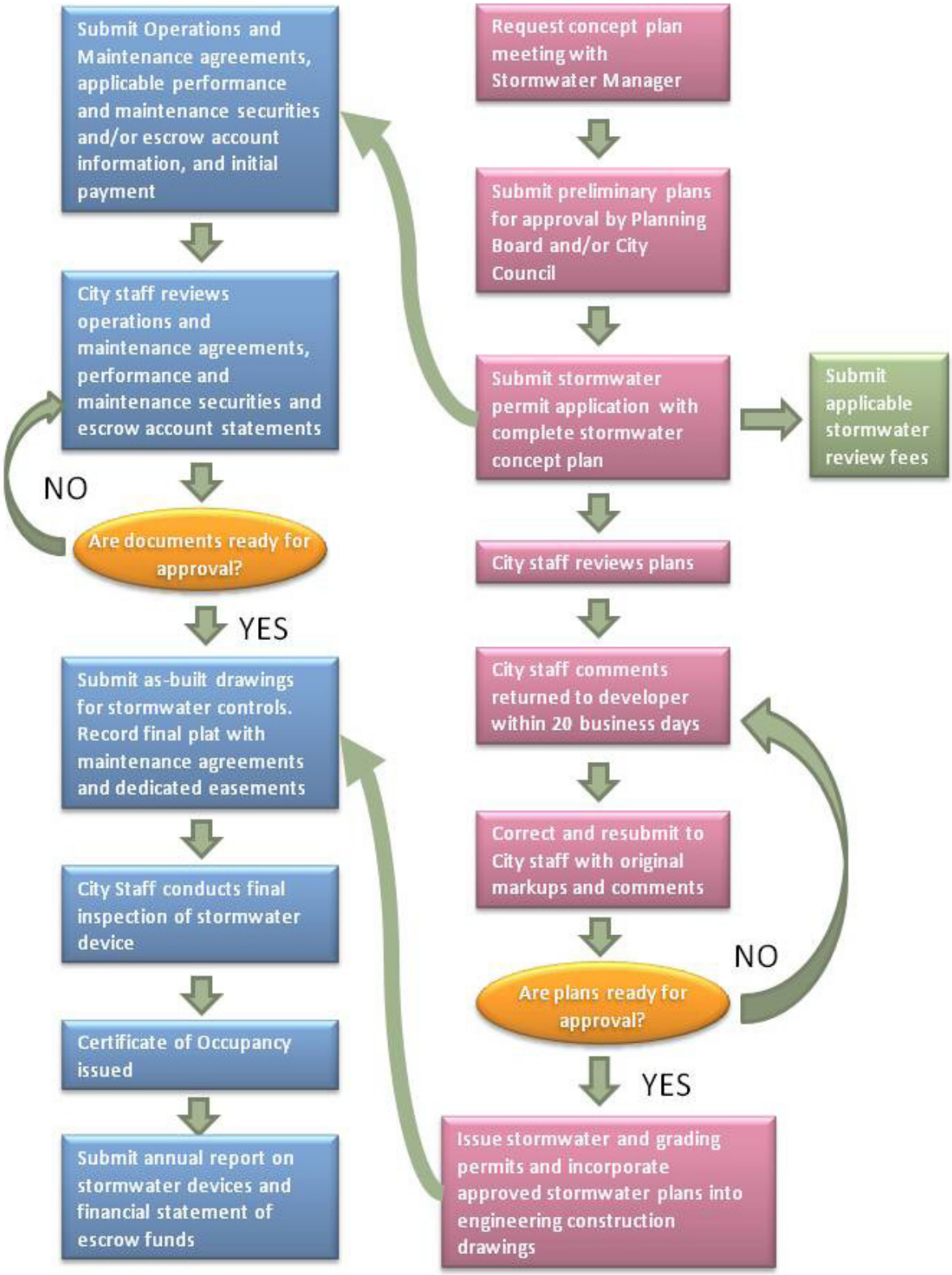
The preliminary site plan review is the formal review of the LID management system in context with the overall development site plan. In jurisdictions that also use permits to manage the construction and operation of stormwater management facilities, a stormwater permit application is typically filed in concurrence with the site plan. A site plan is a land-use plan showing all elements of a proposed development. Site plan reviews are conducted by the agencies with planning, development, and management authority in local government and typically include public works, utilities, parks and recreation, planning, and engineering departments. The review process determines whether each structure and use is compatible with development regulations and existing and future adjacent land uses.

The developer prepares construction drawings and specifications for the site plan review. Construction drawings depict the manner in which the development will actually be built and specifies the materials and methods used in construction. Stormwater and LID management systems should be included as a part of the construction drawings and specifications. A typical set of construction documents will include:

- Site survey
- Demolition and clearing plans
- Layout plans
- Grading plans
- Sediment and erosion control and drainage plans
- Architectural plans
- Planting / landscape plans
- Construction details
- Specifications

The key drawings and specifications that will have the greatest effect on the overall success of an integrated stormwater management plan include:

Figure 7-8. Sample stormwater operations and maintenance agreement (courtesy of the City of Winston-Salem, North Carolina)



- Layout, grading, and drainage
- Sediment and erosion control
- Architectural design
- Landscaping
- Construction details, and specifications for materials and methods
- BMP operation and maintenance plans

Elements of a site plan that are relevant to LID management and maintenance are listed below.

Plan Sheets

- A vicinity map and boundary survey showing general location in relation to major streets, railroads, and waterways, date, and north arrow

Site plans (plan sheets) depicting the following:

- Topography (existing and proposed) at intervals sufficient to provide hydrologic detail extending 100 feet beyond the property boundary
- All perennial and intermittent streams and other surface water features
- Location of watershed divides, direction of water flow, and exits from the site
- Floodplains and any existing flooding areas on and adjacent to the site
- Mean high water line or normal high water line if applicable
- Wetlands and sensitive environmental areas
- Existing stormwater conveyances and structural control facilities (including piping, swales, ditches, ponds)
- Drainage easement location and width
- Analysis of runoff provided by off-site areas upstream of the project site
- Site vegetation (existing and proposed), including limits of clearing and grading
- Soils information with sufficient geotechnical information to determine infiltration capacity
- Proposed site plan or lot layout
- Existing and proposed on-site and adjacent structures including a typical building footprint with dimensions and all concrete and wood deck areas
- Details for the roads, parking area, cul-de-sac radii, sidewalk widths, curb and gutter, all dimensions and slopes
- Existing and proposed on-site and adjacent wells and septic fields

- Type, size, and location of LID structural practices (also referred to as BMPs) including bioretention facilities, swales, filter strips, permeable pavement, and other practices
- Type, size, and location of conveyance and conventional stormwater management facilities and outfall location

- *Supporting Documentation*
- Development project name, date, designer name and firm, owner information
- Method, assumptions, site parameters, and supporting design calculations used in analyzing the existing conditions site hydrology
- Total area of post-development impervious surfaces and other land cover areas
- Unified stormwater sizing criteria runoff calculations for water quality, channel protection, overbank flooding projection, and extreme flood protection
- Documentation and calculations for any applicable site design credits
- Pre-development (or target) water balance (including annual runoff, infiltration, and evapotranspiration volumes or percentages)
- Post-development water balance (annual runoff, infiltration, and evapotranspiration volumes or percentages)
- Allowable tolerance range for the post-development water balance
- Evidence that planned BMPs meet "major design elements" as described in the *North Carolina Division of Water Quality Stormwater Best Management Practices Manual*
- Applicable construction specifications
- Sequence of construction and development phasing
- Maintenance plan
- Evidence of acquisition of applicable permits
- Evidence of acquisition of necessary legal agreements
- Waiver requests

Additional Requirements
Where landscape improvements are integrated into the BMP design, the following information is required:

- Arrangement of planted areas, natural areas, and other landscaped features
- Information necessary to construct the landscape elements shown on the plan drawings
- Descriptions and standards for the methods, materials, and vegetation that are to be used in construction

In addition, the following is required to document maintenance implications:

Concept Plan Components for LID Management

- Development project name; designer name and firm; owner information
- A vicinity map and boundary survey showing general location in relation to major streets, railroads, and waterways, date, and north arrow
- A site data table showing the property's total acreage, zoning classification(s), watershed classification (including the maximum impervious allowed and proposed and proposed uses)
- Mean high water line or normal high water line if applicable
- Delineation of areas within the regulatory floodplain as shown on official floodway maps
- All existing easements, reservations, rights-of-way, and any other restrictions on the use of the land
- Existing topography on the site and within 300 feet of the boundary of the site
- Proposed topography at contour intervals sufficient to provide hydrologic detail
- Delineation of NRCS soil hydrologic groups
- All existing and proposed points of access to public streets and the location of proposed new streets
- Number and general location of proposed structures
- Proposed use of all land and structures, including the number of residential units or the total square footage of any non-residential development
- Type, size, and location of LID structural practices (also referred to as BMPs) including bioretention facilities, swales, filter strips, permeable pavement, and other practices
- Type, size, and location of conveyance and conventional stormwater management facilities, outfall location, and others
- All required yards, buffers, screening, floodplains, and landscaping
- Any screening, buffers, and landscaping proposed over and above that required by the regulations, as well as the proposed treatment of any existing natural features
- Proposed phasing, if any, with specific emphasis on sequencing activities with respect to construction and post-construction practices, and approximate completion time for the project

- Description of maintenance tasks, responsible parties for maintenance, frequency of maintenance, funding, access and safety issues

7.2.2 Site Plan Evaluation

Low Impact Development: A Guidebook for North Carolina assumes a performance goal that post-development volumes of runoff, infiltration, and evapotranspiration match pre-development volumes based on an annual budget criterion. Moreover, BMPs should match removal or sequestration of target pollutants in the watershed as identified by NCDENR (such as TMDLs, Nutrient Sensitive Waters, Shellfish Waters). These performance

goals and the methods for identifying them for any given site are contained in Chapter 2.

Beyond the attainment of the performance criteria, a site plan review should address a number of site design best practices. Discussions between the site plan review team and site developers about specific site parameters and potential changes of specific design elements may yield additional water-quality improvements at little or no cost of time and money.

The following are design review criteria to consider when reviewing site plans for LID (refer to Chapter 3):

Site design:

- Where are the resources on the site (waterways, wetlands, drinking water sources, buffers)?
- Is the design laid out to minimize impacts on water resources and buffers?
- Are natural drainage ways preserved as much as possible? Natural drainage ways are often synonymous with groundwater recharge zones.
- Are grading and filling minimized as much as possible?
- Does the design allow impervious surfaces to be minimized or disconnected? In short driveways or minimized parking area, is runoff directed to landscaped areas?
- Are driveways graded to drain to landscaped areas instead of the street?
- Does the design maintain a percentage of high-value undisturbed open space, or is open space confined to non-developable, low-value land (such as steep slopes and wetlands)?
- Are creeks and waterways buffered (no development within 75 feet of the centerline of a stream)?
- Is there a plan for phased development and clearing to minimize soil disturbance?
- Can vegetated or landscaped swales be used instead of curb and gutter?
- Have bioretention or infiltration features (rain gardens) been incorporated into the landscaping plan?
- Are the above features protected from construction sedimentation (can be met by construction sequencing or location of BMPs)?
- Have pervious alternatives been considered for low-traffic paved areas (gravel, pavers, porous pavement, grassed parking)?
- Are roof drainage downspouts directed to turf or landscaped areas?

Pavement:

- Can the amount and extent of pavement be reduced? Can there be

fewer sidewalks, sidewalks only on one side of the street, shorter driveways, or narrower streets?
- Can impervious surfaces be disconnected and include infiltration or LID conveyance practices in the plan?
- Can alternative paving materials be used for at least some of the pavement (e.g. in parking turnout areas, RV, and overflow parking areas)?
- Has space for infiltration been incorporated into cul-de-sacs and roundabouts? Can they be graded to drain to a central bioretention feature?
- Does the parking lot incorporate pervious pavement for rarely-used spaces?

Bioretention:

- Can parking lot islands incorporate rainwater infiltration?
- Have overflow structures been included?
- Does home landscaping incorporate buffers at lawn / pavement perimeters?
- Are soil types appropriate to permit infiltration within the design period? (such as NRCS soil types A or B soils?

Swales:

- Can swales be used to treat storm water runoff in parking lots, along roadways, and in parks?
- Are drainage flow paths as long as possible to encourage infiltration?
- Does the design provide for an engineered soil matrix that will dewater rapidly?
- Can native vegetation be used instead of turf?
- Who will maintain the swales?

7.3 Maintenance and Enforcement: LID Practices During Construction

It is imperative that post-construction stormwater BMPs either be protected from construction runoff, integrated with construction practices, or both. Because LID stormwater BMPs tend to be smaller in size and larger in number than on conventionally designed sites, and because they also often entail vegetation, they may be harder to differentiate from the surrounding landscape and are more susceptible to impacts from construction. The issues for enforcement of sediment and erosion control for LID are otherwise the same as for sediment and erosion control generally, including additional location-specific considerations (such as more stringent turbidity standards for trout-sensitive waters). See Chapter 6 and the *North Carolina Erosion and Sediment Control Planning and Design Manual* for information on procedures that the developer should follow when constructing LID

projects. The following information is to assist the local government in overseeing these activities.

Developments in North Carolina are subject to the North Carolina Sedimentation Pollution Control Act of 1973, regardless of the amount of disturbed area. However, because the state Division of Land Resources has limited resources to cover the entire state, local governments should consider creating a local sediment and erosion control program to administer the requirements of the act. The procedures that follow assume that the local government is conducting enforcement of the applicable sediment and erosion control regulation (http://www.dlr.enr.state.nc.us/pages/sedimentlocalprograms.html).

When setting up its local program, the local government should follow the performance-based approach set forth in the North Carolina Sedimentation Pollution Control Act of 1973. A performance-based approach ensures that the locality has the power to require the developer to install additional BMPs in the event that the BMPs approved as part of the sediment and erosion control plan do not function as expected or are not adequately protective. The state Division of Land Resources provides an inspector's guide (http://www.dlr.enr.state.nc.us/images/Inspectors%20Guide.pdf) to assist with enforcement.

There are several aspects of sediment and erosion control enforcement that are especially relevant for LID.

1) Natural and sensitive features such as trees, habitats, streams, stream buffers, and wetlands need to be delineated and protected from construction and construction impacts, especially if they are protected by regulation or were used to calculate density bonuses or other incentives.
2) Post-construction stormwater BMPs need to be protected from construction runoff, as the sediment and other pollutants in construction runoff can pollute or damage the BMP, reducing its effectiveness for long-term stormwater treatment (unless they are designed to be used as sediment and erosion control practices during construction and will be converted to post-construction stormwater BMPs at a later time).
3) A sediment and erosion control practice (such as a sediment detention pond or a sediment trap) that is to be converted into a post-construction stormwater BMP may have to be built according to highly specialized specifications.

These considerations should be factored into the process for designing, reviewing, inspecting, and enforcing the sediment and erosion control practices to be used on the site during construction. The first step in

ensuring that excessive sedimentation and erosion do not occur on a site is a strong and enforceable sediment and erosion control plan, which should show:

- The locations and sizes of all sediment and erosion control practices to be used, with references to construction drawings for each or for each type;
- The locations of all post-construction stormwater BMPs and their drainage areas that must be protected from construction runoff;
- Natural features such as streams, ponds, wetlands, and Natural Heritage Inventory sites;
- The locations and extents of all features that should be off limits to construction and construction traffic, such as drip lines for protected specimen trees, critical habitats, and riparian buffers; and,
- Any innovative sediment and erosion control technologies (e.g., skimmers, baffles, and polyacrylamides).

Sediment and erosion control practices should of course be designed to comply with all applicable regulations and be sufficiently protective of water quality. The *North Carolina Erosion and Sediment Control Planning and Design Manual* and other relevant state resources are available at http://www.dlr.enr.state.nc.us/pages/publications.html.

7.4 Local Government Maintenance and Enforcement: LID Practices after Construction

Generally, the local government is advised to conduct plan reviews for post-construction stormwater management along with plan reviews for construction sediment and erosion control (Whisnant, 2007). If the state is overseeing sediment and erosion control for developments in the jurisdiction, another trigger to have stormwater plan review take place locally will be necessary. To see stormwater rules that apply in the given locality, see http://h2o.enr.state.nc.us/su/msi_maps.htm

The issues involved in maintaining post-construction BMPs generally (tracking, maintenance, inspections, enforcement) are all present, sometimes to an even greater degree with LID than with conventional BMP configurations.

Keeping BMPs close to the impacts and pollutant sources they are designed to mitigate makes sense from an environmental perspective, but it can complicate post-construction maintenance and enforcement. Not only do LID BMPs tend to be smaller in size and larger in number compared to conventionally designed sites, but they also often entail using more vegetation, which may make them harder to differentiate from the

surrounding landscape and require specialized knowledge to maintain. Stormwater BMPs such as swales and bioretention areas are often located throughout an LID development, and site constraints may make it necessary to place them on individual private lots, where inspections and enforcement are more complicated than if BMPs are located on common property.

BMPs for LID may also need to be maintained more proactively than BMPs for conventional development. LID practices often involve vegetation and filtration features that can become damaged or dysfunctional with time, vandalism, or large storm events. These impacts may be obscured from view by vegetation or structures, particularly if located in their back yards of private lots.

For these reasons, keeping good records, having proactive maintenance, and enforcing inspections and maintenance requirements are all critical to preserving the long-term functionality and water quality benefits of LID systems. This section discusses ways to manage post-construction maintenance and enforcement responsibilities, which are critical to ensuring that the investments the local government, the developer, and the homebuilder made in stormwater treatment continue to pay water-quality dividends in the long run. Inspecting and maintaining BMPs also helps prevent costly repairs and liabilities.

The School of Government's Stormwater Phase II Model Ordinance for North Carolina Local Governments and Draft Universal Stormwater Model Ordinance give more details and sample provisions on subjects related to post-construction stormwater control. The *North Carolina Stormwater BMP Manual* gives detailed construction and maintenance specifications for engineered BMPs. Keep in mind, however, that LID often includes landscape features such as riparian buffers that need to be monitored and enforced in the post-construction context as well.

If a locally delegated program is not in effect, all construction sediment and erosion control plan review and enforcement is handled by regional offices of the Land Quality Section of the State Division of Land Resources (DENR). Potential violations should be reported immediately by phoning 1-866-STOPMUD.

Policy and Legal Mechanisms for Long-Term Maintenance and Repair

Local governments have a number of options for helping ensure that the entities responsible for long-term BMP maintenance comply with their responsibilities.

Operating Permits: The local government can accept applications and issue permits for the operation of each BMP. This permit would specify maintenance requirements and provisions for enforcement and would typically require renewal after some period of time (5 years, for example).

Maintenance Plans: The local government can make maintenance plans legally enforceable by passing an ordinance that references them and specifies provisions for enforcement.



Figure 7-9. Erosion control fencing protects a creek during construction of a wetland in Wilmington, North Carolina

Financial Performance Guarantees: The local government can require the developer and the landowner to provide for various future costs related to BMP functionality, such as maintenance, repair, replacement, and inspections. There are numerous types of performance guarantees:

- Performance / security / surety bond
- Certificate of deposit
- Letter of credit
- Liens / covenants
- Property escrows

The reader is referred to APA Planning Advisory Service Report #508: Performance Guarantees for Government Permit-Granting Authorities (Feiden and Burby, 2002) for details on performance guarantees and their implementation.

7.4.1 Assigning Responsibility for Long-Term BMP Upkeep

Local governments must pass an ordinance or require a BMP operating permit to specify who is responsible for BMP functionality over the long term. There are several classes of entities that local governments can make responsible for long-term BMP maintenance and repair in North Carolina. The entities responsible may be a combination of the following:

(1) Local governments
(2) Individual landowners
(3) Homeowner's associations, if the site is a subdivision
(4) Stormwater utilities
(5) Soil and Water Conservation Districts (such as Gaston County and Franklin County, North Carolina)

Note that Soil and Water Conservation Districts are a branch of local government; however, because they have their own elected boards and programs separate from the other local government departments, they are listed separately.

Along with establishing who is responsible for long-term functionality of post-construction stormwater BMPs, local governments may also want to consider identifying responsible entities and maintenance specifications for other landscape features, such as riparian buffers, drainage ways, rights-of-way, and utility and other easements. Proactively specifying such

responsibilities can prevent future problems and conflicts. If problems arise and policies are not already in place, decisions made under pressure may set a precedent that incurs future costs for the local government.

Requiring and enforcing maintenance and inspections requirements help ensure that these responsibilities are carried out by the entity responsible. Education and outreach are also central to compliance with the permit or ordinance.



Figure 7-10. A well-maintained bioretention cell in Wilmington, North Carolina

It is important to keep in mind that NPDES and other federal or state permits may make permittees ultimately responsible for the functionality of BMPs in their jurisdiction. Provisions for enforcement on the entities responsible for BMP maintenance are critical to discouraging noncompliance and to the permittee's ability to recover costs of penalties that may be assessed by the regulating agency for noncompliance with the local government's NPDES or other permit.

7.4.2 Transitioning from Construction to Post-Construction

Local governments need to ensure that there is a smooth transition between construction, when the developer or contractor is responsible for the BMPs, and post-construction, when another entity will be responsible for the BMPs. There should be no gaps when no one is responsible for the BMPs.

The process might be outlined as follows:

(1) Have the developer submit all documentation listed below in hard copy and on CD.

- Approved BMP summary sheet
- Approved AND as-built construction drawings
- Approved design calculations
- Approved AND as-built maps of buffers, BMPs, BMP drainage areas, floodplains, and other relevant information

(2) Ensure that construction and post-construction BMP performance guarantees are in place

(3) Require the developer to obtain certification from a qualified third-party professional, or have local government staff conduct inspections, to verify

The USEPA can assess the local government up to $27,500 per day in fines

that the stormwater management system was properly constructed and protected from construction impacts (such as sedimentation) (see 7.4.3). Also certify that any natural features (such as buffers and ponds) that were supposed to be protected from construction impacts were indeed protected.

(4) Withhold issuance of certificates of occupancy until:

- All BMPs are certified to have been constructed to adequate specifications and any corrective measures identified have been taken or at least contractually agreed upon and funded via a performance guarantee
- Performance sureties or guarantees have been verified for post-construction maintenance, inspections, and repairs

(5) Maintain all of this information in perpetuity, in an accessible location, and in a way that can be referenced to parcel and landowner data.

At a minimum, the local government should require the developer to submit a plan or map to scale showing buffers, drainage ways, floodplains, BMPs, and a numbered list of all BMPs on the site so the number is obvious. "As-built" data should be used over "as-approved" designs because they represent actual, on-the-ground conditions. The local government or permittee should maintain this documentation in perpetuity so that it can be provided to the responsible entity in case of loss. This documentation will also be important for local government inspections and enforcement activities.

The as-built certification process should be conducted before final certificates of occupancy are issued to ensure that all BMPs were installed correctly and are functioning properly while the developer is still responsible for them. This verification should be conducted by staff or by an independent professional engineer or registered landscape architect. The *North Carolina Stormwater BMP Manual* lists inspections considerations for each type of BMP.

Optimally, the local government can require that developers have the engineers who designed each structural or engineered BMP develop operation and maintenance (O&M) plans for each BMP in its as-built, post-construction state. These maintenance plans should be detailed but simple enough that lay people who may be contracted to maintain the BMP can follow them. The local government can make this task easier by:

(1) Developing an outline of what should be included in each maintenance plan, such as:

- As-built certification and other inspections documentation
- BMP drainage area delineation so landscape alterations, erosion,

or other issues that may affect the BMP are checked along with the BMP itself
- Specification of activities the maintenance entity is responsible for and how frequently these activities must take place
- Sources for information on persons qualified to inspect, maintain, and repair stormwater BMPs (including persons who have obtained the North Carolina State University BMP inspection and maintenance certification)
- Dated and referenced copies of applicable ordinances and permits
- Dated and referenced copies of penalties for enforcement
- Dated and referenced copies of financial and performance guarantees with statements of potential use (usually, BMP repair or replacement)
- Resources for technical assistance (see Soil and Water Conservation District contact information or Stormwater Managers' Resource Center web address)

(2) Providing different O&M outlines for different types of BMPs
(3) Providing boilerplate maintenance language, preferably which considers local soils and other permanent conditions

The local government should require the responsible entity to maintain these O&M plans in perpetuity and update them as conditions change. These plans should be inspected along with the BMPs to ensure that the plans and the BMPs are being consistently maintained. Obviously, documentation of inspections and follow-up actions should also be maintained by the responsible entity, preferably in the same location as the O&M agreements.

The local government may also consider requiring the developers to prepare O&M plans for nonstructural BMPs and land not in engineered BMPs to address factors and landscape features that affect green infrastructure, the stormwater system, and water quality generally, such as:

(1) Future add-ons and renovations (adding impervious cover, landscaping alterations and on-site wastewater considerations)
(2) Street vacuuming and sweeping
(3) Winter de-icing of roads and driveways
(4) Algae management
(5) Wildlife and pest management, pesticide use, and alternatives
(6) Fertilizer use and alternatives
(7) Yard waste
(8) Hazardous materials management, spill prevention and containment
(9) Pet waste management
(10) Cistern information, if applicable
(11) Buffers and mowing (specify allowable uses and degree of clearing

allowed around riparian buffers, wetlands, and BMPs)
(12) Pervious pavement
(13) Swales (may be mistaken for lawn)

If there is a homeowner's association (HOA) or other property owner's groups, any O&M plans should be incorporated into or referenced in its bylaws, especially if the HOA is the entity to be responsible for the long-term maintenance and functionality of the BMPs. The HOA also needs to include provisions for BMPs on private property in its bylaws so that it has some way to affect maintenance of these BMPs as well.

Keep in mind that the responsible entity is likely to contract landscape maintenance to a private company. It is important that BMP maintenance procedures be communicated to any contractor hired to work on landscaping, including on private lots, even if they have not been hired to work on the site's BMPs per se.

The local government may want to provide guidance and training to HOAs and landscaping contractors on how they can ensure that BMP maintenance responsibilities are correctly carried out and BMPs are protected from other landscaping work. For example, the HOA might be provided with "Do Not Mow" signage to place at the periphery of riparian buffers. The local government might also consider partnering with North Carolina Cooperative Extension to provide the stormwater BMP inspection and maintenance training and certification course for HOA staff and landscaping contractors operating within its jurisdiction. The local government can require that anyone maintaining a BMP in its jurisdiction have this certification, as Durham and Cary, North Carolina have done.

7.4.3 Long-Term BMP Inspections

There are two primary types of inspections that might be conducted: 1) regulatory inspections done to meet legal, ordinance, or permit requirements, and 2) non-regulatory inspections that may be conducted between regulatory inspections to assess performance and maintenance needs.

In Durham, once a developer has completed a BMP and the city has approved the BMP as built, the city prepares an assumption agreement (for the operation and maintenance of the facility) that the new owner executes with the city as required by city ordinance. The agreement obligates the new owner to all of the obligations of the developer or previous owner. When this assumption agreement is executed, the city then provides a digital copy of the as-built documentation to the new owner of the property.

Regulatory Inspections

Inspections required under law, permit, or ordinance should be conducted by a qualified professional, which is usually defined by ordinance as a professional engineer, registered landscape architect, or professional land surveyor. Ideally, the person would also have some official expertise specific to post-construction stormwater management (such as a North Carolina State University Inspection and Maintenance certification or a Certified Professional in Stormwater Quality certification), which can also be required under the ordinance.

Regulatory inspections are usually paid for by the entity responsible for the BMP's maintenance, although inspections may also be funded by a financial-performance guarantee specific to the development or even the individual BMP.

The qualified professional (staff or private sector) should inspect the BMP, comparing it with the BMP's as-built documentation to ensure that it is continuing to function as designed and submit documentation (certified if conducted by a private-sector professional) to the local government as well as with the BMP's operations and maintenance manual. The local government should make this inspection documentation part of the BMP's record and maintain it in perpetuity. Because annual inspections are often required, the local government should consider electronic formats and geo-referenced records to reduce paper volume.

If private-sector professionals and not local government staff conduct regulatory inspections, the local government should also conduct periodic spot-checks of the private-sector certifications and give periodic training to educate professionals on local standards and conditions.

Non-Regulatory Inspections

Non-regulatory inspections assess the state of a BMP between regulatory inspections and therefore improve BMP functionality by catching problems sooner when they may be easier (and cheaper) to fix. Non-regulatory inspections may be courtesy visits requested by the landowner or a concerned neighbor conducted by staff from the stormwater department, the stormwater utility, or Soil and Water Conservation District. They may also be self-inspections conducted by the landowner, the HOA, or a landscape contractor. The local government can help private entities conduct self-inspections by ensuring that O&M plans for each BMP are complete, understandable, and accessible to the entity responsible for maintenance or the contractor. The local government can also provide checklists for such non-regulatory inspections.

In Durham, North Carolina the executed (and recorded) operation and maintenance agreement obligates the owner (permittee) to cause the facility to be inspected by a professional engineer, a registered landscape architect, or a licensed surveyor on an annual basis. The O&M agreement also obligates the owner to maintain the facility to city standards. While the city, by ordinance, holds the property owner responsible, most BMPs in Durham are regulated under the city's NPDES permit. So, ultimately, the city is held responsible.

7.4.4 Maintenance and Enforcement

If the local government is not the entity responsible for BMP compliance, enforcement for noncompliance can be handled in several ways. Civil penalties, such as fines and utility or other service cut-off, are perhaps the most common. Local governments that have obtained performance bonds or guarantees can call them and use them to recoup the cost of the necessary maintenance, inspections, or repairs.

Ultimately, any local government or MS4 subject to NPDES Phase II is responsible for BMP performance within its jurisdiction. The EPA can fine the regulated entity up to $27,500 per day, so it is important that local governments who have made private entities responsible for BMP performance keep this fact in mind when establishing ordinance language regarding fines for noncompliance.

REFERENCES

Blankenship, K. 2008, Jan. DC program seeks 'green solutions' to curb polluted runoff. *Bay Journal* Vol. 17(10).

Center for Watershed Protection (CWP). 1998. *Better Site Design: A Handbook for Changing Development Rules in your Community*. Ellicott City, MD: CWP. www.cwp.org/PublicationStore/bsd.htm (Contains detailed information about research used to develop recommended code changes, a codes and ordinance worksheet for evaluating how codes meet Better Site Design Principles, and specific recommended code changes.)

Fair, A. 2006, Spring. Stormwater best management practices in site plan and subdivision review. *ANJEC Report*. http://www.anjec.org/pdfs/Spring2006ANJECReport.pdf

Feiden, W. and R. J. Burby. 2002. *Performance Guarantees for Government Permit-Granting Authorities* (Report No. 508). Chicago, IL: American Planning Association.

Maryland-National Capital Park and Planning Commission. 2008. *Resident's Guide to the Site Plan Review Process in Montgomery County*. Website. Silver Spring, MD: Montgomery County Planning Board. http://www.mc-mncppc.org/info/resident_guides/site_plan_review/intro.shtml

Metropolitan Area Planning Council (MAPC). *Massachusetts Low Impact Development Toolkit*. Website. Boston, MA: MAPC. http://www.mapc.org/lid.html (Includes a local code checklist.)

New Jersey Department of Environmental Protection (NJDEP). 2004, Feb. *New Jersey Stormwater Best Management Practices Manual*. Trenton, NJ: NJDEP. http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_B.pdf (Contains a municipal regulation checklist.)

North Carolina Department of Environment and Natural Resources (NCDENR). *Environmental Permit Handbook*. Website. Raleigh, NC: NCDENR. http://portal.ncdenr.org/web/csc/start.overview

North Carolina Department of Environment and Natural Resources (NCDENR). Date unknown. *Erosion and Sediment Control Planning and Design Manual*. Raleigh, NC: Division of Land Resources, NCDENR. http://www.dlr.enr.state.nc.us

North Carolina Department of Environment and Natural Resources (NCDENR). 1992, May. *Erosion and Sediment Control Inspector's Guide*. Raleigh, NC: Division of Land Resources, NCDENR. http://www.dlr.enr.state.nc.us/images/Inspectors%20Guide.pdf

North Carolina Department of Environment and Natural Resources (NCDENR). 1998. *Stormwater Management Site Planning* (guidance manual). Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/Site_Planning_Document.pdf

North Carolina State University. 2008. *North Carolina Low Impact Development Center*. Website. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering. www.bae.ncsu.edu/topic/lid

Puget Sound Partnership. 2008. *Stormwater and Low Impact Development*. Website. Olympia, WA. www.psp.wa.gov/our_work/stormwater/lid.htm
Tetra Tech, Inc. 2007, Sept. *Elements of Progressive Stormwater Ordinances Encouraging LID*. Oakland, CA: Ocean Protection Council. (Available upon request.)

U.S. Environmental Protection Agency (U.S. EPA). 2006, Jan. *Protecting Water Resources with Higher-Density Development*. Washington, DC: U.S. EPA. www.epa.gov/smartgrowth/water_density.htm

Whisnant, R. 2007, Feb. *Universal Stormwater Model Ordinance for North Carolina*. Chapel Hill, NC: University of North Carolina Environmental Finance Center. www.efc.unc.edu/projects/stormwater.htm



CHAPTER 8: CASE STUDIES

By Scott Job, Heather Fisher, Jon Calabria, Carter Cone, Miegan Smith Gordon, and Bobby Tucker

This chapter provides four detailed case studies drawn from North Carolina development sites. The case studies will illustrate the concepts and procedures of *Low Impact Development: A Guidebook for North Carolina* in two different contexts.

The first three case studies are development projects (two from the mountains and one from the coastal region) where the designers and developers decided to build LID projects from the ground up. The case studies provide an in-depth profile of the decision-making process at each stage, site constraints and how they affected the design, and how the project team worked through the site review process with regulatory staff. Since the projects pre-date the document *Low Impact Development: A Guidebook for North Carolina*, less emphasis is placed on whether the sites are fully compatible with the guidebook's procedures, but the concepts are included where appropriate.

The fourth case study starts with a site developed under conventional stormwater management techniques (located in the North Carolina piedmont), and performs an alternative analysis of how the site might have been designed using the document *Low Impact Development: A Guidebook for North Carolina*. The analysis includes a comparison of the site design under conventional versus LID stormwater management, including an evaluation of annual hydrology using the methods discussed in Chapter 4, a pollutant loading analysis, and a cost analysis. The discussion will include how real-world constraints limited the menu of LID options, and what choices were made to create the alternative LID site design.

8.1 Case Study #1 – Drover's Road Preserve

8.1.1 Drover's Road Preserve: Introduction

Drover's Road Preserve (http://www.droversroad.com/) is a large-lot residential development on a 186-acre tract in rural Buncombe County, near Asheville, North Carolina. At the outset, the developers chose to protect the site's natural resources and historic past, and to provide a model to the local community of a different way of doing business. At that time in Buncombe County, there was little regulation of development—no stormwater ordinance, no stream buffer protection requirements, and no zoning requirements. The developers could have easily maximized profits—the site has astounding views, and the only limiting factor for housing density was soil properties for placement of on-site septic systems.

Instead, the developers sought out a design firm that could help them accomplish their goals of protecting the landscape and being community leaders, while still realizing a reasonable profit from the endeavor. They chose Equinox Environmental Consultation and Design, a planning and design firm based in Asheville, North Carolina.

Equinox planners focused on developing an overall plan to address multiple goals, including conservation design and LID. Their roles for the project consisted of up-front planning, site design and layout, stormwater management planning, oversight of road and stormwater management construction, and development of restrictive covenants and homeowner educational materials. The business model of Drover's Road Preserve is the sale of empty home sites for individual development (within a strict set of rules and guidelines fitting the vision for the site). Equinox continues to be involved with review of homeowner construction site plans.

8.1.2 Drover's Road Preserve: Background and Project History

At the project's inception, the three landowner partners set out to develop the site differently than much of the development taking place in the region. At the time, most developers were not focused on the protection of natural resources. One common complaint about mountainside development is that the stunning views offered to buyers often result in houses being built on exposed hillsides where they affect the surrounding view shed. Most developers in that area were also not focused on protecting water resources, so sites were frequently cleared all the way to stream edges, and stream channels were often affected by upland sediment erosion.

The Drover's Road Preserve project partners live near the site and have a personal connection to the property. They wanted to protect its natural and water resources, and create something beneficial for the community. Of particular importance to the partners was the protection of several seeps,

DROVER'S ROAD PRESERVE

Site Information

State: North Carolina
County: Buncombe
Zoning: No zoning regulations at time of development
Type of development: Large-Lot Residential Conservation Subdivision
Total Acres: 186
Developed Acres: 76
Number of Lots: 23
Open space: 59% (110 acres in a permanent conservation easement)
LID BMPs: roadside grass swales, bioretention areas, forested riparian buffers, stormwater wetland, and an infiltration meadow

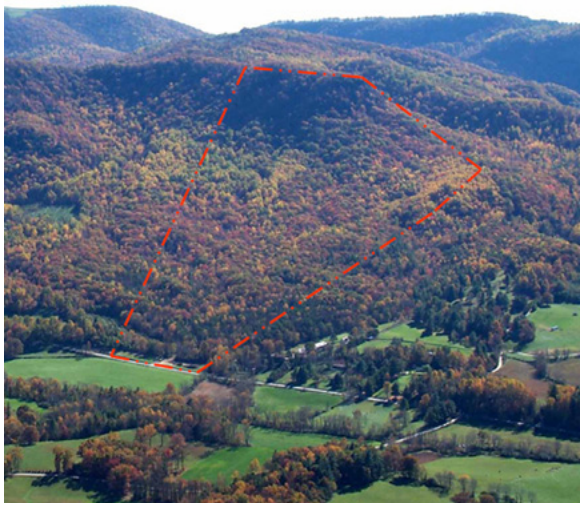


Figure 8-1. Drover's Road Preserve site (North Carolina), with approximate boundaries (courtesy of Flying Cloud Properties, LLC)

springs, and creeks on the property. These water resources were in good condition, having stable banks and few sedimentation problems. Most of the site has mature forest and little disturbance except for a few areas near the front of the property (Figure 8-1).

One of the partners had heard of conservation design, but none of the partners were familiar with LID practices. During initial meetings with the partners, Equinox discussed LID practices and helped the partners understand the strong benefits of protecting the site's water resources. The partners were familiar with conventional stormwater management only, and assumed the site would use curb and gutter. An early recommendation from Equinox was to eliminate curb and gutter and use roadside swales instead; the cost savings could then be used to include additional innovative stormwater practices to support LID goals and to further protect water resources.

Drover's Road Preserve was planned with a multi-disciplinary design team with the following roles:

- Land Planner – consultation and leadership throughout the project
- Biologist – initial assessment and planning
- Botanist – initial assessment and planning
- Landscape Architect – initial assessment and planning and BMP design
- Civil Engineer – road design and construction
- Structural Engineer – bridge crossings
- Soil Scientist – septic suitability
- Surveyors and Construction Company – construction phase

Equinox began the project in 2001 with an extensive conservation planning inventory. The inventory characterized the site's hydrology, scenery, natural heritage, soils and topography, and proximity to other protected areas. The study resulted in a multi-layered map of priority areas for protection. The prioritized protection areas were used to help define a developable-area footprint, which in turn guided the project partners in determining the location of roads, utilities, and home sites. The developable footprint avoided locations with steep slopes, riparian zones, endemic or rare plants and animals, and areas that could affect the surrounding view shed. Conversely, the developable footprint favored areas with slopes less than 20 percent, soils that support septic systems, and areas with former disturbance. The protected area was placed into a conservation easement with Southern Appalachian Highlands Conservancy. Details of the conservation inventory and site assessment are discussed further in Section 8.1.3.

Next, Equinox performed the site design and layout (see Section 8.1.3). At that time, there were no zoning, stormwater management, or buffer protection requirements. The only requirement was to have a soil erosion control plan related to land disturbance. Regardless, the project partners

and Equinox prepared a plan that included protected stream buffers, stormwater management, and innovative BMPs for water quality treatment (Section 8.1.4). Roads were placed to minimize the number of stream crossings. Equinox carefully minimized longitudinal and cross slopes of roads, and established narrow clearing limits. Equinox provided oversight during construction, which was contracted to a separate engineering firm (see Section 8.1.5). Construction began in 2003 and took eight months to complete as a result of several weather-related delays.

Because lots were sold individually without restriction to building contractors, the project partners elected to judiciously use restrictive covenants to meet a number of goals, including those related to conservation design and LID (see Section 8.1.7). The partners developed a document of design guidelines (with input from Equinox) to assist home builders with providing a home site plan tailored to the design concepts and values of the Drover's Road Preserve. A design review committee, a mechanism that ensures home site development has a minimal impact on resources, must approve all plans. As of this writing, house and lot construction are ongoing.

The Drover's Road Preserve website contains more information, including the *Design Guidelines and the Declaration of Covenants, Conditions, and Restrictions* (http://www.droversroad.com/). The site has received recognition from a number of sources to date, including:

- A RiverWise Award for conservation development from RiverLink (http://www.riverlink.org/)
- Best Development of the Year Award from Quality Forward
- A Certificate of Appreciation from the Smithsonian Institute

8.1.3 Drover's Road Preserve: Site Assessment and Design

Guided by a strong conservation ethic, the project partners set out to create a development in harmony with its natural setting and a model for the local community. At the same time, they needed to make a profit from the endeavor and recognized that large home sites surrounded by forests and meadows with outdoor recreation amenities would have a marketable benefit. With help from Equinox, the partners elected to set aside a large portion of the site in a conservation easement, providing permanent protection to the site's most important natural resources. The southernmost part of the site has steep slopes up to a high ridge, with stunning views of the surrounding area. Homes could have been located in the high-sloped area with a great deal of cut and fill, and the sites could have been sold at a premium. However, this valuable part of the site also had the greatest potential to affect the site's creeks and streams, and would have also affected the surrounding view shed for miles. Equinox educated the partners about the tax advantages of conservation easements: placing the most valuable part of a property into a conservation easement increases the tax benefit. As a

Equinox Environmental Consultation & Design, Inc.

TAX ADVANTAGES OF CONSERVATION EASEMENTS

The value of the Conservation Easement

The land that is not part of the development and will be part of the conservation easement may be appraised based on the most valuable economic use. For example, if the value of a 200 acre property is $2,500,000 developed to the highest and best use (Full Yield), but the value after the restriction is $1,000,000, then the value of the Conservation Easement is $1,500,000. The $1,500,000 represents the income tax deduction allowed subject to certain limitations.

Federal Income Tax (in year 2002)

The IRS has set a cap of 30% of the adjusted gross income for individuals. Individuals may carry over an unused portion of the donation for the next five years and deduct the same percentage each year. For example, for an individual who has donated an easement with a value of $100,000 and has an adjusted gross income of $60,000 may deduct 30% of $60,000 ($18,000) in each of years 1 through 5 and the remaining $10,000 in year six.

State Income Tax (in year 2002)

In North Carolina, a special income tax credit (dollar for dollar subtraction of owed income tax) equal to 25% of the fair market value of the donated property with a cap of $250,000 for individuals and $500,000 for corporations is available for land placed in a conservation easement. Any unused portion of the tax credit can be carried over for the next five years. Any remainder can then be claimed as a regular charitable contribution deduction.

Important: The donors of the conservation easement must apply for certification by the North Carolina Department of Environment and Natural Resources that the gift qualifies for conservation purposes in the public interest.

result, the partners included the areas with the steepest slopes and elevation in the conservation easement.

The textbox shows an example of information Equinox provides to interested parties.

Protection of Undeveloped Open Space
To establish which areas of the site were priorities for protection under a conservation easement, Equinox conducted a detailed conservation planning inventory. The following resources were assessed in the inventory, which included features not directly related to LID:

1. *Hydrology.* The site has many unnamed tributaries to Ashworth Creek along the northern boundary of the property, including

three shown on the USGS quadrangle map. There are also several seeps and springs. While Ashworth Creek itself has undergone channelization and has become disconnected from its floodplain, the streams on the site are in good condition, with intact vegetation and few sedimentation problems.

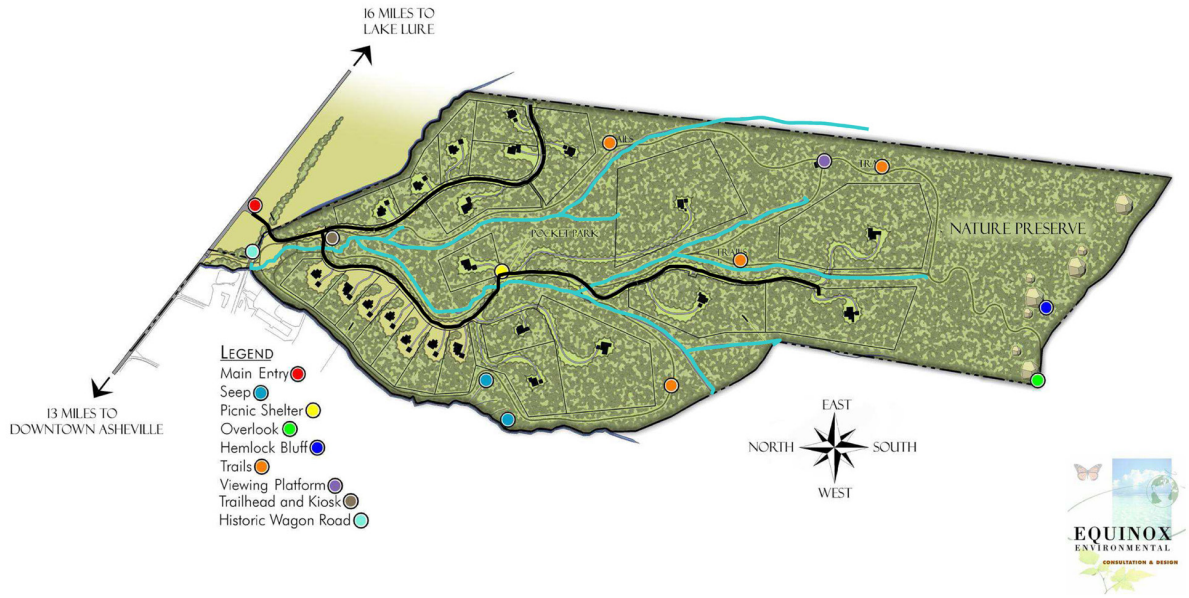
2. *Scenery.* Much of the property has the potential to affect the surrounding view shed, including Highway 74, a scenic byway.
3. *Connectivity to existing and potential conservation lands.* The property is located near other sites with conservation easements, and landowners adjacent to the property have expressed interest in conservation easements. The site is also in the vicinity of Hickory Nut Gap, identified by the Nature Conservancy as a priority protection area, and Ferguson Peak, identified by the North Carolina Natural Heritage Program as significant for protecting the Eastern Woodrat. Maintaining natural area connectivity is a critical element for protecting ecosystems.
4. *Natural heritage.* Though none were observed during the assessment, the site has the potential to be home to several federal and state threatened and endangered species. The site also has a diversity of natural communities and some rare plant communities, potential old growth forest with trees estimated at more than 150 years old, five rare plant species, and more than 230 total plant species.
5. *Soils.* The soils can be grouped into the following categories: flat occasionally flooded soils, soils with gently rolling to somewhat steep slopes, and soils on steep slopes with high erosion potential. There are no FEMA floodplains on the site, but some of the soils were in a class indicative of occasional flooding. The soils in the steep slope category ranged from 30 percent to 95 percent and have high rates of surface runoff; if developed, they could create severe erosions problems.

The inventory was used to establish areas that should be protected by the conservation easement, using the following criteria:

- High slope and ridgeline area in the southern portion of site (including old growth forest)
- Rare plants and rare plant communities
- Seeps, springs, and streams
- Buffers around all water bodies and significant landscape ecological patterns

The buildable area of the site was preferentially located in areas with slopes less than 20 percent, soils that would support septic systems, and previously disturbed areas. Equinox used the conservation and buildable areas to develop three potential site plans showing proposed home sites and roads, and presented them to the project partners. The partners reviewed the

Figure 8-2. Drover's Road Preserve site plan (emphasis added to roads and streams) (courtesy of David Tuch, Equinox Environmental)



potential site plans and advised that they needed three more lots to make the project work financially. Equinox reevaluated the plans and added lots in areas with lower slopes, with a compromise on reducing the contiguous plant community area. This process demonstrates that site inventories using the project's LID and other goals is an effective tool for determining the area of least impact. Likely, a site may have constraints that require adjustments to the plan.

Minimizing Impervious Surfaces

The final site plan (Figure 8-2) incorporated several important LID elements. Lots were clustered at the front of the property, thus reducing overall road length and impervious area. Thin deep lots were used where possible to facilitate the cluster design, though the area requirements for onsite septic systems limited this somewhat (the minimum lot size for accommodating septic systems was about one acre). Shared driveways were used for many lots to minimize stream crossings. The roads used the narrowest allowed width at the time, 16 feet (a typical street width for that type of development was 24 feet). Reducing the road width from 24 feet to 16 feet decreased the amount of impervious

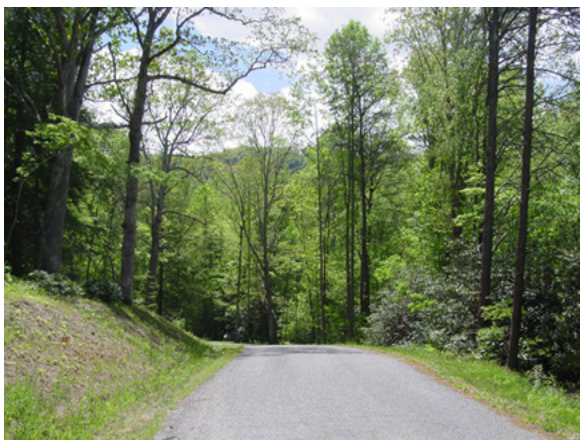


Figure 8-3. Roads have narrow clearing limits and cross slopes no greater than 25 percent (courtesy of David Tuch, Equinox Environmental)

area significantly and also reduced paving cost (Figure 8-3). Mulch was used on the hiking trails, which are located throughout the site (Figure 8-4).

Use of Natural Topography and Minimization of Disturbance and Grading

For the development's roads, the clearing limit for trees and vegetation was 22 to 30 feet, in contrast with a typical clearing limit of 50 to 100 feet. Because bare soil on slopes takes a long time to stabilize, reducing clearing decreases the risk of erosion. When placing roads, Equinox attempted to minimize the road grade (there is an 18 percent maximum allowable grade), and they also minimized cross slopes to 25 percent. There is no standard for cross slopes, and developments in this region often have cross slopes as high as 100 percent. Minimizing grades and cross slopes reduced impacts and erosion risk. Narrow roads and strict clearing limits also lessen visual impacts on the surrounding area. As seen in an aerial photograph from 2005, the roads are barely visible (Figure 8-5). At the time of the photograph, construction of the roads was complete, although only a few houses had been built.



Figure 8-4. Hiking trails use mulch for cover (courtesy of David Tuch, Equinox Environmental)

8.1.4 Drover's Road Preserve: Site Stormwater Management

At the time the development was planned and approved, there were no post-construction stormwater management regulations. Regardless, Equinox and the partners elected to use stormwater management to protect the site's water resources, minimize erosion risk, and reduce pollutant loads in stormwater. The site uses the following techniques and BMPs:

- Roadside swales with erosion control matting
- Two bioretention cells
- A stormwater wetland
- A meadow into which runoff is directed for infiltration
- Stream buffers and minimization of stream crossings
- Limited clearing
- Limited impervious surfaces

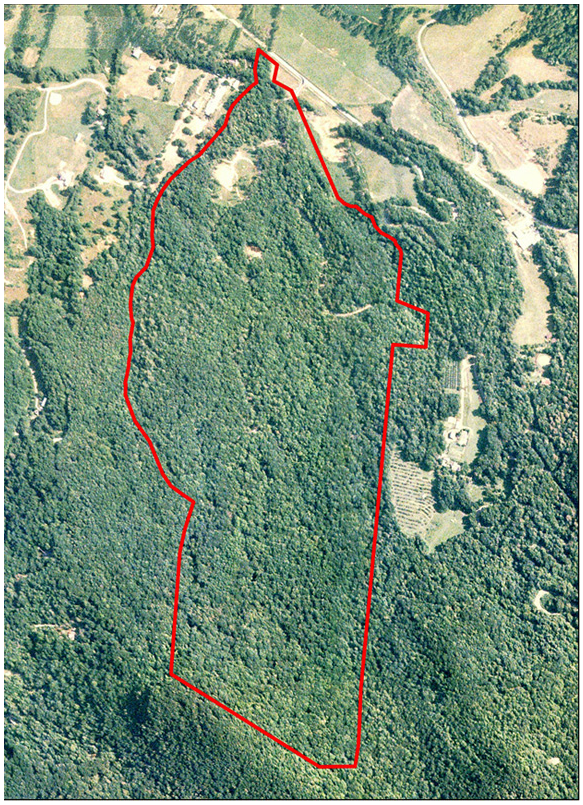


Figure 8-5. Aerial view of the site during summer 2006 (courtesy of David Tuch, Equinox Environmental) Roads were already constructed at this time (source data: parcel boundary Buncombe County NC GIS; aerial, USDA National Agricultural Imagery Program).



Figure 8-6. Roadside grass swales (courtesy of David Tuch, Equinox Environmental)



Figure 8-7. Bioretention during construction (courtesy of David Tuch, Equinox Environmental)



Figure 8-8. Bioretention cell after construction (courtesy of David Tuch, Equinox Environmental)

The non-structural practices include stream buffers, limited disturbance, and an infiltration meadow. The buffers and disturbance limits have already been discussed. The meadow is a common area on the site with wildflowers. A portion of the site's runoff is directed into the meadow for infiltration and treatment.

The structural BMPs include roadside swales, bioretention cells, and a stormwater wetland. Limiting road width allowed for a narrower swale compared to a standard 24-foot road, thus reducing the overall swale cost (Figure 8-6). In steeper sloped areas, permanent erosion control matting was used in place of riprap; the matting product allows grass to grow up through its matrix. In areas with less steep slopes, a biodegradable matting was used. Having grass-lined swales instead of riprap allows for more infiltration, filtering, and uptake of pollutants.

One of the bioretention cells and the stormwater wetland were installed in sediment and erosion control traps from the early construction phase (Figure 8-7). The residents installed the second bioretention cell at a later date to address a perceived drainage problem. The bioretention and stormwater wetlands were designed using guidance from North Carolina Extension and Prince George's County, Maryland, and were sized to treat runoff from the 1.25 inch storm. The bioretention cells use 3 feet of filter media to treat a range of pollutants and pond runoff to a depth of 6 inches (Figure 8-8). The stormwater wetland was placed in an area with naturally wet soils, near one of the creeks (Figure 8-9).

8.1.5 Drover's Road Preserve: Construction Phase

An outside engineering and construction firm was hired to perform the site clearing, grading, and road construction. During the pre-construction meeting and subsequent on-site inspections, the importance of the strict road-clearing limits was emphasized repeatedly. The original plan was to have the construction phase take place as quickly as possible, but there were several weather-related

delays. The construction phase took about eight months to complete.

8.1.6 Drover's Road Preserve: Plan Approval Process

Since there were no post-construction stormwater requirements, the only adjustment to the site plan was made early in the process. Concerns were raised about fire truck access, so Equinox met with the fire marshal and included large-vehicle turnarounds in several locations based on guidance from the meeting. The planning board had no specific comments about the site. Some board members liked the conservation design and LID approach, while others had no opinion so long as the development met requirements. Since the site had two stream crossings, the U.S. Army Corps of Engineers and North Carolina Department of Water Quality reviewed the culverts. The North Carolina Wildlife Resource Commission also reviewed the plan and provided a standard set of comments.



Figure 8-9. Stormwater wetland (courtesy of David Tuch, Equinox Environmental)

8.1.7 Drover's Road Preserve: Lot and Home Site Development

The business model of Drover's Road Preserve was to develop the road and site infrastructure, and then sell the lots individually. In keeping with the overall vision of a place where residents can connect with nature, the development has extensive design guidelines that affect site layout, disturbance, landscape elements, building materials, and architectural patterns. Several of the requirements are directly rooted in LID.

Each lot has individual setbacks to create a narrowly defined "owner discretion zone" where the building and disturbance area must be placed. This zone is usually located in an area with the lowest slope, reducing erosion risk. Also, there is a 20-foot limit of disturbance around the building footprint (Figure 8-10). Driveway widths cannot exceed 10 feet, and there is an additional 10-foot clearing limit around the driveway, which can be distributed on either side (20-foot total clearing limit). Driveway slopes cannot exceed 18 percent.



Figure 8-10. Strict clearing limits adjacent to houses maintain more forest cover and enhance natural beauty (courtesy of David Tuch, Equinox Environmental)

No clearing is permitted within 10 feet of the property boundary, except at the driveway entrance. Vegetation pruning that affects the surrounding view shed is limited and requires prior approval. The guidelines also encourage owners to incorporate stormwater management into their lot site plan, and the guidelines provide an illustration of a rain garden as an example. All site plans must be submitted to the design review committee, which determines whether the plan meets the intent of the guidelines. Figure 8-11 shows an excerpt from the design guidelines illustrating the setbacks and clearing limits. As of this writing, the guidelines are available at the Drover's Road Preserve website (http://www.droversroad.com/). The requirements reflect LID principles by limiting paved surface area and forest disturbance, and by placing the building envelope on an area that reduces erosion risk. Educational materials that communicate LID concepts are distributed to homeowners, helping them understand their role in water resource protection.

8.1.8 Drover's Road Preserve: Cost Considerations

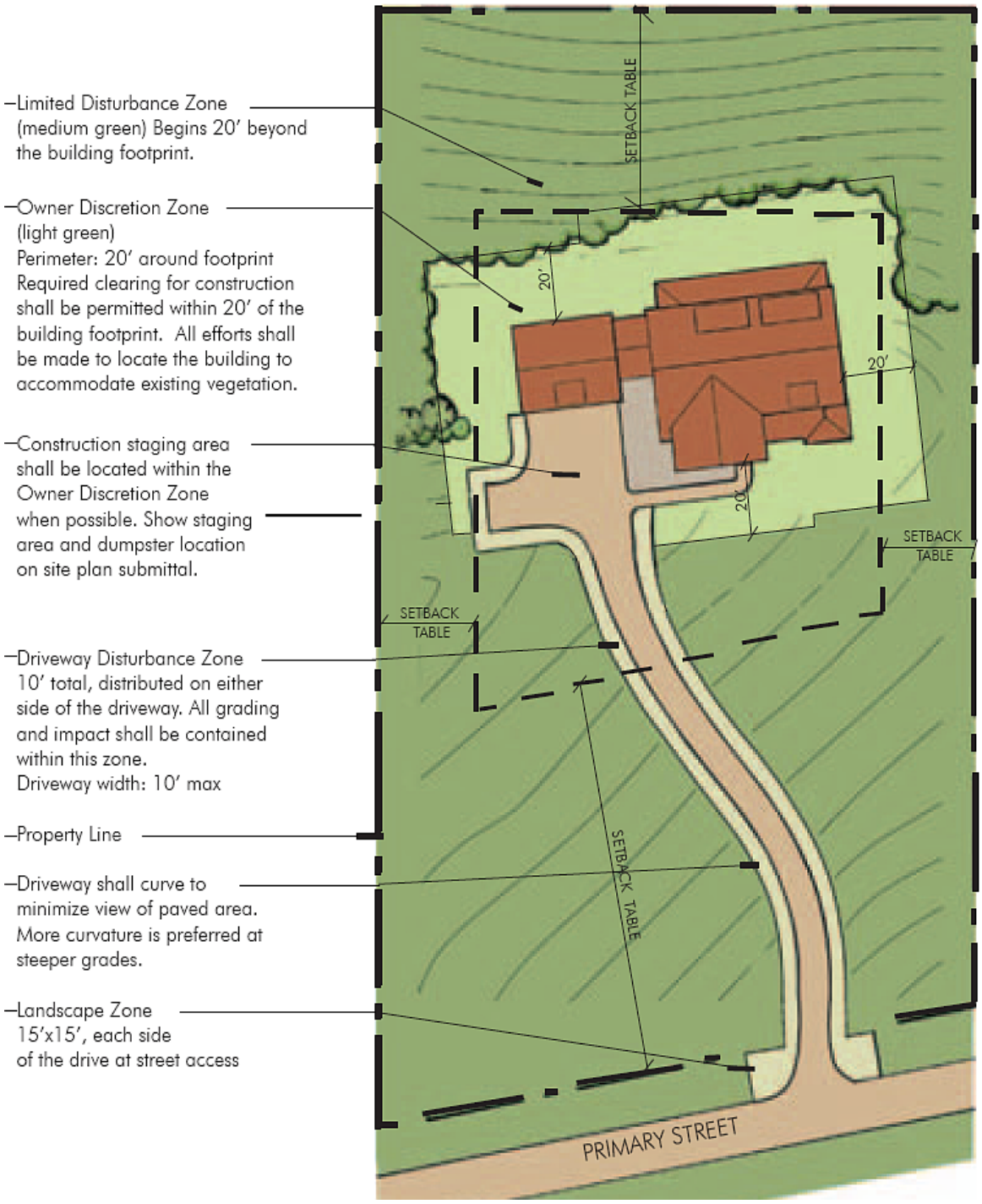
Many of the cost savings and tax benefits that have already been discussed are summarized here. One of the most important benefits was establishing the conservation easement, which provided a substantial tax break to the project partners. The tax benefit allowed them to accept a lower profit margin and allowed them to carry out their vision of a development more in harmony with its natural setting. Many of the LID practices employed also provided a cost savings:

- Steep slopes, which are more expensive to grade and stabilize, were avoided.
- A cluster design and reduced road width, both of which decrease paving costs, and a decrease in impervious area also reduced the cost of stormwater treatment by reducing runoff volume.
- Lower-cost grass swales replaced more expensive curb and gutter.
- Minimal stream crossings, reduced costs for infrastructure design, construction, and plan approval.

The site incorporates stormwater management practices, which were not required and increased the overall cost. However, protection of the site's water resources was an overarching objective from the beginning. When Equinox met with the project partners early in the planning process, they introduced the partners to grass swales as an alternative to curb and gutter. They recommended adding stormwater BMPs to enhance water resource protection and provided cost estimates showing that the savings from curb and gutter elimination could be used to offset the cost of the BMPs.

As lot sales have proceeded, Equinox has performed an analysis of the Drover's Road Preserve lot sales prices, and their data show that the lots fetch 7 percent to 20 percent more than comparable lots in the area. They attribute this to a number of factors, including the site's amenities and

Figure 8-11. Illustration from Design Guidelines document showing example setbacks and clearing limits (courtesy of Flying Cloud Properties, Ltd., 2004)



development vision, the immediacy of the natural areas enveloping each house, and the single-loading layout used in much of the development.

8.1.9 Drover's Road Preserve: Long-term Maintenance

The county had no BMP maintenance requirements at the time of plan approval. However, the project partners and Equinox recognized the importance of long-term maintenance to ensure the protection of water resources. They developed a framework where the responsibility for maintenance is gradually transitioned from the developer to the homeowners' association. The homeowners' association collects fees and is legally required to provide maintenance. There are specialized maintenance plans for both the bioretention cells and the stormwater wetland. For the land in the conservation easement, the project partners made a stewardship contribution to Southern Appalachian Highlands Conservancy, providing for the maintenance of the conservation easement.

8.1.10 Drover's Road Preserve: Conclusion

Although the development pre-dates the document *Low Impact Development: A Guidebook for North Carolina*, this case study illustrates the LID design process discussed in Chapter 3:

1. Set project goals and objectives and identify the program.
2. Inventory, assess, and analyze the site.
3. Review and revise the program based on site constraints.
4. Develop proposals and evaluate.
5. Revise and model.
6. Revise and remodel.
7. Apply regulatory requirements.
8. Model stormwater.
9. Revise and remodel.

The following sequence of events illustrates these guidelines. At the project's inception, Equinox met with the partners and formed an overall plan. After a detailed site assessment determining site constraints and buildable area, proposals were presented to the partners. Based on feedback, Equinox revised the plans, developed the site layout accounting for regulatory requirements (though minimal), and developed the stormwater management plan.

The site also incorporated many of the LID design objectives outlined in Chapter 3, including:

- Limit site disturbance, clearing, and grading to the smallest area possible.
- Use preservation to gain more benefits (environmental and economic) than are possible from creation or mitigation.

- Consolidate natural open space areas whenever possible.
- Incorporate natural filter strips, vegetated areas, channels, and curb inlets in rights-of-way, landscaped areas, and traffic islands.
- Take advantage of existing waterways, vegetated areas, and amenable soil conditions to direct, absorb, clean, recharge, or store water; reduce air pollution; provide wildlife habitat; and add natural amenity value to a development.
- Design impervious areas for the minimum paved area length and width needed to support their intended uses.
- Design for hydrology.
- Design for multiple functions.
- Disconnect impervious areas.

Drover's Road Preserve provides a good example of another principle from Chapter 3—incorporating a balance between LID stormwater management goals and other sustainable design strategies. The site design includes many amenities to encourage outdoor recreation and improve the quality of the residents' lives, including nature trails, a picnic shelter, a horse pasture, and many others. The design guidelines also encourage several other "green" practices, including construction and debris recycling on site, solar orientation for structures, wind breaks, energy efficiency, sustainable building materials, edible plants, and many other practices. LID can and should fit into a larger picture of holistic site planning and design.

Drover's Road Preserve is an excellent example of using LID techniques in the Appalachian mountains of North Carolina. Some of the biggest risks to water resources result from extensive clearing and grading of areas with high relief and steep slopes. Sediment erosion from bank cuts and exposed soils can quickly clog a pristine mountain stream, affecting fish and other aquatic life. Limiting clearing helps a site retain its natural hydrology, both for storm events and on an annual basis. Reducing road grades and cross slopes reduces erosion risk. Restrictive covenants and design guidelines can be used to further limit impacts from the construction of individual lots. Conservation easements can be used to help meet LID and other land protection goals, while providing real financial benefits. Finally, a design that does not try to maximize the development footprint can lead to higher property values and improve the quality of life for those that live there.

Contact information:

David Tuch
Equinox Environmental Consultation & Design, Inc.
37 Haywood Street, Suite 100
Asheville, NC 28801
(828) 253-6856
http://www.equinoxenvironmental.com

TONBO MEADOW

Site Information

City: Wilmington, North Carolina
County: New Hanover
Zoning District: R-15 Zoning and the Resource Protection Overlay of the North Carolina Coastal Area Management Act (CAMA)
Type of development: Single-family Residential Cluster
Acres: 3.2
Number of Lots: 10
Imperviousness: 21%
Open Space: 51% (includes LID BMPs)
LID BMPs: Cisterns, rain gardens, grass swales, porous concrete, and a stormwater wetland
Wastewater Treatment: City sewer

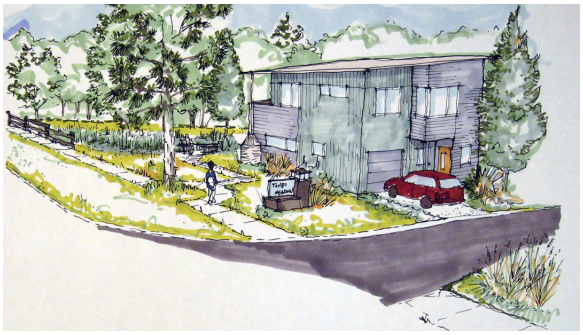


Figure 8-12. Conceptual drawing of future entrance to Tonbo Meadow, North Carolina (courtesy of Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC)

8.2 Case Study #2 – Tonbo Meadow

8.2.1 Tonbo Meadow: Introduction

Tonbo Meadow will be a single-family cluster development in Wilmington, North Carolina, designed with both green building and LID techniques. JiJi Muge, LLC, the project developer, intended to use green building techniques from the project's inception. At the time, it was unclear whether using LID would be allowed under city code, so the property was first designed to have five green-built homes with conventional stormwater. After reviewing the initial design, the developer was not satisfied with the limited aesthetics and minimal environmental qualities of the conventional plan and brought together a team of LID experts to assist with project design. The developer also worked with the City of Wilmington and the Lower Cape Fear Stewardship Development Awards Program to design the development as a model for LID in the area. The team redesigned the property to support 10 single-family lots using LID principles, including reducing pollutants at the source, minimizing impervious surfaces, and using natural or existing drainage features. The proposed design exceeds stormwater control requirements and provides treatment for stormwater runoff from an adjacent property. The development has received approval from the City of Wilmington Subdivision Review Board. The design has already won the Significant Achievement Award from the Lower Cape Fear Stewardship Development Program and is poised to win the highest award from this program and become a model LID development for the Wilmington area and the coastal plain. A conceptual drawing of the development's proposed entrance is shown in Figure 8-12.

8.2.2 Tonbo Meadow: Background and Project History

JiJi Muge selected the site to implement green building techniques and hoped to incorporate LID to the extent allowed by the city code. The developer was familiar with LID techniques and would have used LID for the initial design if the city had an LID ordinance in place. At the time, it was not clear whether the City of Wilmington's code would allow the use of LID. The developer risked designing an innovative site without the assurance that the city would approve the design or provide

the number of variances needed. The site's topography and narrow shape presented a number of constraints as well, and the developer decided to use conventional stormwater management for the initial design. The conventional design allowed for five lots on the property with room for a conventional stormwater pond. The main subdivision road in this design extended the length of the first four lots, and no land was available for common open space.

After reviewing the initial design, JiJi Muge was not satisfied with the limited aesthetics and minimal environmental qualities of the conventional plan layout and stormwater pond. The conventional stormwater pond would have detracted from the aesthetic qualities of the development, and it would have occupied land that could have been used as attractive community open space. Instead, the developer wanted a plan layout and stormwater design that would augment the environmental and community benefits of the site's green buildings.

The developer worked with the City of Wilmington to find ways to apply LID within Wilmington's development requirements. They found that there were options for applying LID using cluster development and variances. The developer brought together a team of LID experts from Redline Engineering, B+O Design Studio, and North Carolina State University to redesign the site using LID. The developer also worked with an environmental planner from the City of Wilmington to design the development. The disciplines and roles of the project team are summarized as follows:

Design Team

- Owner / Developer / Contractor – planning and oversight throughout project
- Design Engineer – layout and design of stormwater management system
- Architect – site layout related to building design
- Landscape Architect – site design related to vegetation and natural area preservation

Outside Experts

- North Carolina State University Department of Biological and Agricultural Engineering – design review and input; stormwater monitoring
- City Planner – design review and input

The design team and LID experts worked together to find LID techniques that could reduce the development's impact on water quality and provide a more attractive, community-oriented development. They used site design guidelines in the *North Carolina Stormwater BMP Design Manual* (July, 2007 version; NCDWQ, 2007) and information from the Low Impact Development Center (LID Center, 2008) and Prince George's County,

Maryland (Prince George's County, 2008). They also used the requirements of the Lower Cape Fear Stewardship Development Awards Program as guidance. Through that effort, the site has received the Significant Achievement distinction from this awards program (LCFSDP, 2007). Once built, the site is expected to receive the program's higher designation of Outstanding Recognition.

JiJi Muge set a number of goals for the Tonbo Meadow LID design centering on achieving an innovative and marketable development, and the team's first goal was to design a low impact development that was financially viable. One option for increasing potential revenue was to increase the lot yield of the development, and designing the site as a cluster development provided that opportunity. The site area was previously less than 3 acres, and the City of Wilmington does not allow cluster developments on less than 3-acre sites. JiJi Muge had to purchase an additional property to meet this minimum requirement for cluster developments. Figure 8-13 illustrates the resulting LID site layout. The design includes one road servicing lots on either side and two lots at the end of the road, serviced by a hammerhead turnaround.

The design team used LID site design techniques and an LID BMP treatment train to meet state and local stormwater requirements. State of



Figure 8-13. LID site layout for the Tonbo Meadow Development, North Carolina (courtesy of Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC)

North Carolina and City of Wilmington requirements, including NPDES Phase II stormwater requirements, required the design to:

a. Control and treat the runoff from the first 1.5 inches of rainfall;
b. Detain the 1-year storm; and,
c. Maintain the pre-development peak flow for the 2- and 10-year storm events.

The design was also required to report the impacts of a 50-year storm event, and all piping was required to pass the 10-year storm requirements. The BMPs used to meet these requirements must be designed according to the *North Carolina Stormwater BMP Manual*. The detention and design requirements were the only requirements relating to water quality imposed by the city and state. The BMPs used to meet stormwater requirements are discussed in more detail in Section 8.2.4.

The site was subject to a number of layout and design requirements. The site is within Wilmington's R-15 zoning district and the Resource Protection Overlay of North Carolina Coastal Area Management Act (CAMA) land use classification, which limited the development to 10 lots when combined with the density bonus for a cluster development. The city required a 25-foot buffer around the entire site and a 15-foot utility easement in front of the lots. Since the site was a cluster development, the city required 40 percent open space, or about 1.3 acres. The site design went beyond this requirement and provided 51 percent open space, or about 1.6 acres, which included open space in individual lots to be maintained by homeowners, community areas to be maintained by a homeowner's association, and some types of BMPs. The team also surpassed tree protection requirements by designing the site layout to minimize the loss of mature trees, which is discussed in more detail in Section 8.2.3.

The team met the above requirements and sought waivers on other requirements to provide opportunities and flexibility in applying LID to the site. The team needed the following variances to use their proposed LID techniques:

1. Lot setbacks waived
2. Street width reduced
3. Sidewalk on one side of street
4. Modified plaza width
5. Modified road curve
6. Use of permeable concrete for driveways
7. Use of permeable concrete for hammerhead turnaround

A variance was not needed for the hammerhead turnaround in lieu of a cul-de-sac, only for the use of permeable concrete. The variances are described in more detail in Sections 8.2.3 through 8.2.5. The development will be

connected to the city sewer system and, therefore, the design did not need to address wastewater on-site.

Once minimum requirements were addressed, the Tonbo Meadow design team sought to achieve a number of site design goals that would lead to a unique, innovative development. They worked toward a site layout that maximized solar radiation for the green buildings and preserved the natural beauty of the site's meadow and woodlands. They also wanted to consider how the development would affect surrounding conditions and downstream water quality. The site drains to sensitive wetlands and water bodies, and these natural resources had already been affected by the surrounding development, which was built prior to stormwater regulations. Because of the lack of stormwater controls and site planning, multi-directional flow between the properties leads to flooding. Considering these conditions, the design team was particularly interested in designing the site so that any additional impacts would be minimized, and they also looked for ways to correct the existing drainage problems. Finally, the team sought to integrate these design goals into a landscape that would be attractive to residents.

This case study illustrates how the LID techniques outlined in this guidebook can be applied successfully to a residential development design within a city. The following sections describe the site layout, stormwater features, and design process, and discusses how these elements illustrate specific strategies in this document.

8.2.3 Tonbo Meadow: Site Assessment and Design

The incorporation of LID principles required a number of creative solutions throughout the design process, and code variances were necessary to implement the final design. The design team incorporated many of the LID design objectives outlined in Chapter 3. It was able to achieve multiple LID design objectives by evaluating the site characteristics in detail and finding methods to overcome constraints to LID.

Pre-developed Condition

The former residents used the Tonbo Meadow site as a family farm where they raised chickens and dairy cattle and grew a few food crops (Figure 8-14). Meadow covers the majority of the upland areas. Many mature hardwood and loblolly pine trees grow on the site. Several barn structures are present, and several of these structures will be reclaimed as part of the new development. The topography follows a decrease in elevation of about 6 feet across the site from north to south. The site contains an existing, overgrown drainage easement at the south corner, and the site receives runoff from adjacent development due to lack of stormwater controls.

According to the New Hanover County Soils Survey, the predominant soil is Seagate Fine Sand. Soil borings revealed a depth to high water between



Figure 8-14. Existing site conditions - site boundaries outlined in red (courtesy of Lara Berkley, ASLA and Scott Ogden, AIA of B+O Design Studio, PLLC)

31 inches and 40 inches below the ground surface. Soils were identified as having an infiltration rate of approximately 2.2 inches per hour. No wetlands, streambeds, floodplains, or riparian zones were identified on the site.

Protection of Undeveloped Open Space

The design process involved the team working together to find ways to protect the largest contiguous area of open space within the development. Toward this goal, the team received a variance from the city to waive the lot setbacks and move lot boundaries closer to the main subdivision road. This variance provided more natural, undisturbed open space within the development. By minimizing the lot sizes to a range of 2,500 to 3,500 square feet, the team reduced street length and allowed more contiguous open space protection. The open space area includes existing meadow, groves of trees, and woodland (Figure 8-15). The largest area of open space represents the highest elevations on the site, land that typically would be used for development.

The team went beyond local tree protection requirements by designing the site layout to minimize the loss of mature trees. The developed area was moved closer to the road to save trees in the back of the property. Then the curve in the new road was modified through a variance from a 100-foot curve to a 60-foot curve, which saved several mature trees. The road curve variance also allowed the new road to meet the existing city street at a right angle, resulting in a safer development entrance than without the variance (the existing city road has a blind curve as traffic approaches the development). A few trees will have to be removed or relocated to accommodate the road curve and other site development requirements.

A variance was also used to modify the plaza width, which is the space between the road and the sidewalk. The requirement is for a 5-foot plaza width, but the variance allowed for a 3-foot width, which provided more flexibility for incorporating the open space and LID BMPs.

The team's efforts exemplify how using multiple strategies can maximize undeveloped open space. They applied a number of LID design objectives outlined in Chapter 3, including:

- Reduce road frontages and driveway lengths.
- Limit site disturbance, clearing, and grading to the smallest area necessary.
- Use preservation to gain more benefits than are possible from creation or mitigation.
- Consolidate natural open space areas whenever possible.

The open space protection efforts also contributed to other site design goals, as described in the following section.



Figure 8-15. Existing meadow and woodlands to be preserved as undisturbed open space (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC)

Using Natural Topography to Minimize Disturbance and Grading

The team used the existing topography and flow paths to determine the locations of the infiltration areas, stormwater wetlands, and grass swales. The team located the lots on the southernmost portion of the site to take advantage of the existing drainage pattern, and the stormwater wetland will be constructed from an existing drainage ditch. Using natural topography helped minimize the amount of land disturbance and grading needed to construct the stormwater system.

Using a cluster design and protecting large, contiguous areas of open space also minimized construction disturbance. The perimeter buffer required by the city will remain undisturbed where possible, and native evergreens will be planted where the buffer is disturbed during construction.

The LID design objectives relevant to these efforts include:

- Limit site disturbance, clearing, and grading to the smallest areas necessary.
- Incorporate natural filter strips, vegetated areas, channels, and curb inlets in rights-of-way, landscape areas, and traffic islands.
- Take advantage of existing waterways, vegetated areas, and amenable soil conditions to direct, absorb, clean, recharge, or store water; reduce air pollution; provide wildlife habitat; and add natural amenity value to a development.

The integration of stormwater BMPs into the existing drainage paths is discussed in more detail in Section 8.2.4.

Minimizing Impervious Surface

The design team minimized impervious surface by reducing lot sizes and road surface area and receiving variances on street and sidewalk requirements. The smaller lot sizes reduced the length of road required from 600 feet to 300 feet and helped preserve the meadow at the back of the property. The street terminus was designed with a hammerhead turn, which requires less pavement than the traditional cul-de-sac (Figure 8-16).

The team received a variance to reduce street width from 20 feet to 18 feet. The streets were designed with an 18-foot-wide asphalt section and a 1-foot header curb on each side, which is a flat curb along a road surface that will direct runoff as sheet flow off the road into grass swales. This combination of asphalt and curb will provide a 20-foot travel lane. The conventional road would have used 24 feet of pavement (20 feet of asphalt and 2 feet of valley curb and gutter on either side). The team also received a variance to restrict the sidewalk to one side of the street. These techniques could be used only along the main road within the Tonbo Meadows development: the city required the use of conventional curb and gutter along the frontage with Greenville Loop Road.



Figure 8-16. Conceptual drawing of Tonbo Meadow hammerhead turnaround designed to use porous pavement (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC)

These multiple strategies exemplify the design steps necessary to minimize impervious surface. The design team used the following LID design objectives:

- Design impervious areas for the minimum required paved area length and width needed to support their intended uses.
- Modify traditional layouts to reduce road frontages and driveway lengths.
- Carefully locate and design sidewalks to maximize community benefits from the impervious surface.

Many of the design elements are linked. The measures taken to increase protected open space also helped to reduce impervious surface on this site. An effective and comprehensive LID design will account for and take advantage of these relationships.

Interception and Infiltration

The design team developed strategies to maximize interception and infiltration on the site. The BMP treatment trains, which are described in Section 8.2.4, will use a combination of cisterns, grass swales, and rain gardens to treat stormwater runoff and promote infiltration. The grass swales and rain gardens are designed to infiltrate stormwater, and the cisterns will provide infiltration through their use in irrigation.
Using permeable concrete reduced the impact of impervious surface and took advantage of the high infiltration rate of existing soils. The team received variances to use permeable concrete instead of conventional concrete for the driveways and hammerhead turnaround. Their efforts to maximize open space and protect trees, as described above, also provided greater opportunities for interception and infiltration.

Overall, the design exemplifies the following LID design objectives relating to interception and infiltration:

- Substitute pervious materials for impervious materials where possible.
- Direct rooftop runoff away from impervious areas or conveyance systems and onto pervious surface areas such as turf or vegetated areas or into cistern systems.
- Design for hydrology.
- Manage development impacts at the source (or as close to it as possible).

Section 8.2.4 provides more details on how the BMP treatment trains were designed to meet these and other LID design objectives.

Cost Reduction in Design

The team did not focus on using LID over a conventional design to reduce costs. The developer's desire was to design a state-of-the-art development, and the team anticipated that the design would cost more than a conventional development. The only reduction in costs will be through decreased utility infrastructure and paving, but these costs will likely be offset by the cost of permeable pavement.

8.2.4 Tonbo Meadow: Site Stormwater Management

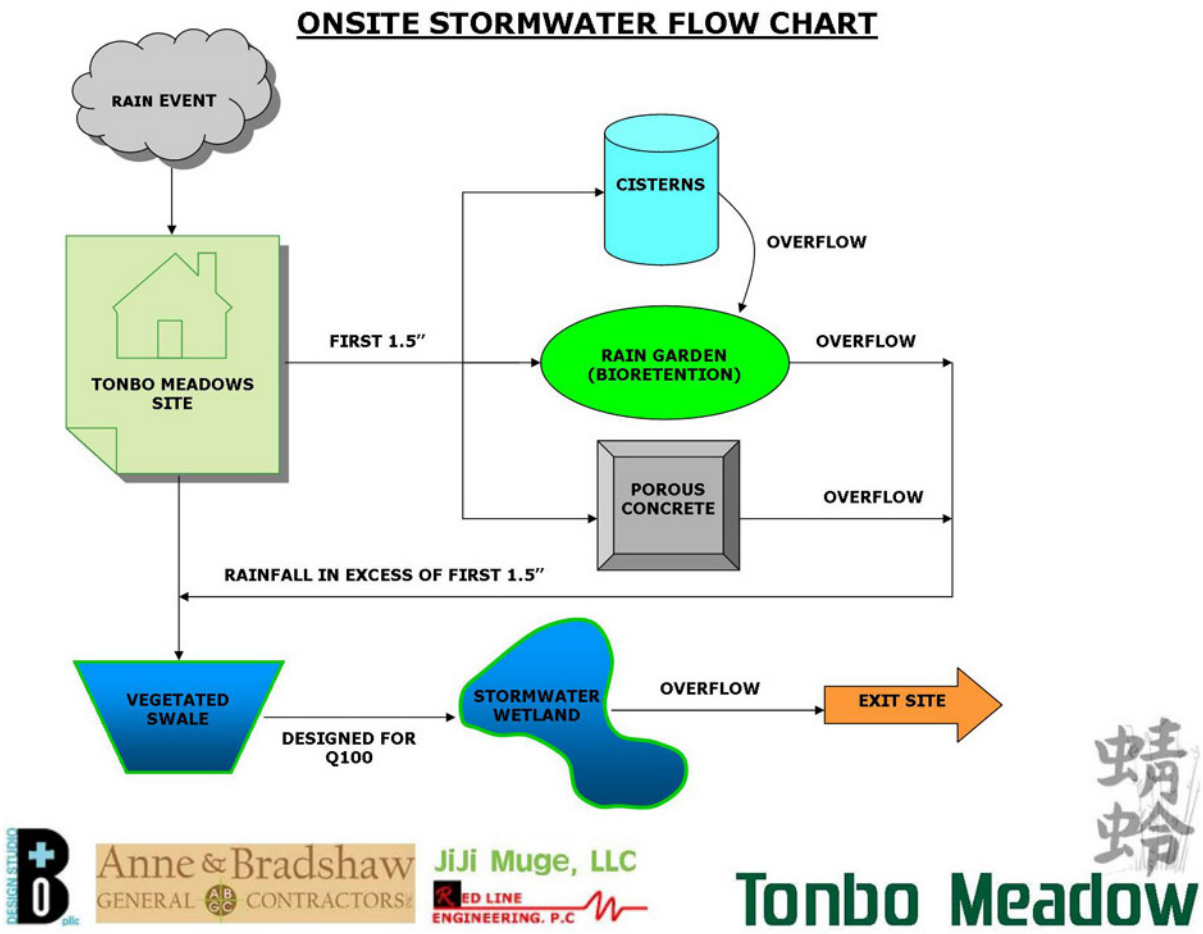
The Tonbo Meadow design team selected LID BMPs that could be integrated into the site's natural drainage paths. The stormwater system was designed to treat pollutants at the source and provide additional treatment through treatment trains. They also integrated the BMPs into the overall landscape design, which—combined with the protected open space—will provide an attractive community for residents to enjoy. Their stormwater design is an example of how LID meets multiple treatment goals and produces a highly marketable development.

The system of LID BMPs designed for Tonbo Meadow is illustrated in Figure 8-17, noting the locations of the rain gardens and stormwater wetland. The existing topography was used to locate all BMPs using the existing drainage paths with minimal need for grading. The hammerhead



Figure 8-17. Location of rain gardens and stormwater wetland within Tonbo Meadow site design (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC)

Figure 8-18. On-site stormwater routing schematic for Tonbo Meadow (courtesy of Gary McCabe, P.E., Red Line Engineering)



turnaround and all driveways will be constructed with permeable concrete to retain and infiltrate stormwater runoff.

Figure 8-18 illustrates how on-site stormwater runoff will be routed through the stormwater BMPs. All roof runoff is routed first to cisterns, which residents will use for lawn and garden irrigation. Rain gardens will receive runoff from the lots. When rain exceeds the cistern design storm, runoff will bypass the cisterns and flow into the rain gardens as well. Each rain garden will treat runoff from two to three houses. Overflow from the rain gardens will enter grass swales along the road. Grass swales will convey stormwater runoff to a stormwater wetland for further treatment. *Low Impact Development: A Guidebook for North Carolina*'s Chapter 4: LID Stormwater BMP recommends treatment trains, like this one, be used to compound the benefits of individual BMPs. By using BMPs in series, the design team maximized retention storage and infiltration.

Grass swales will be constructed along both sides of the road, partially in the road right-of-way, and will control and treat the road area, undisturbed open space, and other common pervious areas. The grass swales will transport any excess stormwater flow from the entire site to the stormwater wetland.

The stormwater wetland will be about one-fifth of an acre, which is about the same as the surface area of the conventional stormwater pond in the initial design. The LID design will provide a walkway and overlook for residents, and signs will be posted that educate the residents on the environmental functions of the wetland. This design is an example of using LID to achieve human functionality, as described in Chapter 3.

Since the site is at a lower elevation than the surrounding property, it receives untreated stormwater from surrounding residential developments. The stormwater wetland was designed to control and treat both on-site runoff and the runoff received from the surrounding development. This is an example of how an LID development can account for adjacent land uses and reduce the impact of other developments, as discussed in Chapter 3 (3.4.5 Addressing Surrounding Land Uses).

The stormwater system was designed according to the state and local BMP sizing requirements discussed earlier. The runoff from the first 1.5 inches of rainfall will flow to the permeable concrete areas or rain gardens. Swales transport the overflow from these practices to the stormwater wetland. To meet stormwater requirements, the stormwater wetland will detain the 1-year, 24-hour storm and match the peak flow of the 2-year and 10-year, 24-hour storms. The team provided additional hydrology benefits, beyond the minimum requirements, by designing the stormwater wetland to control the 100-year storm, which will mitigate any flooding from larger storm events. There were no pollutant removal requirements other than the state requirement to treat the runoff from the first 1.5 inches of rainfall and to design the stormwater BMPs according to the *North Carolina Stormwater BMP Manual*. All stormwater requirements were met through the BMP treatment train, and no additional detention was necessary.

Incorporating the stormwater BMPs into the existing landscape was challenging for the design team. The site's flat topography, combined with the site's long and narrow shape, provided little flexibility for using existing drainage paths. For these reasons, the LID stormwater design required more creativity than a larger, wider tract with more varied topography. The supplemental property bought by the developer provided a low point for the stormwater wetland, and the existing drainage paths route stormwater BMP runoff to that wetland. This property was originally purchased to satisfy requirements for a cluster development, but the acquisition also provided a means to accommodate an LID stormwater design.

An important aspect of LID is designing BMPs to mimic natural processes and wildlife habitat. Towards this goal, specific native plant communities will be incorporated into landscaping for stormwater BMPs and other common areas to provide habitat for butterflies, dragonflies, birds, bats, and other wildlife. The design incorporates the stormwater system into the landscaping to improve the human habitat has well. The stormwater features and conservation area are designed to be highly visible, attractive elements of the community and have been given names like "The Wetlands" and "The Meadows."

8.2.5 Tonbo Meadow: Construction Phase

Since Tonbo Meadow has not yet been built, specific construction practices are not known at this time. Much of the design work will help reduce construction-phase impacts to the site. The meadow, woodland, and most of the existing trees will be protected from disturbance. Using the existing drainage paths has minimized grading. Native plantings will replace any vegetation removed during construction.

The installation of BMPs and permeable pavement will be timed to prevent clogging to bioretention filter media and concrete pores. BMPs will be graded during site grading. The BMPs will not be installed until house construction is completed and the disturbed areas are permanently stabilized. If a house is adjacent to a rain garden, the rain garden will not be installed until the house is constructed. This prevents sediment, sheet rock dust, and other particles released during construction from clogging the filter media. The driveways and hammerhead turnaround will be graded initially, and the underlying stone will be laid before construction has been completed. The permeable concrete will not be installed until the site is stable and adjacent construction is complete.

8.2.6 Tonbo Meadow: Plan Approval Process

The design team collaborated on a design that would be accepted by the City of Wilmington and meet the team's LID design goals. The team's efforts exemplify the collaborative LID design process described in Chapter 3. As part of the process, the team sat around a table and shared ideas, sometimes sketching with colored pencils. The major roles of each team member were as follows:

- The stormwater design engineer shared ideas about using the existing drainage paths and incorporating LID techniques.
- The landscape architect provided ideas on saving trees and preserving natural areas.
- The building architect provided guidance on house orientation for maximum solar radiation and other green building techniques.
- The developer provided ideas on the overall design.

The team met many times and would work between meetings on refining their sketches and ideas. They also met with LID design experts from North Carolina State University (Dr. Bill Hunt, PE, and Jason Wright, EI), who suggested which BMPs to use. For example, Hunt and Wright noted that the lowest area on the property had a 12-inch horizon of hardpan clay; this observation led to designing the stormwater wetland at that location, an ideal site for the BMP. Phil Prete, REP, environmental planner for the City of Wilmington, provided input and guidance on meeting city code as well as the criteria for the Lower Cape Fear Stewardship Development Awards Program.

City regulations and physical site constraints presented a number of challenges for the design team. They made several key decisions during the design process, and through these decisions, they were able to overcome the constraints. These major decisions were:

- *To use LID despite the lack of a local LID ordinance:* After making the decision to pursue LID, the team found ways to use variances and existing regulations to achieve LID design goals.
- *To preserve the meadow area in the back of site:* This was a challenging decision because the preserved area was the most developable land on the site (highest elevation). This decision shortened road and utility length and allowed the design team to achieve a substantial reduction in impervious surface.
- *To purchase additional property for cluster development status:* This decision added costs but allowed the developer to increase the density and make LID a viable design option. Without adding this piece of low-lying property, the stormwater system could not have been designed using existing topography.

The input from design team members and outside experts helped the developer make informed decisions about the design. The collaborative process ensured that the team considered the full suite of design options available for the site.

Each variance described in the previous sections represents a regulatory constraint that was overcome by negotiations between the design team and the City of Wilmington. One of the most challenging constraints for the team was using permeable pavement, which required considerable negotiation with the city government.

The team had originally proposed permeable concrete for all sidewalks, driveways, and the hammerhead turnaround. In addition, the proposed design used raised boardwalks for portions of the sidewalks. The team had also proposed an LID road design for the development frontage along Greenville Loop Road.

The city did not have experience with maintaining and replacing permeable pavement on roadways and only minor experience maintaining permeable parking lots. Conventional concrete is less expensive and more readily available than permeable concrete, and the city wanted to avoid any highly expensive or difficult maintenance needs related to the permeable pavement. The team reached a compromise with the city to use permeable pavement only for the driveways and hammerhead turnaround. The city plans to maintain the hammerhead turnaround, and the homeowners will be responsible for maintaining the driveways. The city required the use of conventional pavement for the remaining road surface and all sidewalks, including those proposed as raised boardwalks.

The lack of city code supporting LID was a major challenge for the design team and led to a long design and plan review process. The team had to find ways to use the existing cluster design regulations to accommodate LID techniques. An LID ordinance would have reduced the design and review process for this development by an estimated 1 to 2 years because the developer would have used LID with the initial design. The Tonbo Meadow design provided the city with an opportunity to test what LID ordinance language is needed to provide opportunities for similar developments. Tonbo Meadow will be the first development to successfully use Wilmington's cluster design requirements to achieve a low impact development.

8.2.7 Tonbo Meadow: Cost Considerations

At the time of this publication, the financial outcome could not be estimated for the Tonbo Meadow LID design. The team anticipates that the attractive, livable nature of the development, as well as the green building and LID amenities, will lead to a highly marketable development. Potential buyers and real estate agents have already been contacting the developer indicating interest. Because people are moving to the area from California and other areas where LID and green-built developments are more widely available, demand for innovative developments may exceed supply within the Wilmington area. The development design has been featured in a number of news articles, helping to promote interest in Tonbo Meadow and innovative design in general. The increase of lot yield from 5 to 10 lots will help increase the revenue from the design, but the saleable benefits of using LID on the site will remain uncertain until the development is built and the lots are sold.

The design team made several choices to use expensive LID techniques as a means of building a state-of-the-art development and becoming a pioneer in LID for the area. The intensive plantings for the BMPs will represent a substantial portion of the LID cost, yet the establishment of native plant communities within the stormwater design will provide wildlife, water quality, and aesthetic functions that would not be realized through less expensive planting plans. The choice to use permeable concrete also added

a substantial cost over a conventional development design. Tonbo Meadow will be the first development in Wilmington to use permeable concrete on a road surface. As more developments use this surface, the availability of permeable concrete materials and contractor experience will continue to increase, and costs are likely to decrease in the future. LID techniques that cost less than conventional development are expected to offset the planting and permeable concrete costs to some degree. The greatest savings will come from reducing impervious surface and lot size, which will lower road, utility, and grading costs.

As local governments enact LID ordinances, developers may have more opportunities to apply LID in a cost-effective and marketable manner. The Tonbo Meadow design team would have lowered costs on the design phase if the City of Wilmington had established LID regulations, allowed flexibility in development design, and offered faster plan review. The design team's efforts helped educate the City of Wilmington on the challenges of implementing LID under the current requirements, and Tonbo Meadow has likely provided an easier, less-costly direction for future LID development in Wilmington.

8.2.8 Tonbo Meadow: Long-term Maintenance

The Tonbo Meadow homeowner's association (HOA) will be responsible for the long-term maintenance of the LID stormwater system. The HOA will own easements for all stormwater BMPs in lots and common areas. Maintenance agreements will specify the frequency of inspection and maintenance, probably by a landscape maintenance crew.

North Carolina State University's Department of Biological and Agricultural Engineering (BAE) is conducting long-term monitoring of Tonbo Meadow to research the water quality and hydrology benefits of the site's treatment trains. This will be BAE's first opportunity to monitor BMPs in series.

8.2.9 Tonbo Meadow: Conclusion

The Tonbo Meadow LID design was the result of a collaborative design process that involved the developer, building architect, landscape architect, and stormwater design engineer, as well as city planners and university researchers. The case study reflects the type of design and process recommended in this guidebook for achieving a development that applies LID to the greatest extent practical. The Tonbo Meadow LID design achieved the following LID design goals outlined in this guidebook:

- Modify traditional layouts to reduce road frontages and driveway lengths.
- Limit site disturbance, clearing, and grading to the smallest areas necessary.
- Use preservation to gain more benefits (environmental and

Figure 8-19. Conceptual drawing of the Tonbo Meadow development (courtesy of Lara Berkley, ASLA, and Scott Ogden, AIA, of B+O Design Studio, PLLC)



economic) than are possible from creation or mitigation.

- Consolidate natural open space areas whenever possible.
- Incorporate natural filter strips, vegetated areas, channels, or alternative practices where possible in rights-of-way, landscape areas, and traffic islands to address street, sidewalk, and driveway stormwater.
- Take advantage of existing waterways, vegetated areas, and amenable soil conditions to direct, absorb, clean, recharge, or store water; reduce air pollution; provide wildlife habitat; and add natural amenity value to a development.
- Design impervious areas for the minimum required paved area length and width needed to support their intended uses.
- Carefully locate and design sidewalks to maximize community benefits from the impervious surface.
- Substitute pervious materials for impervious materials where possible.
- Direct rooftop runoff away from impervious areas or conveyance systems and onto pervious areas such as turf or vegetated areas or into cistern systems.
- Design for hydrology.
- Manage development impacts at the source (or as close to it as possible).

The Tonbo Meadow stormwater system design exemplifies the successful application of LID guidelines as well. The design provides an example of how BMPs in series, or treatment trains, can compound the benefits of single BMPs. The design demonstrates how a stormwater system can be incorporated within the existing landscape and can provide both wildlife habitat and human functionality while reducing the overall environmental impact of a development. Addressing existing drainage problems and treating stormwater from adjacent developments also addressed surrounding

land uses, as recommended in this guidebook. Figure 8-19 provides a preview of the completed development. For more information about this development site and progress on construction, visit the Tonbo Meadow website at http://tonbomeadow.com/.

Credits for Development Design and Figures:

Pam Fasse and Brad Karl
JiJi Muge, LLC
P.O. Box 221
Wrightsville Beach, NC 28480
(910) 232-1474

Pam Fasse and Brad Karl
Anne & Bradshaw, General Contractors
P.O. Box 221
Wrightsville Beach, NC 28480
(910) 256-5203

Gary McCabe, P.E.
Red Line Engineering, P.C.
2664 Timber Drive, Suite 405
Garner, NC 27529
(919) 606-4560

Lara Berkley, ASLA
Scott Ogden, AIA
B + O design studio, PLLC
205 Princess Street
Wilmington, NC 28401
(910) 251-2707

8.3 Case Study #3 – North Carolina Arboretum

8.3.1 North Carolina Arboretum: Introduction

The North Carolina Arboretum in Asheville is the site of several model projects that demonstrate how stormwater can be effectively managed to protect and improve the health of the environment. The two case study projects described were built on the grounds of the arboretum in 2001, after a partnership between the North Carolina Arboretum and North Carolina State University's Water Quality Group, in the Department of Biological and Agricultural Engineering, was established. At that time, the French Broad River Watershed Education Training Center was created to develop educational programs and projects related to the partnership's goal of preserving and improving the quality of the region's waterways. The two cooperatively designed and constructed projects are the subject of regularly

scheduled tours and workshops for professionals and non-professionals alike. The training center's website is www.bae.ncsu.edu/programs/extension/wqg/frenchbroad/.

8.3.2 North Carolina Arboretum: Background and Project History

The North Carolina Arboretum is a 434-acre public garden within the 6,302-acre Bent Creek Experimental Forest, a part of the larger Pisgah National Forest. Topographically, the arboretum combines steep slopes and deep valleys with an elevation range of 2,000 to 2,800 feet above sea level. The soils on the site are geographically typical and associated loams—Hayesville, Evard, Tate, Brevard, Tusquitee, Saluda and Fanin—with slow to moderate infiltration rates. Eroded areas are present within the site, and it can be assumed that soil depths vary accordingly. Hydrologically intermittent and perennial streams that drain into wetlands and Bent Creek and then into the French Broad River serve the site. Bent Creek itself is a trout stream and flows through the arboretum from southeast to northwest. The arboretum property is a second-growth forest, in USDA climatic zone 7a, that is characterized by a predominately oak canopy with significant numbers of hickories and other hardwoods. Species distribution varies markedly between drier hilltops and ridges and moister lower slopes and ravines. Flowering dogwood dominates the deciduous understory of few shrubs and a sparse herbaceous groundcover. Along primarily north-facing slopes and steep rock outcrops is a dense understory of rhododendron and mountain laurel and often no ground cover. The floodplain along Bent Creek supports the greatest diversity of species, and the understory is dense. Pioneer species are common, and vines and brambles form thickets in some places. The annual mean rainfall at the arboretum is 45 inches.

From the beginning, the arboretum had the unique opportunity to "build into the existing forest," and the concept master plan identified five distinct land use zones within the forest to structure the needed uses of the property. The flatter-sloped areas (labeled the 'central' and 'western' zones), would be developed for support facilities, access roads, parking, and easily accessible demonstration gardens. Steeper slopes, coves, and ravines (the 'southern' and 'eastern' zones), would be devoted to wildlife habitat plant collections under the existing forest canopy, and there would be little or no forest disturbance. The Bent Creek Corridor, the fifth zone, was recognized as a sensitive resource and designated as the site for a water garden. Paths were located to connect facilities and points of interest. Overall, the suitability of each zone for the proposed use minimized site disturbance and grading, maintained natural drainage patterns, and preserved native vegetation and natural site features, fundamental LID principles.

8.3.3 North Carolina Arboretum: Site Assessment and Design

While preparing the concept master plan, the Bent Creek site was explored on foot and evaluated to thoughtfully locate roads, buildings, and gardens

Figure 8-20. North Carolina Arboretum masterplan

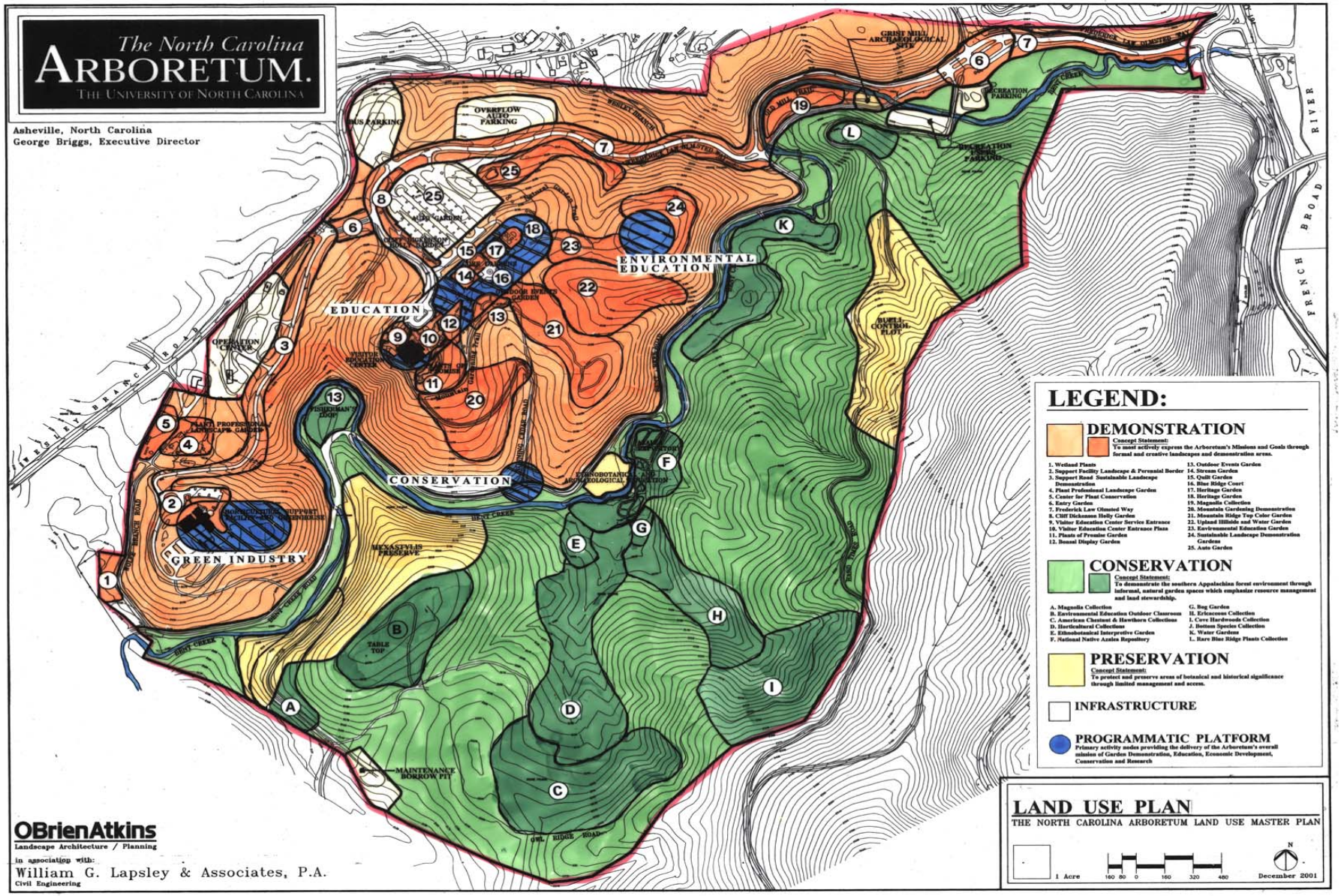




Figure 8-21. Operations Center at the North Carolina Arboretum during the retrofitting process

to minimally impact Bent Creek and the existing landscape. At the time (1986), LID principles and practices as such were not being discussed. The design team and the founders of the arboretum, however, recognized how important it was to protect and enhance the diverse and rich existing native flora of the Bent Creek Forest.

As a concept plan is intended to be an ever-changing and responsive tool, the North Carolina Arboretum embarked on a new quest in 2002. The purpose of the most recent land use study was "to provide guidance for current capital development projects." These projects included the Operations Center, which was completed in 2004, and several retrofits following low impact development principles and practices were employed as the site was developed. The land use study updated the inventory of site features, refined programming focus topics, and organized the arboretum site into three land use zones: Demonstration, Conservation, and Preservation (Figure 8-20). They correspond to the original master plan zones, but the new designations help express the arboretum's evolving mission and values. The Operations Center and the later constructed Baker Exhibit Center, which also utilizes LID principles and practices, are in the Demonstration Zone. The Demonstration Zone highlights creative landscapes, hospitality, and educational programming. Within the Conservation Zone, emphasis is on resource management and land stewardship. Informal, natural garden spaces provide opportunities to explain riparian, forest, and stream ecology with a focus on stormwater and water quality issues. The Preservation Zone identifies areas of botanical and historical significance that are to be protected from development.



Figure 8-22. Green roof at the North Carolina Arboretum Operations Center during routine maintenance

8.3.4 North Carolina Arboretum: Site Stormwater Management

LID at the Operations Center

The North Carolina Arboretum's Operations Center (Figure 8-21) is approximately 10,000 square feet and was built using low impact development techniques. It is the first of 15 state-constructed facilities that follow Triangle J High Performance Building Guidelines. At the Operations Center a green roof, rain garden, rain

pockets, permeable parking, a cistern, a wetland pool system, turf reinforced swales, and a level spreader function together to treat stormwater runoff before it enters a jurisdictional wetland and eventually Bent Creek. Because Bent Creek is a trout stream, it is critical that even treated stormwater runoff be sufficiently cooled before being released. Trout are cold-water fish, thriving where waters are free of pollution and rich in oxygen, and are very sensitive to changes in water temperature. High temperature exposure for even short periods is fatal; warm water exposure quickly leads to behavioral and metabolic disturbances.

Stormwater runoff at the Operations Center is treated by at least two integrated practices. The green roof (Figure 8-22) drains into a rain garden (Figure 8-23) at the base of the building and on to the level spreader. Some roof runoff is treated through rain pockets, the wetland pools, and the turf-reinforced swales. The wetland pools (Figure 8-24) also collect runoff from the center's lawn and permeably paved and gravel parking areas (Figure 8-25) before draining into the swale. The wetland pools were designed to remain inundated at times and are planted with native species that tolerate periodic flooding. In the wetland pools, stormwater creates habitats similar to vernal pools. The rain pockets are also planted with indigenous species that can withstand variable drought and inundation cycles.

The level spreader (Figure 8-26) is the final stormwater treatment feature at the Operations Center. The function of the level spreader is to disperse the high velocity of runoff, which can cause erosion. The level spreader at the Operations Center is a fabric sock that is filled with mulch and an indigenous seed mix and is sited to intercept and diffuse runoff. Runoff fills the area behind the spreader then flows evenly over the crest, or lip, of the spreader. A less damaging sheet of water flows into the riparian buffer.

LID at The Baker Exhibit Center

The Baker Exhibit Center is the capstone project of a five-year building plan at the arboretum, the



Figure 8-23. Water discharged from the green roof is released to this linear rain garden at the Operations Center



Figure 8-24. Wetland pools at the Operations Center shortly after installation



Figure 8-25. Installing the permeable parking lot at the Operations Center



Figure 8-26. Level spreader at the Operations Center



Figure 8-27. Baker Center rain garden at the North Carolina Arboretum just after initial planting



Figure 8-28. Monoculture events lawn rain garden at the North Carolina Arboretum

result of a November 2000 bond referendum and a capital campaign. The bond referendum allowed the construction of the Baker Exhibit Center, the Operations Center, new gatehouses, and infrastructure improvements.

The Baker Exhibit Center, which opened in the fall of 2007, functions as the primary welcome and orientation center for more than 225,000 arboretum visitors annually. It houses the arboretum's information center as well as an exhibit hall and greenhouse. The grounds surrounding the Baker Exhibit Center feature contemporary ideas for cultivated gardens. A significant component of the Baker complex is a large rain garden at the front entrance of the building.

The Baker Exhibit Center rain garden (Figure 8-27) is prominently situated in the center of the front driveway and drop-off area of the building. The rain garden receives water from a higher-level events lawn, portions of the building, and the parking area and road. The events lawn (Figure 8-28) has high infiltration media and is underlain with dual 18-inch culverts with flow restrictions to release infiltrated rainwater downhill to the rain garden through a conventional collection system. Runoff from the road encircling the rain garden is directed into it. Rain gardens reduce nutrients and pollutants in stormwater runoff by filtration, plant uptake, sedimentation, microbial action, and absorption. Plants for the rain garden are selected to survive periodic inundation and drought. From the rain garden the treated water drains under the road to a turf-reinforced swale, an ephemeral pool, and runoff collects in an extant sediment basin.

8.3.5 North Carolina Arboretum: Conclusion

Since its establishment, the North Carolina Arboretum has fulfilled its mission to "cultivate connections between people and plants through conservation, education, garden demonstration, economic development, and research." It has become a major tourist attraction, allowing its vision to touch an ever-expanding audience, and a valuable resource for the community,

the region, and beyond. Through its partnership with the French Broad Training Center, highly visible low impact development features have been constructed that enable thousands of visitors annually to understand how the hydrologic cycle works and to recognize stormwater as the resource it is and the landscape amenity it can be.

8.4 Case Study #4 – Conventional Versus LID Design at a Piedmont Site

8.4.1 Comparative Case Study: Introduction

The final case study site, which is located in the North Carolina piedmont, was developed under conventional stormwater management techniques in accordance with state and local stormwater regulations at the time of development. The objective of this case study was to redesign the site using the guidelines presented in the document *Low Impact Development: A Guidebook for North Carolina* and illustrate how LID strategies could have been implemented given the limitations of real-world constraints. Annual hydrology, pollutant loading, and cost were evaluated and compared between the conventional and LID site designs.

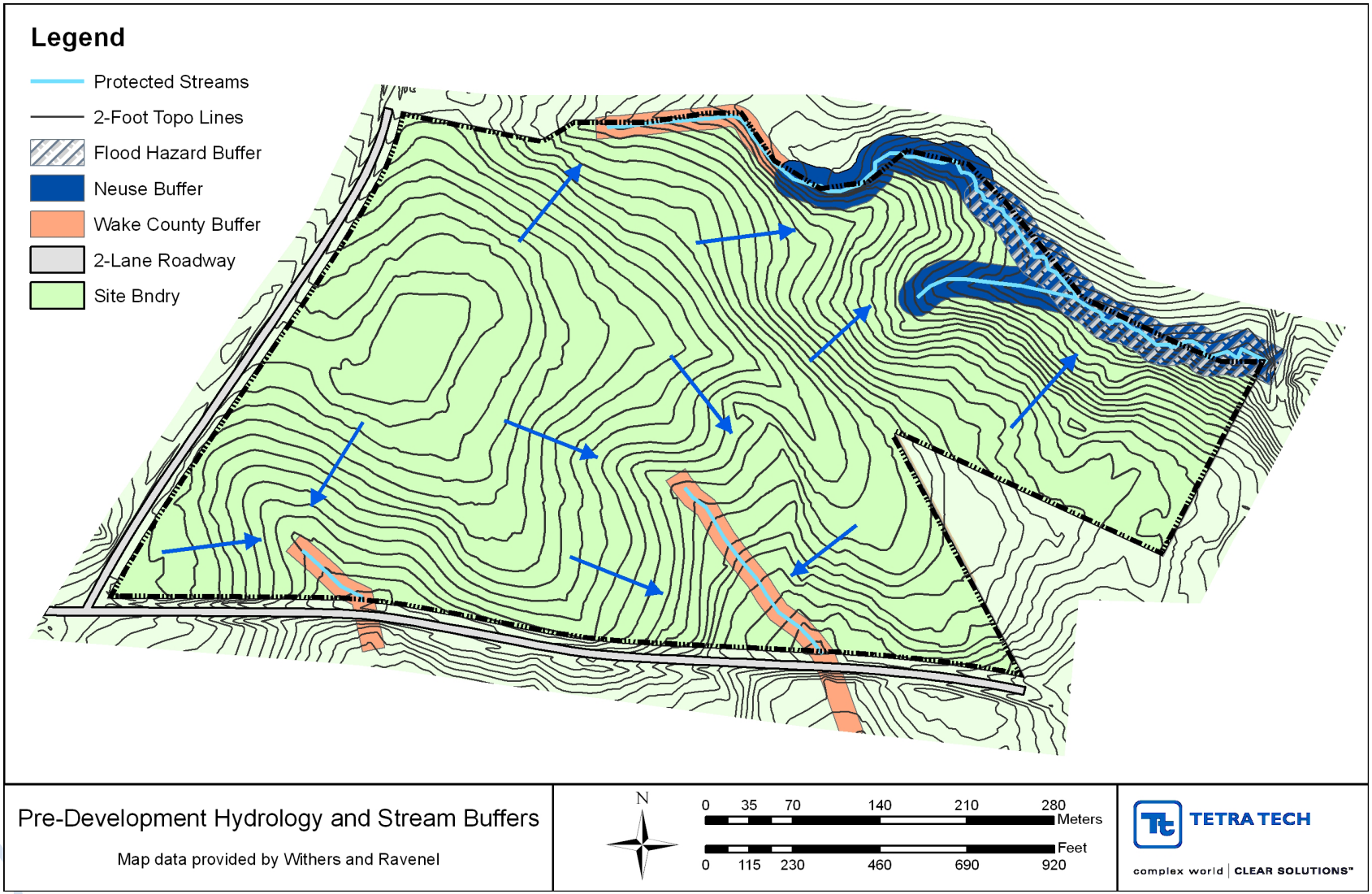
Figure 8-29 (following page) shows the site boundary, topography and flow direction, stream channels, and required stream buffers. The highest elevations on the site are located on the western side of the property and generally slope eastward toward three separate drainage areas. The study site is bordered on the south and west by two-lane roads. The north side of the development is separated from a lower density residential neighborhood by a protected stream channel and riparian area. This north side of the site comprises the majority of the protected streams within the development, which all flow to the Neuse River. Undeveloped forest borders the development to the east.

8.4.2 Comparative Case Study: Conventional Site Design

Site Description

The development in the case study site is a 67-acre, 47-lot low-density residential neighborhood in Wake County, North Carolina. Withers & Ravenel, a local civil and environmental engineering firm, designed the development. The development is zoned R-40W (Residential-40 Watershed District), which specifies a minimum lot size of 40,000 square feet and a minimum lot width of 110 feet. The average lot size is approximately 1.1 acres, and the development includes a recreation center with a tennis court and swimming pool. In-situ soils are more than suitable for subsurface wastewater disposal, and all of the wastewater is treated on-site by individual septic and drain field systems using conventional design. Since water is supplied to the neighborhood by a large community system owned by

Figure 8-29. Case study site footprint



a cooperative, no drain field setbacks from wells were required. Soils are predominantly Appling sandy loam or Cecil sandy loam, which have a hydrologic soil group classification of B and surface runoff values ranging from low to medium. The roads have a width of 20 feet, no curb and gutter, and use roadside swales and culverts to convey runoff to level spreaders adjacent to stream buffers. The road width is much less than average when compared to similar developments in the region: the goal was to reduce the site's impervious area to allow home site builders a wider range of options for house area and lot layout.

Some modifications were made to the original site design for the purposes of the case study. A more typical road width of 27 feet was chosen, and curb and gutter replace the roadside swales. The average house footprint was reduced to 2,000 square feet. These changes allow the site to be more representative of conventional stormwater management and lot layout, providing a better baseline for a comparison to LID design. It is important to note that the real site with its original design would have performed differently in the assessments that follow.

Development Regulations

Regardless of geographic location, local development and environmental regulations influence how neighborhoods are designed and built. The case study development was subject to regulations from county zoning and stream protection ordinances, as well as regional watershed protection mandates, all of which are discussed below.

Stream Buffers

The site contains several protected headwater stream channels that are subject to buffer protection according to either the Neuse River Riparian Buffer Rules or Wake County water supply watershed rules. For the portion of the stream channels with a drainage area less than 25 acres, Wake County required a 30-foot protective buffer plus a 20-foot building setback. Under the Neuse Buffer rules, intermittent streams (located in the northeast region of the site) required a 50-foot protective buffer with no building setback (30-foot protected buffer plus a 20-foot managed vegetated buffer). In addition, the existence of flood hazard soils (approximately 0.5 acres) in the intermittent stream channel required a 50-foot protective buffer plus a 20-foot building setback. Neuse Buffer rules also require that diffuse flow be maintained when stormwater is discharged to a buffer. This requirement is typically met using level spreaders.

Recreation / Open Space Requirements

For R-40W zoning, Wake County development ordinances specify a minimum open space requirement of 1/35th acre per lot, which can be met on-site or through a payment of 1/35th of the property value to Wake

County Parks and Recreation. As a result, the 47 lots required at least 1.3 acres to be allocated for community open space, which was more than met with the recreation center. Since this site is not considered a cluster development, protected stream buffers could not be used to meet the open space requirement.

Stormwater Regulations

At the time of development, for lots zoned as R-40W to be exempt from installing stormwater BMPs, the site's impervious surface could not exceed 15 percent. All of the lots met this requirement except the recreation center, which was actually built as part of a second phase of the project. Therefore, a conventional dry detention basin was installed below the recreation center to reduce the peak flow rate during the 10-year storm to pre-development levels. The 4-foot-deep detention basin, which does not have extended detention, can safely pass the 10-year storm through the riser. In addition, Wake County requires a maximum nitrogen loading rate of 3.6 lbs/acre-year. Since the recreation site was constructed after the implementation of the nitrogen rules, the additional nitrogen loading from the calculated loading rate of 4.56 lbs/acre-year was offset through a mitigation payment of approximately $1,400 (in lieu of installing additional BMPs). The site plan for the remainder of the development was permitted before the nitrogen rules took effect and were thus exempt from nitrogen mitigation.

Conventional Site Layout

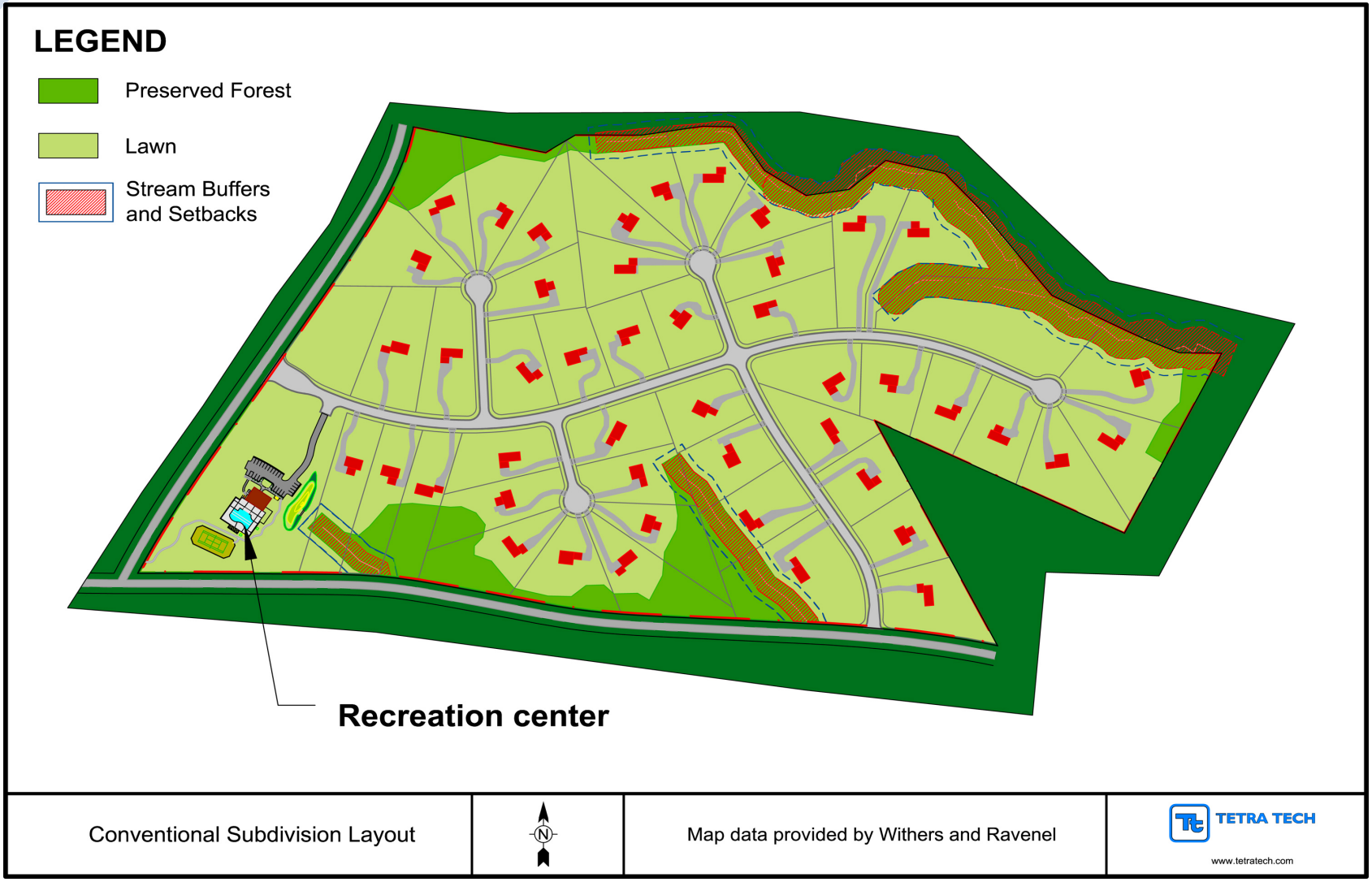
Figure 8-29 shows elevation and natural hydrology of the site, including flow direction, and the three types of required stream buffers. Due to the rolling topography and locations of the protected drainage channels, development options were somewhat constrained.

The development layout designed according to conventional site and stormwater guidelines is displayed in Figure 8-30. Note that the preserved woodland was mostly limited to the stream buffers only. The large lot boundaries extend all the way to the development boundary, leaving only 2.7 acres (not including the recreation center) for community open space and forest preservation. The cul-de-sac roadway design provides several benefits to developers, including the possibility to build on land not suited to a grid street pattern, a slight reduction in impervious surface area, and higher home values.

Conventional Site Stormwater Management

Since Phase 1 of the development required no BMPs, stormwater management was limited to curb-and-gutter storm drains that conveyed the runoff through reinforced concrete pipe (RCP) culverts to the nearest drainage channel. Along the northern end of the site, the Neuse Buffer rules mandated that stormwater be discharged into level spreaders prior

Figure 8-30. Conventional subdivision layout



to entering the protected channel. The conventional storm drain system required 2,869 feet of 15 diameter RCP, 675 feet of 18 inch diameter RCP, and 21 catch basins to safely convey the stormwater off-site. See Figure 8-31 for an outline of the conventional stormwater infrastructure.

Conventional Site Annual Hydrology Analysis

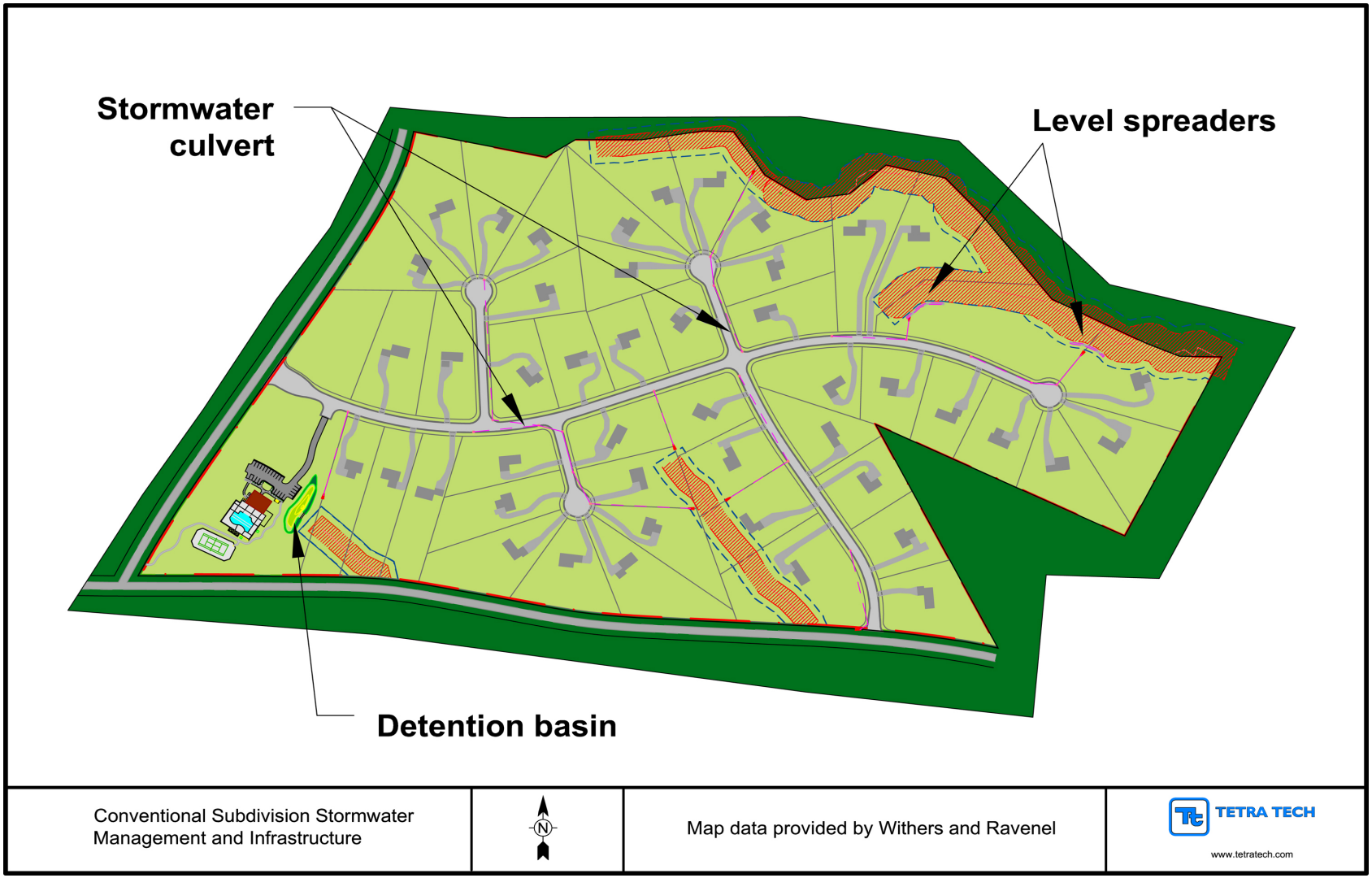
Using the methods discussed in Chapter 2, the annual hydrology was calculated and compared to the water quantity performance goal discussed in that chapter. Prior to development, the study site was an undeveloped green field comprised primarily of deciduous forest. Using the assumptions from Chapter 4, undisturbed woods yield only 5 percent of annual rainfall to surface runoff, while 45 percent and 50 percent exit the site via infiltration and ET, respectively. According to Table 2-6 in Chapter 2, a residential green field site in the piedmont of North Carolina is allowed a 5 percent tolerance of annual hydrology components. Thus, an annual hydrology goal of 10 percent or less runoff is acceptable to meet the fundamental LID hydrologic objective. The calculated annual hydrology components for the conventional site design, however, fall substantially short of this target. As shown in Table 8-1, approximately one third of the total site annual rainfall is converted to runoff, while similar percentages are attributed to infiltration and ET. Also included in the table are the assumed annual hydrology components for each land use class (based on Tables 2-3 and 2-4 in Chapter 2 and in this case, for the conventional dry pond BMP.

Table 8-1. Annual hydrology for conventional site design

Residential Area Fate				
Land Use	**Area (ac)**	**Runoff**	**Infiltration**	**ET**
Woods	7.1	5%	45%	50%
Lawn	47.9	30%	35%	35%
Impervious	8.4	80%	5%	15%
Recreation Center Fate				
Land Use	**Area (ac)**	**Runoff**	**Infiltration**	**ET**
Lawn	3.37	30%	35%	35%
Impervious	0.77	80%	5%	15%
Treatment: Dry Pond		86%	7%	7%
SITE TOTAL	67. 6	33%	35%	32%

To meet the Water Quantity Performance Goal outlined in Chapter 2, the LID design approach needs to reduce annual runoff by at least 23 percent. Reaching this target given site constraints is one of the objectives of the LID design in this case study.

Figure 8-31. Conventional subdivision stormwater management and infrastructure



8.4.3 Comparative Case Study: Low Impact Development Site Design

Alternative Development Options

The study site was designed under a zoned minimum lot size of 40,000 square feet. Wake County allows two other alternative subdivision designs that regulate lots based on density standards—cluster development and open space development. Both development options provide an alternative that is more efficient and better suited to the concepts of LID. The benefits from cluster and open space subdivision designs from an LID perspective include:

- Less site disturbance through more compact road and utility networks;
- Reduction in impervious surface, stormwater runoff, and non-point source pollutant loading; and,
- Conservation of usable open space that protects environmentally sensitive areas, provides native habitat corridors, creates community recreation areas, and preserves an area's rural and historic character.

Table 8-2 lists the lot and subdivision standards defined by Wake County for the three development options.

Table 8-2. Subdivision standards by development type

Standard	Conventional	Cluster	Open Space
Minimum lot area per dwelling (ft^2)	40,000	20,000	14,000
Maximum overall site density (unit/acre)*	NA	1	1
Minimum lot width (ft)	110	75	60
Minimum lot frontage (ft)	30	15	15
Minimum required open space (% of total subdivision land area)	0%	≥ 25%	≥ 40%
Recreation area requirement	1,245 ft^2 per lot	1,245 ft^2 per lot	1,245 ft^2 per lot

* Applies only to cluster and open space options.

In developments using on-site wastewater treatment, clustered development allows for drain fields to be located in common areas, which may provide additional space for recreation and wildlife habitat.

One of the major constraints on any development not serviced by a centralized sewer and treatment system is wastewater treatment. Development is usually located to take advantage of the soils most suitable for long-term wastewater application, typically found lower on

a hill slope. Although decentralized wastewater systems can benefit LID by recycling water locally, the location and design of LID versus on-site wastewater practices can conflict with each other (see Chapter 5). For example, LID attempts to protect the lesser sloped riparian areas adjacent to natural drainage channels from development and preserve better soils for stormwater infiltration and retention. Depending on in-situ soils and required setback limits, conventional septic drain fields may require a significant land area, which can increase lot size and the amount of affected land. Two alternatives to the conventional drain field include the dual alternating drain field and the off-site common drain field area. The dual alternating system replaces the need for a backup drain field by independently dosing multiple treatment areas. This technology requires only about 75 percent of the land area of conventional drain fields but costs approximately the same. If part of a site is developed according to cluster or open space standards but individual drain fields can not be sited on the smaller lots, a communal off-lot area can be devoted to multiple drain fields. This type of system not only reduces the total land area needed for wastewater treatment due to fewer setbacks, but can also provide a community recreation area. For further details on these two on-site systems see Chapter 5, LID and Decentralized Wastewater Technology and Management.

LID Site Layout

LID Site Design Goals

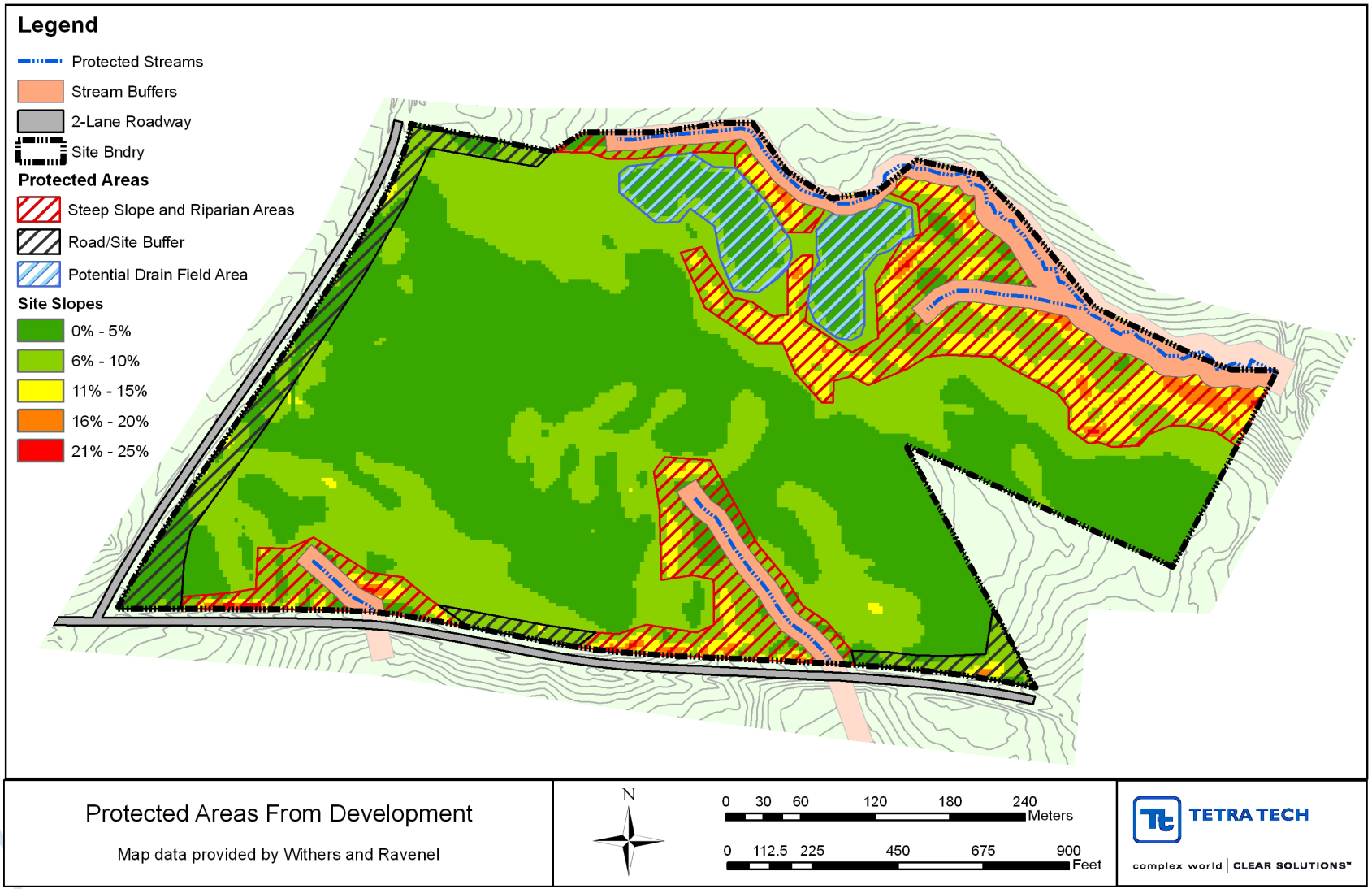
The steps identified in Chapters 3 and 5 were used to guide the redesign of the conventional subdivision layout to meet LID objectives. As such, the team endeavored to:

1. Identify and protect streams and required buffers.
2. Identify and protect areas of steep slopes.
3. Locate optimal areas for common area wastewater drain fields (lower elevations and lesser slopes).
4. Consider locations of roadway on south and west sides of the property, and the undeveloped forest and riparian areas to the east and north sides.
5. Assess topography for ideal road layout to reduce grading and site disturbance.

Note that a lack of information regarding in-situ soils, important vegetation, and natural habitat areas prevented the use of several of the site assessment criteria included in the Chapter 3. For the purpose of this case study, soils and vegetation were assumed to be uniform throughout the site.

Figure 8-32 shows the areas designated as high priority for protection from development. These include the stream buffers, additional riparian areas, steep sloped areas (> 10% slope), potential common drain field areas, and a buffer adjacent to the outside roads to reduce visual impacts.

Figure 8-32. Desired areas for protection from development



Once the targeted protected areas were identified, the roadway and lot layouts were designed. The roadway was aligned on the ridge lines for several reasons: to reduce grading, limit the amount of impervious area draining to the roadway (allowing for smaller roadside swales), and ensure that runoff and wastewater can gravity drain away from the houses to the back yards of the lots for the septic drain field and stormwater treatment located behind the lots. The shape of the site and the location of the protected areas created a long and relatively narrow developable footprint, which was a constraint for decreasing overall road length in the cluster design. The LID design kept the cul-de-sac roadway due to the constraints of the site, but included a community greenway trail (discussed later) to improve neighborhood connectivity, ease of use, and alternative transportation options. To reasonably construct 47 housing lots but preserve as much of the targeted protected areas as possible, the second access point to the subdivision (southeast location) was removed and replaced with an asphalt greenway trail that could be used for alternative modes of transportation (bicycles and motorcycles / scooters). The final impact footprint for the LID subdivision design is illustrated in Figure 8-33.

Preserving open space and reducing disturbance is a significant LID goal. Therefore, this LID case study design designated 13 lots as open space with an average size of 17,400 square feet, and the remaining lots as cluster lots with an average size of 26,100 square feet. This option allowed approximately 36 percent of the total site area (including protected stream buffers) to remain undeveloped forest. Much of the original forest cover was also retained. Wastewater from the 13 open space development lots was treated by an adjacent common area drain field that provided an additional 8 percent of the total site area over what was required for community recreation and open space. A 0.72 acre open space lot with protected forest and lawn or community garden space was created near the 13 higher density lots to provide multi-functional amenities. The community recreation center was included in the LID design but relocated to the eastern edge of the property for added privacy.

Road widths were decreased from 27 feet (back of curb to back of curb) to 20 feet, and grass-lined swales replaced the conventional curb-and-gutter storm drain system. Road frontages and driveway lengths were reduced from an average of 170 feet for the conventional design to about 50 to 70 feet. To further reduce impervious area, 26 of the 47 lots were designed with shared driveways. All of these modifications can be implemented at a lower cost to the developer than traditional lot and roadway designs. The general LID subdivision design is illustrated in Figure 8-34.

In summary, the following LID lot and roadway design strategies were implemented in this case study:

- Modified lot layouts to reduce road frontages and driveway lengths
- Reduced road widths

Figure 8-33. Final impact footprint

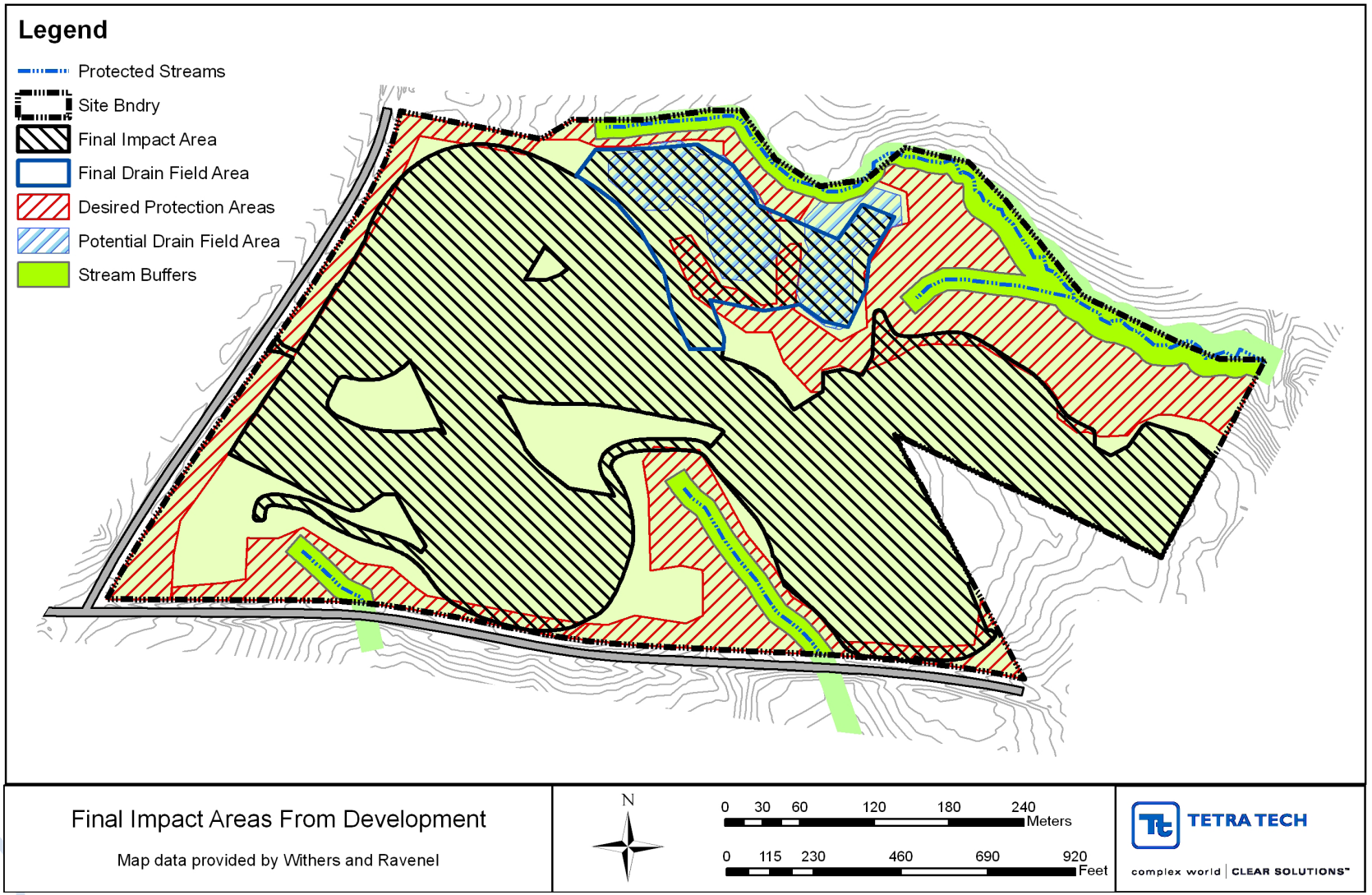
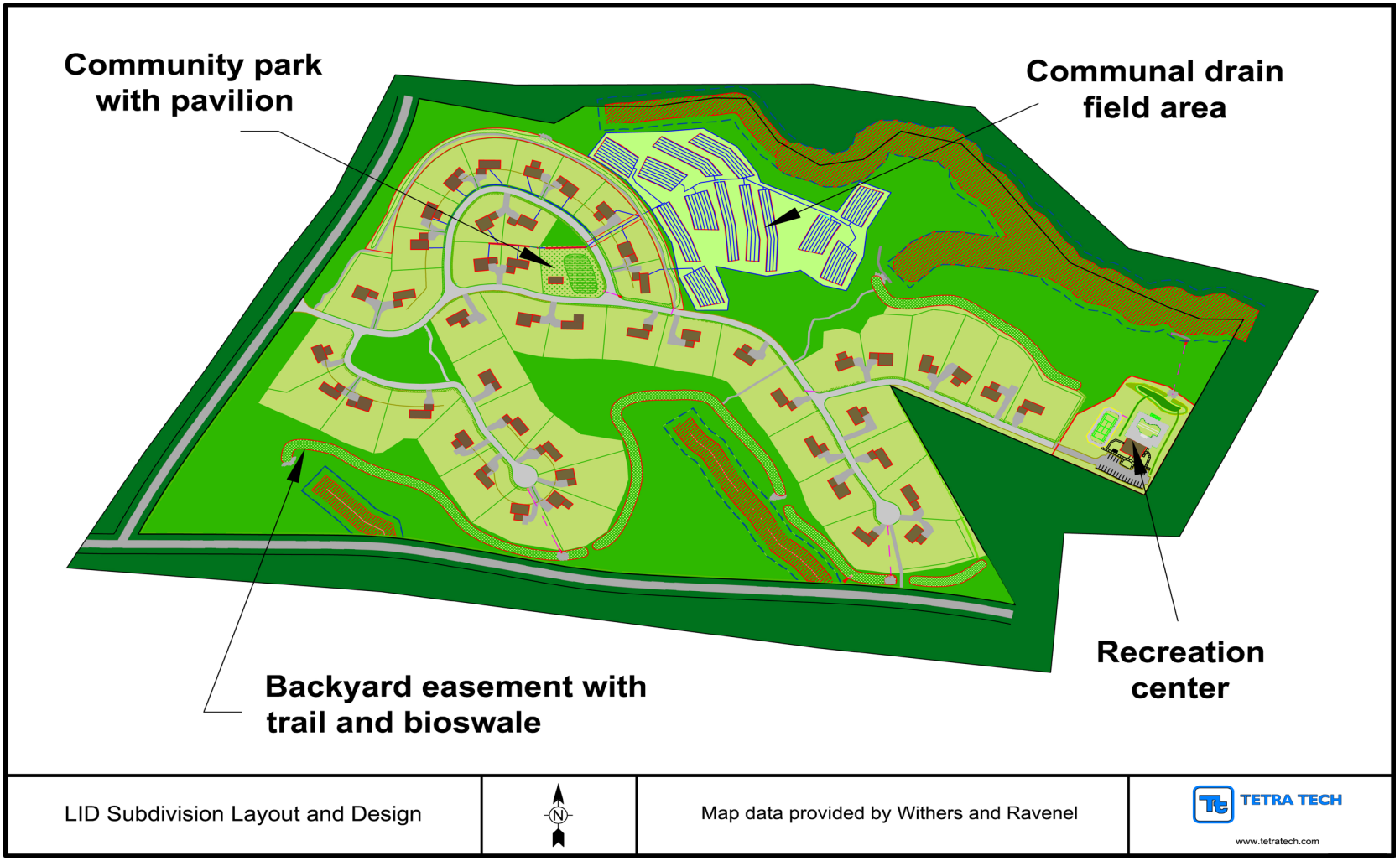


Figure 8-34. LID subdivision layout and design



- Grass-lined swales for stormwater conveyance
- Alignment of roadways to reduce grading
- Preservation of natural areas within lots (20 percent for cluster lots and 30 percent for open space lots)

In addition to reducing and disconnecting impervious surfaces, other simple design strategies can significantly increase infiltration and evapotranspiration. In this case study, amending the soils under lawns was assumed to help the site match the post-development annual hydrology with the LID target, without considerable added cost. This strategy is as simple as stockpiling the disturbed topsoil on-site during construction (instead of selling and exporting it off-site) and replacing it prior to the seeding or laying of sod or lawn grass. Light tilling of hard pan and compost amendments also helps promote healthy and deeper root growth that improves infiltration and ET, and decreases irrigation and fertilizer demands. Although little quantification exists for hydrologic fates of soil-amended lawns, a conservative estimate of 25 percent runoff, 35 percent ET, and 40 percent infiltration was used for the annual hydrologic fate analysis.

LID Site Stormwater Management

Although non-structural BMPs were implemented as much as possible to more cost-effectively reduce runoff, several structural stormwater BMPs (in addition to the two level spreaders installed per Neuse Buffer rules) were necessary to meet the LID hydrologic goals discussed in Chapter 2. Figure 8-35 shows the LID stormwater management strategy for the site, as well as the different drainage areas used for the hydrologic fate analysis. Notice how the roadside swales and backyard bioswales are designed to maximize pervious flow length before runoff is discharged to stream channels.

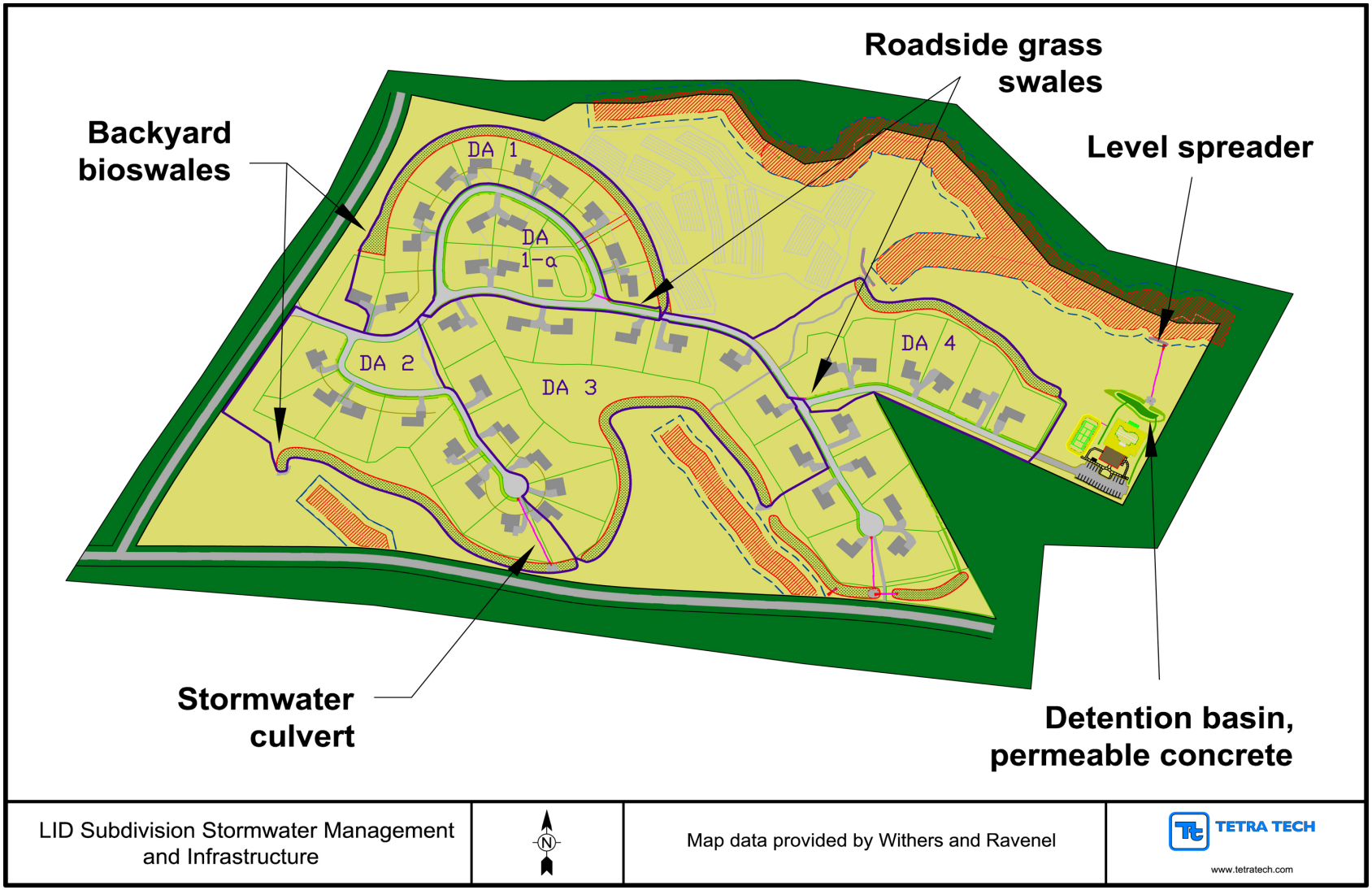
Grass-Lined Road Swales

The first BMP in the treatment train, the roadside swales were implemented throughout the site to collect and safely convey the roadway runoff to the backyard bioswales. They were designed according to the "Best Hydraulic Section" defined by Malcom (2003) to handle the 25-year, 24-hour storm event without overtopping the banks. Using 4:1 side slopes and assuming regular maintenance, the swales had top widths and peak flows ranging from 3.5 to 10 feet and 1.4 to 8.3 cubic feet per second.

Backyard Bioswale

The major BMP implemented with regards to cost and land area (as well as vital to obtaining pre-development hydrology), the backyard bioswale is essentially a long linear bioretention cell constructed primarily on contour (with sloped underdrains). The bioswale is sized to treat the water quality volume (runoff from a 1-inch rainfall event) that was calculated using the

Figure 8-35. LID subdivision stormwater management and infrastructure



SCS Curve Number Method. Outlet weirs were designed to safely pass the 25-year storm event. The bioswale contains a 3-foot bottom width, 4-foot depth of engineered bioretention media, 3:1 side slopes, and an extended detention water quality volume depth of 9 inches.

Most important, this BMP is multifunctional. The backyard bioswale and adjacent area not only capture, treat, and infiltrate runoff, but also provide a contiguous habitat corridor throughout the subdivision as well as a public greenway for neighborhood connectivity and alternative transportation. A 30-foot public easement was provided adjacent to the rear lot boundaries to accommodate the bioswale, greenway trail (which also serves as a filter strip up-gradient of the bioswale), and areas for preservation or new vegetation planting by homeowners. An added benefit to locating this BMP adjacent to lots and within public open space is to create community accountability for maintenance through the neighborhood association (as set forth by the Wake County Unified Development Ordinance for R-40W zoned subdivisions).

Dry Pond

Since the recreation center was constructed as a second phase to the project and exceeded impervious limits, additional BMPs were required to match the pre-development peak from the 25-year storm event. Although this BMP performs poorly for pollutant removal and for meeting LID hydrology targets, the dry pond from the conventional development design was retained to satisfy stormwater regulations at the lowest cost.

Permeable Pavement

An 8-foot buffer around the outside of the tennis court as well as the entire poolside area was converted to permeable concrete. Although permeable pavements are not always suitable for heavy clay soils in the piedmont, clogging from fine sediment is not likely to occur within the recreation center. Underdrains were installed under the permeable pavement to drain to the grass swales that discharge to the detention basin.

Additional Option: Rainwater Harvesting

A truly multifunctional BMP can be achieved by installing a rainwater cistern at the recreation center building that would not only help reduce annual runoff from this more impervious portion of the development, but also provide "free" water for landscape irrigation, toilet flushing, and possibly pool refill during drier periods. Ideally, every home in the subdivision could benefit from harvesting rainwater, but a large system at the recreation center would have a higher likelihood of the stored runoff being used and of receiving proper maintenance.

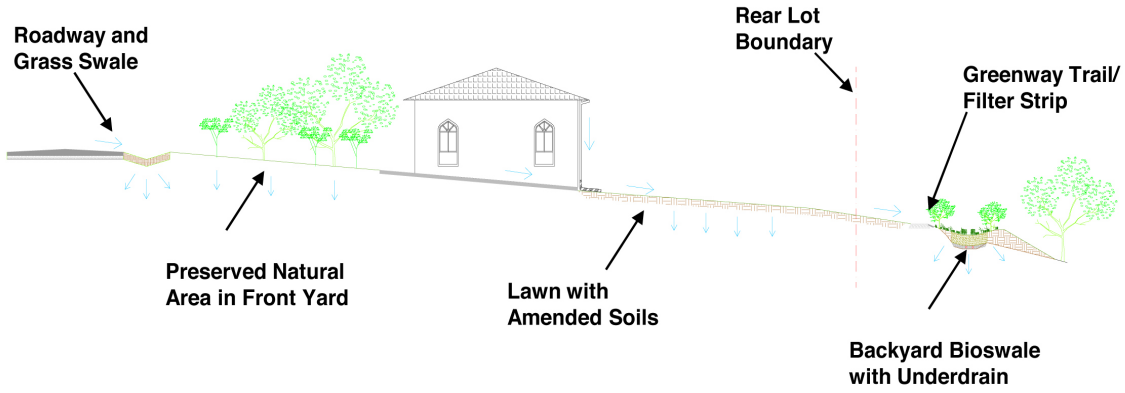


Figure 8-36. Section of typical lot layout showing drainage pattern and LID BMPs

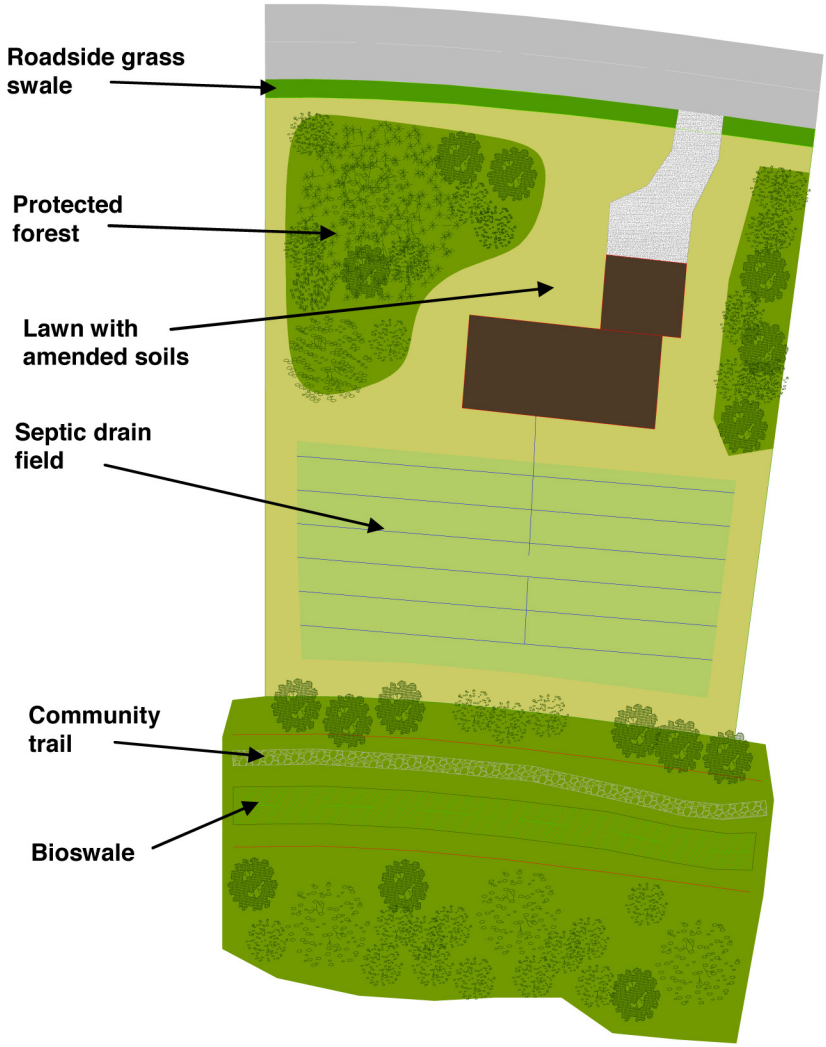


Figure 8-37. Overhead view of typical lot

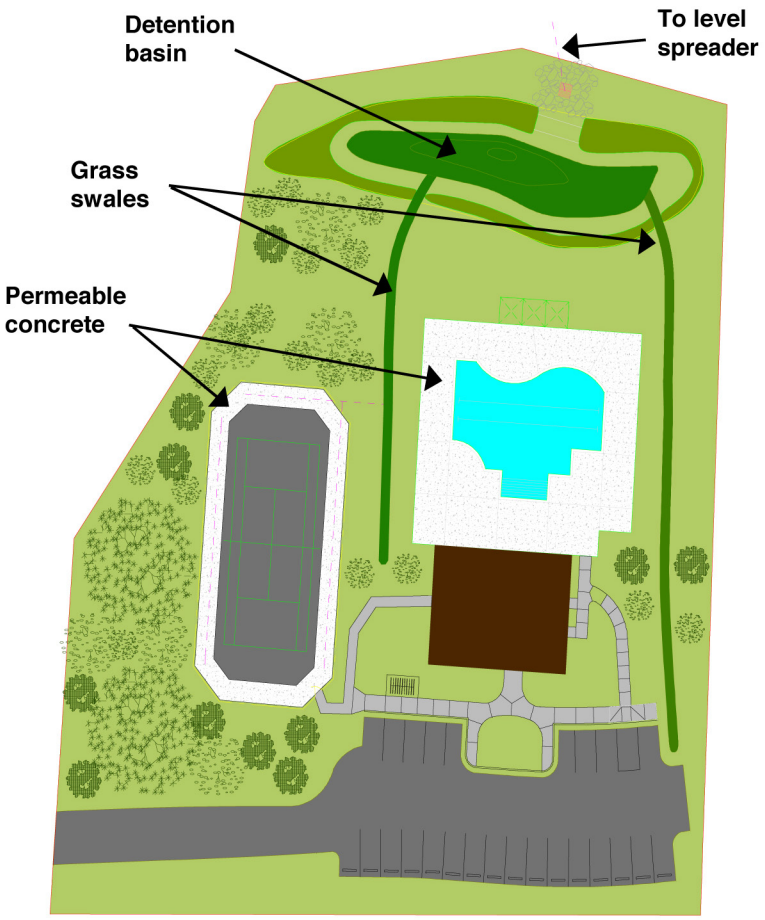


Figure 8-38. Recreation Center and BMPs

Detailed Figures Showing Stormwater Management

The following figures help illustrate how areas of the site would be designed with regards to stormwater runoff, natural area preservation, and relative location to the associated BMPs. Figure 8-36 is a section of a lot with a backyard septic drain field and bioswale / greenway. Figure 8-37 shows an overhead view of the same lot. Figure 8-38 shows an overhead view of the recreation center layout.

LID Site Annual Hydrology Analysis

As discussed previously, the LID annual hydrology target for this residential green field development is no more than 10 percent runoff, 45 percent infiltration, and 45 percent ET. Developing an entire site makes achieving this objective not only very costly but practically impossible. By preserving approximately 36 percent of the total site area for natural woodland, the LID subdivision design reaches the annual hydrology goal. All of the original 47 housing lots were included in the LID design, which also complied with all site and regulatory constraints. Notably, the objective was attained using conservative estimates of annual hydrologic fate for the BMPs (Table 8-3).

As shown in Table 8-4, the hydrologic fate analysis was more involved for the LID design than the conventional design due to the multiple drainage areas within the development that each contained different land uses and received varying BMP treatment. A BMP treatment train treated the runoff before it left the site. Drainage Areas (DAs) 1 through 4 initially treat the roadway runoff through a grass swale that subsequently drains to the backyard bioswale. The bioswale also receives excess runoff from each lot. In DA 4, the runoff from the bioswale also discharges to a level spreader before entering the stream buffer. As previously mentioned, the recreation center uses permeable pavement around the tennis court with an underdrain

connected to grass swales that also receive runoff from the parking lot and building. The grass swales discharge to the dry pond that finally discharges to a level spreader. Refer to Figure 8-27 for the drainage area locations.

Table 8-3. Assumed hydrologic fate values for BMPs

	Hydrologic Fate		
BMP Type	**Runoff**	**Infiltration**	**ET**
Grass swale	90%	5%	5%
Bioswale	40%	25%	35%
Detention basin	86%	7%	7%

Table 8-4. Summary of post-treatment annual hydrologic fates for drainage areas (DAs) and for the entire site

		Hydrologic Fate		
Drainage Area	**Area (ac)**	**Runoff**	**Infiltration**	**ET**
DA 1-a	3.2	13%	40%	46%
DA 1	5.3	11%	43%	46%
DA 2	7.8	10%	44%	47%
DA 3	10.3	9%	44%	47%
DA 4	5.9	10%	43%	47%
Recreation Center	1.8	38%	26%	35%
Remaining Lots	3.8	12%	43%	45%
Protected Area	29.4	9%	44%	47%
TOTAL	67.6	10%	43%	46%

Table 8-5. Example hydrologic fate analysis table for DA 2 under the LID scenario

		Hydrologic Fate		
Land Use	**Area (ac)**	**Runoff**	**Infiltration**	**ET**
Woods	2.5	5%	45%	50%
Lawn	4.1	25%	40%	35%
Impervious surface	1.1	80%	5%	15%
Permeable pavement	0.0	30%	5%	65%
Total	7.79	27%	36%	37%
BMP Treatment		Runoff	Infiltration	ET
Road Swale		24%	38%	38%
Bioswale		10%	44%	47%

Each drainage area required detailed calculations to determine the overall hydrologic fate of rainfall. Table 8-5 provides an example of the calculations, using DA 2. A pre-BMP treatment hydrologic fate total was calculated using each land use classification and associated area and hydrologic fate.

Listed last in the table are the subsequent hydrologic fate totals as runoff passes through the treatment train. As shown, the final hydrologic fate total for DA 2 is 10 percent runoff, 44 percent infiltration, and 47 percent ET.

LID Site Construction Plan

All of the LID principles and concepts outlined in the Chapter 6 also apply to the construction phase of this site. For this development in particular, proper construction phasing is even more important due to the long, contiguous BMP design that makes it difficult to build and protect the BMPs if housing and lot construction occur randomly throughout the site. A better approach would phase construction by drainage area outlined in Figure 8-35 to focus site disturbance and erosion control practices in smaller areas. The following provides an example of how construction phasing might be performed for the LID site design:

1. Clear, grade, and build roadways and subsequently seed and stabilize roadside swales to the extent possible.

Within each drainage area:

2. Starting with the up-gradient lots first, fence off areas for vegetation and soil protection.
3. Install silt fence at rear lot boundary.
4. Clear areas for house, drain field, and extra lawn.
5. Following major house construction, install drain field and subsequently stabilize the lot.
6. Clear easement for backyard bioswale and greenway trail and construct.
7. Upon lot stabilization, remove backyard silt fence.

8.4.4 Comparative Case Study: Conventional Versus LID Design Pollutant Loading and Cost Comparison

Pollutant Loading Comparison of Conventional and LID Designs

The pollutant loads of the conventional and LID scenarios were estimated using the Upper Neuse Site Evaluation Tool (SET) Hydrology / Pollutant Component, which is part of the SET spreadsheet tool developed by Tetra Tech (2005) with funding from the State of North Carolina through a Clean Water Act Section 319 grant. The SET is designed for a relatively quick assessment of site-scale annual pollutant loading, storm event peak flow and runoff volume, and costs associated with stormwater management.

Three scenarios are simultaneously tested in the SET—pre-developed conditions, post-developed conditions with no BMPs, and post-developed conditions with BMPs. It uses an enhanced version of the Simple Method for relating annual runoff to annual pollutant loads, TR-55 for storm event

peak flow and runoff volume, an NRCS method for site-scale storm event hydrographs, a simplified approach for estimating the effect of selected BMPs on the hydrograph, and BMP / stormwater management cost equations based largely on research conducted in North Carolina. The SET is particularly useful for assessing various LID techniques for stormwater management.

In the Upper Neuse SET, BMP removal efficiencies are based on the NCDWQ's *Stormwater Best Management Practices Manual* (2007). Event mean concentrations and pollutant loads are calculated based on regional and national studies, with modifications to reflect local piedmont conditions. Further information about the Upper Neuse SET is available on the Upper Neuse River Basin Association website: http://www.unrba.org/set/

The SET was used to estimate pollutant loads from the conventional and LID site designs for sediment, total phosphorus, and total nitrogen. For the pollutant analysis, the SET requires input of area for each land cover class—forest, managed pervious (lawn and landscaped areas), and impervious surface. Drainage areas, defined as the area draining to a stormwater BMP or BMP treatment train, further divide the land areas. Pollutant reductions are therefore applied only to the land areas draining to the specific BMP.

Table 8-6 shows the SET removal efficiencies for the BMPs used in the case studies. Note that NCDWQ does not provide pollutant removal credit for conventional dry detention basins or permeable pavement. The backyard bioswales are assumed to have the same performance as bioretention. The front yard swales are classified as grass swales.

Table 8-6. BMPs and removal efficiencies in the Upper Neuse SET

	Removal Efficiency		
BMP	**TN**	**TP**	**TSS**
Conventional Dry Detention	0%	0%	0%
Bioretention	35%	45%	85%
Grass Swale	20%	20%	35%
Permeable Pavement	0%	0%	0%

Four scenarios are presented—pre-developed conditions (forest), the site design with conventional stormwater management, the LID site design without BMP treatment, and the LID site design with BMP treatment. Although the conventional site does have a conventional dry detention basin, since it receives no pollutant removal credit the results are identical with or without BMPs. Results are shown in Table 8-7 and Figure 8-39.

Figure 8-39. Scenario pollutant loads

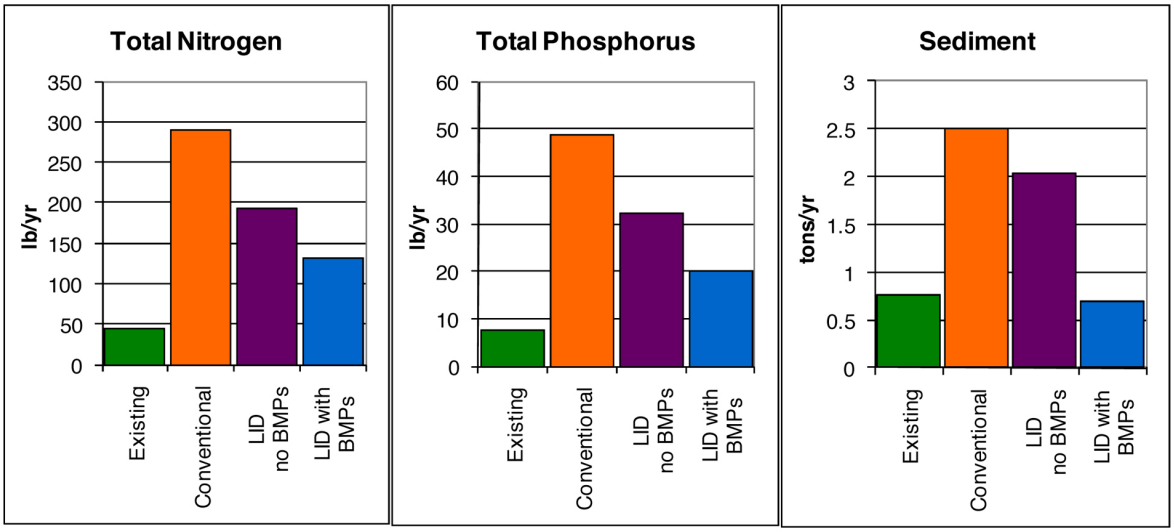


Table 8-7. Scenario pollutant loads

Scenario	TN (lb/yr)	TP (lb/yr)	Sediment (tons/yr)	TN rate (lb/ac/yr)
Existing	45	7.7	0.76	0.66
Conventional	289	48.8	2.51	4.28
LID without BMPs	193	32.2	2.04	2.85
LID with BMPs	132	19.9	0.7	1.95

Even without BMP treatment, the LID site loads are considerably less than those of the conventional site. The increase in forested land and decrease in impervious cover both contribute to the reduction. The BMPs in the LID design further mitigate pollutant loads. The high sediment removal rate from bioretention results in a post-developed site load that is actually less than pre-developed conditions. The nutrient loads are more than double the pre-developed site loads, but are still less than half of the conventional site loads.

Table 8-7 also shows per-acre annual nitrogen loading rates. Although the SET does not use the same methodology as the NCDWQ TN Export Worksheet for the Neuse River Basin Model Stormwater Program, it generally produces comparable loading rates. The conventional site exceeds the 3.6 lb/ac/yr target, and a mitigation payment would be required without additional stormwater treatment. On the other hand, the LID site meets the TN target even without BMP treatment.

This analysis shows that a combination of practices reduces the impact of stormwater pollutants. Using a combination of increase in natural forest

cover, decrease in impervious area, and BMPs for water quality treatment has resulted in a site that is more protective of downstream water resources.

Cost Comparison of Conventional and LID Designs

The costs of the conventional and LID scenarios were estimated using the Upper Neuse SET Cost Component, which is part of the SET spreadsheet tool developed by Tetra Tech. It provides planning-level cost estimates for stormwater BMPs and other construction site elements. The cost assumptions for the tool are documented in a Tetra Tech report (2005). The user enters a whole-BMP measurement, such as volume in cubic feet, and the tool calculates a cost estimate for construction, design and engineering, and inspection and maintenance costs. The user may also enter quantities for pavement, stormwater pipes, and other site elements.

One adjustment was made to the original Upper Neuse SET developed in 2005. The SET adjusts for inflation using an annual rate of 3 percent. Asphalt prices in the North Carolina piedmont have risen by roughly 10 percent annually in recent years. To account for this increase, asphalt prices were adjusted by 10 percent annually instead of 3 percent. Other costs were expected to have increased annually by the approximate inflation rate.

The SET assumes that inspection and maintenance costs over 20 years represent roughly 50 percent of the construction cost. Design and engineering costs are assumed to be 25 percent of the construction cost.

Table 8-8 presents the cost estimates produced by the SET Cost Component. The estimates are displayed in thousands of dollars. The SET produces estimates representing the likely range of costs for a particular BMP or site component. The ranges account for the extent to which individual designs or site constraints may vary.

Two adjustments were made to the cost estimates produced by the SET to account for expected costs of the backyard bioswales and permeable pavement. The SET assumes that bioswales (called "water quality swales" in the SET) cost roughly $3 to $7 per square foot less than bioretention cells. This cost difference is expected based on the differences between bioretention and water quality swale construction. The cost for water quality swales assumes that grass is planted instead of more expensive plantings for bioretention cells, which represents a significant portion of the cost difference. The cost difference is also due to the economies of scale that can be realized by implementing a contiguous length of water quality swale versus multiple, separate bioretention areas. Although the cost difference should hold true for this case study, the cost of water quality swales is likely to fall in the upper portion of the cost estimate. Therefore, the high end of the cost range for water quality swales was applied to both the low end and high end total costs in Table 8-8. The high end cost of permeable concrete

was also applied to both low and the high end of the total cost because the cost of permeable concrete is expected to fall within the high end of the cost range.

Table 8-8. Cost estimate for piedmont case study conventional and LID designs (in thousands)

Project Component	**Construction, Design, and Engineering Cost (Thousands)**		**20-Year Maintenance Cost (Thousands)**		**Total Cost (Thousands)**	
Stormwater BMPs	Conv.	LID	Conv.	LID	Conv.	LID
Conventional Dry Detention	$3 - $11	$3 - $11	$1 - $4	$1 - $4	$4 - $15	$4 - $15
Level Spreader	$3 - $8	$1 - $3	$1 - $3	$0.4 - $1	$4 - $11	$1 - $4
Water Quality Swale		$51 - $85		$18 - $30		$69 - $115
Grass Swale		$11 - $15		$4 - $5		$15 - $20
Subtotal	$6 - $19	$66 - $114	$2 - $7	$23 - $40	$8 - $26	$89 - $154
Stormwater System						
Curb and Gutter	$114 - $154		$40 - $55		$154 - $209	
Stormwater Pipes	$88 - $118	$15 - $20	$32 - $43	$5 - $7	$120 - $161	$21 - $28
Catch Basins	$23 - $31	$4 - $6	$8 - $11	$1.6 - $2.1	$31 - $42	$6 - $8
Rip Rap	$0.3 - $0.5	$0.05 - $0.07	$0.1 - $0.2	$0.02	$0.4 - $0.7	$0.07 - $0.09
Subtotal	$225 - $304	$19 - $26	$80 - $109	$7 - $9	$305 - $413	$27 - $36
Pavement						
Conventional Asphalt for Roads	$716 - $895	$472 - $591	$216 - $270	$178 - $223	$932 - $1,165	$650 - $814
Conventional Asphalt for Recreation Center Parking	$58 - $72	$51 - $64	$23 - $29	$20 - $26	$81 - $101	$71 - $90
Conventional Concrete for Pool / Tennis Court	$58 - $75	$33 - $42	$23 - $30	$13 - $17	$81 - $105	$46 - $59
Permeable Concrete for Pool / Tennis Court		$20 - $65		$7 - $23		$27 - $88
Conventional Concrete for Driveways	$673 - $865	$250 - $321	$269 - $346	$100 - $128	$942 - $1,211	$350 - $449
Remaining Conventional Concrete for Rec. Center	$43 - $56	$35 - $45	$17 - $22	$14 - $18	$60 - $78	$49 - $63
Subtotal	$1,548 - $1,963	$861 - $1,128	$548 - $697	$332 - $435	$2,096 - $2,660	$1,193 - $1,563
Septic Tank Costs[1]		$1 - $2		$0.5 - $1		$2 - $3
Total Cost Range[2]	$1,779 - $2,286	$1,026 - $1,270	$630 - $813	$391 - $485	$2,410 - $3,099	$1,418 - $1,756

[1] Based on best professional judgment

[2] The high end cost estimates for permeable pavement and water quality swales were applied to both the low and high end of the total cost range

Table 8-8 is divided into several sections—stormwater BMPs, stormwater system, pavement, and septic tank costs. According to the SET estimates, the LID development design is estimated to cost about 40 percent less than the conventional design. A savings is achieved because the higher cost of BMPs is offset by the lower cost of stormwater system and pavement. The LID BMPs are estimated to cost 6 to 11 times more than the conventional dry detention pond. However, pavement costs for the LID design, including both conventional and permeable pavement, are about 40 percent less than for the conventional design. Further savings are achieved with the LID stormwater system, which costs about 90 percent less than a conventional stormwater system. The additional on-site septic system infrastructure for the LID design does not present a significant additional cost when comparing the total cost estimates of both designs.

This case study demonstrates how an LID development can be designed at a lower cost than conventional design by offsetting higher BMP costs with the reduction of impervious surfaces and stormwater infrastructure. The reduction in pavement and infrastructure provides the additional benefit of reducing water quality and hydrology impacts compared to conventional development patterns.

REFERENCES

Lower Cape Fear Stewardship Development Program. 2008, April (accessed). Website. Wilmington, NC: New Hanover Soil and Water Conservation district. http://www.stewardshipdev.com/

Low Impact Development Center (LID Center). 2008, May (accessed). Website. Beltsville, MD: LID Center. www.lowimpactdevelopment.org

North Carolina Department of Environment and Natural Resources (NCDENR). 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

Prince George's County. 2008, May (accessed). *LID National Manuals*. Website. Key Largo, MD: Low Impact Development Center, Prince George's County Department of Environmental Resources, Programs and Planning Division. http://www.lowimpactdevelopment.org/publications.htm#LID_National_Manuals

Small, S. 1998. *Preserving Family Lands: Book I—Essential Tax Strategies for the Landowner* (3rd rev. edition). Newton, MA: Landowner Planning Center.

Tetra Tech, Inc. 2005. *Upper Neuse Site Evaluation Tool Model Documentation*. Research Triangle Park, NC: Upper Neuse River Basin Association.



BIBLIOGRAPHY

American Planning Association (APA). 2006, Dec. *Essential PAS Info Packet* (PAS EIP-15). Chicago, IL: APA.

Atlanta Regional Commission (Facilitator). 2001, August. *Georgia Stormwater Management Manual*. Atlanta, GA: Atlanta Regional Commission. http://www.georgiastormwater.com/

Backstrom, M. 2002. Sediment transport in grassed swales during simulated runoff events. *Water Science and Technology* Vol. 45(7): 41-49.

Backstrom, M. 2003. Grassed swales for stormwater pollution control during rain and snowmelt. *Water Science and Technology* Vol. 48(9): 123-134.

Barrett, M. E. 2003. Performance, cost, and maintenance requirements of Austin sand filters. *Journal of Water Resources Planning and Management* Vol. 129(3): 234-242.

Bean, E. Z., W. F. Hunt, and D. A. Bidelspach. 2007a. Field survey of permeable pavement surface infiltration rates. *Journal of Irrigation and Drainage Engineering* Vol. 133(3): 247-255.

Bean, E. Z., W. F. Hunt, and D. A. Bidelspach. 2007b. Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. *Journal of Irrigation and Drainage Engineering* Vol. 133(6): 583-592.

Beattie, D. and R. Berghage. 2004. Green roof media characteristics: the basics. In *Proceedings of the 2nd International Conference on Greening Rooftops for Sustainable Communities* (Portland, Oregon, June 2-4, 2004). Toronto, Ontario: Green Roofs for Healthy Cities–North America.

Berghage, R. D., D. Beattie, A. R. Jarrett, et al. 2009, Feb. *Green Roofs for Stormwater Runoff Control* (EPA/R/600/R-09/026). Cincinnati, OH: U.S. EPA, National Risk Management Research Laboratory. http://www.epa.gov/nrmrl/pubs/600r09026/600r09026.pdf

Beyerlein, D., S. Bolton, D. Booth, et al. 2006, Oct. 26. Partnership recommendations to improve water quality and habitat by managing stormwater runoff; protect ecosystem biodiversity and recover imperiled species; provide water for people, fish and wildlife, and the environment. *Letter to the Puget Sound Partners*. Olympia, WA: Puget Sound Partnership, Puget Sound Water Quality Action Team.

Blankenship, K. 2008, Jan. D.C. program seeks 'green solutions' to curb polluted runoff. *Bay Journal* Vol 17(10).

Cappiella, K., and K. Brown. 2001. *IC and Land Use in the Chesapeake Bay Watershed*. Ellicott City, MD: Center for Watershed Protection.

Center for Watershed Protection (CWP), Site Planning Roundtable. 1998, Aug. *Better Site Design: A Handbook for Changing Development Rules in your Community*. Ellicott City, MD: CWP. www.cwp.org/PublicationStore/bsd.htm

Center for Watershed Protection (CWP), Site Planning Roundtable. 1998, April. *Consensus Agreement on Model Development Principles to Protect our Streams, Lakes and Wetlands*. Ellicott City, MD: CWP.

City of Salinas. 2007, July. *Development Standards Plan: Low Impact Development Designs and Practices for Urban Storm Drainage Management*. Salinas, CA: City of Salinas. http://www.swrcb.ca.gov/centralcoast/water_issues/programs/stormwater/muni_phase1/docs/salinas-dsp.pdf

Clar, M. 2000. "Applications of Low Impact Development Techniques." Paper presented at the International Symposium on Water Sensitive Ecological Planning and Design (February 25-26, 2000). Cambridge, MA: Harvard Graduate School of Design.

Coffman, L. 2007, Oct. *Low Impact Development Guidance Manual* (Draft). Bolivia, NC: Brunswick County Commissioners.

Collins, K. A., W. F. Hunt, and J. M. Hathaway. 2008a. Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering* Vol. 13(12): 1146-1157.

Collins, K. A., W. F. Hunt, and J. M. Hathaway. 2008b. Nutrient and TSS removal comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering* (submitted).

Consortium of Institutes for Decentralized Wastewater Treatment (CIDWT). 2007. *Decentralized Wastewater Treatment Glossary*. Knoxville, TN: University of Tennessee. http://www.onsiteconsortium.org (verified April, 2008).

Deal, N. E., J. Buchanan, K. Farrell-Poe, et al. 2007. Speaking the same language: a glossary for the decentralized wastewater treatment field. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Dierkes, C., L. Kuhlmann, J. Kandasamy, and G. Angelis. 2002. Pollution retention capability and maintenance of permeable pavements. In *Proceedings of the 9th International Conference on Urban Drainage, Global Solutions for Urban Drainage* (Portland, OR). Reston, VA: ASCE.

Dietz, M. E. 2007. Low impact development practices: a review of current research and recommendations for future directions. *Water, Air and Soil Pollution* Vol. 186: 351-363.

Dietz, M. E. and J. C. Clausen. 2006. Saturation to improve pollutant retention in a rain garden. *Environmental Science and Technology* Vol. 40(4): 1335-1340.

Fair, A. 2006, Spring. *Stormwater Best Management Practices in Site Plan and Subdivision Review*. ANJEC Report. http://www.anjec.org/pdfs/Spring2006ANJECReport.pdf

Feiden, W. and R. J. Burby. 2002. *Performance Guarantees for Government Permit-Granting Authorities* (Report No. 508). Chicago, IL: American Planning Association.

Ferguson, B. K. 2005. *Porous Pavements*. Boca Raton, FL: CRC Press.

Foss, A. 2005, June. *Low Impact Development: An Alternative Approach to Site Design*. PAS Memo. Chicago, IL: American Planning Association.

France, R. L. 2002. *Handbook of Water Sensitive Planning and Design*. Boca Raton, FL: CRC Press.

Greene, R. S., B. H. Ward, and D. L. Lindbo. 2007. Remote wastewater nitrification fields. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Hamilton, G. W. and D. V. Waddington. 1999. Infiltration rates on residential lawns in central Pennsylvania. *Journal of Soil and Water Conservation* Vol. 54(3): 564-568.

Hathaway, A. M., W. F. Hunt, and G. D. Jennings. 2008. A field study of green roof hydrologic and water quality performance. *Transactions of the ASABE* Vol. 51(1): 37-44.

Hathaway, J. M. and W. F. Hunt. 2007. *Little Sugar Creek -Westfield Level Spreader: Final Monitoring Report*. Charlotte, NC: City of Charlotte.

Hathaway, J. M. and W. F. Hunt. 2008. Field evaluation of level spreaders in the piedmont of North Carolina. *Journal of Irrigation and Drainage Engineering* Vol. 134(4): 538-542.

Hathaway, J. M. and W. F. Hunt. 2006. *Level Spreaders: Design, Construction, and Maintenance* (AG-588-9). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf

Hinman, C. 2005, Jan. *Low Impact Development: Technical Guidance Manual for Puget Sound* (Publication no. PSAT 05-30). Olympia, WA: Puget Sound Action Team (with Washington State University, Pierce County Extension). http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

Horner, R, C. May, E. Livingston, et al. 2001. *Structural and Non-Structural BMPs for Protecting Streams*. Crawfordsville, FL: Watershed Management Institute.

Hsieh, C-H. and A. P. Davis. 2005. Evaluation and optimization of bioretention media for treatment of urban storm water runoff. *Journal of Environmental Engineering* Vol. 131(11): 1521-1530.

Hunt, W. F. and W. G. Lord. 2006. *Bioretention Performance, Design, Construction, and Maintenance* (AG-588-5). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf

Hunt, W. F. 2003. *Pollutant Removal Evaluation and Hydraulic Characterization for Bioretention Stormwater Treatment Devices*. Ph.D. Dissertation. University Park, PA: Pennsylvania State University.

Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *ASCE Journal of Irrigation and Drainage Engineering* Vol. 132(6): 600-608.

Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006a. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* Vol. 132(6): 600-608.

Hunt, W. F. and K. A. Collins. 2008. *Permeable Pavement Research and Design Implications* (AG-588-14). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/PermeablePavement2008.pdf

Hunt, W. F. and W. G. Lord. 2006. *Stormwater Wetland and Wet Pond Maintenance* (AG-588-7). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/WetlandMaintenance2006.pdf

Hunt, W. F., C. S. Apperson, S. G. Kennedy, and W. G. Lord. 2005. *Mosquito Control for Stormwater Facilities* (AG-588-4). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Mosquitoes2005.pdf

Hunt, W. F., C. S. Apperson, S. G. Kennedy, et al. 2006b. Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA. *Water Science and Technology* Vol. 52(6-7): 315-321.

Hunt, W. F., J. T. Smith, S. J. Jadlocki, et al. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *ASCE Journal of Environmental Engineering* (in press).

Hunt, W. F., J. T. Smith, S. J. Jadlocki, et al. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *Journal of Environmental Engineering* Vol. 134(5): 403-408.

Hunt, W. F., M. R. Burchell, J. D. Wright, and K. L. Bass. 2007. *Stormwater Wetland Design Update* (AG-588-12). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/WetlandDesignUpdate2007.pdf

Interlocking Concrete Pavement Institute (ICPI). 2004. *Concrete Grid Pavements* (Tech Spec 8). Washington, DC: ICPI.

Jarrett, A. R., W. F. Hunt, and R. D. Berghage. 2008. Evaluating a spreadsheet model to predict green roof stormwater management. In *Proceedings of the 2nd National Low Impact Development Conference*. Reston, VA: ASCE.

Jones, M. P. 2008. *Annual Hydrology of a Stormwater Wetland in Eastern and Central North Carolina*. Internal report. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Jones, M. P. and W. F. Hunt. 2006. *Choosing a Pump for Rainwater Harvesting* (AG-588-8). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/Pumps4Cisterns2006.pdf

Jones, M. P. and W. F. Hunt. 2007. *Designing Urban Stormwater BMPs for Trout Waters* (AG-588-10). Raleigh, NC: Cooperative Extension, North Carolina State University. www.bae.ncsu.edu/stormwater/PublicationFiles/BMPsColdTemps2007.pdf

Jones, M. P. and W. F. Hunt. 2008. Wet pond and wetland impacts on runoff temperature. *Journal of Biological Engineering* (in review).

Jones, M. P. and W. F. Hunt. 2009. Bioretention impact on runoff temperature in trout-sensitive waters. *Journal of Environmental Engineering* (in press).

Jordan Cove Urban Watershed Project. Website. Waterford, CT: University of Connecticut, College of Agriculture and Natural Resources. www.jordancove.uconn.edu

Joubert, L., P. Flinker, G. Loomis, D. Dow, A. Gold, D. Brennan, and J. Jobin. 2004. *Creative Community Design and Wastewater Management*. Project No. WU-HT-00-30. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by University of Rhode Island Cooperative Extension, Kingston, RI.

Karasawa, A., K. Toriiminami, N. Ezumi, and K. Kamaya. 2006. Evaluation of performance of water-retentive concrete block pavements. In *Proceedings of the 8th International Conference on Concrete Block Paving, Sustainable Paving for Our Future* (San Francisco, CA). Herndon, VA: ICPI.

Kwiatkowski, M., A. L. Welker, R. G. Traver, et al. 2007. Evaluation of an infiltration best management practice utilizing pervious concrete. *Journal of the American Water Resources Association* Vol. 43(5): 1-15.

Lehner, P., G. Aponte-Clark, D. Cameron, et al. 1999, May. Low impact development. In *Stormwater Strategies: Community Responses to Runoff Pollution*. Washington, DC: Natural Resources Defense Council. http://www.nrdc.org/water/pollution/storm/stoinx.asp

Li, H., L. J. Sharkey, W. F. Hunt, and A. P. Davis. 2008. Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland. *Journal of Hydrologic Engineering* Vol. 13(4) (in press).

Lindbo, D. L., J. Lynn, K. Neal, G. Young and A. Amoozega. 2007. Applying soil morphology to long term acceptance rate determination. In K. Mancl (ed.), *On-Site Wastewater Treatment, Proceedings of the 11th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

Lindbo, D. L., T. M. Campbell, N. Deal, and R. Hollowell. 1998. Performance of sand-lined trench and conventional systems within a management entity. In D. M. Sievers (ed.), *On-Site Wastewater Treatment, Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems*. St. Joseph, MI: ASABE.

MacMullan, E. and S. Reich. 2007. *The Economics of Low-impact Development: A Literature Review*. Eugene, OR: ECONorthwest. http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf

Maryland-National Capital Park and Planning Commission. 2008. *Resident's Guide to Site Plan Review Process in Montgomery County*. Website. Silver Spring, MD: Montgomery County Planning Board. http://www.mc-mncppc.org/info/resident_guides/site_plan_review/intro.shtm

Maxted, J. and E. Shaver, 1997. The use of retention basins to mitigate stormwater impacts on aquatic life. In L. A. Roesner (ed.), *Effects of Watershed Development and Management on Aquatic Ecosystems*. New York, NY: American Society of Civil Engineers.

May, C. W., E. B. Welch, R. R. Horner, et al. 1997a. *Quality Indices for Urbanization Effects in Puget Sound Lowland Streams* (Water Resources Series Technical Report No. 154, Publication 98-04). Olympia, WA: Washington Department of Ecology.

McCuen, R. H., G. Moglen, E. Kistler, and P. Simpson. 1979. *Policy Guidelines for Controlling Stream Channel Erosion with Detention Basins*. College Park, MD: Department of Civil Engineering, University of Maryland (prepared for the Water Management Administration, Maryland Department of the Environment, Baltimore, MD).

Metropolitan Area Planning Council (MAPC). *Massachusetts Low Impact Development Toolkit*. Website. Boston, MA: MAPC. http://www.mapc.org/lid.html

North Carolina Cooperative Extension. *Backyard Rain Gardens.* Website. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering. www.bae.ncsu.edu/topic/raingarden

NAHB Research Center. 2003, July. *The Practice of Low Impact Development*. Washington, DC: U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

New Jersey Department of Environmental Protection (NJDEP). 2004, Feb. *New Jersey Stormwater Best Management Practices Manual*. Trenton, NJ: NJDEP. http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_B.pdf

North Carolina Department of Environment and Natural Resources (NCDENR). 1992, May. *Erosion and Sediment Control Inspector's Guide*. Raleigh, NC: Division of Land Resources, NCDENR. http://www.dlr.enr.state.nc.us/images/Inspectors%20Guide.pdf

North Carolina Department of Environment and Natural Resources. 1998. *Stormwater Management Site Planning* (guidance manual). Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/Site_Planning_Document.pdf

North Carolina Department of Environment and Natural Resources. 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

North Carolina Department of Environment and Natural Resources. Date unknown. *Erosion and Sediment Control Planning and Design Manual*. Raleigh, NC: Division of Land Resources, NCDENR. http://www.dlr.enr.state.nc.us

North Carolina Department of Environment and Natural Resources. *Environmental Permit Handbook*. Website. Raleigh, NC: NCDENR. http://portal.ncdenr.org/web/csc/start/overview

North Carolina General Assembly. 2005. Laws and Rules for Sewage Treatment and Disposal Systems, North Carolina Gen. Stat. 130A-333, 4, Rule 1900, Title 15A, Subchapter 18A. *North Carolina Administrative Code*. Raleigh, NC: State of North Carolina.

North Carolina State University. 2008. *North Carolina Low Impact Development Center.* Website. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering. www.bae.ncsu.edu/topic/lid

North Carolina State University. *Going Native: Urban Landscaping for Wildlife with Native Plants*. Website. Raleigh, NC: North Carolina State University. www.ncsu.edu/goingnative.

Plant Conservation Alliance, Alien Plants Working Group (PCA–APWG). *Weeds Gone Wild*. Website. Washington, DC: Bureau of Land Management. http://www.nps.gov/plants/alien/

Prince George's County. 1997. *Low-Impact Development Guidance Manual*. Largo, MD: Prince Georges County Department of Environmental Resources (prepared by Tetra Tech, Fairfax, VA).

Prince George's County. 1999, June. *Low-Impact Development Design Strategies: An Integrated Design Approach*. Largo, MD: Prince George's County Department of Environmental Resources, Programs and Planning Division.

Prince George's County. 2000, January. *Low Impact Development: An Integrated Design Approach*. Largo, MD: Prince Georges County, Department of Environmental Resources.

Puget Sound Partnership. 2008. *Stormwater and Low Impact Development*. Website. Olympia, WA. www.psp.wa.gov/our_work/stormwater/lid.htm

Randall, J. and J. Marinelli. 1996. *Invasive Plants: Weeds of the Global Garden* (Handbook No. 149). New York, NY: Brooklyn Botanic Garden Club, Inc.

Sharkey, L. J. 2006. *The Performance of Bioretention Areas in North Carolina: A Study of Water Quality, Water Quantity, and Soil Media*. Ph.D. thesis. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Shaver, E. 2000, April. *Low Impact Design Manual for the Auckland Region* (Technical Publication 124). Auckland, New Zealand: Auckland Regional Council.

Stafford County. 2003, March. *Stormwater Management Design Manual*. Stafford, VA: Stafford County Commissioners. http://co.stafford.va.us/Homepage/Planning_&_Zoning_Applications_&_Information.shtml

Stribling, J. B. 2001. Relating Instream Biological Condition to BMP Activities in Watersheds. Paper presented at the Conference on Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation (Snowmass, CO). New York, NY: United Engineering Foundation.

Swift, L.W., G. B. Cunningham, and J. E. Douglass. 1987. Climatology and hydrology. In W. T. Swank and D. A. Crossley (eds.), *Forest Hydrology and Ecology at Coweeta*. New York, NY: Springer-Verlag.

Tetra Tech, Inc. 2007, Sept. *Elements of Progressive Stormwater Ordinances Encouraging LID*. Oakland, CA: Ocean Protection Council. (Available upon request)

Town of Warsaw, Virginia. Date unknown. *Town of Warsaw Low Impact Development Stormwater Management Policy*. Warsaw, VA: Town Office.

Tyner, J. S., W. C. Wright, and P. A. Dobbs. 2009. Increasing exfiltration from pervious concrete and temperature monitoring. *Journal Environmental Management* doi:10.1016/2009.02.007. (in press) http://john.s.tyner.googlepages.com/pervconcrete.pdf

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA–NRCS). 1986. *Urban Hydrology for Small Watersheds* (Technical Release No. 55). Washington, DC: USDA–NRCS.

U.S. Environmental Protection Agency (U.S. EPA). 2000, Oct. *Low Impact Development (LID); A Literature Review* (EPA-841-B-00-005). Washington, DC: Office of Water and Low Impact Development Center.

U.S. Environmental Protection Agency. 2003. *Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (EPA 832-B-03-001). Washington, DC: Office of Water, U.S. EPA.

U.S. Environmental Protection Agency. 2005. *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems: An Introduction to Management Tools and Information for Implementing EPA's Management Guidelines* (EPA-832-B-05-001). Washington, DC: Office of Water, U.S. EPA.

U.S. Environmental Protection Agency. 2005, Dec. *Using Smart Growth Techniques as Stormwater Best Management Practices* (EPA 231-B-05-002). Washington, DC: U.S. EPA. www.epa.gov/smartgrowth

U.S. Environmental Protection Agency. 2006, Jan. *Protecting Water Resources with Higher-Density Development*. Washington, DC: U.S. EPA. www.epa.gov/smartgrowth/water_density.htm

U.S. Environmental Protection Agency. 2007, Dec. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (EPA 841-F-07-006). Washington, DC: U.S. EPA. www.epa.gov/owow/nps/lid/costs07/

Virginia Department of Transportation (VDOT). *Guidelines for 1993 AASHTO Pavement Design*. Richmond, VA: Virginia Department of Transportation – Materials Division, Pavement Design and Evaluation Section. http://www.virginiadot.org/business/resources/bu-mat-pde-AASHTOForConsultants0503.pdf

Watershed Education for Communities and Officials (WECO). 2009 (draft). *Low Impact Development: An Economic Fact Sheet*. Raleigh, NC: Cooperative Extension, North Carolina State University. www.ncsu.edu/WECO/LID

Whisnant, R. 2007, Feb. *Universal Stormwater Model Ordinance for North Carolina*. Chapel Hill, NC: University of North Carolina Environmental Finance Center. www.efc.unc.edu/projects/stormwater.htm

Helpful LID and Stormwater Web Resources

Center for Watershed Protection's Stormwater Center
http://www.stormwatercenter.net/

Construction Industry Compliance Assistance Center
http://www.cicacenter.org/

Low Impact Development Center
http://www.lowimpactdevelopment.org

National Association of Home Builders Research Center
http://www.toolbase.org/ToolbaseResources/level4DG.aspx?ContentDetailID=3225&BucketID=4&CategoryID=19

NCDENR Stormwater and General Permits Unit
http://h2o.enr.state.nc.us/su/index.htm

North Carolina Low Impact Development Group
www.bae.ncsu.edu/topic/lid/

North Carolina State University Department of Soil Science
http://www.soil.ncsu.edu/programs/septicsystem/

Prince George's County, Maryland, Department of Environmental Resources
http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/index.asp

Puget Sound Water Quality Action Team
http://www.psp.wa.gov/

U.S. Environmental Protection Agency – Low Impact Development
http://www.epa.gov/owow/nps/lid/

U.S. Environmental Protection Agency – Stormwater Program
http://www.epa.gov/npdes/stormwater/

U.S. Environmental Protection Agency – Nonpoint Source Program
http://www.epa.gov/owow/nps/urban.html

Urban Land Institute
http://www.uli.org

Watershed Education for Communities and Officials, North Carolina State University
www.ncsu.edu/WECO

North Carolina State University Stormwater Engineering Group
http://www.bae.ncsu.edu/stormwater/

Select LID, Stormwater, and Site Design Printed Resources

LID Manuals

Georgia Department of Natural Resources. 2006. *Coastal Georgia Green Growth Guidelines*. http://crd.dnr.state.ga.us/content/displaycontent.asp?txtDocument=969

Huntersville, North Carolina. *Water Quality Ordinance and Design Manual*. http://www.charmeck.org/Departments/LUESA/Water+and+Land+Resources/Programs/Water+Quality/Huntersville+Ordinance/Home.htm

New Jersey Department of Environmental Protection (NJDEP). 2004, Feb. *New Jersey Stormwater Best Management Practices Manual*. Trenton, NJ: NJDEP. http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_B.pdf

Prince George's County. 1999. *Low Impact Development Design Strategies: An Integrated Design Approach*. Largo, MD: Prince George's County, MD, Department of Environmental Resources, Programs and Planning Division. http://www.epa.gov/owow/nps/lid/lidnatl.pdf

Prince George's County. 1999. *Low Impact Development Hydrologic Analysis*. Largo, MD: Prince George's County, MD, Department of Environmental Resources, Programs and Planning Division. http://www.epa.gov/owow/nps/lid/lid_hydr.pdf

Puget Sound Action Team. 2005. *Low Impact Development Technical Guidance Manual For Puget Sound*. Olympia, WA. Publication No. PSAT 05-03. http://www.psat.wa.gov/Publications/LID_tech_manual05/lid_index.htm

Shaver, E. 2000, April. *Low Impact Design Manual for the Auckland Region* (Technical Publication 124). Auckland, New Zealand: Auckland Regional Council. http://www.arc.govt.nz/auckland/low-impact-design/low-impact-design_home.cfm.

U.S. Department of Defense. 2004. *Low Impact Development Manual*. Washington, DC: U.S. Department of Defense. UFC 3-210-10. http://www.ccb.org/docs/UFC/3_210_10.pdf

U.S. Department of Housing and Urban Development. 2003. *The Practice of Low Impact Development*. Washington, DC: Office of Policy Development and Research. http://www.huduser.org/

White, Nancy. 2003. *Protecting Estuarine Water Quality Through Design*. The Sound Front Series. Raleigh, NC: North Carolina Sea Grant, North Carolina State University. http://www.ncsu.edu/seagrant

Other Manuals (Stormwater, etc.)

Center for Watershed Protection. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Ellicott City, MD. http://www.cwp.org/

Center for Watershed Protection. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide For Managing Urbanizing Watersheds*. Ellicott City, MD.

North Carolina Department of Environment and Natural Resources. 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf

North Carolina Department of Environment and Natural Resources. 1998, Feb. *Stormwater Management Site Planning Manual*. Raleigh, NC: Division of Water Quality, NCDENR. http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm

State of Virginia. 2001. *The Economic Benefits of Protecting Virginia's Streams, Lakes and Wetlands, and the Economic Benefits of Better Site Design in Virginia*. Richmond, VA: State of Virginia, Department of Conservation and Recreation. http://www.dcr.virginia.gov/sw/docs/swmecon.pdf



APPENDICES

APPENDIX A

North Carolina Hydrophysiographic Regions

By Thomas Blue, PE, PLS

North Carolina has diverse geographic regions (Figure A-1). The three principal regions, from west to east, are the mountains, the piedmont, and the coastal plain. Some applications of LID principles and practices will differ for each region, depending on regional constraints.

Mountain soils are usually loamy in character, with gravel and rocks common. In the Mountain region, some of the common challenges include steep slopes, shallow bedrock, and low infiltration areas. Piedmont soils are usually clayey in character, especially below the topsoil. Common challenges in the Piedmont region are similar to the Mountains, with slopes being generally less steep and the ground having less shallow bedrock. Coastal plain soils are usually sandy in character, with strata of underlying sands, clays, and rocks. Common challenges in the Coastal Plain region include flat landscapes and high water tables. These are generalizations, as there is great variability across these regions. Exceptions to these generalizations occur in each region. There are relatively wide, flat plains in the Mountains with high water tables, generally adjacent to rivers. There are steep slopes with rock outcrops and low water tables in the Coastal Plain region.

Within these principal regions, various hydrophysiographic regions are present. A hydrophysiographic region is an area where the climate and land combine to produce a distinct hydrologic character. Though further subdivisions can be made, relative to low impact development, there are nine fairly distinct hydrophysiographic regions in North Carolina:

Brown - Appalachian Mountains
Green - Southern Highlands
Orange/Yellow - Rainshadow Highlands
Red - Piedmont
Maroon - Triassic Basin
Blue - Coastal Plain
Tan - Sandhills
Purple - Tidewater
Lemon Yellow - Barrier Islands

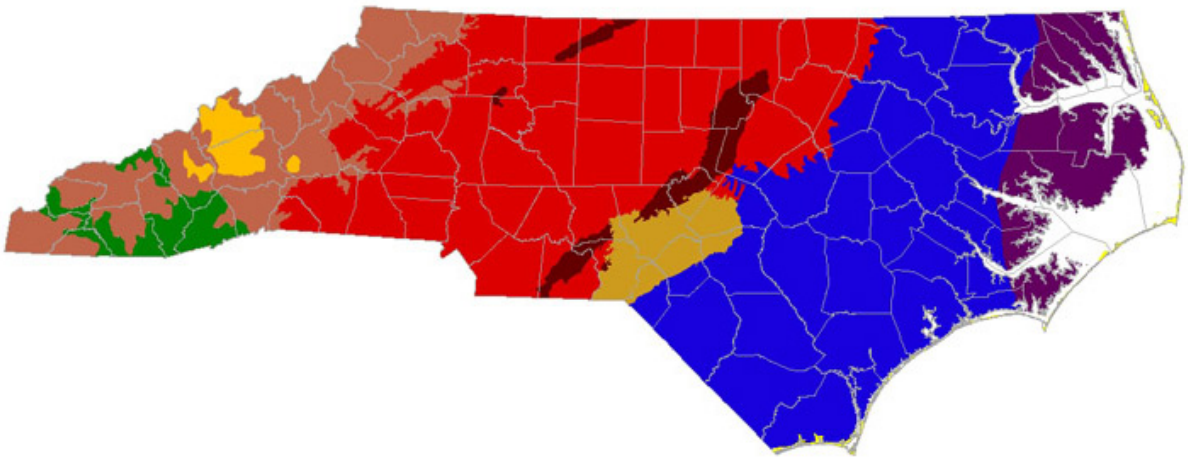


Figure A-1. North Carolina hydrophysiographic regions

the Appalachian mountains, southern highlands, rainshadow highlands, piedmont, Triassic basin, coastal plain, sandhills, tidewater, and barrier islands.

Significant challenges in all of these areas are locations of rapid development that place a great deal of pressure on marginal soils and sites. The various hydrophysiographic regions are illustrated in Figure A-1. The soil systems, which strongly influence the hydrophysiographic region boundaries and character, are illustrated in Figure A-1. Detailed information on soil systems can be found in *Soil Systems of North Carolina* (Daniels et al., 1999). Specific information on soil series and related information can be found in USDA NRCS County Soil Surveys, which are available for each county in North Carolina.

A.1 Mountain Region

The Mountain region is the smallest of the three principal regions, comprising approximately 16 percent of North Carolina. Elevation ranges from roughly 1,500 feet at the eastern boundary to 6,684 feet at the summit of Mount Mitchell. As in all the regions, soils are variable and related to slope as well as landscape position. Mountain soils tend to be fairly thin, with soil thickness increasing from upslope to downslope. The soils are typically gray to black in color and are usually loamy in character, with gravel and rocks common. Some more clayey soils are present. Soils tend to be coarser (sandier) in the valleys and may also contain layers of high gravel content. Soils on north-facing and east-facing slopes tend to have more organic matter and are moister than those on the south and west slopes. The valleys are frequently used for intensive agriculture while slopes remain wooded. There are three hydrophysiographic regions within the Mountain region: the Appalachian Mountains, the southern highlands and the rainshadow highlands.

A.1.1 Appalachian Mountains Hydrophysiographic Region

The Appalachian Mountains hydrophysiographic region (brown zone in Figure A-1) is characterized by high relief with steep slopes and typified by loamy/gravelly soils, rock outcrops, high stream base flow in many areas, high flash flood potential, moderate precipitation, large channel gradients, wide ranges of ground infiltration potentials (very low to very high), lower air and soil temperatures (10°F or more difference from other parts of North Carolina in some locations), and more frozen precipitation. The average annual precipitation in the Appalachian Mountains hydrophysiographic region is approximately 56 inches.

A.1.2 Southern Highlands Hydrophysiographic Region

The southern highlands hydrophysiographic region (green zone in Figure A-1) maintains the general characteristics of the Appalachian Mountains and is a subset of the Appalachian Mountains. Relative to hydrologic character, the distinguishing difference is precipitation. The southern highlands receive very high average annual precipitation. The region is nearly a temperate rain forest with many waterfalls, driven by moisture from the Gulf of Mexico condensing and falling in the region. The average annual precipitation in the southern highlands is approximately twice the North Carolina average. In some areas (particularly at higher elevations), the annual precipitation may exceed 120 inches in a given year—which is almost three times the North Carolina average. The average annual precipitation in the southern highlands hydrophysiographic region is approximately 90 inches.

A.1.3 Rainshadow Highlands Hydrophysiographic Region

The rainshadow highlands (yellow zone in Figure A-1) also maintains the general characteristics of the Appalachian mountains and is a subset of the Appalachian mountains. Relative to hydrologic character, as with the Southern Highlands, the distinguishing difference is precipitation. The nearby Southern Highlands to the southwest intercept moisture from the Gulf of Mexico. As a result, the Rainshadow Highlands receive relatively low average annual precipitation. The average annual precipitation in the Rainshadow Highlands is the lowest in North Carolina and much lower than the surrounding Mountains. The average annual precipitation in the Rainshadow Highlands hydrophysiographic region is approximately 43 inches. In some areas, the annual precipitation may be less than 35 inches in a given year.

A.2 Piedmont Region

The piedmont region comprises approximately 39 percent of North Carolina. This region rises from approximately 200 feet along much of the Fall Line (the dividing line between the piedmont and the coastal plain) to nearly 1,500 feet at the base of the Appalachian Mountains. It consists of rolling hills and was named for the piedmont region of Italy, which it was thought to closely resemble. Piedmont soils are usually clayey in character, especially below the topsoil. Upper horizons may be more loamy or sandy in texture. These horizons, however, are usually removed during real estate development construction activities. Therefore, the clayey characteristics will generally be the soil parameters controlling post-development hydrologic response. Some areas of the piedmont region contain relatively shallow soils (<36 inches to bedrock). Additionally, areas of expansive clays are also

present in various areas, especially the Triassic Basin. In most areas (outside stream valleys), the water table tends to be fairly deep. The piedmont region is the most populated area within North Carolina, including 7 of the 8 most populous cities in the state (Charlotte, Raleigh, Greensboro, Winston-Salem, Durham, Cary, and High Point). There are two hydrophysiographic regions within the piedmont region and the Triassic Basin.

A.2.1 Piedmont Hydrophysiographic Region

The piedmont hydrophysiographic region (red zone in Figure A-1) is typified by clayey soils, moderate and rolling relief, moderate to low stream base flows, and moderate to low infiltration capacity. The soil color is dominantly red. Areas outside urban / suburban complexes are often farmland. The average annual precipitation in the piedmont hydrophysiographic region is approximately 44 inches.

A.2.2 Triassic Basin Hydrophysiographic Region

The Triassic Basin hydrophysiographic region (dark red zone in Figure A-1) is typified by expansive (swelling) clayey soils, low to very low infiltration potential (generally the lowest in North Carolina), low to very low stream base flows, and high drought potential. The soil color is typically gray. Many geologic components in this region are very hard and noncontiguous (islands). The Triassic Basin hydrophysiographic region is relatively undeveloped and mainly forested. Soil conditions make agriculture, construction, stormwater infiltration, and septic systems difficult to undertake. The average annual precipitation in the Triassic Basin hydrophysiographic region is approximately 46 inches.

A.3 Coastal Plain Region

The Coastal Plain region is the largest of the three principal regions, comprising approximately 45 percent of North Carolina. Elevations range from roughly 200 feet along the northern western edge and roughly 550 feet along the southern western edge to sea level at the Atlantic Ocean and adjacent sounds. Relief in the Coastal Plain varies from moderately steep dissected plains to relatively flat landforms. From west to east along the Coastal Plain are a series of large-scale terraces, thought to have formed from fairly rapid drops in shoreline elevations as the Atlantic Ocean receded. Soils are usually sandy to very sandy in character, with some areas of underlying clays and rocks. Coastal plain soils tend to be fairly thick, generally deepening from the west to the east, with some areas containing sands hundreds of feet deep. The soils are typically white to yellow in color. Much of the Coastal Plain region is used for intensive agriculture and timber production. There are 4 hydrophysiographic regions within

the Coastal Plain: the Coastal Plain, the Sandhills, Tidewater, and Barrier Islands.

A.3.1 Coastal Plain Hydrophysiographic Region

The Coastal Plain hydrophysiographic region (blue zone in Figure A-1) is typified by wide areas of low relief with some low rolling hills. Soils are dominantly sandy and generally deep. There are some areas of higher relief near streams and rivers from long-term erosion. Rolling hills tend to have less relief in the northern portion of the Coastal Plain hydrophysiographic region (generally north of the Neuse River). Soil infiltration capacity typically ranges from moderate to high, often dependent upon water content. The water table is generally moderate (<8 feet below ground surface) to high (<3 feet), with high water tables in winter months restricting infiltration. Carolina Bays (ovoid wetlands with low sand ridge boundaries) are common landscape features in the southern portion of this region (generally south of the Neuse River). The Coastal Plain hydrophysiographic region generally has moderate stream base flows. The rivers and streams, from the Neuse River south and more pronounced in the eastern portion, have carved asymmetric valleys in response to the general dip of the geologic rock features towards the south, and the southern walls are often well marked and several feet to tens of feet high. The drained and level uplands are generally managed for timber production or farming, while the wetlands remain wooded. The average annual precipitation in the Southern Coastal Plain hydrophysiographic region is approximately 50 inches, increasing from west to east across the region.

A.3.2 Sandhills Hydrophysiographic Region

The Sandhills hydrophysiographic region (tan zone in Figure A-1) is typified by moderate rolling hills and wide, flat ridges. Soils are dominantly sandy, ranging from a few deep to hundreds of feet deep. Perched water tables on hill slopes, due to low permeability lenses of clayey deposits (clay lenses), are not uncommon. In other areas (outside stream valleys), the water table tends to be moderately deep (>20 feet below ground surface) or deeper (>40 feet). Restrictive layers of plinthite and sandstone are also common, often found at around 4 feet to 8 feet depth on ridges and hill slopes. The Sandhills hydrophysiographic region generally has high to very high stream base flows, and high to very high infiltration capacity, with these increasing from west to east in the region. The Sandhills hydrophysiographic region is so sandy that small streams can “disappear” into the soil and “reappear” hundreds of feet downslope. Longleaf pine communities naturally dominate the areas where fire suppression and intensive logging has not occurred. The average annual precipitation in the Sandhills hydrophysiographic region is approximately 48 inches.

A.3.3 Tidewater Hydrophysiographic Region

The Tidewater hydrophysiographic region (purple zone in Figure A-1) is typified by high water tables (<3 feet from ground surface), with large expanses of wetlands and much of the region only a few feet above sea level. Soils are dominantly sandy and deep, with horizons of accumulated organic matter at the surface where not removed by farming, burning, or other processes. Relief is low, commonly only a few inches of rise per mile. The high water tables restrict infiltration potential. Though soils are sandy, the combination of high water tables, low infiltration, and very low relief results in relatively slow stormwater runoff rates and significant ponding and flooding. Available water provides for higher evapotranspiration than in other hydrophysiographic regions of North Carolina. Extensive drainage channels constructed throughout the region allows the land to be farmed. The area has some of the most productive agriculture in the state. The western edge is defined by Suffolk Scarp, one of the large-scale Coastal Plain terraces. The average annual precipitation in the Tidewater hydrophysiographic region is approximately 52 inches, increasing from west to east across the region.

A.3.4 Barrier Islands Hydrophysiographic Region

The Barrier Islands hydrophysiographic region (yellow zone in Figure A-1) are aeolian (windblown) sand deposits from ocean beach faces. The soils are very sandy with very high infiltration potential where high water tables are not present. Only the Sandhills hydrophysiographic region comes close to the average infiltration potential of the Barrier Islands. Relief can be significant, ranging from sea level to more than 100 feet on the top of some dunes. Many areas, however, are much lower in elevation and generally less than 20 feet above sea level. Relatively frequent severe storms influence the land surface. Water tables range from very shallow (<1 feet from ground surface) to very deep (>40 feet) on tops of dunes. The average annual precipitation in the Barrier Islands hydrophysiographic region is approximately 55 inches.

APPENDIX B

Alternative Site-Assessment Hydrologic Metrics for Urban Development

By Kathy M. DeBusk, EI and William F. Hunt, P.E., Ph.D.

Introduction

As precipitation falls to the ground, it may infiltrate, be taken up by plants and return to the atmosphere through evaporation or evapotranspiration, or leave the site as surface runoff. In undeveloped conditions, the majority of precipitation infiltrates the subsurface or is returned to the atmosphere through evapotranspiration. The development of new urban land is typically associated with a substantial decrease in infiltration and evapotranspiration and an increase in surface runoff (Meyer, 2005; Nelson et al., 2006). Increases in volumes and peak flows of surface runoff lead to the impairment of surface water bodies and water quality degradation (Schoonover and Lockaby, 2006).

The idea of low impact development (LID) arose in the 1990s as the negative impacts of development and traditional stormwater management became more apparent. Originally proposed by Prince George's County, Maryland, the idea is now being adopted in many parts of the United States. The overall goal of LID is to "mimic the pre-development site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff" (Prince George's County, MD, 1999). While traditional stormwater management focuses on flood control by reducing peak-flow rates, LID addresses reduction in total runoff volume in addition to peak-flow rates (Dietz, 2007).

North Carolina's LID manual introduces a novel approach to mitigating stormwater impacts due to development. The approach includes an evaluation of the pre-development hydrologic cycle for a site and assigning a set of percentages that indicates how much of the total precipitation leaves the site as runoff, infiltration, and evapotranspiration. The goal of this strategy is to provide a means of evaluating how well a site meets the objectives of LID: a site's post-development percentages should mimic the pre-development percentages as closely as possible. However, no method currently exists to evaluate how well a developed site meets the LID goal of replicating pre-development (or target) hydrology. Currently, it is common for regulatory agencies to use a surrogate, such as treatment of a design storm, or capture of the water quality volume, to perform this analysis. The goal of this paper is to present a research-based method for estimating the pre-development hydrologic fate of different types of land uses in different regions of North Carolina.

Research was compiled on the four primary categories of the hydrologic cycle: precipitation, evapotranspiration, infiltration and runoff. Experimental data from previous research were used to generate recommended pre-development percentages for the state of North Carolina. Because hydrologic components depend on a number of external factors such as precipitation, temperature, vegetative characteristics, and soil permeability, recommended percentage values assigned to land uses and management practices varied based on a site's physiographic region, precipitation, and soil and vegetative characteristics.

Methods

Precipitation

As shown in Figure B-1, the state of North Carolina is divided into three primary physiographic regions: coastal plain, piedmont and Blue Ridge Mountains. Each region has relatively unique temperature, precipitation, vegetative, and soil characteristics. Due to the unique precipitation patterns within the Blue Ridge region, it can be divided further into a wet (rain shed) and dry (rain shadow) region. Ten years of precipitation data were collected for Asheville, Brevard, Raleigh, and Castle Hayne, North Carolina, to represent the Blue Ridge rain shadow, Blue Ridge rain shed, piedmont and coastal plain regions, respectively (NC-SCO, 2008). Data were reported in hourly increments for Asheville, Raleigh, and Castle Hayne and in daily increments for Brevard. For each location, annual precipitation totals for each of the ten years were calculated and the median of these values determined. The median values represent the annual precipitation depth for the region corresponding to each location.

Evapotranspiration (ET)

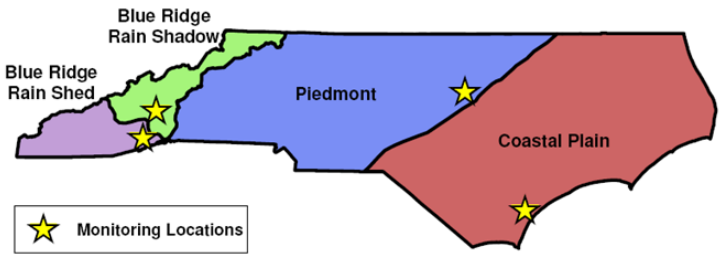


Figure B-1. The four primary physiographic regions used for this study were the coastal plain, piedmont, Blue Ridge rain shadow and Blue Ridge rain shed
Monitoring locations for each region were the cities of Castle Hayne, Raleigh, Asheville and Brevard, North Carolina respectively.

Variations in precipitation, temperature and soil type result in vegetative characteristics unique to each region of North Carolina. Four principal land cover types were investigated (undisturbed woods, disturbed woods, undisturbed meadow, disturbed meadow / residential lawn) and a representative

species was assigned to each land cover / region combination. Statistics published by the USDA Forest Service identified oak / gum / cypress, oak / hickory and oak / hickory as the primary species in undisturbed woods for the coastal plain, piedmont, and mountain regions, respectively (Connor and Sheffield, 2001; Brown and Sheffield, 2003; Connor, 2003; Brown, 2003). The North Carolina Division of Forest Resources named loblolly pine as the dominant species for disturbed woods in the coastal plain and piedmont regions, and eastern white pine for the mountain region (New, 2008). Undisturbed meadows in the piedmont and mountain regions consist primarily of Kentucky 31 fescue and a mixture of common Bermuda grass and crabgrass in the coastal plain region (Johnson, 2008). Residential lawns are dominated by a combination of hybrid Bermuda grass, centipede grass, and zoysiagrass in the coastal plain and a mix of Kentucky 31 bluegrass and various fescues in the mountain region. The piedmont region is transitional between these two groups of grasses (Burton, 2008). Table B-1 summarizes the vegetative species assigned to each physiographic region and land cover type.

Each species mentioned above was investigated, and data from previous research experiments were assembled from the following sources: Aronson et al., 1987; Baldwin et al., 2006; Bastug et al., 2003; Carrow, 1995; Devitt et al., 1992; Fu et al., 2004; Hebert and Jack, 1998; Jensen et al., 1990; Ladekarl et al., 2005; Lewis et al., 2000; Lu et al., 2005; McNulty et al., 1997; McNulty et al., 1996; Restrepo and Arain, 2005; van Bavel and Harris, 1962; Xinmin et al., 2007; Zhou et al., 2008.

The data were then used to determine a representative annual ET depth for each land use/region combination. The stipulations of the majority of the experimental studies necessitated the adjustment of the ET values to account for moisture conditions and non-growing season periods.

Although non-growing season ET is minimal, it was still accounted for in annual ET depths. Due to the lack of experimental studies on non-

Table B-1. Vegetative species representing each land cover / region combination

	Coastal Plain	**Piedmont**	**Mountains**
Disturbed meadow / residential lawn	Hybrid Bermuda grass, centepede, zoysiagrass	Mix of coastal and mountain species	Fescues, Kentucky bluegrass
Meadow	Common Bermuda grass, crabgrass	Kentucky 31 fescue	Kentucky 31 fescue
Disturbed woods	Loblolly Pine	Loblolly Pine	Eastern White Pine
Undisturbed woods	Oak, gum, cypress	Oak, hickory	Oak, hickory

growing season ET, potential evapotranspiration (PET) was used to determine the relationship between growing season and non-growing season ET. Thirty years of daily potential ET data — as calculated using the Penman-Monteith method (Jensen et al., 1990) — were acquired for the representative location in each physiographic region (NC-SCO, 2008). The percentage of annual PET attributable to each month was calculated for each year data were available, and these percentages were then averaged to determine the mean percentage of annual PET that occurs during each month. An example of the monthly PET distribution for Raleigh, North Carolina, is shown in Figure B-2. Using the percentage distributions, ET amounts obtained from each study were then adjusted to include non-growing season ET. For example, if a study involving vegetation assigned to the piedmont region reported 520mm of ET for a period spanning May to August, this should account for approximately 49 percent of the annual ET (according to the established monthly percentages). Therefore, the annual ET — accounting for months January through April and September through December — would be roughly 1,061mm. A graphical explanation of this example may be found in Figure B-2.

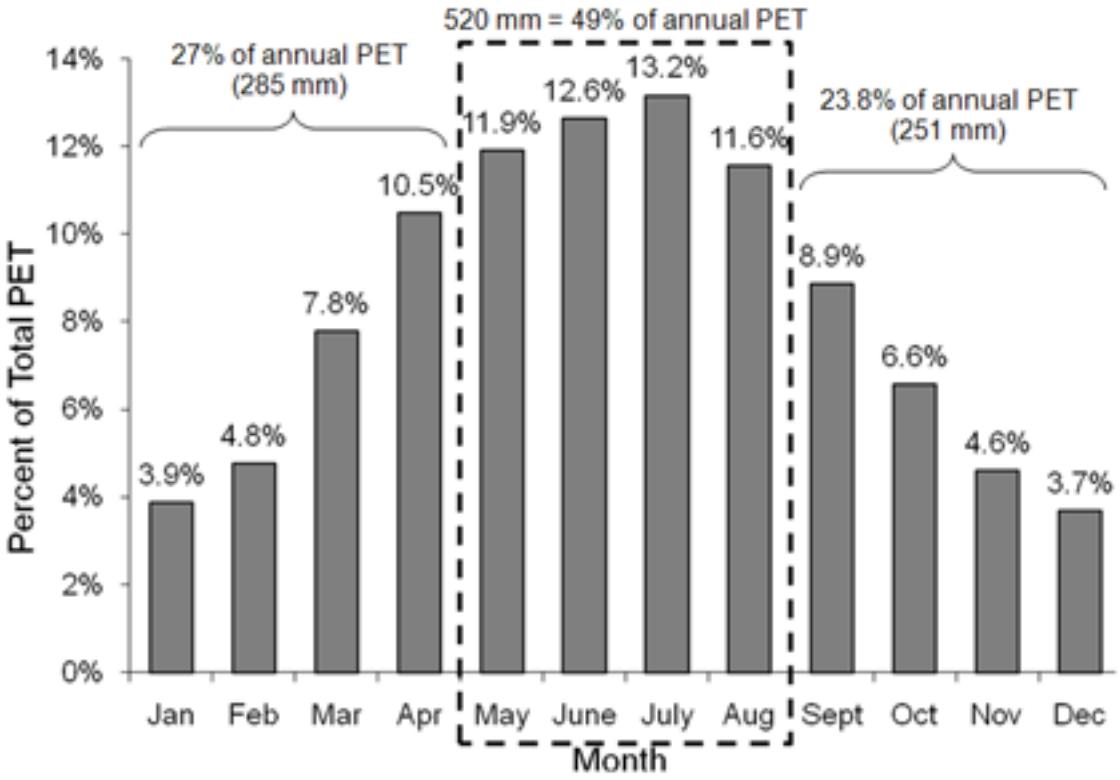
Furthermore, the majority of the studies (Aronson et al., 1987; Bastug et al., 2003; Carrow, 1995; Fu et al., 2004; van Bavel et al., 1962; Xinmin et al., 1962) on turf grasses reported ET for well-watered vegetative conditions, resulting in higher values than would be experienced in natural moisture conditions. Most of these studies did not report the amount of water added to the grasses as irrigation; therefore, it was assumed that the amount of irrigation water added to a well-watered urban lawn would be similar to the amount of extra water added during the experiments. Irrigation meter data were obtained from the Town of Cary, North Carolina, for more than 4,000 residential lots for the year 2007 (Goodwin, 2008). Parcel acreages were adjusted using the appropriate impervious percentage from the SCS Curve Number method, and an annual water volume per acre was calculated for each parcel. The assumption was made that irrigation water was applied to all pervious areas of the lot. Outliers were removed from the data set and the resulting median annual irrigation amount was 315,874 gal/acre/year, or 295 mm/yr. This depth was then subtracted from the median ET value for undisturbed meadow and residential lawn land covers (for each region) and the resulting values became the representative values for annual ET depth.

Runoff

It was a priority in the development of this approach that the resulting hydrologic percentages be based on experimental data. As there are few published studies on runoff depths for various land use types, experimental infiltration rates were used to calculate runoff depths. The SCS method assigns a curve number to a site based on land cover and hydrologic soil

Figure B-2. PET in the piedmont region

The columns in this graph represent the percentage of annual PET that can be attributable to each month of the year for the piedmont region. These values were calculated from 30 years of daily PET acquired for Raleigh, North Carolina (detailed procedure described in previous paragraph). If a piedmont region study spanning from May to August reports an ET loss of 520mm, it can be assumed that these four months represent 49.3% of the total annual PET. To determine an annual ET amount, the months of the year not reported in the study must be accounted for. If 520mm represents 49.3% of the annual PET, then 100% of the annual PET would be equal to 520mm divided by 0.493, or 1055 mm.



group (HSG) (USDA, 1986). However, the curve numbers assigned to the various land cover / HSG combinations were determined by analyzing raw precipitation and runoff data from the 1950s, and a method for relating infiltration rates to specific curve numbers does not currently exist. Therefore, a technique was developed to correlate the acquired infiltration rates with SCS curve numbers.

The hydrologic soil groups link curve numbers and infiltration rates. HSG A consists of soils with a minimum infiltration rate of 3.61 cm/hr. HSGs B and C describe soils with infiltration rates between 1.45 and 3.61 cm/hr and 0.15 and 1.45 cm/hr, respectively, while HSG D soils have an infiltration rate of less than 0.15 cm/hr (USDA, 2007). Experimental infiltration data were collected from previous experimental studies (Pitt et al., 2001a; Pitt et al., 2001b; Gregory et al., 2006; Steinbrenner et al., 1955; Steinbrenner et al., 1950; Huang et al., 1996; Jakobsen et al., 1985; Croke et al., 1999;

Johnson et al., 1980; Burk et al., 1999; Naeth et al., 1990; Hamilton et al., 1999) on soil infiltration characteristics and each study was assigned a HSG based on the infiltration rate results. For example, if a study reported an average infiltration rate of 0.75 cm/hr, the site was assigned an HSG of C. If there were multiple studies with the same land use / HSG combination, the data were grouped together and the 25th percentile was calculated and deemed conservatively representative of that particular land use / HSG grouping. A curve number was then assigned to the group based on the land use and HSG. "Undisturbed meadow" was classified as 'meadow' in the curve number classification system. "Disturbed lawn" was described as 'pasture, grassland or range; fair condition'. "Disturbed woods" and "undisturbed woods" were both classified as 'woods', but described as 'fair condition' and 'good condition', respectively. Table B-2 summarizes the representative infiltration rate and curve number for each HSG / land use combination.

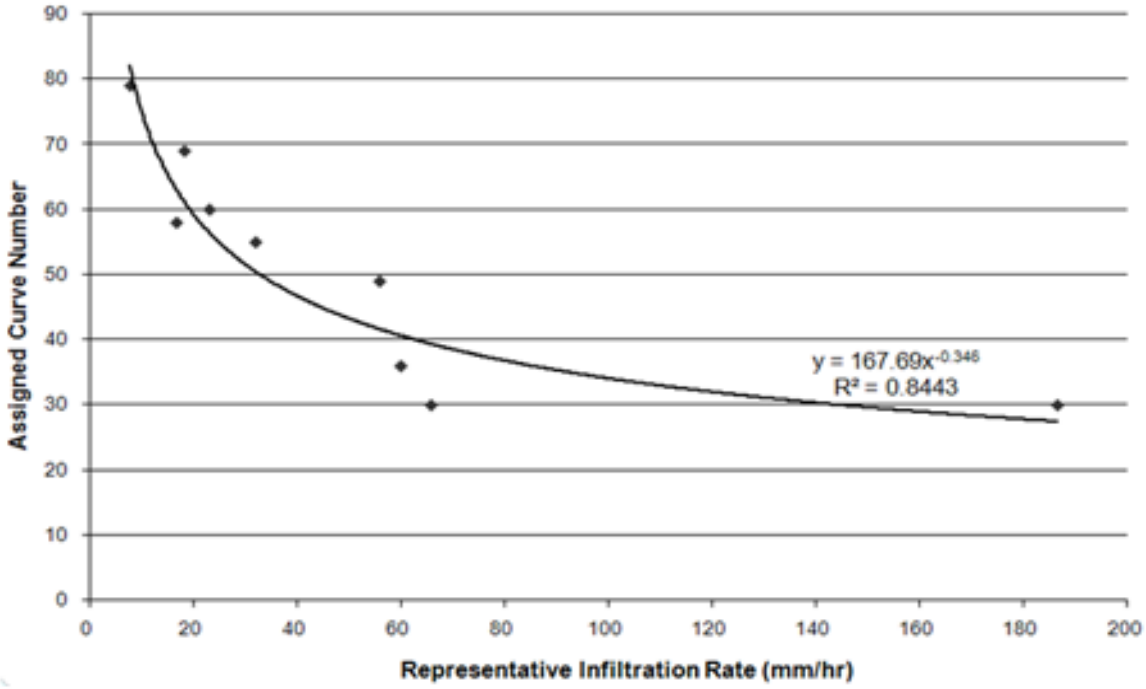
Table B-2. A summary of representative infiltration rates and assigned curve numbers for each land use / HSG combination

HSG	Land Use	Representative Infiltration Rate (cm/hr)	Assigned Curve Number
A	Undisturbed Meadow	24.13	30
	Disturbed Lawn	10.01	49
	Disturbed Woods	11.68	36
	Undisturbed Woods	64.26	30
B	Undisturbed Meadow	2.06	58
	Disturbed Lawn	2.54	69
	Disturbed Woods	2.31	60
	Undisturbed Woods	3.20	55
C	Undisturbed Meadow	--	--
	Disturbed Lawn	1.30	79
	Disturbed Woods	--	--
	Undisturbed Woods	--	--

-- no data available

The representative infiltration rates were plotted against the corresponding designated curve numbers for all HSG / land use combinations and a trend line was drawn, as shown in Figure B-3. The type of trend line was chosen based on the highest R^2 value. The equation for the chosen trend line describes the relationship between SCS curve numbers and soil infiltration rates based on experimental values (equation 1).

Figure B-3. Assigned curve numbers plotted against representative infiltration rates for each land use / soil type grouping with fitted trend line



$y = 167.69x^{-0.3463}$ (1)

where y = curve number, and
x = infiltration rate (mm/hr).

Representative Infiltration Rate (mm/hr)

Equation 1 was used to calculate a curve number for each infiltration study and the studies were then grouped according to soil type and land use. The median curve number for each land use / soil type group was then calculated. For simplification, two groups were formed: HSGs A and B were consolidated and considered 'sandy soils' and HSGs B and C were grouped together and considered 'clay-influenced soils'. These data are displayed in Table B-3.

Table B-3. Calculated median curve numbers for sandy soils and clay-influenced soils, classified by land use type

Land Use	Sandy (HSGs A/B)	Clay-Influenced (HSGs B/C)
Undisturbed Woods	36	57
Disturbed Woods	48	63
Undisturbed Meadow	46	67
Disturbed Lawn	51	75

The lack of available data for clay-influenced soils necessitated the extrapolation of study results. There were no data available for HSG D, so this HSG was not included in our results (hence, an A/B group and a B/C group). The only data available for HSG C were for the land use 'disturbed lawn', so these data were used to generate a median curve number for the HSG B/C 'disturbed lawn' classification. The other three land uses did not have data associated with HSG C: therefore, the median curve number was calculated using only HSG B data. There were data available for all land use types with HSGs A and B, so the median curve number calculated for these groups included data for HSGs A and B.

After representative curve numbers were determined for each land use / soil type combination, rainfall data for each representative location were analyzed to determine total precipitation depth and antecedent dry period (ADP) for each individual event within the ten year period. A storm was considered separate from a preceding event if the time between recorded precipitation was at least six hours. Daily precipitation data were used for Brevard; therefore, each day was considered separate from the previous day when analyzing individual events. The ADP was also used to determine the antecedent runoff condition (ARC). If precipitation occurred less than 1 day prior to a given event, ARC I was used; ARC II was used for a time interval of one to four days, and an interval of greater than four days stipulated the use of ARC III. Variations in the curve numbers due to the ARC were obtained from the National Engineering Handbook (USDA, 2007).

Runoff was then calculated for each individual storm event using the NRCS TR-55 method. A representative curve number was determined based on the land use assignment (as shown in Table B-3) and the variation dictated by the ARC. For a given location, the representative annual depth of runoff produced by each land use / soil type combination was determined by taking the median of total annual runoff depths for all analyzed years. As precipitation varies with physiographic region, annual runoff was calculated for each unique combination of land use, soil type and region.

Infiltration

As mentioned previously, four hydrologic cycle components were included in this approach: precipitation, infiltration, runoff, and evapotranspiration. Any precipitation that did not leave the surface in the form of runoff or evapotranspiration was assigned to infiltration. Therefore, infiltration was calculated for each category by subtracting the runoff and evapotranspiration depths from the precipitation depth.

Results and Discussion

Tables B-4 and B-5 summarize the representative values for precipitation, ET, runoff, and infiltration as calculated by the method previously described. Table B-4 displays data for sandy soils, or those consisting of HSGs A and/or B, and Table B-5 represents data for clay-influenced soils, or HSGs C and/or D.

Tables B-6 and B-7 summarize the percentage of annual precipitation that contributes to each hydrologic component for each land use type in each physiographic region for sandy and clay-influenced soils, respectively.

There are several discernable differences among the percentage distributions for different land uses. Runoff percentages for clay-influenced soils are higher than those for sandy soils, while infiltration percentages are lower. This is expected, as HSGs C and D have lower infiltration rates than HSGs A and B. The disturbed lawn land use, regardless of soil type or region, consistently produces higher runoff values and lower infiltration values than the other land uses. This is most likely due to the soil compaction associated with urban and disturbed lands.

The differences in the assigned dominant vegetative species result in considerable variation in ET percentages among the different regions: in the coastal plain the 'undisturbed woods' land use has the highest ET percentage, while the 'undisturbed meadow' has the highest value in the Blue Ridge region. However, ET values in the piedmont region are very similar among the different land uses. A comparison of ET values in the coastal plain versus the Blue Ridge rain shed regions show that a cooler, wetter climate results in lower ET values than a drier, warmer climate.

As ET can vary greatly among different species and types of vegetation, assigning the correct type of vegetation to a given land use is critical in obtaining an accurate percentage distribution. This is an area that requires additional research, as the vegetative species assigned to each land use category in this approach are an estimate and do not reflect the detail and variation that is present in natural conditions. When assessing a specific

Table B-4. Calculated annual depths for each land use / region category in sandy soils (HSGs A/B) and each hydrologic cycle component: precipitation (P), evapotranspiration (ET), runoff (RO), and infiltration (IT)

Land Use	Annual Depths (cm)															
	Coastal Plain				**Piedmont**				**Blue Ridge - Rain Shadow**				**Blue Ridge - Rain Shed**			
	P	ET	RO	IT	P	ET	RO	IT	P	ET	RO	IT	P	ET	RO	IT
Undisturbed Woods	130.5	95.2	1.0	34.34	115.4	79.1	0.3	36.0	111.0	68.6	0.2	42.2	166.1	68.6	1.1	96.4
Disturbed Woods		87.5	4.3	38.73		80.3	1.4	33.7		46.0	1.4	63.6		46.0	5.2	114.9
Undisturbed Meadow		78.1	3.5	48.95		70.9	1.1	43.5		78.7	1.1	31.2		78.7	4.2	83.3
Disturbed Lawn		74.2	4.8	51.54		75.1	1.8	38.6		75.2	1.9	33.9		75.2	6.4	84.5

Table B-5. Calculated annual depths for each land use / region category in clay-influenced soils (HSGs C/D) and each hydrologic cycle component: precipitation (P), evapotranspiration (ET), runoff (RO), and infiltration (IT)

Land Use	Annual Depths (cm)															
	Coastal Plain				**Piedmont**				**Blue Ridge - Rain Shadow**				**Blue Ridge - Rain Shed**			
	P	ET	RO	IT	P	ET	RO	IT	P	ET	RO	IT	P	ET	RO	IT
Undisturbed Woods	130.5	95.2	6.5	28.82	115.4	79.1	3.1	33.2	111.0	68.6	3.5	38.9	166.1	68.6	10.3	87.2
Disturbed Woods		87.5	8.7	34.3		80.3	5.3	29.8		46.0	5.9	59.1		46.0	16.4	103.7
Undisturbed Meadow		78.1	10.4	42.02		70.9	7.3	37.3		78.7	8.2	24.2		78.7	21.7	65.7
Disturbed Lawn		74.2	17.1	39.23		75.1	13.1	27.3		75.2	15.7	20.2		75.2	38.2	52.7

Table B-6. Summary of the percentage of annual rainfall contributing to each hydrologic component for each land use / region category for sandy soils (HSGs A/B)

	Percentage of Annual Rainfall (%)											
	Coastal Plain			**Piedmont**			**Blue Ridge - Rain Shadow**			**Blue Ridge - Rain Shed**		
Land Use	ET	Runoff	Infiltration	ET	Runoff	Infiltration	ET	Runoff	Infiltration	ET	Runoff	Infiltration
Undisturbed Woods	73.0	0.7	26.3	68.5	0.3	31.2	61.8	0.2	38.0	41.3	0.7	58.0
Disturbed Woods	67.0	3.3	29.7	69.6	1.2	29.2	41.4	1.3	57.3	27.7	3.1	69.2
Undisturbed Meadow	59.8	2.7	37.5	61.4	1.0	37.7	70.9	1.0	28.1	47.4	2.5	50.1
Disturbed Lawn	56.8	3.7	39.5	65.0	1.5	33.4	67.7	1.7	30.6	45.2	3.9	50.9

Table B-7. Summary of the percentage of annual rainfall contributing to each hydrologic component for each land use / region category for clay-influenced soils (HSGs C/D)

	Percentage of Annual Rainfall (%)											
	Coastal Plain			**Piedmont**			**Blue Ridge - Rain Shadow**			**Blue Ridge - Rain Shed**		
Land Use	ET	Runoff	Infiltration	ET	Runoff	Infiltration	ET	Runoff	Infiltration	ET	Runoff	Infiltration
Undisturbed Woods	73.0	5.0	22.1	68.5	2.7	28.7	61.8	3.1	35.1	41.3	6.2	52.5
Disturbed Woods	67.0	6.7	26.3	69.6	4.6	25.8	41.4	5.4	53.2	27.7	9.8	62.5
Undisturbed Meadow	59.8	8.0	32.2	61.4	6.3	32.3	70.9	7.4	21.8	47.4	13.1	39.6
Disturbed Lawn	56.8	13.1	30.1	65.0	11.3	23.6	67.7	14.1	18.2	45.2	23.0	31.7

parcel or area to determine pre-development hydrologic percentages, a field visit is strongly suggested to evaluate the vegetative species present and assign more accurate ET values. This applies to runoff and infiltration calculations as well.

Additionally, the ET values presented herein are based on experimental research studies in well-watered conditions. While this was attempted to be taken into account when determining a representative ET value by subtracting the median residential irrigation amount, this is a rudimentary approach. More accurate ET values for meadows and lawns could be obtained through additional research studies that focus on natural moisture conditions as opposed to well-watered conditions.

Model Accuracy

One research study has focused specifically on developing a detailed hydrologic budget for an undeveloped forest and provides experimental data with which the results from the presented research-based model can be compared. The Coweeta Long Term Ecological Research program is located in the Blue Ridge – Rain Shed region of North Carolina and has been dedicated to the study of forest hydrology since 1933. For more information on Coweeta, see Swift et al. (1987) or www.coweeta.ecology.uga.edu. Swift et al. (1987) examined the hydrologic fate of rainwater in this undeveloped, forested watershed and, based on 37 years of collected data, estimated that approximately 50 percent of precipitation infiltrated, 40 percent evapotranspired, and 10 percent left the site as runoff (see Table B-8). Results produced by the method described in this paper were very similar. For an undisturbed wooded site located in the Blue Ridge Rain Shed region with clay-influenced soils (HSGs B/C), this method estimated that 52.5 percent of precipitation infiltrated annually, 41.3 percent evapotranspired, and 6.2 percent left the site as runoff (Table B-8). When compared to the experimental values reported by Swift et al. (1987), there is only a difference of 2.5 percent, 1.3 percent and 3.8 percent for infiltration, ET, and runoff, respectively.

Table B-8. Percentage of annual precipitation that leaves a site as infiltration, evapotranspiration, and runoff, as estimated by experimental data and the presented research-based method for the Coweeta watershed

	Infiltration	**Evapotranspiration**	**Runoff**
Experimental data (Swift et al., 1987)	50%	40%	10%
Research-based method (presented herein)	52.5%	41.3%	6.2%
Difference	2.5%	1.3%	3.8%

Conclusions

Describing a site's pre-development and post-development hydrology is a novel way of implementing and evaluating low impact development (LID). The primary goal of LID is to reduce runoff through storage, ET, and infiltration. Comparing a site's pre-development (or target) hydrology, that is the percent of annual water fate with respect to runoff, infiltration and ET, to post-development hydrologic fate, allows for a rapid and accurate evaluation of a site's overall adherence to LID principles. In addition, this method provides designers, planners, and developers with a tangible, numeric target for post-development conditions while allowing flexibility in how that target is achieved, thus helping LID become a more attractive and feasible style of development. While this is currently a regional approach and institutes broad assumptions, further research will allow for more detail and accuracy in determining representative percentages.

REFERENCES

Aronson, L. J., A. J. Gold, R. J. Hull and J. L. Cisar. 1987. Evapotranspiration of cool-season turf grasses in the humid Northeast. *Agronomy Journal* 79: 901-905.

Baldwin, C. M., H. Liu, L. B. McCarty, W. L. Bauerle and J. E. Toler. 2006. Response of six bermudagrass cultivars to different irrigation intervals. *Horticulture Technology* 16(3): 466-470.

Bastug, R. and D. Buyuktas. 2003. The effects of different irrigation levels applied in golf courses on some quality characteristics of turfgrass. *Irrigation Science* 22: 87-93.

Brown, M. J. 2003. *Forest Statistics for the Mountains of North Carolina, 2002*. Asheville, NC: USDA Forest Service.

Brown, M. J. and R. M. Sheffield. 2003. *Forest Statistics for the Piedmont of North Carolina, 2002*. Asheville, NC: USDA Forest Service.

Burk, A. R., S. D. Chanasyk and E. Mapfumo. 1999. Influences of land disturbance and management regime on infiltration and runoff. *Canadian Agricultural Engineering* 41(3): 127-134.

Burton, M. 2008. Assistant Professor, North Carolina State University Department of Crop Science. Personal communication. 13 June.

Carrow, R. N. 1995. Drought resistance aspects of turf grasses in the southeast: Evapotranspiration and crop coefficients. *Crop Science* 35:1685-1690.

Conner, R. C. 2003. *Forest Statistics for the Northern Coastal Plain of North Carolina, 2000*. Asheville, NC: USDA Forest Service.

Conner, R. C. and R. M. Sheffield. 2001. *Forest Statistics for the Southern Coastal Plain of North Carolina, 1999*. Asheville, NC: USDA Forest Service.

Croke, J., P. Hairsine and P. Fogarty. 1999. Runoff generation and re-distribution in logged eucalyptus forests, south-eastern Australia. *Journal of Hydrology* 216: 56-77.

Devitt, D. A., R. L. Morris and D. C. Bowman. 1992. Evapotranspiration, crop coefficients and leaching fractions of irrigated desert turfgrass systems. *Agronomy Journal* 84: 717-723.

Dietz, M. E. 2007. Low impact development practices: A review of current research and recommendations for future directions. *Water Air and Soil Pollution* 186 (1-4): 351-363.

Fu, J., J. Fry and B. Huang. 2004. Minimum water requirements of four turf grasses in the transition zone. *HortScience* 39(7): 1740-1744.

Goodwin, L. 2008. Water Resources Manager, Town of Cary, North Carolina. Personal Communication. 10 October.

Gregory, J. H., M. D. Dukes, P. H. Jones and G. L. Miller. 2006. Effect of urban soil compaction on infiltration rate. *Journal of Soil and Water Conservation* 61(3): 117-123.

Hamilton, G. W. and D. V. Waddington. 1999. Infiltration rates on residential lawns in central Pennsylvania. *Journal of Soil and Water Conservation* 54(3): 564-568.

Hebert, M. T. and S. B. Jack. 1998. Leaf area index and site water balance of loblolly pine (Pinus taeda L.) across a precipitation gradient in East Texas. *Forest Ecology and Management* 105: 273-282.

Huang, J., S. T. Lacey and P. J. Ryan. 1996. Impact of forest harvesting on the hydraulic properties of surface soil. *Soil Science* 161(2): 79-86.

Jakobsen, B. F. and E. L. Greacen. 1985. Compaction of sandy forest soils for forwarder operations. *Soil and Tillage Research* 5:55-70.

Jensen, M. E., R. D. Burman and R. G. Allen. 1990. *Evapotranspiration and Irrigation Water Requirements*. ASCE Manuals and Reports on Engineering Practice No. 70. New York, NY: ASCE.

Johnson, M. G. and R. L. Beschta. 1980. Logging, infiltration capacity and surface erodibility in Western Oregon. *Journal of Forestry* (June).

Johnson, S. E. 2008. Assistant Professor, North Carolina State University Department of Crop Science. Personal communication. 13 June.

Ladekarl, U. L., K. R. Rasmussen, S. Christensen, K. H. Jensen and B. Hansen. 2005. Groundwater recharge and evaportranspiration for two natural ecosystems covered with oak and heater. *Journal of Hydrology* 300: 76-99.

Lewis, D., M. J. Singer, R. A. Dahlgren and K. W. Tate. 2000. Hydrology in a California oak woodland watershed: a 17-year study. *Journal of Hydrology* 240: 106-117.

Lu, J., G. Sun, S. G. McNulty and D. M. Amatya. 2005. A comparison of six potential evapotranspiration methods for regional use in the southeastern United States. *Journal of the American Water Resources Association* 41(3): 621-633.

McNulty, S. G., J. M. Vose and W. T. Swank. 1997. Regional hydrologic response of loblolly pine to air temperature and precipitation changes. *Journal of the American Water Resources Association* 33(5): 1011-1022.

McNulty, S. G., J. M. Vose and W. T. Swank. 1996. Loblolly pine hydrology and productivity across the southern United States. *Forest Ecology and Management* 86: 241-251.

Meyer, S. C. 2005. Analysis of base flow trends in urban streams, northeastern Illinois, USA. *Hydrogeology Journal* 13: 871-885.

Naeth, M. A., R. L. Rothwell, D. S. Chanasyk and A. W. Bailey. 1990. Grazing impacts on infiltration in mixed prairie and fescue grassland ecosystems of Alberta. *Canadian Journal of Soil Science* 70: 593-605.

NC-SCO. 2008. State Climate Office of North Carolina. North Carolina State University, Raleigh, NC. http://www.nc-climate.ncsu.edu/ Accessed: 15 September 2008.

Nelson, R. A., J. A. Smith, and A. J. Miller. 2006. Evolution of channel morphology and hydrologic response in an urbanizing drainage basin. *Earth Surface Processes and Landforms* 31: 1063-1079.

New, B. 2008. Branch Head, North Carolina Division of Forest Resources. Personal communication. 13 June.

Pitt, R., S. Chen, and S. Clark. 2001a. Compacted urban soils effects on infiltration and bioretention stormwater control designs. In *Proceedings of the 9th International Conference on Urban Drainage*. Portland, OR: IAHR, IWA, EWRI, ASCE.

Pitt, R., S. Chen and S. Clark. 2001b. Infiltration through compacted urban soils and effects on bioretention design. In *Proceedings of the Low Impact Development Roundtable Conference*. Baltimore, MD.

Prince George's County. 1999, June. *Low-Impact Development Design Strategies: An Integrated Design Approach*. Largo, MD: Prince George's County Department of Environmental Resources, Programs and Planning Division.

Restrepo, N. C. and M. A. Arain. 2005. Energy and water exchanges from a temperate pine plantation forest. *Hydrological Processes* 19:27-49.

Schoonover, J. E. and B. G. Lockaby. 2006. Land cover impacts on stream nutrients and fecal coliform in the lower piedmont of West Georgia. *Journal of Hydrology* 331: 371-382.

Steinbrenner, E. C. 1955. Effect of tractor logging on physical properties of some forest soils in southwestern Washington. In *Soil Science Society Proceedings 1955*. Soil Science Society of America.

Steinbrenner, E. C. 1950. An improved method for determining the water permeability of forest soils. In *Soil Science Society Proceedings 1950*. Soil Science Society of America.

Swift, L. W., G. B. Cunningham and J. E. Douglass. 1987. Climatology and Hydrology. In *Forest Hydrology and Ecology at Coweeta*. Eds: W. T. Swank and D.A. Crossley. New York, NY: Springer Verlag. pp. 35-57.

USDA. 2007. Chapter 7: Hydrologic Soil Groups. *National Engineering Handbook, Part 630: Hydrology*. Washington, DC: USDA Natural Resources Conservation Service.

USDA. 1986. *Urban Hydrology for Small Watersheds*. Technical Release 55. Washington, DC: U. S. Department of Agriculture Soil Conservation Service.

van Bavel, C. H. M. and D. G. Harris. 1962. Evapotranspiration rates from bermudagrass and corn at Raleigh, North Carolina. *Agronomy Journal* July/August: 319-322.

Xinmin, Z., H. Lin, B. Xiuju, Z. Bingxiang, C. Fahe and S. Xinzhang. 2007. The most economical irrigation amount and evapotranspiration of the turf grasses in Beijing City, China. *Agricultural Water Management* 89: 98-104.

Zhou, G., G. Sun, X. Wang, C. Zhou, S. G. McNulty, J. M. Vose and D. M. Amatya. 2008. Estimating forest ecosystem evapotranspiration at multiple temporal scales with a dimension analysis approach. *Journal of the American Water Resources Association* 44(1): 1-14.

APPENDIX C
Code and Ordinance Checklist

To help you identify ways to promote LID using code and ordinance language, see the list below of recommended code and ordinance changes arranged by development theme. Some recommendations may not be appropriate for your community.

Clearing and Grading

- ☐ Restrict to minimum needed for building footprints, construction access, and setbacks.
- ☐ Establish slope protection criteria.
- ☐ Establish requirements for retention of native vegetation and tree canopy.
- ☐ Require contractors to reestablish permeability of soils compacted by construction vehicles. For example, till or amend soils of lawn areas prior to seeding.
- ☐ If on-site wastewater treatment is to be used, allow reserve septic fields to remain uncleared.

Dimension and Density

- ☐ Relax side yard setbacks and allow narrower frontages for flexible lot placement.
- ☐ Reduce height restrictions and increase floor area ratios to reduce building footprints.
- ☐ Permit reduction in frontage requirements where appropriate.
- ☐ Amend density standards and allowances to encourage natural area protection in exchange for higher densities. Low-density development may appear to be better for water resources, but at a regional or watershed level, higher density development generates less stormwater per unit. Typically, stormwater management requirements for low-density development are minimal and may not sufficiently protect water resources. Moreover, higher density development can produce economies of scale that may make superior designs and stormwater treatment systems, such as constructed wetlands, more financially feasible in the short run and easier to maintain in the long run.

Natural Systems

- ☐ Allow or encourage BMPs in required landscape areas and open spaces (but not riparian buffers, which should remain undisturbed).
- ☐ Refer to or provide links to forest and tree preservation ordinances to raise awareness that forested lands are critical to stormwater infiltration.
- ☐ In conjunction with requirements to protect individual or specimen trees, require a minimum percentage of preserved canopy coverage.
- ☐ Permit open space developments (conservation subdivision design) by right, not only by waiver.
- ☐ Provide a definition of "open space."
- ☐ Protect vegetation along all water features (intermittent and perennial streams, floodplains, and wetlands) and other critical environmental features such as steep slopes.
- ☐ In mountainous communities, consider a steep slope ordinance as a tool for directing development to areas with less risk to human safety and erosion impacts.

- ☐ Minimize disturbance and restrict development on slopes greater than 15 percent, or less in areas with highly erodible soils. Require revegetation where disturbance occurs.
- ☐ Promote preservation of areas with 25 percent or greater slope.
- ☐ Encourage or require that building footprints be concentrated on slopes of 10 percent or less.

Parking Requirements

- ☐ Set and enforce parking ratio and stall size maximums to curb excess parking construction.
- ☐ Allow and encourage shared parking for commercial and residential uses, and reduce parking requirements near mass transit stops.
- ☐ Establish landscaping requirements for parking areas that include vegetated islands with bioretention functions.
- ☐ Allow or require pervious materials for spillover parking.

Street Standards

- ☐ Considerations for street layout should include reducing street length and minimizing total paved area (including cul-de-sacs). Identify the need to reduce cut and fill, do not run streets across steep hillsides, route streets along ridgelines, protect important features, and do not run streets across steep hillsides.
- ☐ Permit a minimum pavement width of 18 to 22 feet on low-traffic local streets in residential areas. It is especially important to involve public works officials and emergency response officials in this discussion.
- ☐ Permit the use of open section roadways with roadside swales. Do not require conventional curbs for the full length of all streets in residential areas. Where curbs are deemed necessary to protect the roadway edge, allow perforated curbs, also known as curb cuts (which allow runoff to flow into swales) or flat "aprons" that are flush with the road surface.
- ☐ Allow narrower rights-of-way when appropriate, permeable surfaces, and bioretention swales in rights-of-way.
- ☐ Establish criteria for the design of roadside swales to ensure adequate stormwater treatment and conveyance capacity.
- ☐ Permit placement of utilities under the paved section of the right-of-way or immediately adjacent to the road edge (so land adjacent to the roadway can be used for swales).
- ☐ Permit use of permeable paving for parking lanes in residential neighborhoods, and sidewalks.
- ☐ Permit sidewalk placement on only one side of the street in low-density residential areas.
- ☐ Provide flexibility with sidewalk layout, such as an alternative pedestrian circulation layout that uses common areas, rather than street rights-of-way.
- ☐ Design sidewalks so that the runoff is disconnected from the stormwater conveyance system.
- ☐ Allow landscaped islands and bioretention within cul-de-sacs.
- ☐ Minimize the required radii for cul-de-sacs. A radius of 35 feet is optimal, depending on emergency vehicles.

APPENDIX D
Glossary of Terms

"The difference between the right word and the nearly right word is the same as that between lightning and the lightning bug." –Mark Twain

A

Acute Toxicity: Toxic effects (usually lethal or sub-lethal) due to short-term exposures to chemicals.

Advanced Wastewater Treatment: Wastewater treatment that extends beyond the secondary, or biological, stage of treatment and includes the removal of nutrients and suspended solids.

Aerobic: Containing oxygen. Conditions that contain oxygen, organisms that require oxygen to survive, or any chemical / biological processes that occur in the presence of oxygen.

Aerobic Treatment Units: A term traditionally used to describe proprietary devices that directly introduce air into wastewater by mechanical means to maintain aerobic conditions within the pretreatment component.

Algae: Members of a large group of primarily aquatic organisms that contain chlorophyll and other pigments and can carry out photosynthesis, but lack true roots, stems, or leaves and range from single cells to large multicellular structures. Examples of algae include seaweed, kelp, dinoflagellates, and diatoms.

Algal Bloom: The rapid growth of algae in a system due to excessive amounts of nutrients and the appropriate physical and chemical conditions.

Alkalinity: A measurement of the buffering ability of water (or the capacity of water to resist changes in pH), or the ability of a base to neutralize an acid.

Anaerobic: Lacking oxygen. Conditions that lack oxygen, organisms that can survive without oxygen, and any chemical or biological process that occurs without oxygen.

Anoxia: Absence of oxygen.

Anoxic: Lacking oxygen.

Anthropogenic: Of, relating to, or resulting from human activity.

Aquaculture: The cultivation and harvest of aquatic plants and animals.

Aquifer: A stratum of rock or soil that contains groundwater.

Assimilative Capacity: Capacity of a water body or watershed to receive and absorb pollutants while maintaining designated uses and water quality standards.

B

Baseflow: The amount of stream flow contributed by groundwater sources.

Baseline Data: Information about existing chemical, biological, or physical conditions.

Beneficial Use: Uses of a water resource, such as recreation, aquatic life, and human consumption, that is protected by state water quality standards.

Benthic Macro Invertebrates: Animals without backbones or internal skeletons that live on or near the bottom of a water body.

Benthos: All organisms living at or near the bottom of an aquatic habitat.

Best Management Practices (BMPs): Methods, measures, or practices to prevent or reduce water pollution. Examples include treatment requirements, operating procedures, erosion control practices, fertilizer and animal waste management, and runoff control in urban systems.

Bioaccumulation: The process by which contaminants accumulate within the tissues of an individual organism.

Biochemical Oxygen Demand (BOD): The potential amount of oxygen consumed in the degradation of organic material by bacteria.

Biological Assessment: Evaluations of the condition of water bodies using surveys and other direct measurements of species diversity and species abundance (of macro invertebrates, fish, and plants) to determine whether water bodies support survival and reproduction of desirable fish, shellfish, and other aquatic species and how aquatic life reacts to water quality.

Biological Diversity (Biodiversity): The number and variety of living organisms on earth in all forms and at all levels, including ecosystem diversity, species diversity, and genetic diversity.

Biological Wastewater Treatment: Treatment process in which bacterial or biochemical activity is used to treat organic matter in wastewater.

Biological Integrity: Supporting and maintaining the biological components of an aquatic ecosystem to a level comparable to that of natural habitats of the surrounding region.

Bioindicators: Organisms that determine changes in water quality and pollutant levels within a system.

Bioretention Area: (also known as rain garden) A depressed landscaped area that filters and infiltrates stormwater runoff.

Biota: All of the organisms, including bacteria, plants, and animals, that live in a particular location or area.

Brownfield: Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

Buffer: A vegetated area, forested or otherwise vegetated, located between water bodies such as streams, wetlands, and lakes, that provides a permanent barrier against runoff from development, agriculture, construction, and other land uses. Buffers are designed to filter pollutants in runoff before the pollutants reach surface waters.

C

Carrying Capacity: The maximum population of a particular organism that a given environment can support without detrimental effects.

Channelization: Hydrologic modifications and straightening of stream shape that may cause dramatic changes in the stream ecosystem.

Chemical Oxygen Demand (COD): A measure of the amount of organic matter in water or wastewater.

Chlorophyll: Green pigment found in photosynthetic organisms that can be used as an indicator of algal biomass.

Chronic Toxicity: Toxic effects (usually non-lethal) from long-term exposures to chemicals.

Cistern: A tank that collects rain water from rooftops and temporarily stores it for reuse.

Cluster (or Open Space) Development: Designs that incorporate open space into a development site. In cluster patterns, buildings and roads are arranged on a compact portion of the site to reserve areas of common open space or greenways; these areas can be used for recreation or preserved as naturally vegetated land.

Cluster Wastewater Treatment System: A wastewater treatment system that serves two or more sewage-generating dwellings or facilities; typically includes a comprehensive, sequential land-use planning component and private ownership. The most appropriate soil in a development is used for the cluster soil treatment area. This system relies on a large soil treatment area that serves multiple facilities. The soil treatment area may be adjacent or remote to these facilities (EPA 2003; 2005).

Coastal Zone: Coastal waters and the ocean affect adjacent shorelines that influence the uses of the ocean and its ecology. The Coastal Zone may include islands, transitional and intertidal areas, salt marshes, wetlands, and beaches.

Collaboration: A problem-solving process in which parties work together informally to resolve an issue. The issue may or may not be contentious.

Combined Sewer Overflow: Discharge of the combination of stormwater and sanitary wastewater during storms when the capacity of the sewer system to transport, store, or treat the increased flow is exceeded.

Combined Sewer System: A wastewater collection and treatment system for both stormwater runoff and municipal sewage.

Confluence: A flowing together of two rivers or more streams; the junction of two or more streams.

Connectivity: A measurement of the continuity of a corridor such as a riparian corridor. Connectivity promotes valuable natural functions, such as movement of animals through their habitat and transport of materials and energy, which help maintain the integrity of natural communities.

Consensus: A method of making collaborative decisions in which all parties' interests are addressed and everyone accepts the decision.

Conservation Easement: A voluntary legal agreement between a landowner and a conservation organization (land trusts and the like) or public agency that limits some portion of the land's uses; conservation easements preserve undeveloped land to benefit the environment. Landowners voluntarily give up certain development rights while still retaining ownership of the land.

Cost-Effective Solution: A financially viable solution to a problem.

Cost-Sharing: Sharing the costs of constructing and implementing a Best Management Practice (BMP) between more than one funding source.

Critical Habitat: Areas that are essential for the conservation of federally endangered or threatened species. Such areas may require protection or certain management practices.

Cross Slope: The slope perpendicular to the direction of the road (as opposed to grade, which describes the steepness of the road).

D

Decomposition: The breakdown of organic substances by microorganisms.

Designated Uses: Uses for water resources identified by state water-quality standards that must be upheld or achieved as required by the Clean Water Act (CWA). Examples of designated uses include aquatic habitat, fisheries, and public water supply.

Detention: The slowing, collecting, or detaining of stormwater runoff prior to release into receiving waters.

Discharge: The release or placement of wastewater, dredged or fill materials, or other substances directly into surface waters.

Dissolved Oxygen: The amount of oxygen present in the water column. Dissolved oxygen is important for aerobic organisms and proper biological functioning. Less than 5 parts per million of oxygen in water can cause stress to aquatic organisms. The lower the oxygen concentrations, the greater the stress.

Drip Distribution: The application of effluent over an infiltrative surface via pressurized drip irrigation emitters and associated devices and parts (pump, filters, controls, and piping). May apply effluent either subsurface or on the surface.

Dual Alternating Drain Fields: A final treatment and dispersal component consisting of multiple, independently dosed soil treatment areas.

E

Ecological Integrity: Supporting and maintaining all components, biological, physical, and chemical components, of an ecosystem to a level comparable to that of natural habitats of the surrounding region.

Ecosystem: The network of a biological community and its surrounding interconnected physical and chemical environment.

Edge: The outer boundary of a habitat patch.

Edge Effect: A condition in which otherwise suitable habitat becomes less suitable for a species because it is adjacent to non-habitat land. This degradation of habitat may be due to predator species that live outside the patch, or increased competition with species that live outside the habitat patch.

Effluent: Treated or untreated wastewater that is discharged into the environment from a treatment plant, sewer, or industrial facility.

Endemic: A species that occurs in only a limited number of places.

EPT: Insect groups (Ephemeroptera, Plecoptera, and Trichoptera) that are generally intolerant of many types of pollution. Low EPT abundance may signify poor water quality.

Erosion: The wearing away of rock and soil due to wind, weathering, water, ice, or other physical, chemical, or biological forces. The rate of erosion may be increased by land use activities.

Estuary: A coastal area where fresh water from rivers and streams mixes with salt water from the ocean. Bays, sounds, and lagoons along coasts may be estuaries. Segments of rivers and streams connected to estuaries are considered part of the estuary.

Eutrophication: Process by which a water body undergoes an increase in dissolved nutrients, often leading to algal blooms, low dissolved oxygen, and changes in community structure. This process occurs naturally over time, but can be accelerated by human activities that increase nutrient inputs into aquatic ecosystems.

Evapotranspiration: The flux of water from land and water surfaces to the atmosphere by the combined processes of evaporation and transpiration. Evaporation can occur from hard surfaces such as rooftops and parking lots, from water surface features such as ponds, lakes, streams, marshes, and oceans, from soil surfaces, especially ponded and wet areas, and from vegetative surfaces such as forest canopies. Transpiration is the general uptake and release of water by vegetation to the atmosphere.

Exotic Species: A recently introduced species, or a species that is living in a location that is outside of its normal or historical range.

Extinct Species: A species no longer in existence.

Extirpated Species: A species no longer surviving in regions that were once part of its range.

F

Facilitation: Assistance provided to a group of people by an impartial party (facilitator) in order to help the group conduct a satisfying meeting or series of meetings.

Fecal Coliform: Bacteria found in the fecal matter of warm-blooded animals. Fecal coliform is harmless to human health, but indicates other harmful pathogens.

First Flush: Stormwater that initially runs off an area that is more polluted than the stormwater that runs off later.

Floodplain: Area of land on each side of a stream channel that is inundated periodically by flood waters.

Fragmentation: The process whereby a large patch of habitat is broken down into many smaller patches of habitat, resulting in a loss in the amount and quality of habitat.

G

Gauging Station: A particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Geodatabase: A GIS-based computer program where both mapping information and other data such as water quality can be combined, mapped, and tracked.

GIS (Geographical Information Systems): Computer program for storing, mapping, analyzing, and displaying geographically referenced data, that is, data identified according to location.

Gravity Trenches: A trench typically 36 inches wide filled with 12 inches of approved stone or other media, which uses the force of gravity to convey wastewater. In general, trenches are installed in an excavation such that the bottom of the infiltrative surface is typically 0 to 36 inches below original ground elevation. A final cover of suitable soil stabilizes the completed installation, supports vegetative growth, and sheds water.

Greenfield: Land not previously developed or polluted.

Green Roof: A rooftop garden that consists of vegetation and soil, or a growing medium, planted over a waterproofing membrane. Additional layers, such as a root barrier and drainage and irrigation systems, may also be included.

Greenway: A linear open space established along a natural corridor, such as a river, stream, ridgeline, rail-trail, canal, or other route for conservation, recreation, or alternative transportation purposes. Greenways can connect parks, nature preserves, cultural facilities, and historic sites with business and residential areas.

Ground Water: Water occurring beneath the earth's surface, typically in aquifers, that supplies wells and springs, and is a key source of drinking water.

H

Habitat: An area with specific physical and environmental conditions in which a particular plant or animal lives.

Habitat Integrity: Supporting and maintaining the physical and environmental conditions of an aquatic ecosystem to a level comparable to that of natural habitats of the surrounding region.

Hardness: The presence of minerals, such as calcium and magnesium, in surface and groundwater.

Header Curb: Flat curb that allows runoff to flow off streets onto adjacent pervious areas.

Heavy Metals: Metals that do not degrade over time and are thus an environmental concern. Examples of heavy metals are cadmium, mercury, nickel, and lead.

Historical Data: Background information on historical conditions of an ecosystem and activities that may have occurred on or near the site of interest. Historical data helps explain the existing conditions of the ecosystem and may be useful in determining target conditions for restoration and other projects.

Human-Induced Disturbances: Disturbances to ecosystem structure and function due to human activities and land uses.

Hydric Soils: Soils inundated with water long enough to become anaerobic. Hydric soils are often indicative of wetlands.

Hydrologic Fates: Rainfall / precipitation has one of three eventual fates: (1) it runs off, (2) it infiltrates into the ground and becomes either shallow interflow or deep seepage, or (3) it evapotranspires.

Hydrologic Unit Cataloging (HUC): Cataloging of watersheds of various geographical scales, using numerical codes developed by the USGS.

Hydrology: Movement and distribution of groundwater and surface water in a system.

Hypoxia: Low dissolved oxygen concentrations in aquatic environments.

I

Impaired Water: Water bodies with decreased water quality due to pollution that are only partially supporting, or do not support, their designated uses.

Impervious Surface: A surface that does not allow water to penetrate. Examples of impervious surfaces include asphalt, rooftops, and concrete.

Individual Wastewater Treatment System: Serves one sewage-generating dwelling or facility.

Infiltration: The process by which a liquid drains or seeps into the earth, stormwater pipes, and the like.

Infiltration Device / Well: A BMP designed to introduce surface water into groundwater.

Interest: A concern, need, or value which in a dispute often gives rise to a specific stance (see "position") taken by a disputing party.

Intermittent Stream: A stream that flows only at certain times of the year, or does not flow continuously.

L

Land Use: The way land is used or developed, such as the types of buildings and activities permitted. Particular land uses are often associated with different types of pollution, such as erosion and sedimentation from construction activities.

Land Use Planning: Planning and creating policies to guide the way in which land and resources will be used.

Leachate: Water that picks up contaminants as it flows through wastes, pesticides, fertilizers, or other potential pollutants.

Level Spreader: A BMP used to spread out the flow of stormwater, creating a thin sheet of flow to pass through a riparian buffer.

Loading: Entry of pollutants into a body of water.

Low Pressure Pipe: A system that applies effluent to an infiltrative surface via pressurized pipe and drilled orifices and associated devices and parts (including pump, filters, controls, and piping). The distribution via a network of small diameter laterals (typically 1¼ inch) with small orifices (typically 1/8 to 3/16 inch) installed in a soil treatment area.

M

Meander: A curve in a river or stream.

Media Filters: A device that uses unsaturated materials to treat effluent by reducing BOD and removing suspended solids. The biological treatment is facilitated by microbial growth on the surface of the media.

Mitigation: Actions taken to avoid, reduce, or compensate for the effects of human-induced environmental damage. It can include projects such as restoration and enhancement of negatively affected ecosystems, or creation of an ecosystem.

Mitigation Banking: The restoration, creation, enhancement, or, in exceptional circumstances, the preservation of wetlands or other ecological resources which will compensate for unavoidable wetland or other ecological resource losses at another site or in future development (NCSE).

Monitoring: Repeated observation, measurement, or sampling at a site, on a scheduled or event basis, for a particular purpose.

N

Natural Disturbances: Natural events that disturb the structure and function of an ecosystem such as floods, drought, earthquakes, fire, and lightning.

Non-Point Source (NPS) Pollution: Pollution that enters water bodies from a variety of sources. NPS pollution is caused by runoff from rainfall or snowmelt that moves over and through the ground, washing natural and human-made pollutants into surface waters and underground sources of drinking water.

No-till Farming: Farming method in which the soil is left undisturbed.

Nutrients: Substances such as nitrogen and phosphorous that are required by plants and animals for growth. In some circumstances, excessive nutrient additions to surface waters may result in excessive algal or plant growth and, subsequently, the accumulation and decay of increased organic matter.

Nutrient Management: A best management practice (BMP) developed to minimize the amount of nutrients entering surface and groundwater by limiting the amount of nutrients applied to the land to only as much as the crop is estimated to use.

O

Off-site Wastewater Treatment System: An individual drain field that is located more the 500 feet away from the source. The soil treatment area may be located in a common area, on special purpose lots, or on easements. It differs from a cluster system in that each facility has a separate dedicated soil treatment area.

Open Space: Land set aside for public or private use within a development that is not built upon.

Overlay Districts: Zoning districts in which additional regulatory standards are superimposed on existing zoning. Overlay districts provide impose special restrictions in addition to those required by basic zoning ordinances.

Oxygen Demanding Materials: Materials such as organic wastes and food wastes that use up dissolved oxygen in the water column as they decompose.

P

Package Treatment Plant: A term commonly used to describe a modular aerobic treatment system unit serving multiple dwellings or establishments that collectively generate relatively large flows (greater than 1,500 gallons per day).

PAHs: Polycyclic aromatic hydrocarbons, a group of organic contaminants that form from the incomplete combustion of hydrocarbons such as coal, oil, gas, wood, garbage, or other organic substances.

Parallel Distribution: A pressure or gravity distribution of effluent that proportionally and simultaneously loads multiple sections of a final treatment and dispersal component.

Pathogen: A disease-causing organism (viruses, bacteria, or fungi can be pathogenic organisms).

Perennial Stream: A stream that flows continuously throughout the year.

Permeable: Soil or other material that allows the infiltration or passage of water or other liquids.

Pesticides: Chemicals or substances designed to eliminate insects and other pests.

Pesticide Management: A best management practice developed to reduce the pollution of water, soil, air, and non-targeted organisms by limiting the use, quantity, placement, timing, and application method of pesticides.

Plaza Width: Distance between a sidewalk and a road.

Point Source Pollution: Pollution that can be traced to a single point, or output, such as a pipe.

Pools: A section of a stream with slow-moving, deep water. In natural streams, pools and riffles are alternating.

Position: Stance taken by a party which indicates specific perspectives or solutions that the party will or will not accept (see: “Interest”).

Pressure Manifold: A pipe network having several outlets through which effluent is moved under pressure. Once the effluent leaves the pressure manifold, it flows through the trench by gravity.

Pump Tank: Part of a wastewater treatment system, a dosing tank which provides storage of effluent and houses a pump and associated appurtenances to convey effluent to another pretreatment process or a final treatment and dispersal component.

R

Receiving Waters: Surface waters, whether natural or man-made, into which materials are discharged.

Restoration: The management of physical, chemical, or biological characteristics of a site with the goal of returning natural or historic functions to sites that formerly supported wetlands.

Riffle: A section of a stream with fast-moving, turbulent, shallow water with a rocky bottom. In natural streams, pools and riffles alternate.

Riparian: Of, relating to, living on, or located on the banks of a watercourse such as a river, stream, or lake.

River Basin: Area encompassing all the land drained by streams and creeks flowing downhill into a major river. All water that falls within the basin flows into these streams and rivers.

Runoff: Water flowing across the land that does not infiltrate the soil, but drains into surface or groundwater, or when rainfall exceeds the infiltration capacity of the land.

S

Sand Filter: A small-scale BMP placed underground that uses sand to remove certain pollutants.

Sedimentation: Particles of soil, sand, silt, clay, or organic matter that are deposited onto the bottom of any surface water or are left behind when water leaves.

Septic Tank: A water-tight, covered receptacle for treatment of sewage; receives the discharge of sewage from a building, separates solids that can settle or float from the liquid, digests organic matter by anaerobic bacterial action, stores digested solids through a period of detention, allows clarified liquids to discharge for additional treatment and final dispersal, and attenuates flows.

Serial Distribution: A gravitational distribution of effluent that progressively loads one trench to a pre-determined level before passing through a relief line or device to the succeeding trench; effluent passes through the distribution media before entering succeeding trenches, which may be connected to provide a single uninterrupted flow path.

Single-loading: Lots are placed on one side of a street, and the other side remains undeveloped. This has been shown to enhance property value, but may be inefficient from an LID standpoint since the road serves fewer lots.

Sinuosity: Describes the amount of curvature in a stream channel.

Situation Assessment: A social science activity that occurs early in a watershed planning process and involves identifying watershed stakeholders, learning what concerns stakeholders and what they hope to gain in a watershed planning process, and identifying potential conflicts.

Spray Irrigation: The application of effluent over the ground surface via pressurized nozzles and associated devices and parts (including pump, filters, controls, and piping).

Stormwater Runoff: Runoff that picks up contaminants deposited on impervious surfaces during its flow to surface waters or groundwater.

Streambank Stabilization: Prevention of stream bank erosion and deterioration through vegetation or other stabilizing structures.

Stream Corridor: Spatial scale defining the ecosystem surrounding a stream, linear in shape, that includes the stream channel, riparian vegetation, floodplains, streambank, tributary streams, and trails, roads, and other development.

Stream Restoration: The management of morphological, ecological, and hydrological characteristics of a stream with the goal of returning natural or historic functions to the stream system.

Subsoiling: To disturb the soil layer(s) below and usually including the surface layer for the purpose of improving aeration, percolation, and root growth.

Suspended Solids: Organic and inorganic particles suspended in the water column and carried by the water. The presence of suspended solids in water may reduce the amount of light reaching the water column, clog the gills of fish and other animals, and are often associated with toxic contaminants that bind to particles.

Swales: Minor channels usually lined with grass used to transport runoff from less developed areas.

T

Total Maximum Daily Load (TMDL): Calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards and allocation of that amount to the pollutant's sources.

Total Suspended Solids (TSS): The weight of all suspended solids in water.

Transitional Upland Fringe: Areas of land on each side of a stream bank, beyond the floodplain, that act as a transitional zone between floodplain and surrounding land.

Tributary: A stream or river that feeds into a larger stream, lake, or river.

Turbidity: A measurement that indicates the amount of suspended solids in the water column.

V

Vegetative Clearing: The removal of riparian and upland vegetation for land use purposes.

W

Water Cycle: The cycle in which water evaporates from surface waters, condenses into clouds, and falls again to the earth as rain or other forms of precipitation.

Water Quality Standards: Laws and regulations that maintain limits, or criteria, for certain chemical, biological, and physical parameters to protect designated uses.

Water Table: The depth at which the ground is saturated with water.

Watershed: Ecosystem consisting of three major components—stream channel, floodplain, and upland areas—that function together and drain to water bodies, including lakes, rivers, estuaries, wetlands, streams, and the surrounding landscape (groundwater recharge areas are also considered).

Watershed Advisory Group: Assembly of a group of key participants, such as local citizens, public officials, landowners, local business owners, and public interest groups, who represent a variety of community interests, are affected by watershed initiatives, and will play an active role in the watershed planning process.

Watershed Stakeholder: Anyone who influences the quality of waters in a watershed (such as industry, municipalities, boaters, agriculture, or forestry), and anyone who is affected by the quality of waters in a watershed (such as fisherman, swimmers, or waterfront homeowners).

Wetlands: Areas that are frequently inundated or saturated with water for periods of time long enough to support vegetation suited for survival in saturated soils. Wetlands may include bogs, swamps, and marshes.

Wetland Creation: Creation of wetlands at a location where there was previously no wetland, or where no wetland has existed in the past 100 to 200 years (Lewis, 1989; Gwin et al., 1999).

Wetland Enhancement: The manipulation of the physical, chemical, or biological characteristics of a wetland (undisturbed or degraded) site to heighten, intensify, or improve specific function(s) or for a purpose such as water quality improvement, flood water retention, or wildlife habitat resulting in a change in wetland function(s).

Wetland Establishment: The manipulation of physical, chemical, or biological characteristics to develop a wetland that did not previously exist on an upland or deep-water site resulting in a gain of wetland acres.

Wetland Protection / Maintenance: Removing a threat to, or preventing decline of, conditions in or near a wetland. Includes purchase of land or easement, repairing water control structures or fences, structural

protection such as repairing a barrier island, or preservation.

Z

Zoning: Designation and regulation of areas of land for particular land uses. Zoning is delineated in a town, county, or other municipality.

References for this glossary are included in the Watershed Glossary document posted on the website www.ncsu.edu/WECO.

North Carolina State University and North Carolina A & T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, veteran status, or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A & T State University, U.S. Department of Agriculture, and local governments cooperating.

The use of brand names in this publication does not imply endorsement by the North Carolina Cooperative Extension Service of the products or services named nor discrimination against similar products or services not mentioned.

Published by North Carolina Cooperative Extension Service
Designed by Lee-Anne Milburn
Printed by Theo Davis Printing of Zebulon, North Carolina

Support provided by a USEPA 319 grant administered through the NCDENR Division of Water Quality



















AG-716
06/09-200-VB
E09-51836