Chapter 6

SITE PLANNING AND DESIGN CONSIDERATIONS

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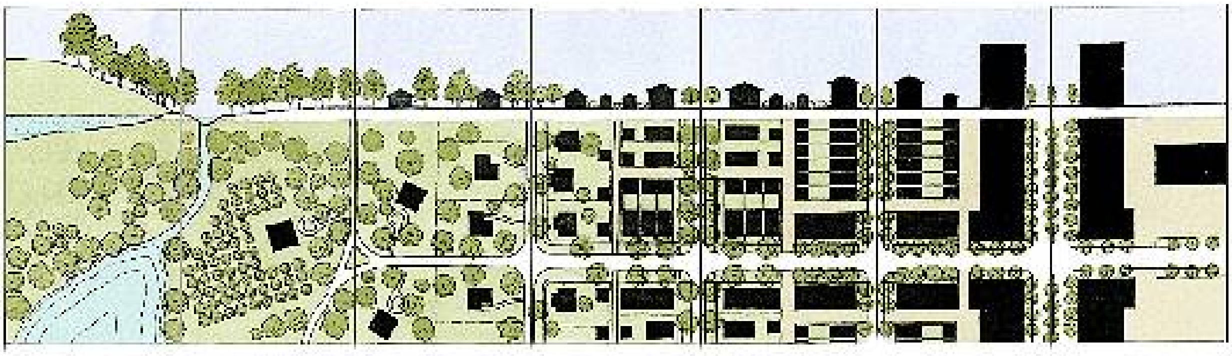


6.0. INTRODUCTION

As research, technology, and information transfer have improved over recent years, alternative approaches are being sought by citizens and governments to reduce the impacts of stormwater runoff from new development and redevelopment. Developers and designers also are seeking alternatives to expedite permitting processes, reduce construction costs, reduce long-term operation and maintenance costs, and increase property values.

Careful site planning at the outset of a project is the most effective approach for preventing or reducing the potential adverse impacts from development. Site planning is a preventive measure that addresses the root causes of stormwater problems. In the past, “stormwater management” has been defined largely as stormwater *disposal*. Stormwater management in Virginia can be significantly improved by approaching the task differently than this. A new and better approach is based on a conceptual understanding of stormwater, which is more comprehensive in scope and addresses the full array of stormwater issues.

In order to protect Virginia’s water resources, we must pay attention to recharging groundwater and maintaining a balance in the hydrologic cycle, preventing flooding, and maintaining water quality and the ecological values that have historically characterized Virginia waters. This different perspective further challenges us to prevent stormwater from becoming a problem, and to avoid highly engineered structural solutions that are expensive to both build and maintain. Where feasible, this new approach focuses on using natural systems and processes to achieve stormwater management objectives.

At the same time, this new approach is intended to enhance the natural functions of beneficial site resources. The end result is a site design that enhances existing wetlands, promotes the critical functions of floodplains, and integrates with riparian buffer systems, even while satisfying stormwater requirements. This approach maximizes the value achieved for the money spent.

The purpose of this chapter is to provide guidance for managing stormwater at land development projects in a manner that provides the optimum opportunity to protect and conserve natural resources, maintain the pre-development hydrologic regime, minimize the potential negative impacts of stormwater runoff, and minimize the human “footprint” on the environment.

While reducing the impacts from stormwater runoff may be achieved through both regulatory and non-regulatory techniques, this chapter focuses on the site-level planning and design tools that provide the best opportunity to accomplish the above goals. The techniques for doing this most effectively are represented under the banner of the terms “Better Site Design,” “Sustainable Site Design,” or, as DEQ prefers to label it, “Environmental Site Design”(ESD).

6.1. ENVIRONMENTAL SITE DESIGN

How do we describe Environmental Site Design, and how does it differ from “Conventional Design?” Environmental Site Design incorporates non-structural and natural approaches to new development and redevelopment projects to reduce impacts on watersheds by conserving natural areas, reducing impervious cover and better integrating stormwater treatment into the landscape. The aim of environmental site design is to reduce the environmental impact, or “footprint,” of the site while retaining and enhancing the owner/developer’s purpose and vision for the site. Many of the environmental site design concepts employ non-structural on-site treatment that can reduce the cost of infrastructure while maintaining or even increasing the value of the property relative to conventional designed developments.

For the purposes of this chapter, Conventional Design can be viewed as the style of suburban development that has evolved over the past 50 years, which generally involves larger lot development, clearing and grading of significant portions of a site, wider streets and larger cul-de-sacs, large monolithic parking lots, enclosed drainage systems for stormwater conveyance, and large “hole-in-the-ground” detention basins.

It is important to point out that Environmental Site Design (ESD) techniques/practices are *not* the same thing as Low Impact Development (LID) practices, and vice versa, although these strategies overlap and complement one another. The goals of environmental site design are set out in the following section. The goal of LID is to manage the process by which each site responds to hydrologic and hydraulic impacts of development through the use of a specific array of practices.

Environmental site design employs small-scale stormwater management practices, non-structural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources. This includes:

- Optimizing conservation of natural features (e.g., drainage patterns, soil, vegetation, etc.);
- Minimizing impervious surfaces (e.g., pavement, concrete channels, rooftops, etc.);
- Slowing down runoff to maintain discharge timing and to increase infiltration and evapotranspiration on the development site; and
- Using other non-structural practices or innovative technologies approved by DEQ.

Each ESD practice incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. ESD principles and practices are considered at the earliest stages of design, implemented during construction, and sustained in the future as a low-maintenance natural system. Also, it is important to recognize that ESD practices are more appropriately applied to greenfield development, where there is ample space and soil conditions to apply the principles and practices. ESC principles may be difficult to apply at typical redevelopment sites, where space is limited and costly and "urban" (mixed, dense) soils exist.

Environmental site design is intrinsically associated with the concept of sustainability and the emerging *sustainable site design* movement, reflected in the 2009 release of the Sustainable Sites Initiative^{TM} (SSI), an interdisciplinary partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b). For more information on the SSI, including a discussion of its scoring and certification criteria, see **Appendix 6-E** of this chapter.

6.1.1. Environmental Site Design Principles

Environmental Site Design techniques are mostly applied at sites of new development. It is more difficult to achieve ESD at redevelopment sites due to lack of space, compacted soils, and the constructed drainage system and utilities that are already in place. There are several very important principles involved in accomplishing ESD effectively.

6.1.1.1. Achieve Multiple Objectives

Stormwater management should be comprehensive in scope, with management techniques designed to achieve multiple stormwater objectives. These objectives include managing both the peak flow rate and total volume (i.e., balance with the hydrologic cycle of the site), as well as water quality control and water temperature maintenance. Comprehensive stormwater management involves addressing all of these aspects of stormwater.

"Treatment train" configurations with multiple structural techniques may be required in some situations in order to achieve comprehensive objectives. However, the objective in ESD is to try to achieve multiple comprehensive objectives with simpler, rather than more complex, management systems.

6.1.1.2. Integrate Stormwater Management and Design *Early* in the Site Planning and Design Process

In the past, the street and lot layouts of development sites have been decided upon first, often based on criteria that have little or nothing to do with the site's natural features or ecology. Stormwater control measures would then be squeezed into leftover spaces on the site, whether or not they were best suited for this purpose. Tacking stormwater management decisions on at the *end* of the site design process almost invariably leads to less than ideal results.

For comprehensive stormwater management objectives to be optimized, stormwater management must be incorporated into site design from the outset, integrated into the concept/sketch plan phase of development, just as traffic and circulation are integrated at that stage. In fact, the configuration of the natural drainage system and management of runoff generated by the development should carry significant weight in determining the site's use and the site plan configuration. Along with early site mapping and natural resource inventory (see **Figure 6.1** below), site planners need to consider incorporation of ESD techniques and practices into the overall site design process, and not engineer them after the fact.

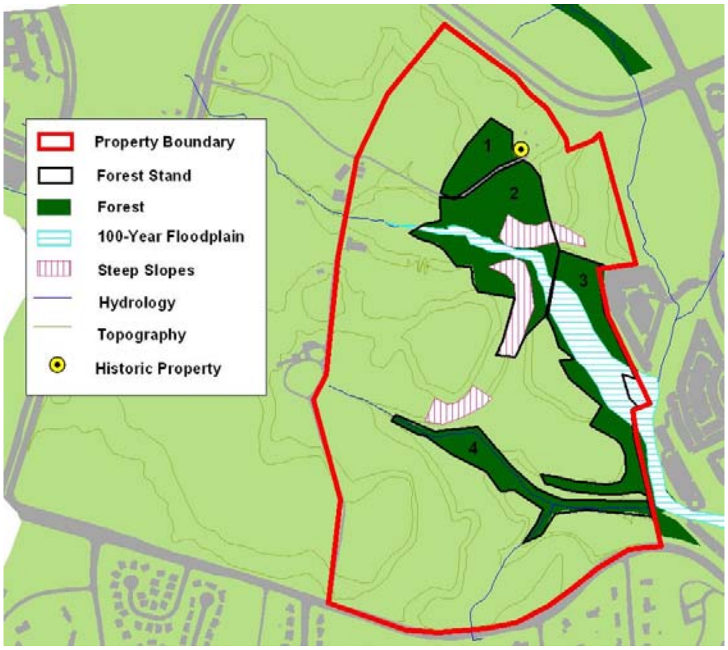


Figure 6.1. Site Natural Resource Inventory Map
Source: Chesapeake Bay Stormwater Training Partnership

6.1.1.3. Prevent Problems to Avoid Having to Mitigate Them

The first objective in stormwater management strategizing is *prevention*. Approaches to site design which can reduce stormwater runoff generation from the outset are the most effective, although such area-wide *planning* decisions are typically not actually thought of as stormwater management per se. For example, effective clustering significantly reduces the length of roads and, thus, the amount of imperviousness, when compared to conventional development. Arrangement of units with minimal setbacks reduces driveway length, thus, the amount of imperviousness. Reduction in street width and other street design considerations further subtract from total impervious cover. Such important elements of site design are rarely thought of as part of conventional stormwater management practices, yet they result in significant stormwater quantity and quality benefits.

6.1.1.4. Conserve Resources and Minimize Land Cover Changes

Minimization of impacts refers to reducing the extent of construction and development practices that adversely impact the hydrologic conditions of the site. This includes limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure. Conserving specific sensitive lands on a site is a crucial early step in the planning process. Obviously, any areas of a site that are conserved will not be converted to impervious cover. The general benefits of conservation can be enhanced by locating and protecting certain hydrologic features such as drainage paths, permeable soils, steep slopes, etc.; and, in accordance with appropriate zoning and subdivision requirements, strategically locating setbacks, easements, woodland conservation zones, buffers, utility corridors, and other permanent site features to enhance the overall goals of maintaining the pre-developed hydrology (LIDWG, 2005).

Fixed improvements such as roads, houses or buildings, sanitary and storm sewer utility corridors, etc., should be located on the site so as to minimize unnecessary grading and/or compaction of the natural soil horizon, clearing of trees, and creating of impervious surfaces (LIDWG, 2005). Specific recommendations include:

- Reducing the size of cleared area (i.e., preserve as much woodland as possible) and reforest areas of the site where feasible.
- Locating cleared/graded areas outside of permeable soils and vegetated areas.
- Minimize the use of turfgrass (which requires more maintenance, fertilizer and pesticides) by establishing more naturalized landscaping with native vegetation
- Designing roads, sidewalks, and parking areas to minimize land cover impacts.

6.1.1.5. Design the Development to Fit the Terrain

Developments that are designed to “fit the terrain” of the site require significantly less grading and soil disturbance than those that are designed without regard for the existing topography. Road patterns should match the landform by placing roadways parallel to contour lines where possible. In doing so, natural drainageways can be constructed along street rights-of-way, thereby reducing the need for storm pipe systems. Open space development, allowable in many municipalities, can help preserve large natural areas and open space as well as make it possible to design around topographical constraints.

6.1.1.6. Apply Decisions that Have the Effect of Maintaining the Natural Site Hydrology

The most common parameter used to account for changes in site condition is the runoff curve number (CN). As the value of the site’s CN increases from the pre-development condition to the post-development condition, temporary storage becomes necessary to mimic the pre-development CN. Site development factors most responsible for the determination of the CN are generally related to the land cover type. Of specific concern is the area of impervious cover as a fraction of the total site area, since it has such a pronounced effect on the hydrologic response of the site. Other factors include the soil infiltration rate and condition of the land cover. Key objectives in mimicking the site’s pre-development hydrology include preserving the site’s runoff rate and patterns, maintaining the pre-development volume, frequency, and duration of runoff, and sustaining groundwater recharge, stream baseflow and stream water quality. Ideally, the post-development drainage patterns and time of concentration (Tc) should closely resemble those of the pre-development condition. The Tc, in conjunction with the CN, determines the peak discharge rate for a storm event. From theoretical considerations, site and infrastructure components that affect time of concentration and travel time include:

- Travel distance (flow path);
- Slope of the ground surface and/or water surface;
- Ground surface roughness; and
- Channel shape and pattern.

These concepts are applied to ESD by using techniques that control the Tc by modifying the following aspects of flow and conveyance within the development:

- Maximize sheet flow;
- Modify/lengthen the flow path;
- Minimize site and lot slopes;
- Disconnect impervious area runoff
- Use open swale drainage; and
- Maximize site and lot vegetation.

6.1.1.7. Manage Stormwater As Close to the Point of Origin (Generation) As Possible; Minimize Collection and Conveyance

From both an environmental and economic perspective, redirecting runoff back into the ground, as close to the point of origin as possible costs less money and maintains natural hydrology. Pipes, culverts, and elaborate systems of inlets to collect and convey stormwater work against management objectives, in most cases increasing the challenges of managing stormwater holistically. Such systems increase flows and increase rates of flow, all making erosive stormwater forces worse. Structural collection and conveyance systems are increasingly expensive, both to construct and maintain. Furthermore, almost without exception, these systems suffer from failures and, therefore, should be avoided if at all possible. A corollary principle is to avoid concentrating stormwater flows, which is achieved when stormwater is not conveyed long distances, but rather recycled into the ground at or near the source.

6.1.1.8. Rely to the maximum on natural processes that occur within the soil and the plant community

The soil offers critical pollutant removal functions through physical processing (filtration), biological processing (various types of microbial action), and chemical processing (cation exchange capacity and other reactions). Plants similarly provide substantial pollutant uptake/removal potential, through physical filtering, biological uptake of nutrients, and even various types of chemical interactions. The final destination of pollutants is important. Pollution is often just a resource out of place – too much of a good thing in the wrong location; elements that are often useful to vegetation and within the soil mantle. Natural processes can work effectively to minimize these types of pollution problems.

Environmental site design is based on a philosophy – a vision for the environment – that is neither pro-development nor anti-development. Environmental site design is grounded on the positive notion that environmental balance can be maintained as new communities are developed throughout our watersheds, if basic principles are obeyed. Environmental site design means understanding our natural systems such as our essential water resources and making the commitment to work within the limits of these systems whenever and wherever possible. As stated above, ESD is grounded on recognition of a principle stated in **Chapter 4**: that stormwater is ultimately a precious resource to be used carefully, rather than a waste product in need of disposal.

6.1.2. Soils and Vegetation Provide Key Natural Processes in Environmental Site Design

Before describing specific aspects of ESD, a quick review is in order regarding the nature and extent of the natural systems and processes that are important to the success of the ESD solutions. Keep in mind that the following information is very much condensed; numerous details have been omitted for the sake of brevity and user friendliness.

6.1.2.1. Soil-Linked Processes for Water Quality/Quantity Management

Soil constitutes an extremely valuable resource, and documenting the complete array of these soil-based processes would require a separate Handbook altogether. Environmental site design, as with other stormwater control measures, relates in important ways to the soil mantle and the manner in which water moves across and through this soil. Understanding how much of what type of soil is in place is essential when assessing stormwater impacts and stormwater management needs. The type of soil existing on a site may turn a management problem into an opportunity. For example, soil type influences how much water can be infiltrated per time period, based on soil permeability. Soil permeability rating, therefore, is a critical variable in ESD. Soil type will also affect pollutant removal potential. Soil erodibility is an important factor as well. Factors such as depth to bedrock and depth to seasonal high water table also have important ramifications for ESD.

Soil surveys, provided by the USDA-NRCS on a county-by-county basis, provide a considerable amount of information relating to all relevant aspects of soils. Soil with a coarse texture (i.e., having large particle size such as sand) has a high rate of infiltration. Soil with extremely small particle size (clayey soil) has a low rate of infiltration. Understanding these soil characteristics is an essential first step in ESD. When dealing with structural practices which rely on infiltration (e.g., infiltration basins and trenches, dry wells, etc.), the Hydrologic Soil Group (HSG) classification and permeability rating is crucial for determining success. Typically a permeability of at least 1/2-inch per hour is required for structural control measures. Because ESD often does not involve the type of soil disturbance and potential compaction problems that can occur with construction of structural controls, somewhat lower permeability – perhaps as low as 1/4-inch per hour – can be tolerated and put to good use. However, when permeability rates are that low, extreme care must be taken with design and construction, because there is little margin for error. Furthermore, it is possible that locating an infiltration BMP on soils with such a low permeability may result in a larger footprint for the practice. So the trade-offs must be considered carefully.

At the same time areas of such poor permeability but with good stands of vegetation may function quite satisfactorily and offer opportunity which should not be ignored at a site (a well-developed root zone associated with established vegetation can significantly improve poor soil infiltration and permeability). For example, an otherwise questionable HSG C soil, if not disturbed and if reasonably well vegetated, may offer surprisingly good opportunity for receiving and infiltrating stormwater created by new impervious surfaces elsewhere on the site. The presence of stems and roots can substantially enhance infiltration and permeability. Conversely, even seemingly good soils (HSG B), if substantially disturbed and compacted, can become far less permeable, as is typical of the yards in many mass-graded residential subdivisions. In such cases permeability ratings should be reduced. However, sandy HSG A soils may be able to withstand disturbance problems more readily than heavier soils with clay content, and therefore may not experience this same kind of loss of permeability.

Although reliance on the published soil data is acceptable for most feasibility studies and conceptual planning, detailed planning should be accompanied by field sampling (using saturated bore holes) and verification of soil types and classes. The size of the site, geologic complexity, and other factors will determine the number of bore holes necessary at each site.

Soils are very important for their ability to remove pollutants entrained in stormwater, through a complex of physical, chemical, and biological mechanisms. Above all, the soil mantle must be understood to be a vast and complex system, a rich and diverse community of organisms – thousands, even millions of organisms per cubic inch – all of which have complex functions which can become the basis of impacts if damaged or destroyed, or become mechanisms for treatment if understood and properly used. The various types of processes which occur as the result of soil microbe action and the other essential elements of the soil community, when fully understood, can be used quite effectively for stormwater management purposes. Soil microflora are abundant and diverse, including innumerable species of bacteria, fungi, actinomycetes, algae, and viruses. These species process organic material (one type of stormwater-linked pollutant) as food and energy sources in various ways. Physically, particulate pollutants are caught and filtered by the soil mantle as well. Many of the soil-based functions which are chemically-oriented (e.g., adsorption, etc.) occur through the mechanisms of cation exchange driven by, among other factors, surface area of soil particles. Such functions are especially important for their ability to remove soluble pollutants such as nutrients. Even in large particle sandy soils where surface area is low (72 sq cm per gram), significant pollutant reduction can occur through these chemical mechanisms. Cation exchange capacity (CEC) is used as a measure of pollutant reduction potential and can be determine through soil testing.

Pollutant removal potential often varies indirectly with permeability. For example, soils that are extremely sandy (large particle size, fewer particles) can be expected to have excellent permeability but borderline CEC values. In fact extremely sandy soils may have such low CEC values that they are typically not as effective in removing either soluble or particulate pollutants from stormwater. In no way should “hot spot” runoff from roads, gasoline stations, auto repair centers or fast food parking lots be cycled through sandy infiltration systems without being pretreated through some sort of filtering mechanism. Conversely, heavy clayey soils may have limited permeability, yet typically do an excellent job of removing a wide variety of pollutants due to their high CEC ratings.

6.1.2.2. Vegetation-Based Processes for Water Quality and Quantity Management

Vegetation provides a host of useful functions which are vital to effective environmental site design. These functions typically reflect the close connection between water quantity and water quality issues:

- Vegetation absorbs the energy of falling rain, promoting infiltration, minimizing erosion, etc.
- Roots hold soil particles in place, like structural steel in reinforced concrete, preventing erosion.

- Vegetation (blades, stems, trunks, etc.) provides friction that slows runoff velocity and filters out particulate pollutants; as the velocity slows, not only is the erosive force reduced, but sediment already entrapped will begin to settle out, as will other pollutants. Reduced velocity also means increased opportunity for infiltration.
- Vegetation provides for a richer organic soil layer which improves soil porosity and structure, maximizing the absorptive capacity of the soil and promoting infiltration.
- Vegetation "consumes" many different types of stormwater-linked pollutants through absorption from the root zone. In addition to the positive effects on sediment and sediment-bound phosphorus, even solubilized nitrogen is taken up through a series of complex processes and transformations, as are some metals and other compounds.

6.2. STORMWATER MANAGEMENT THROUGH ENVIRONMENTAL SITE DESIGN

In the context of stormwater management, the goal of environmental site design should be to promote runoff control through the use of the natural drainage system and to reduce the environmental impacts of commonly used land development and drainage methods. In addition to maintaining natural drainage, ESD should (1) provide a natural open-space based drainage system using undeveloped flood plains and drainage swales; (2) avoid channelization within the natural drainage system; and (3) maintain forest cover and other natural vegetation to the extent feasible. These practices will result in maintenance or enhancement of the normal water table level.

By maintaining or restoring the natural drainage system, runoff from even a 100-year storm should be managed with minimal problems. Runoff generated by higher frequency storms (e.g., 5-10 year storms) should be handled on the individual sites. At the site scale, runoff can be managed in various ways, including (1) capturing it for reuse on the site; (2) directing it to primary and secondary swales where vegetation will retard flow and allow water to infiltrate permeable soils; (3) holding it on identified recharge areas; and (4) directing it into detention and retention facilities, as necessary.

Development projects can be designed to reduce their impact on watersheds when careful efforts are made to conserve natural areas, reduce impervious cover and better integrate stormwater treatment. By implementing a combination of these nonstructural ESD approaches, it is possible to reduce the amount of runoff and pollutants that are generated from a site and provide for some nonstructural on-site treatment and control of runoff. The volume of stormwater runoff and the mass of pollutant loads can be reduced as much as 20-60 percent on most development sites (even up to 100 percent on some sites) simply by implementing the land development principles and practices advocated in this chapter. When applied early in the site design and layout process, environmental site design techniques can sharply reduce stormwater runoff and pollutants generated at a development site, and also reduce the size and cost of both the stormwater conveyance system and stormwater management practices. Important stormwater management objectives include:

- Preventing soil erosion and increases in nonpoint pollution from development projects;
- Preventing stormwater impacts rather than having to mitigate them;
  - Minimizing the extent of land disturbance and impervious surfaces;

  - Minimizing pollutants in stormwater runoff from new development and redevelopment;
  - Restoring, enhancing, and maintaining the chemical, physical, and biological integrity of receiving waters to protect public health and enhance domestic, municipal, recreational, industrial and other uses of water;
  - Aiming to maintain 100% of the average annual pre-development groundwater recharge volume;
  - Capturing and treating stormwater runoff to remove pollutants;
  - Implementing a channel protection strategy to protect receiving streams;
  - Preventing increases in the frequency and magnitude of out-of-bank flooding from large, less frequent storms;
  - Protecting public safety through the proper design, construction and operation of stormwater management facilities;
- Managing stormwater (quantity and quality) as close to the point of origin as possible and minimizing the use of large or regional-scale collection and conveyance facilities;
- Preserving natural areas and native vegetation and reducing the impact on watershed hydrology;
- Using simple, nonstructural methods for stormwater management that are lower in cost and have lower maintenance needs than structural controls;
- Creating a multifunctional landscape; and
- Using natural drainage pathways (the site’s hydrology) as a framework for site design.

6.3. THE BENEFITS OF ENVIRONMENTAL SITE DESIGN

Many Virginia communities are currently struggling with the issue of balancing economic growth with protection of their natural resources and water quality. As stated earlier, the rise in impervious cover associated with new development affects local water resources by reducing the infiltration of rainfall and increasing the volumes of stormwater runoff that eventually enter local water bodies. The application of environmental design principles can help developers and local governments recognize increased economic and environmental benefits through reduced infrastructure requirements, decreased need for clearing and grading of sites, and less expenditure to meet stormwater management requirements due to reduced runoff volumes and pollutant export from sites.

There is a common misconception that ESD and LID are more expensive to implement than conventional stormwater management techniques. This derives from the fact that the conventional method of costing stormwater facilities (in the same manner as ponds or centralized facilities) is no longer valid. Environmental site design and LID cause us to rethink how we place value and calculate the cost-benefit of environmental protection.

Communities are asking different costing questions, such as what happens at the end of a 50-year cycle for a pond, or how long can we expand or protect our stormwater infrastructure capacity using grey and green techniques. For example, ten years ago vegetated roofs were thought to be cost-prohibitive to use here in the United States. Yet, as of this writing, at least several North American cities (e.g., Toronto, Chicago, Portland) have built over a hundred vegetated roofs each, while several European cities have already place vegetated roofs on about 15 percent of all buildings. The performance-based technology market-driven approach used by ESD and LID has helped to drive the costs down to the point where they can compete with conventional stormwater management technologies. In many cases, these approaches are proving to have less net cost than conventional stormwater controls. For example, see the document entitled *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices*, published by the U.S. Environmental Protection Agency, available at www.epa.gov/nps/lid .

There is also a common misconception that ESD and LID practices are difficult to maintain. In reality, if you look at performance record of runoff reduction practices (e.g., bioretention cells, permeable pavement, and vegetated roofs) where they haven't been adequately maintained, they still have a high level of pollutant removal and runoff reduction efficiency. This is important in an era when routine inspection and maintenance is often not performed. Furthermore, ESD and LID practices constitute a distributed management approach, inherently building redundancy into the system. Therefore, if some of the systems perform less than optimally, fail, or are not maintained, redundant decentralized practices at the site prevent the effect from being catastrophic, as with dam breaches or system overloads.

Several researchers have employed redesign comparisons to demonstrate the benefits of environmental site design over a wide range of residential lot sizes and commercial applications. For example, Center for Watershed Protection (CWP, 1998b) demonstrated that ESD techniques could reduce impervious cover and stormwater runoff by 7 to 70 percent, depending on site conditions. **Figure 6.2** below illustrates a redesign analysis for a medium density residential subdivision. The analysis suggested that ESD techniques could reduce impervious cover and annual runoff volume by 24%, cut phosphorus loadings by half, and increase site infiltration by 55%, compared to a traditional subdivision.

In another analysis (CWP, 2003), the CWP evaluated the application of environmental design techniques to development projects in several Virginia localities. The following are examples of the economic benefits that can be gained through encouraging the use of environmental design techniques:

- For a 45-acre medium density residential site in Stafford County, Virginia, using environmental site design techniques would have saved $300,547 compared to a more conventional design, due to reduced infrastructure and stormwater costs (CWP, 1998b).
- Studies have found that construction savings can be as much as 66 percent by using the open space designs encouraged in environmental site design techniques (CWP, 1998a).
- Environmental site design can also reduce the need to clear and grade 35-60 percent of the total site area. Since the total cost to clear, grade, and install erosion and sediment control practices can range up to $5,000 per acre, reduced clearing can result in significant cost savings to builders (Schueler, 1995).
- A summary of 40 years of fiscal impact studies showed that smart growth consumes 45 percent less land, costs 25 percent less for roads, 15 percent less for utilities, 5 percent less for housing, and 2 percent less for other fiscal impacts than current trends of sprawl development (Burchell and Listokin, 1995).
- A 1990 study for the City of Virginia Beach compared the costs and benefits of conventional and smart growth development patterns. The study found that the smart growth pattern resulted in 45 percent more land preserved, 45 percent less in infrastructure costs to the city,

and a 50 percent reduction in impervious surfaces due to roads (Siemon, Larsen and Purdy, et al., 1990)

Figure 6.2. Comparative Analysis of Stonehill Estates in the Pre-development Condition (top), the Conventional Design (middle), and the Open-Space Design (bottom)
Source: Center for Watershed Protection (1998)

To illustrate the economic advantages of environmental site design, **Table 6.1** provides a short summary of the environmental cost benefits realized for four development projects in Virginia that have applied a number of Model Development Principles advocated by the Center for Watershed Protection (CWP, 2000b).

Table 6.1. Benefits of Environmental Site Design vs. Convention Development: 4 Virginia Studies

Case Study	Percent of Natural Areas Conserved	Percent Reduction in Impervious Cover	Percent Reduction in Stormwater Impacts			Percent Reduction in Total Infrastructure Cost
			Runoff	N Load	P Load	
Fields at Cold Harbor Hanover County, VA	80.4	25.3	12.2	6.4	6.4	47.2
Governor's Land James City County, VA	49.3	21.7	14.3	17.5	17.3	14.5
Rivergate Alexandria, VA	0*	32	30	25	28	49
The Arboretum III Chesterfield County, VA	5.1	12	19.7	36	37.1	Not calculated
* Open space area is maintained as landscaped parkland						

Source: CWP (2000b) and the James River Association

The assessment of Model Development Principle application in Virginia found that for the three residential case studies, the use of environmental site design could save up to 49 percent in total infrastructure costs, compared to conventional development (CWP, 2000b). Estimated total infrastructure costs include the costs of roads, gutters, sidewalks, landscaping, and stormwater control practices. In all these cases, the designs incorporating environmental site design saved the developers more than $200,000 in infrastructure costs, while producing the same number of housing units.

In addition, other more intangible economic benefits that may be derived from the use of environmental site design techniques are not included in the case studies. Environmental site design techniques continue to provide benefits to the community beyond improving water quality and stormwater runoff management that extend long after the developer has sold the lots. Some examples of these benefits include:

- Reduced operation and maintenance costs for roads and stormwater system
- Increased property values for homes and businesses
- Increased open space available for recreation
- More pedestrian friendly neighborhoods
- Reduced annual cost for mowing
- Protection of sensitive forests, wetlands, and habitats
- More aesthetically pleasing and naturally attractive landscapes
- Improved air quality (more forest cover)
- Less temperature fluctuation from paved surfaces
- Reduced heating and cooling costs for homeowners from tree preservation

- Decreases in flooding incidence and associated damage
- Improved pollutant removal from the filtering action of forest and stream buffer areas.

For a more detailed summary, consult *The Economic Benefits of Protecting Virginia's Streams, Lakes, and Wetlands,"* prepared by the Center for Watershed Protection. Studies have found that developments that permanently protect open space are often more desirable to live in, and consequently have higher property values (CWP, 1998a). **Table 6.2** illustrates the cost savings for both local governments and developers associated with using environmental site design, most of which are related to infrastructure, maintenance, and stormwater-related costs.

Table 6.2. Percent Savings Due to Compact Growth Patterns (1992 – 1997)

Area of Impact	Lexington, KY and Delaware Estuary	Michigan	South Carolina	New Jersey
Infrastructure Roads	14.8 – 19.7	12.4	12	26
Utilities	6.7 – 8.2	13.7	13	8
Developable Land Preservation	20.5 – 24.2	15.5	15	6
Agricultural Land Preservation	18 – 29	17.4	18	39

(Source: Burchell et al., 1998)

In summary, each environmental site design technique provides environmental and economic benefits to both the developer and the community at large. When techniques are applied together at a development site, they can result in tangible savings for the developer in the form of:

- Reduced construction (e.g., clearing and grading) costs;
- Reduced infrastructure costs (e.g., paving and piping)
- Smaller and less costly structural stormwater BMPs
- Faster sales and lease rates
- Easier compliance with wetland and other resource protection regulations
- More land available for building since fewer structural BMPs are needed
- Credits toward LEED^{TM} certifications.

Cost savings really start to add up when many ESD techniques are applied together. Research indicates that infrastructure savings alone can range from 5-65%, depending on site conditions, lot size and the extent that ESD techniques are applied (Cappiella et al, 2005; CWP, 1998b; Liptan and Brown, 1996; Dreher and Price, 1994; and Maurer, 1996). **Table 6.3** below compares the economic and environmental benefits that can be expected for individual environmental site design techniques.

*Table 6.3. Comparison of Benefits of Environmental Site Design Techniques**

Environmental Site Design Technique	Minimizes Land Disturbance	Preserves Vegetation & Habitat	Lowers Capital Costs	Lowers O&M ** Costs	Raises Property Value
Preserve Undisturbed Natural Areas	○	○	○	○	◖
Preserve Riparian Buffers	○	○	○	○	◖
Preserve and Plant Trees	◖	○	●	○	○
Avoid Floodplains	○	○	○	○	◖
Avoid Steep Slopes	○	○	○	○	◖
Fit Design to the Terrain	○	◖	○	○	○
Locate Development in Less Sensitive Areas	◖	◖	○	○	◖
Reduce Limits of Clearing and Grading	○	○	○	◖	◖
Use Open Space Development	○	○	○	○	◖
Consider Creative Development Design	○	○	◖	◖	◖
Reduce Roadway Lengths and Widths	○	◖	○	○	◖
Reduce Building Footprints	◖	◖	○	○	◖
Reduce the Parking Footprint	◖	◖	○	○	◖
Reduce Setbacks and Frontages	◖	◖	◖	◖	◖
Use Fewer or Alternative Cul-de-Sacs	◖	◖	○	○	◖
Create Parking Lot Stormwater Islands	◖	◖	◖	◖	◖
Use Buffers and Undisturbed Areas (for SWM)	○	○	○	○	◖
Use Natural Drainageways Versus Storm Sewers	◖	◖	○	◖	◖
Use Vegetated Swales Versus Curb & Gutter	◖	◖	○	◖	◖
Drain Runoff to Pervious Areas	◖	◖	○	○	◖
Infiltrate Site Runoff or Capture It for Reuse	◖	◖	○	◖	◖
Stream Daylighting for Redevelopment Projects	●	○	◖	◖	◖

Key: ○ = Often provides indicated benefit
◖ = Sometimes provides a modest benefit
● = Does not provide benefit

* Comparison is intended for general purposes and will vary on a site-by-site basis
** O&M = Operation and Maintenance

Source: Adapted from MPCA (2006)

6.4. ENVIRONMENTAL SITE DESIGN PROCESS

As noted in **Section 6.1.1.2**, site design should be done ***in unison with*** the design and layout of stormwater infrastructure in attaining stormwater management and land use goals. Key concepts in ESD parallel requirements of state and federal wetland permitting programs, as follows:

- ***Avoid*** the Impacts – Use environmental site design techniques to preserve natural features and fit the site design to the natural terrain and natural features (see **Figure 6.3** below)
- ***Minimize*** (or *reduce*) the Impacts – Reduce mass grading and impervious cover.
- ***Mitigate*** (or *manage*) the Impacts – Use natural features and Environmental Site Design techniques to manage stormwater

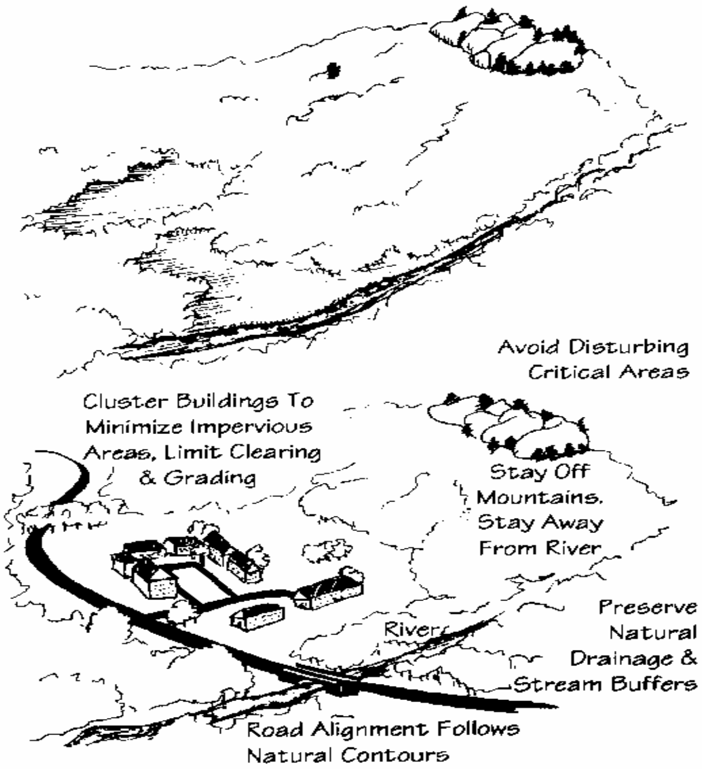


Figure 6.3. Fit the Site Design to the Natural Terrain and Natural Features
Source: CNMI and Guam Stormwater Management Manual (2006)

Once sensitive resource areas and site constraints have been avoided, the next step is to minimize the impact of land alteration by reducing mass grading and the amount of impervious surfaces. Finally, for the areas that must be impervious, choose alternative and "natural-systems" stormwater management techniques as opposed to the more conventional structural ("pipe-to-pond") approach. The goal is to disconnect runoff from impervious surfaces and promote filtration, infiltration and on-site use that mimics the pre-development hydrologic regime of the site and minimizes harmful impacts on the streams that receive runoff discharge from the site.

The aim is to reduce the environmental "footprint" of the site while retaining and enhancing the owner/developer's purpose and vision for the site. Many of the ESD concepts can reduce the cost of infrastructure while maintaining or even increasing the value of the property, especially when incorporated early into the site design. For example, **Figure 6.4** below is a map representing a natural resource inventory of a 15-acre development site. **Figure 6.5** below is a more traditional plan layout for this site, with 25 lots, each exceeding ½-acre in area. A more traditional subdivision street design is used, with curb-and-gutter configuration draining into underground storm sewers. Minimal stream buffers and natural areas have been preserved. Much of the original vegetation from the site would have to be removed during the grading process. Using the Virginia Runoff Reduction Method Spreadsheet to calculate water quality treatment requirements for this site, we would calculate a required runoff "Treatment Volume" of 18,100 cubic feet. This is the volume of runoff that would have to be captured by BMPs and treated to remove the necessary amount of pollutants in order to comply with the water quality requirements in the Virginia SWM Regulations.

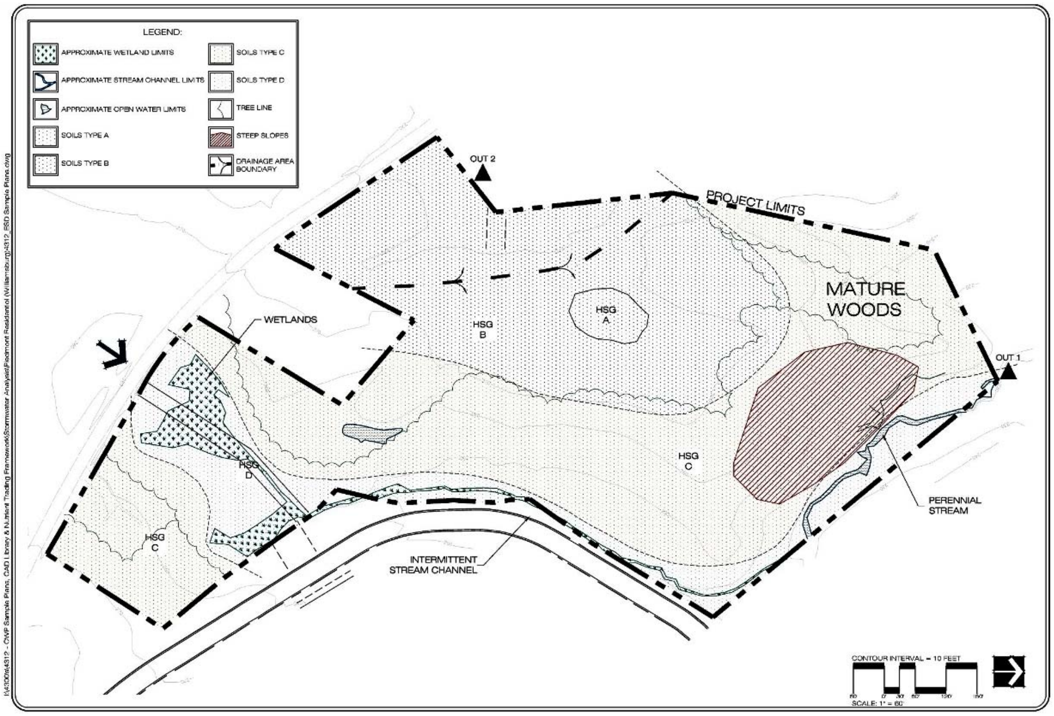
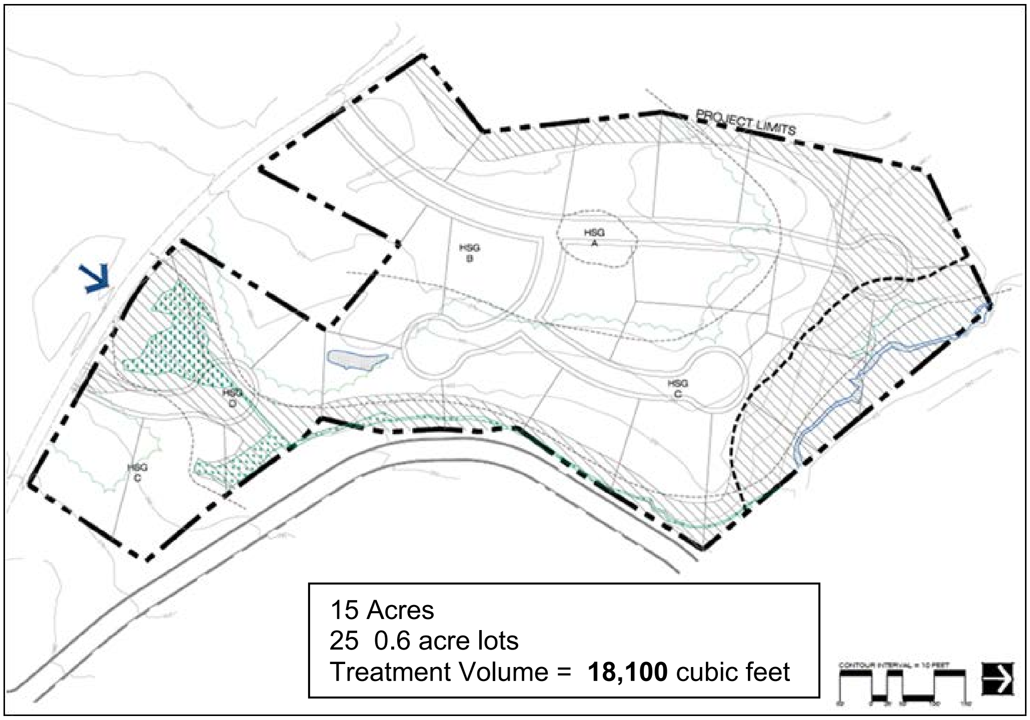


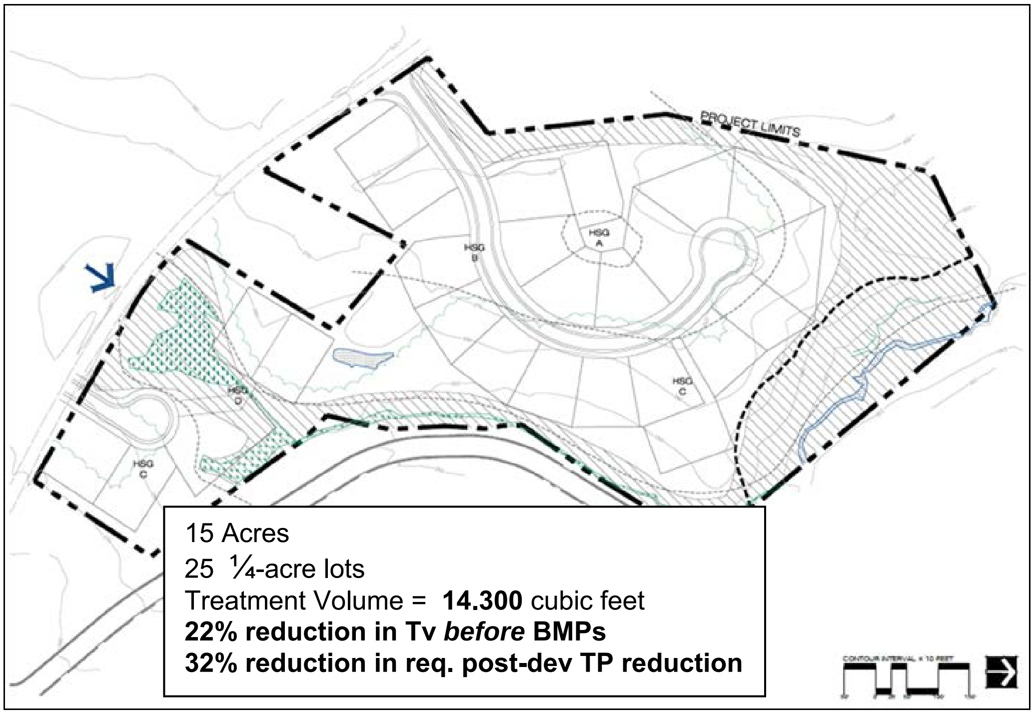
Figure 6.4. Natural Resource Inventory Site Map
Source: Center for Watershed Protection



15 Acres
25 0.6 acre lots
Treatment Volume = **18,100** cubic feet

Figure 6.5. Traditional Site Plan
Source: Center for Watershed Protection

By contrast, **Figure 6.6** reflects the application ESD techniques. Smaller ¼-acre lots are clustered in a tighter configuration on the site. The streets are narrower and shorter, minimizing impervious cover, and the streets drain to surface swales that allow for runoff filtering and infiltration. More of the site's original vegetation is conserved as buffers or other open space, which also reduces the amount of stormwater runoff. When we apply the Spreadsheet to this alternative design, we calculate a runoff Treatment Volume of only 14,300 cubic feet. **That is a 25% reduction in the amount of runoff that must be treated and a smaller pollutant reduction requirement (due to less pollutants being generated in runoff from the site), achieved simply by applying Environmental Site Design techniques alone, *before* any stormwater management BMPs have been chosen and applied to the site.**



15 Acres
25 ¼-acre lots
Treatment Volume = **14.300** cubic feet
22% reduction in Tv *before* BMPs
32% reduction in req. post-dev TP reduction

Figure 6.6. Contrasting Environmental Site Design for the Same Site
Source: Center for Watershed Protection

Reduction of adverse stormwater runoff impacts through the use of Environmental Site Design should be the first consideration of the design engineer. Operationally, economically, and aesthetically, the use of Environmental Site Design techniques offers significant benefits over treating and controlling runoff downstream. Therefore, all opportunities for using these methods should be explored and all viable options exhausted before considering the use of structural stormwater controls.

The use of Environmental Site Design typically results in a reduction of the required runoff peak flows and volumes that need to be conveyed and controlled on a site and, therefore, the size and cost of necessary drainage infrastructure and structural stormwater controls. In some cases, the use of Environmental Site Design practices may eliminate the need for structural controls entirely. Hence, Environmental Site Design concepts can be viewed as both a water quantity and water quality management tool.

6.4.1. Environmental Site Design Site Planning Checklist

The following checklist (**Table 6.4** below) is provided to help site designers ensure that they do *not* overlook any opportunities to integrate ESD into their site plans. The list includes 12 criteria that cover the main concepts addressed by ESD. Ideally, a designer should be able to answer "Yes" or "Does Not Apply" (N/A) to every criterion. If a designer answers "No" to any of the criteria, he should give careful consideration to the reasons why the criteria cannot be applied to the site.

Table 6.4. Environmental Site Design Checklist Example

Check All of the Following ESD Practices That Were Implemented On-Site	Yes	No	N/A
Environmental mapping was conducted at the site prior to layout	X		
Natural areas were conserved (e.g., forests, wetlands, steep slopes, floodplains)	X		
Stream, wetland and shoreline buffers were reserved			X
Disturbance of permeable soils was minimized	X		
Natural flow paths were maintained across the site	X		
The building layout was footprinted to reduce clearing and grading at the site	X		
Site grading promotes sheetflow from impervious areas to pervious areas	X		
Site design was evaluated to reduce creation of unnecessary impervious cover	X		
Site design was evaluated to maximize the disconnection of impervious cover	X		
Site design was evaluated to identify potential hotspot generating areas for stormwater treatment	X		
Erosion and sediment control practices and post-construction stormwater management practices were integrated into a comprehensive site plan	X		
Tree planting was used at the site to convert turf areas into forest	X		

Source: Chesapeake Bay Stormwater Training Partnership

6.4.2. List of Stormwater Environmental Site Design Techniques and Practices

The stormwater-related ESD practices and techniques covered in this Handbook are grouped into four categories and are listed below:

A. Conserving of Natural Features and Resources

1. Preserve Undisturbed Natural Areas
2. Preserve Riparian Buffers
3. Preserve or Plant Trees
4. Avoid Floodplains
5. Avoid Steep Slopes

B. Using Lower Impact Site Design Techniques

6. Fit Design to the Terrain
7. Locate Development in Less Sensitive Areas
8. Reduce Limits of Clearing and Grading
9. Utilize Open Space Development
10. Consider Creative Development Design

C. Reducing Impervious Cover in Site Design

11. Reduce Roadway Lengths and Widths
12. Reduce Building Footprints
13. Reduce the Parking Footprint
14. Reduce Setbacks and Frontages
15. Use Fewer or Alternative Cul-de-Sacs
16. Create Parking Lot Stormwater "Islands"

D. Using Natural Features and Runoff Volume Reduction for Stormwater Management

17. Use Buffers and Undisturbed Filter Areas
18. Use Creative Site Grading, Berming and Terraforming
19. Use Natural Drainageways and Vegetated Swales, Not Storm Sewers/Curb & Gutter
20. Drain Rooftop Runoff to Pervious Areas
21. Infiltrate Site Runoff or Capture It for Reuse
22. Stream Daylighting for Redevelopment Projects

More detail on each site design practice is provided in the Environmental Site Design Practice Summaries in the next section of this chapter. These summaries provide the key benefits of each practice, examples and details on how to apply them in site design.

6.4.3. Using Stormwater Environmental Site Design Practices

Site design should be done in unison with the design and layout of stormwater infrastructure in attaining stormwater management goals. The following bullets describe the stormwater-related ESD process that use the four ESD categories:

- Identify existing natural features and resources and delineate site conservation areas
- Design the site layout to preserve conservation areas and minimize stormwater impacts
- Use various techniques to reduce impervious cover in the site design
- Use natural features and conservation areas to manage stormwater quantity and quality

The first step in stormwater-related ESD involves identifying significant natural features and resources on a site such as undisturbed forest areas, stream buffers and steep slopes that should be preserved to retain some of the original hydrologic function of the site.

Next, the site layout is designed such that these conservation areas are preserved and the impact of the development is minimized. A number of techniques can then be used to reduce the overall imperviousness of the development site.

Finally, natural features and conservation areas can be utilized to serve stormwater quantity and quality management purposes.

6.5. ENVIRONMENTAL SITE DESIGN TECHNIQUES AND PRACTICES

6.5.1. Conserving Natural Features and Resources

Conservation of natural features is integral to environmental site design. Natural areas generate the least amount of stormwater runoff and pollutant loads and establish and maintain the desired pre-development hydrology for the site. The first step in the ESD process is to identify and preserve the natural features and resources that can be used in the protection of water resources by reducing stormwater runoff, providing runoff storage, reducing flooding, preventing soil erosion, promoting infiltration, and removing stormwater pollutants. Next, designers modify the layout of the development project to take advantage of natural features, preserve the most sensitive areas, and mitigate any stormwater impacts. Open space design is one of the most effective environmental site design techniques for preserving natural areas at residential sites without losing developable lots. Some of the natural features that should be taken into account include the following:

- Perennial streams
- Intermittent and ephemeral streams
- Zero order streams
- Springs and seeps
- Aquifer recharge areas
- Riparian stream buffers
- Wetlands/tidal marshes
- Wetland buffers
- Floodplains
- Existing drainage areas and drainage divides
- Forest stands
- Other significant vegetative cover
- Ridge tops and steep slopes
- Sinkholes, caves and other karst features
- Highly erodible soils
- Highly permeable soils
- Shallow bedrock
- High water tables
- Other critical areas

Delineation of natural features is typically done through a comprehensive site analysis and inventory before any site layout design is performed. From this site analysis, a concept plan for a site can be prepared that provides for the conservation and protection of natural features. **Figures 6.7 and 6.8** below show how to use GIS map layers to delineate natural features on a parcel's base map and, from that information, develop a composite site resource map.

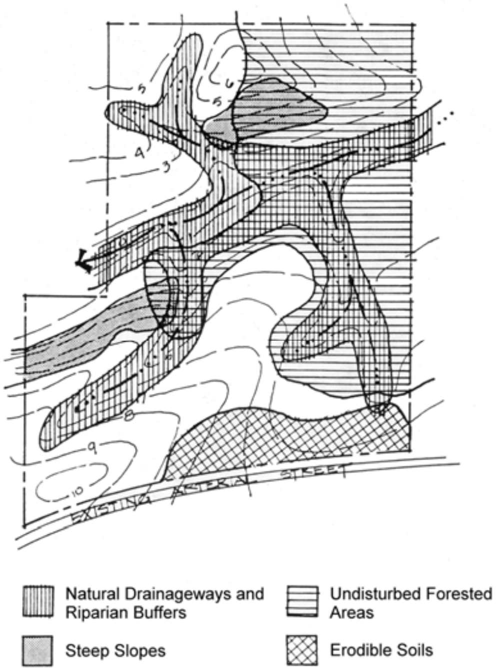


Figure 6.7. Map Delineating Natural Feature on a Site
Source: MPCA (1989)

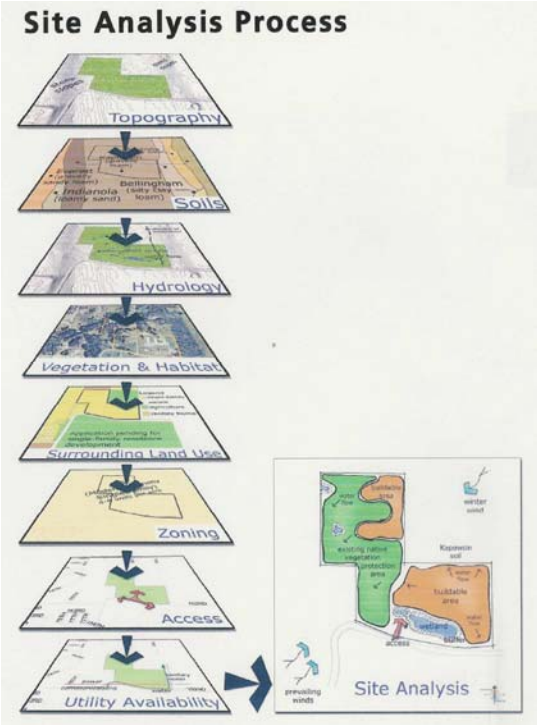


Figure 6.8. A Composite Map Developed from GIS Map Layers
Source: Puget Sound LID Technical Manual (2005)

6.5.1.1. Environmental Site Design Practice #1: Preserve Undisturbed Natural Areas

KEY BENEFITS	USING THIS PRACTICE
• Conserving undisturbed natural areas helps to preserve a portion of the site's natural predevelopment hydrology • Can be used as nonstructural stormwater filtering and infiltration zones • Helps to preserve the site's natural character and aesthetic features • May increase the value of the developed property	• Delineate natural areas before performing site layout and design • Ensure that conservation areas and native vegetation are protected in an *undisturbed state* throughout construction and occupancy

Figure 6.9. A Subdivision with Conserved Natural Areas

Clearing and grading of native vegetation should be limited to the minimum needed to (1) build on lots, (2) allow access, and (3) provide fire protection. Important natural features and areas such as undisturbed forested and vegetated areas, natural drainageways, stream corridors, wetlands and other important site features should be delineated and placed into conservation areas. A suggested limit of disturbance (LOD) is 5 to 10 feet out from building pads (**Figure 6.10** below).

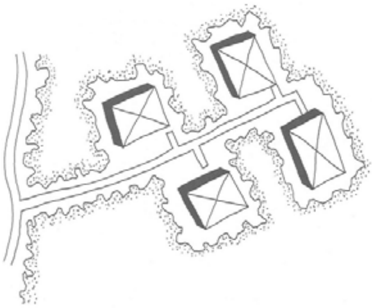


Figure 6.10. Site Footprinting
Source: Center for Watershed Protection

Preserving such areas on a development site helps to preserve the original hydrology of the site and aids in reducing the generation of stormwater runoff and pollutants. Undisturbed vegetated areas also promote soil stabilization and provide for filtering, infiltration and evapotranspiration of runoff.

Natural conservation areas are typically identified through a site analysis using maps and aerial/satellite photography, or by conducting a site visit. These areas should be delineated before any site design, clearing or construction begins. When done before the concept plan phase, the planned conservation areas can be used to guide the layout of the site. **Figure 6.11** shows a site map with undisturbed natural areas delineated.

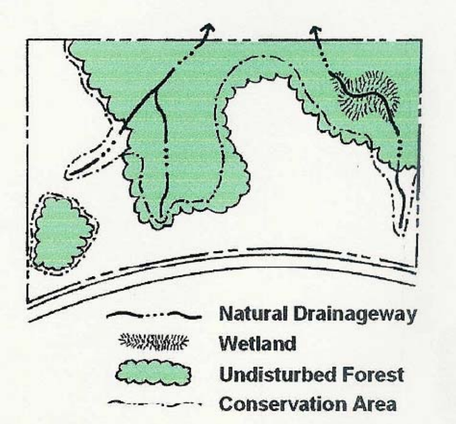


Figure 6.11. Delineation of Natural Conservation Areas
Source: ARC (2006)

Conservation areas should be incorporated into site plans and clearly marked on all construction and grading plans to ensure that equipment is kept out of these areas and that native vegetation is not undisturbed. The boundaries of each conservation area should be mapped to illustrate the limit which should not be crossed by construction activity. Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements. Buildings and roads should be located *around* the natural topography and drainage to avoid unnecessary land disturbance.

The undisturbed soils and vegetation of natural areas promote infiltration, runoff filtering and direct uptake of pollutants. Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground. Vegetation also pumps soil water back into the atmosphere which increases storage available in the soil. Native vegetation also prevents erosion by stabilizing soil, filtering sediment and pollutants from runoff, and absorbing nutrients from the soil and groundwater.

Wetlands provide many benefits to society, including habitat for fish and wildlife, natural water quality improvement, flood storage, shoreline erosion protection, and opportunities for recreation and aesthetic appreciation. Wetlands are among the most productive and biodiverse ecosystems in the world – comparable to rain forests and coral reefs (EPA, 2007c). Estuaries and their coastal marshes are important nursery areas for the young of many game (recreational) and commercial fish and shellfish.

Wetlands help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water. Furthermore, a large part of recreational bird-watching – an outdoor recreational activity that is growing in popularity even faster than biking, walking, skiing or golf – is associated with wetlands and aquatic habitats, in large part because many birds are wetland-dependent.

Preserving areas where threatened or endangered species exist is also a wise decision and is typically required by law. As frustrating as this may seem to landowners and developers, there are good scientific reasons to preserve the habitat of these species. Species extinctions can disrupt the interactions and feedback mechanisms of natural ecosystems that have developed over time to be relatively stable and resistant to pests and diseases. Stable natural ecosystems control more than 95 percent of the potential crop pests and carriers of human diseases (Erlich, 1985).

Invasive species compete with and harm plant and animal communities and disrupt natural ecosystems. Some 5,000 plant species have escaped into natural ecosystems, resulting in millions of dollars in control costs (Pimentel et al., 2005). Invasive species on the site should be identified when the development site is initially assessed. Then, as the development area is being cleared, effort could be made to remove any invasive species present. Such actions could help to methodically reduce or remove invasive species from an area or region.

A point that is often not considered during the planning of a development project and the preservation of natural open space on the development site is reducing the risk of catastrophic wildfire. Designing defensible space around structures protects property from wildfire damage by reducing flame heights and making fires easier to extinguish (Firewise Communities). When fuel loads exceed historical conditions, high intensity fires are more likely to occur, causing significant ecological damage (see SAFC). Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives.

Where vegetation must be established on the site, choose to restore appropriate plants and plant communities that are native to the ecoregion of the site, to contribute to regional diversity of flora and provide appropriate habitat for native wildlife. Native plants provide habitat for native wildlife, including important pollinator species (e.g., insects, birds and bats) that are necessary for plant reproduction, including cultivation of nearby crops. Up to 80 percent of the world’s food plant species are dependent on pollination by animals (Buchman and Nabhan, 1996). Wildlife habitat also supports recreational and educational opportunities.

As discussed in **Section 6.4.3** above, there are many environmental and economic reasons to establish native trees rather than lawn areas that require more intensive management, especially in open space to be conserved on the site. Not the least of these reasons is minimizing the application of chemical fertilizers and pesticides needed to maintain the desired appearance health and appearance of turfgrass.

Preserving natural areas creates many economic benefits including decreased heating and cooling costs, higher property values and improved habitat (Cappiella, 2005). To approach full ecological function, it is recommended that natural grassland areas should be five acres or larger and a forested areas should be in the range of 20-40 acres. However, smaller areas will still yield water quality and other environmental benefits. When there is not enough conserved area on the development site to meet these thresholds, the designer should attempt to connect on-site conservation areas with similar areas off-site.

Leadership in Energy and Environmental Design (LEED®) and the Sustainable Sites Initiative (SSI). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. The SSI point credit system was designed by the American Society of Landscape Architects (ASLA) and the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b). **Appendix 6-D** of this Chapter provides a more thorough discussion of the site planning process and design considerations as related to SSI credits. It is anticipated that SSI credits may eventually be blended into LEED credits. However, DEQ is not affiliated with any of the creators of LEED or SSI, and any information on applicable points suggested here is based only on perceived compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through LEED or SSI resources.**

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.3: Preserve wetlands	0 (Prerequisite)
1.4: Preserve threatened and endangered species	0 (Prerequisite)
4.1: Control and manage known invasive plants found on the site	0 (Prerequisite)
4.8: Preserve plant communities native to the ecoregion	2 - 6
4.9: Restore plant communities native to the ecoregion	1 - 5
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.2. Environmental Site Design Practice #2: Preserve Riparian Buffers

KEY BENEFITS	USING THIS PRACTICE
• Riparian buffers can be used as nonstructural stormwater filtering and infiltration zones • Keeps structures out of the floodplain and provides a right-of-way for large flood events • Helps to preserve riparian ecosystems and habitats	• Delineate and preserve naturally vegetated riparian buffers • Ensure that buffers and native vegetation are protected throughout construction and occupancy • Consult the local plan review authority for applicable buffer requirements and minimum or recommended widths
This practice reflects the CWP Better Site Design Principles #17 (Buffer Systems) and #18 (Buffer System Management)	

Naturally vegetated riparian buffers should be delineated and preserved or restored along the shorelines of all perennial streams, rivers, lakes, and wetlands. The primary function of buffers is to protect and physically separate a stream, lake or wetland from future disturbance or encroachment. Given the importance of riparian forests in the ecology of headwater streams, characteristics such as width, target vegetation and allowable uses within the buffer should be managed to ensure that the goals designated for the buffer are achieved.

Buffers are not merely setbacks, but vegetated systems managed to protect targeted soil and water resources. If properly designed, a buffer can stabilize soils, provide stormwater management functions, provide a right-of-way during floods, and sustain the integrity of stream ecosystems, wildlife corridors and habitats. An example of a riparian stream buffer is shown in **Figure 6.12**. Improved water quality resulting from riparian buffers can increase property values of waterside properties by up to 15 percent (Braden and Johnston, 2004). Riparian forest buffers should be maintained, and reforestation with native species should be encouraged where no wooded buffer exists. Proper restoration should include not just trees all layers of the forest plant community, including understory, shrubs and groundcover,. A riparian buffer can be of fixed or variable width, but should be continuous and not interrupted by impervious areas that allow stormwater to concentrate and flow into the stream without first flowing through the buffer.

Figure 6.12. Riparian Stream Buffer
Source: Center for Watershed Protection

Ideally, riparian buffers should be sized to include the 100-year floodplain as well as steep banks and freshwater wetlands. For proper performance, buffer depth will depend on the size of the stream and the surrounding conditions; but a minimum 25-35 foot undisturbed vegetative buffer is needed for even the smallest perennial streams and a 50-foot or larger undisturbed buffer is ideal. Even with a 25-35 foot undisturbed buffer, additional zones can be added to extend the total buffer to at least 100 feet from the edge of the stream (100 feet in Chesapeake Bay Preservation Areas). The three distinct zones are shown in **Figure 6.13** below.

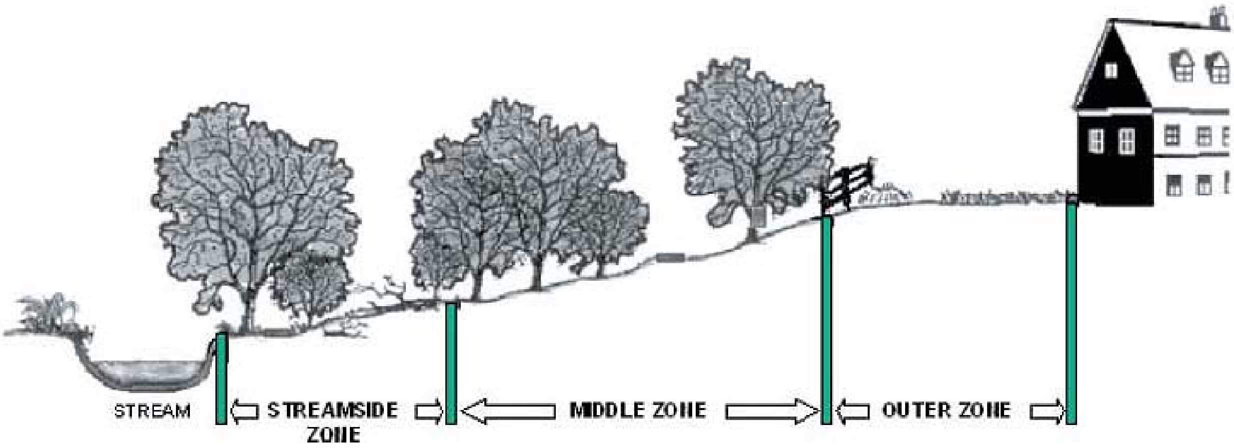


Figure 6.13. Three-Zone Stream Buffer System
Source: CWP (1998a)

The buffer is often viewed as simply a line drawn on a map that is virtually invisible to contractors and landowners. In order to increase awareness of the buffer and the need for its protection, the boundaries should be marked with appropriate signage. Local governments may provide such signage. Some localities also implement buffer awareness programs and literature for their citizens.

To optimize stormwater treatment, the outer boundary of the buffer should have a stormwater depression area and a grass filter strip. Runoff captured within the stormwater depression is spread across a grass filter designed for sheet flow conditions, and discharges to a wider forest or shrub buffer in the middle or streamside zones that can fully infiltrate and/or further treat storm flow. The function, vegetative target and allowable uses vary by zone as described in **Table 6.5**.

Table 6.5. Riparian Buffer Management Zones

Criteria	Streamside Zone	Middle Zone	Outer Zone
Width	Minimum 25 feet plus wetlands and critical habitat (35 feet is better for both forest and wildlife habitat); protect the physical integrity of the stream ecosystem.	Variable, depending on stream order, slope, and extent of 100-year floodplain (min. 25 feet, but generally 50-75 feet); provides a buffer between upland development and the streamside zone.	25-foot minimum setback from structures; prevent encroachment and filter backyard runoff.
Vegetative Cover	Undisturbed mature forest. Reforest, if grass.	Managed forest, with some clearing allowed.	Forest encouraged, but usually turfgrass.
Allowable Uses	**Very Restricted** e.g., flood control, utility easements, rights-of-way, footpaths, limited water access, trimming for sight lines.	**Restricted** e.g., some passive recreational uses, some stormwater controls, pedestrian and bike paths, tree removal by permit.	**Unrestricted** e.g., residential uses including lawn, garden, compost, yard wastes, and most stormwater controls.

Source: MPCA (2006)

These recommendations are minimum criteria that should apply to most streams. Some streams and watersheds may require additional measures to achieve protection. In some areas, specific laws and regulations (e.g., the Chesapeake Bay Preservation Act) or local ordinances (e.g., drinking water reservoir protection) may require stricter buffers than are described here. The buffer widths discussed herein are not intended to modify or supersede deeper or more restrictive buffer requirements that are already in place.

As stated above, the streamside or inner zone should consist of a minimum of 25-35 feet of undisturbed mature forest. In addition to runoff protection, this zone provides bank stabilization as well as shading and protection for the stream. This zone should also include wetlands and any critical habitats, and its width should be adjusted accordingly. The middle zone provides a transition between upland development and the inner zone and should consist of managed woodland that allows for infiltration and filtration of runoff. An outer zone allows more clearing and acts as a further setback from impervious surfaces. It also functions to prevent encroachment and filter runoff. It is here that flow into the buffer should be transformed from concentrated flow into sheet flow to maximize ground contact with the runoff. Level spreaders can be used to accomplish this.

When establishing or enhancing riparian buffers on a development site, it is important to manage the buffer in a way that reduces the risk of catastrophic wildfire. Increasingly, development is occurring near wildland environments where wildfire is a major element of the native plant community. Development is expanding into the wildland/urban interface where structures are located next to large areas of natural vegetation. Designing defensible space around structures protects property from wildfire damage. Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives

A Fire Hazard Rating System and National Wildland/Urban Interface Fire Protection Program has been established, which provides recommendations for target vegetation around structures. **Table 6.6** below presents a rating system for estimating the hazard potential of developing in a wildland/urban interface area. If a community has a high potential risk for wildfire, then it makes sense to consider the vegetation management techniques that are described in **Table 6.7** below. The most common technique is to clear or reduce vegetation that is within 70 feet of structures.

Development within the riparian buffer should be limited only to those structures and facilities that are absolutely necessary. Such limited development should be specifically identified in any codes or ordinances enabling the buffers. When construction activities do occur within the riparian corridor, specific mitigation measures should be required, such as deeper buffers or riparian buffer improvements.

Generally, the riparian buffer should remain in its natural state. However, some maintenance is periodically necessary, such as preventing concentrated flows, removing exotic plant species when these species are detrimental to the vegetated buffer, and removing diseased or damaged trees.

Table 6.6. Sample of Fire Hazard Rating System in the Wildland/Urban Inteface (adapted from the National Wildland/Urban Interface Fire Protection Program) [1]

Hazard Rating Category	Description of Hazard	Point Range	
I. Fuel Hazard Rating [2]	Low, medium or high hazard fuels (grasses, mixed hardwoods, evergreen timber)	Grasses	1 pt
		Woodland (open understory)	2-3 pts
		Woodland (heavy brush)	4 pts
		Large evergreen timber	5 pts
II. Slope Hazard Rating [2]	Mile, moderate, steep, to extreme slopes	Mild slopes (< 5%)	1 pt
		Moderate slopes (6-15%)	2 pts
		Steep slopes (16-25%)	3 pts
		Extreme slopes (> 25%)	4 pts
III. Structure Hazard Rating	Roof and siding material combustibility	Non-combustible roof & siding	1 pt
		Non-comb. roof, comb. siding	3 pts
		Comb. roof, non-comb. siding	7 pts
		Comb. roof & siding	10 pts
IV. Safety Zone Rating [2]	Number of homes that do not have a safety zone of at least 30 feet	30% of homes	3 pts
		31-60% of homes	6 pts
		61-100% of homes	10 pts
V. Means of Access for Emergency Vehicles [3]	Number of access points or width of access	Only one access point	3 pts
		Width for one-way traffic only	3 pts
		Road grades > 15%	2 pts
		Turn-around inadequate	3 pts
		Bridge width limits emrg. equip.	3 pts
VI. Additional Factor Rating [3]	Other items that contribute to hazard potential	Most road names not marked	2 pts
		Subdiv. Entrance not marked	2 pts
		Individual home #s not marked	2 pts
		Power lines not buried	2 pts
		Lack of mun. water sources	2 pts
		Area lacks static water sources	2 pts
		Long distance from fire dept.	2 pts
		Ease of plowing for fire line	1-5 pts

Total Hazard Rating: (0-19 = Low Risk; 20-39 = Medium Risk; 40-60 = High Risk

[1] Total hazard rating is the sum of all points awarded

[2] For Hazard Rating Categories I – IV, assign points based on the one criterion that best describes the existing site conditions.

[3] For Hazard Rating Categories V and VI, points are awarded for all criteria that apply.

Table 6.7. Recommendations for Target Vegetation Around Structures in Medium- to High-Wildfire Areas (adapted from the National Wildland/Urban Interface Fire Protection Program)

Zone	Distance from Combustible Structure	Target Vegetation
A	Primary setback zone – 20 feet	All natural vegetation cleared; plant only low level, fire-resistant vegetation (lawn, low-level ground covers; examples include: lily-of-the-valley, periwinkle, bearberry, lilac)
B	Wet zone – 70 feet	Most natural vegetation removed; area irrigated during dry conditions; planted with low-level, fire-resistant vegetation
C	Thinning zone – 120 feet	Remove all dead/dying vegetation and up to 50% of live natural vegetation (target the most flammable, large foliage, shaggy bark, plants that develop dry or dead undergrowth, etc., for removal)
D	Thinning zone – 150 feet	Remove all dead/dying vegetation and up to 30% of live natural vegetation

Buffers can provide many different ecosystem services and economic benefits, including:

- Reduced small drainage problems and complaints
- Reduced risk of flood damage
- Reduced stream bank erosion
- Enhanced pollutant removal
- Location for greenways and trails
- Sustained integrity of stream ecosystems and habitat
- Protection of wetlands associated with the stream corridor
- Prevention of disturbance of steep slopes
- Mitigation of stream warming
- Protection of important stream corridor habitat for wildlife
- Increased adjacent property values. Some examples of positive market influence include the following:
    - When managed as a "greenway," stream buffers can increase the value of adjacent parcels, as illustrated by several studies. Pannypack Park in Philadelphia is credited with a 33 percent increase to the value of nearby property. A net increase of more than $3.3 million in real estate is attributed to the park (CBF, 1996). Another greenway in Boulder, Colorado was found to have increased aggregate property values by $5.4 million, resulting in $500,000 of additional tax revenue per year (Fausold and Lilieholm, 1996).
    - Homes situated near seven California stream restoration projects had a 3-13 percent higher property value than similar homes located on unrestored streams (Streiner and Loomis, 1996). Most of the perceived value of the restored stream was due to the enhanced buffer, habitat, and recreation afforded by the restoration.
    - Housing prices were found to be 32 percent higher if they were located next to a greenbelt buffer in Colorado (Correll et al., 1978). Nationally, buffers were thought to have a positive or neutral impact on adjacent property in 32 out of 39 communities surveyed (Schueler, 1995).
    - Effective shoreline buffers can increase the value of urban lake property. A recent study in Maine found that water clarity was directly related to property values. Specifically, a measurable improvement in water clarity (visibility depth increased by 3 feet) resulted in $11 to $200 more per foot of shoreline property, potentially generating millions of dollars in increased value per lake (Michael et al., 1996).

The following actions help to minimize the risk of buffer encroachment and damage:

- Make sure buffers appear on site plans and are clearly labeled.
- Make sure buffers also appear on separate clearing and grading plans.
- Identify buffers and discuss buffer protection measures during the pre-construction meeting.
- Make sure construction inspectors assure that buffer integrity is not violated.
- Disclose the presence and location of buffers, with notes regarding limitations of use, on recorded plat maps.
- Implement a local buffer awareness program for citizens.
- Mark buffer boundaries with appropriate signage.

For additional guidance pertaining to planting vegetation in riparian buffer areas, see DEQ's guidance document entitled *Riparian Buffer Modification and Mitigation Guidance Manual*, available at the following website:

http://www.deq.virginia.gov/Programs/Water/LawsRegulationsGuidance/Guidance/StormwaterManagementGuidance.aspx

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.3: Protect and restore riparian, wetland, and shoreline buffers	3 - 8
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.3. Environmental Site Design Practice #3: Preserve or Plant Native Trees

KEY BENEFITS	USING THIS PRACTICE
• Reduce stormwater runoff • Increase nutrient uptake • Stabilize streambanks • Provide shading and cooling • Provide pleasing aesthetic values • Provide or enhance wildlife habitat • Better resist disease and harsh conditions	• Perform an inventory of the existing forest and identify trees to protect. • Design the development with conservation of native vegetation in mind. • Protect designated trees during and after construction. • Plant additional trees and native vegetation at the development site.
This practice reflects the CWP Better Site Design Principle #20 (Tree Conservation)	

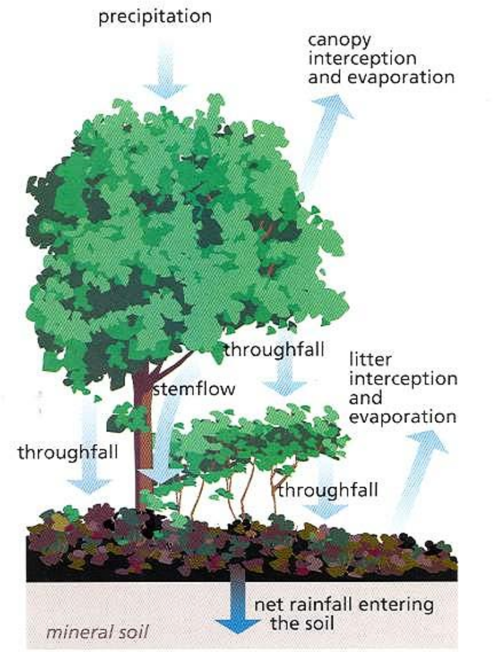


Figure 6.14. The Benefits of Tree Canopy for Stormwater Management

Native trees, shrubs and grasses are important contributors to the overall quality and viability of the environment. One of the most cost-effective ESD practices is to conserve or plant trees and shrubs at new development or redevelopment sites, clustering tree areas and promoting the use of native plants (see contrast in **Figures 6.15 and 6.16** below). Wherever feasible, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote natural vegetation. This reduces stormwater runoff, reduces nutrient pollution (see **Figure 6.17** below), provides streambank stabilization, provides shading and cooling, and provides wildlife habitat (Cappiella, 2005). Forest soils actively promote greater infiltration rates due to surface organic matter and macro-pores created by tree roots. Forests intercept rainfall in their canopy, reducing the amount of rain that reaches the ground and increasing potential water storage in forest environments.

Figure 6.15. Subdivision with Tree Preservation.
Source: Center for Watershed Protection

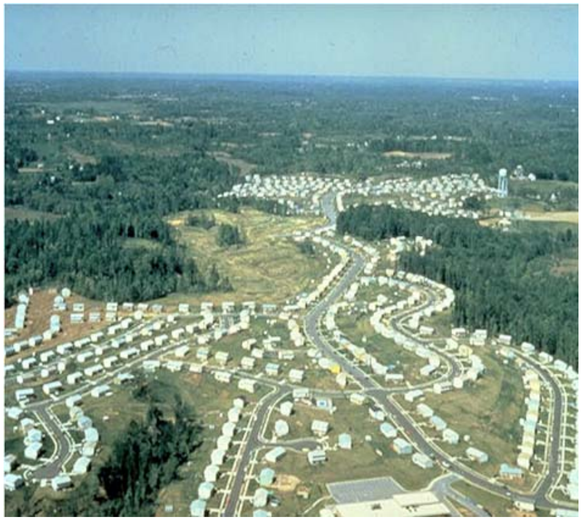


Figure 6.16. Subdivision Cleared and Grubbed from Property Line to Property Line
Source: Center for Watershed Protection

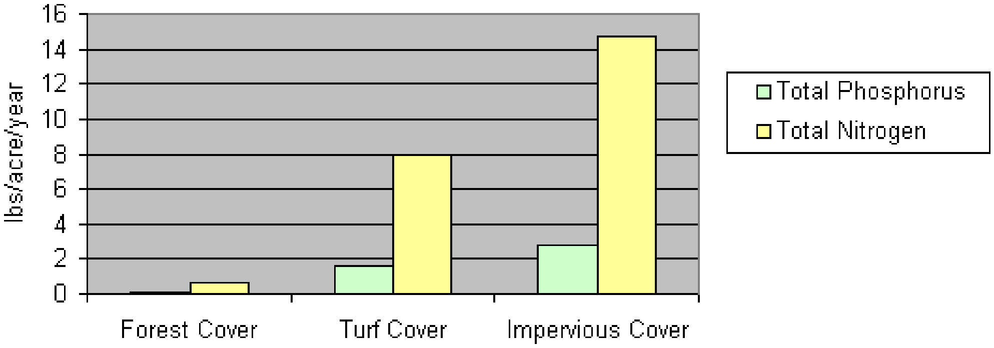


Figure 6.17. Comparison of Annual Nutrient Loads from Different Land Covers
Source: Chesapeake Bay Stormwater Training Partnership

Existing trees can be protected or new ones provided and used for applications such as landscaping, stormwater management practice areas, conservation areas, and erosion and sediment control. Where protection of existing trees and forest cover is desired, the developer should perform an inventory of existing trees and forest cover on the site as part of the site evaluation. Care should be taken to identify and preserve the highest quality forest stands prior to development. Specific mature tree/native vegetation targets can be established at the pre-development stage, based on reference sites and historic records. A professional arborist or forester can provide reliable advice regarding the health of trees and recommendations about what trees to preserve. Priority should be given to protecting or establishing hydrologically-connected tree clusters. In particular, trees within locally designated Resource Protection Areas

(RPAs) in localities subject to the Chesapeake Bay Preservation Act or elsewhere adjacent to streams are prime candidates for preservation (see the preceding Practice #2, *Preserving Riparian Buffers*).

As discussed in **Appendix 6-D** of this chapter, there are many environmental and economic reasons to establish trees instead of extensive lawn areas that require more intensive management, especially in open space to be conserved on the site. Having less lawn would result in less application of chemical fertilizers, pesticides and irrigation water, which are needed to maintain the desired health and appearance of turfgrass and which represent significant routine expenditures. Native species are generally preferable, requiring less attention and maintenance over time because their characteristics are attuned to the climatic zone of the site. The following are additional examples of the economic benefits of conserving or restoring tree and forest cover through the development process:

- A 1993 survey of members of the National Association of Homebuilders indicated that over 69 percent of the respondents described themselves as increasing the number of trees on their properties and were either thinking of or committed to continuing the practice (Andreason and Tyson, 1993).
- Two regional economic surveys documented that conserving forests on residential and commercial sites enhanced property values by an average of 6-15 percent and increased the rate at which units were sold or leased (Morales, 1980, and Weyerhauser, 1989).
- It has been conservatively estimated that over $1.5 billion per year is generated in tax revenue for communities in the U.S. due to the value of privately-owned trees on residential property (USDA, as cited by the National Arbor Day Foundation, 1996).
- Single family homes in Athens, Georgia, with an average of five trees in the front yard, sold for 3.5-4.5 percent more than houses without trees (National Arbor Day Foundation, 1996).
- A study of 14 variables that might influence the price of suburban homes in Manchester, Connecticut and Greece, New York found that trees ranked sixth in influencing the selling price. Trees on the property increased sale prices by 5-15 percent (National Arbor Day Foundation, 1996).
- Another study found that large old street trees (**Figure 6.18** below) were the most important indicator of community attractiveness (Coder, 1996). This community attractiveness is important due to its positive impact on property value. This same study stated that a $242 savings per home per year in cooling costs could be achieved when trees are present.
- In Austin, Texas, tree canopy was estimated to reduce stormwater flows by up to 28%, saving the city $122 million (MacDonald, 1996).
- In Atlanta, Georgia, officials estimate that the significant loss of trees and other vegetation over 25 years had resulted in a 6-9 degree elevation in temperature, increasing energy consumption for cooling, and a 4.4 billion cubic foot increase in stormwater runoff; officials estimated that at least $2 billion would be required to build containment facilities capable of storing the excess stormwater runoff (MacDonald, 1996, and American Forests, as cited in U.S. Water News, 1997)
- The Center for Watershed Protection has estimates of the long-term costs of maintaining different kinds of open-spaces in the urban landscape (**Table 6.8** below), showing that maintaining natural open space areas is by far the least expensive type of open space.

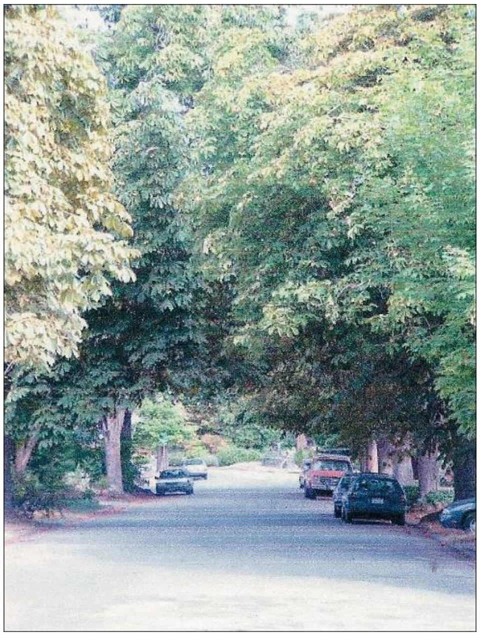


Figure 6-18. Street Trees in Seattle
Source: Puget Sound LID Technical Manual

Table 6.8. The Comparative Costs of Open Space Maintenance

Open Space Mgmt Strategy	Annual Maintenance Cost
Natural Open Space (only maintenance is trash/debris cleanup	$75/acre
Lawns (regular mowing)	$240 - $270/acre
Passive Recreation (trails, bike paths, etc.)	$200/acre

Source: CWP

Trees are ideal for all projects (see **Figure 6.19** below), including those where space is limited, in which trees can be placed along street frontages and in common space. Urban areas with higher numbers of trees exhibit hydrology more similar to natural conditions compared to urban areas without a tree canopy. Trees intercept storm water and retain a significant volume of the captured water on their leaves and branches, allowing for evaporation and providing runoff reduction benefits. For example, a large oak tree can intercept and retain more than 500 to 1,000 gallons of rainfall in a given year (Capiella, 2005). Since forest cover results in a lower runoff coefficient, areas of the development site under forest cover actually receive credit for runoff reduction in the Virginia Runoff Reduction Method Spreadsheet calculations. This is an additional incentive to conserve and restore forest cover on sites, since less total runoff means lower costs to manage the runoff.

Figure 6.19. Potential Tree Planting Areas at a Development Site
Source: MPCA (2006)

While the most effective interceptor trees are large canopied evergreen trees, deciduous trees can also provide a benefit. For example, a leafless Bradford Pear will retain more than one-half the amount of precipitation intercepted by an evergreen cork oak (Xiao et al., 2000b). The shade provided by trees keeps the ground under the trees cooler, thereby reducing the amount of heat gained in runoff that flows over the surface under the trees. This attenuation of heat in stormwater helps control increases in local stream temperatures. The presence of strategically located tree canopies also typically results in lower heating and cooling costs for adjacent buildings. Furthermore, on slopes, tree roots hold soil in place and prevent erosion.

The length of the slope of land draining toward tree cover should not exceed 150 feet from pervious areas and 75 feet from impervious areas. The gradient of land draining toward tree cover should not exceed 6 to 8 percent, depending upon the type of ground cover, unless a level spreader is used to convert runoff to sheet flow prior to entering the forested area (see Virginia Stormwater Design Specification No. 2, "Sheet Flow to a Vegetated Filter Strip or Conserved Open Space" – http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html). Ideally, forested areas should have multiple layers of vegetation, including herbaceous vegetation on the ground surface and a layer of native shrubs as understory vegetation (**Figure 6.20** below).

When establishing or enhancing riparian buffers on a development site, it is important to manage the buffer in a way that reduces the risk of catastrophic wildfire. Designing defensible space around structures protects property from wildfire damage. Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives. A Fire Hazard Rating System and National Wildland/Urban Interface Fire Protection Program has been established, which provides recommendations for target vegetation around structures. More specific guidance about this can be found in **Tables 6.6 and 6.7** in **Section 6.5.1.2** (the previous practice – #2, *Preserve Riparian Buffers*).

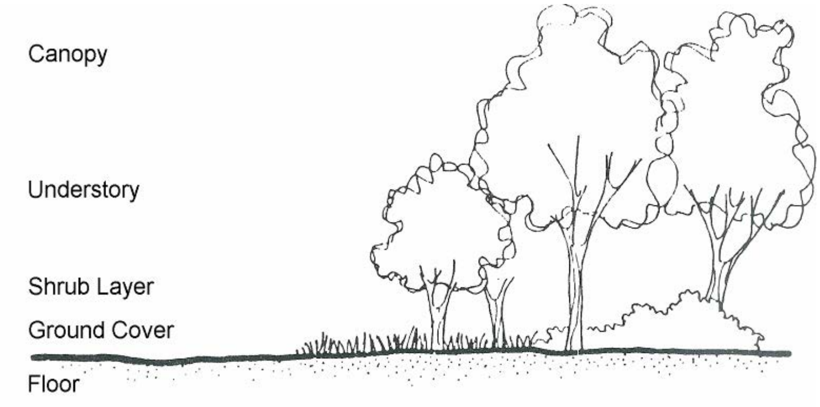


Figure 6.20. Preserve or Establish Multiple Layers of Vegetation
Source: Day and Crafton (1978)

It is important to note that existing trees that are being preserved on the development site must be protected from the impacts of the construction process. Protective measures may include the use of signs, geotextile web fencing, or visible flagging (**Figure 6.21** below).The critical root zone(s) (CRZ) must be delineated (**Figure 6.22**) and protective barriers erected to prevent equipment from moving over and compacting the soils over the CRZs (**Figure 6.23**). Furthermore, construction materials should not be stored over CRZs, because the weight of the stored materials can also result in compacted soils (see **Figure 6.24** below).

Figure 6.21. Tree Protection Sign
Source: Adapted from State of Maryland

Figure 6.22. Compacted Soil
Source: Center for Watershed Protection

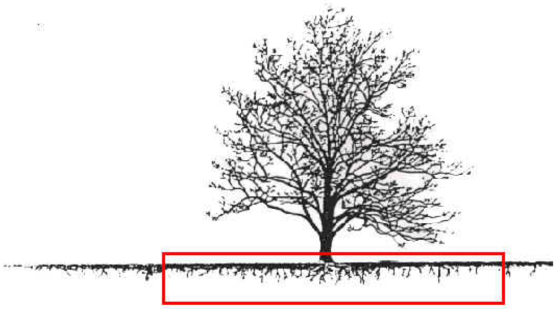


Figure 6.23. Most of a Tree's Roots Exist in the Top 1-Foot of Soil Depth and Extend Well Beyond the Canopy Drip Line
Source: City of Broomfield, Colorado

Figure 6.24. Construction Materials Stored Within Critical Root Zones of Trees Being Preserved
Source: Center for Watershed Protection

Site reforestation involves planting trees on existing turf or barren ground at a development site with the goal of establishing a mature tree canopy that can intercept rainfall, maximize infiltration and increase evapotranspiration. Trees can also be planted in stormwater management practices (e.g., bioretention areas, constructed wetlands, etc.) and in sidewalk planting pits. Whatever the target area, once the sites are selected, they should be evaluated for soil quality and other pertinent features, and the planting sites should be improved as needed (e.g., soil amendments). Tree planting sites and tree species should be chosen to fit the purpose of the development project and to withstand the constraints of an urban setting (see **Figure 6.25** below). Typically, inexpensive saplings are planted, coupled with quick establishment of an appropriate native ground cover around the trees so as to stabilize the soil and prevent influx of invasive plants. Turfgrass should be kept at least 24 inches from tree trunks.

Figure 6.25. (a – upper left): residential trees; (b – upper right): street trees; (c – center left): trees at a commercial site; (d – center right): trees at a parking lot; (e – lower left): parking lot trees at a commercial office building; (f – lower right): trees, bioretention, and conserved open space around and within a parking lot. Source: Sacramento (2007)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.2: Use appropriate, non-invasive plants	0 (Prerequisite)
4.7: Use native plants	1 - 4
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.4. Environmental Site Design Practice #4: Avoid Floodplains

KEY BENEFITS	USING THIS PRACTICE
• Preserving floodplains provides a natural right-of-way and temporary storage for large floods Keeps people and structures out of harm's way • Helps to preserve riparian ecosystems and habitats • Can be combined with riparian buffer protection to create linear greenways	• Obtain maps of the 100-year floodplain from the local review authority • Ensure that all development activities do not encroach on the designated floodplain areas

Floodplains are the low-lying flat lands that border streams and rivers. Floodplain areas should be avoided for homes and other structures to minimize risk to human life and property damage, and to allow the natural stream corridor to accommodate flood flows. When a stream reaches its capacity and overflows its channel after storm events, the floodplain provides for storage and conveyance of these excess flows. In their natural state they reduce flood velocities and peak flow rates by the passage of flows through dense vegetation.

Floodplains play an important role in reducing sedimentation and filtering runoff, recharging groundwater, and providing travel corridors and habitat for both aquatic and terrestrial life. They can also provide an urban oasis for human health, recreation and well-being. Development in floodplain areas can reduce the ability of the floodplain to convey stormwater, potentially causing safety problems or significant damage to the site in question, as well as to both upstream and downstream properties. Most communities regulate the use of floodplain areas to minimize the risk to human life as well as to avoid flood damage to structures and property.

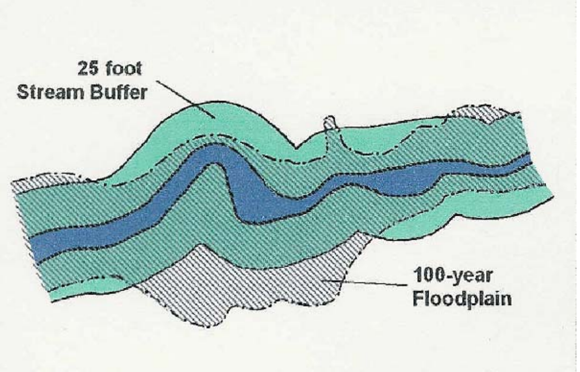


Figure 6.26. Floodplain Boundaries in Relation to a Riparian Buffer
Source: Georgia Stormwater Management Manual (2006)

Ideally, the entire 100-year full-buildout floodplain should be avoided for clearing or building activities, and should be preserved in a natural undisturbed state. Floodplain protection is complementary to riparian buffer preservation. Both of these ESD techniques preserve stream corridors in a natural state and allow for the protection of vegetation and habitat. Depending on the site topography, the boundaries of the100-year floodplain may lie inside or outside of a preserved riparian buffer corridor, as shown in **Figure 6.26**.

Maps of the 100-year floodplain can typically be obtained through the local review authority. Developers and builders should also ensure that their site design comply will any other relevant local floodplain and FEMA requirements.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.2: Protect floodplain functions	0 (Prerequisite)

6.5.1.5. Environmental Site Design Practice #5: Avoid Steep Slopes

KEY BENEFITS	USING THIS PRACTICE
• Preserving steep slopes helps to prevent soil erosion and degradation of stormwater runoff • Steep slopes can be kept in an undisturbed natural condition to help stabilize hillsides and soils • Building on flatter areas will reduce the need for cut-and-fill and grading	• Avoid development on steep slope areas, especially those with a grade of 15% or greater • Minimize grading and flattening of hills and ridges

Steep slopes should be avoided due to the potential for soil erosion and increased sediment loading. Excessive grading and flattening of hills and ridges should be minimized. Developing on steep slope areas has the potential to cause excessive soil erosion and stormwater runoff during and after construction. Past studies by the SCS (now NRCS) and others have shown that soil erosion is significantly increased on slopes of 15 percent or greater. In addition, the nature of steep slopes means that greater areas of soil and land area are disturbed to locate facilities on them compared to flatter slopes, as demonstrated in **Figure 6.27**.

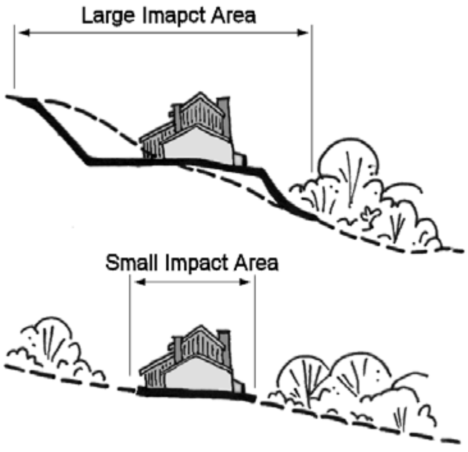


Figure 6.27. Flattening Steep Slopes for Building Sites Uses More Land Area Than Building on Flatter Slopes
Source: Georgia Stormwater Management Manual (2006)

Therefore, development on slopes with a grade of 15% or greater should be avoided if possible to limit soil loss, erosion, excessive stormwater runoff, and the degradation of surface water. Excessive grading should be avoided on all slopes, as should the flattening of hills and ridges. Steep slopes should be kept in an undisturbed natural condition to help stabilize hillsides and soils.

On slopes greater than 25%, no development, regrading, or stripping of vegetation should be considered unless the disturbance is for roadway crossings or utility construction and it can be demonstrated that the roadway or utility improvements are absolutely necessary in the sloped area.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6

6.5.2. Using Low Impact Site Design Techniques

After a site analysis has been performed and conservation areas have been delineated, there are numerous opportunities in the site design and layout phase to reduce both water quantity and quality impacts of stormwater runoff. These primarily deal with the location and configuration of impervious surfaces or structures on the site and include the following practices and techniques covered over the next several pages:

- Fit the Design to the Terrain
- Locate Development in Less Sensitive Areas
- Reduce Limits of Clearing and Grading
- Utilize Open Space Development
- Consider Creative Development Design

The goal of lower impact site design techniques is to lay out the elements of the development project in such a way that the site design (i.e. placement of buildings, parking, streets and driveways, lawns, undisturbed vegetation, buffers, etc.) is optimized for effective stormwater management. That is, the site design takes advantage of the site's natural features, including those placed in conservation areas, as well as any site constraints and opportunities (topography, soils, natural vegetation, floodplains, shallow bedrock, high water table, etc.) to prevent both on-site and downstream stormwater impacts. **Figure 6.28** shows a development that has utilized several lower impact site design techniques. **Figures 6.29 through 6.31** show other aspects of low-impact development. Stormwater management practices that contain runoff volume on-site for reuse or infiltration are emphasized.

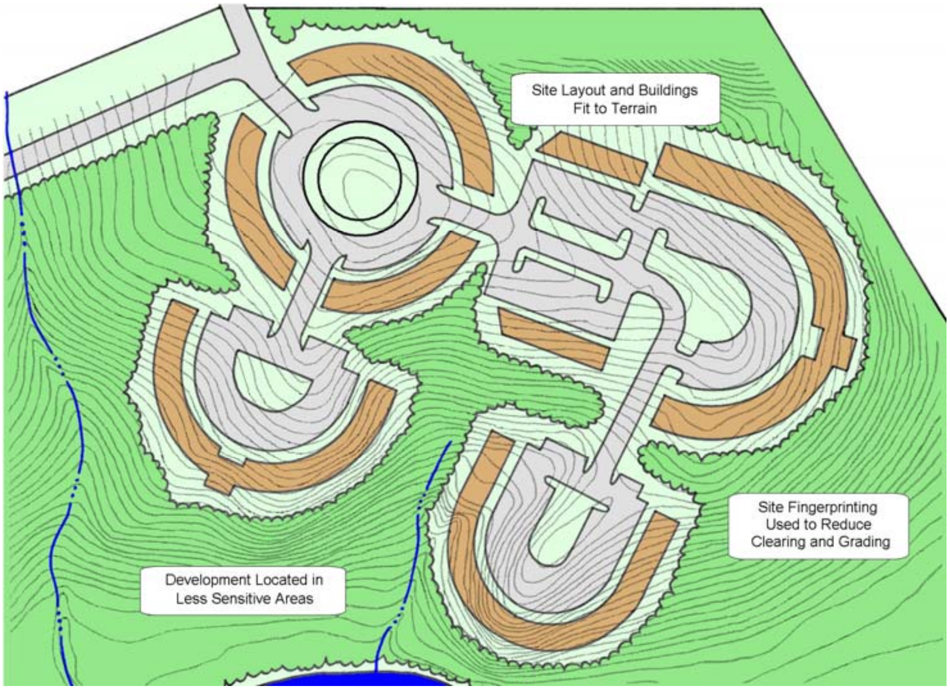


Figure 6.28. Development Design Using Several Lower Impact Site Design Techniques
Source: ARC (2006)

Figure 6.29. Composite Site Analysis of a Residential Lot
Source: Puget Sound LID Technical Manual (2005)

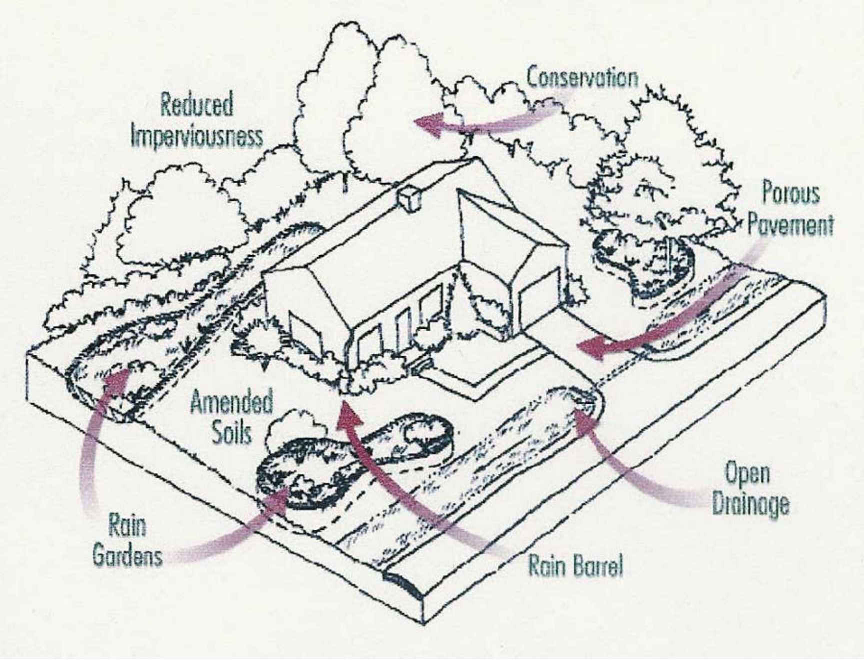


Figure 6.30. LID Practices Incorporated at a Residential Lot
Source: Puget Sound LID Technical Manual (2005)

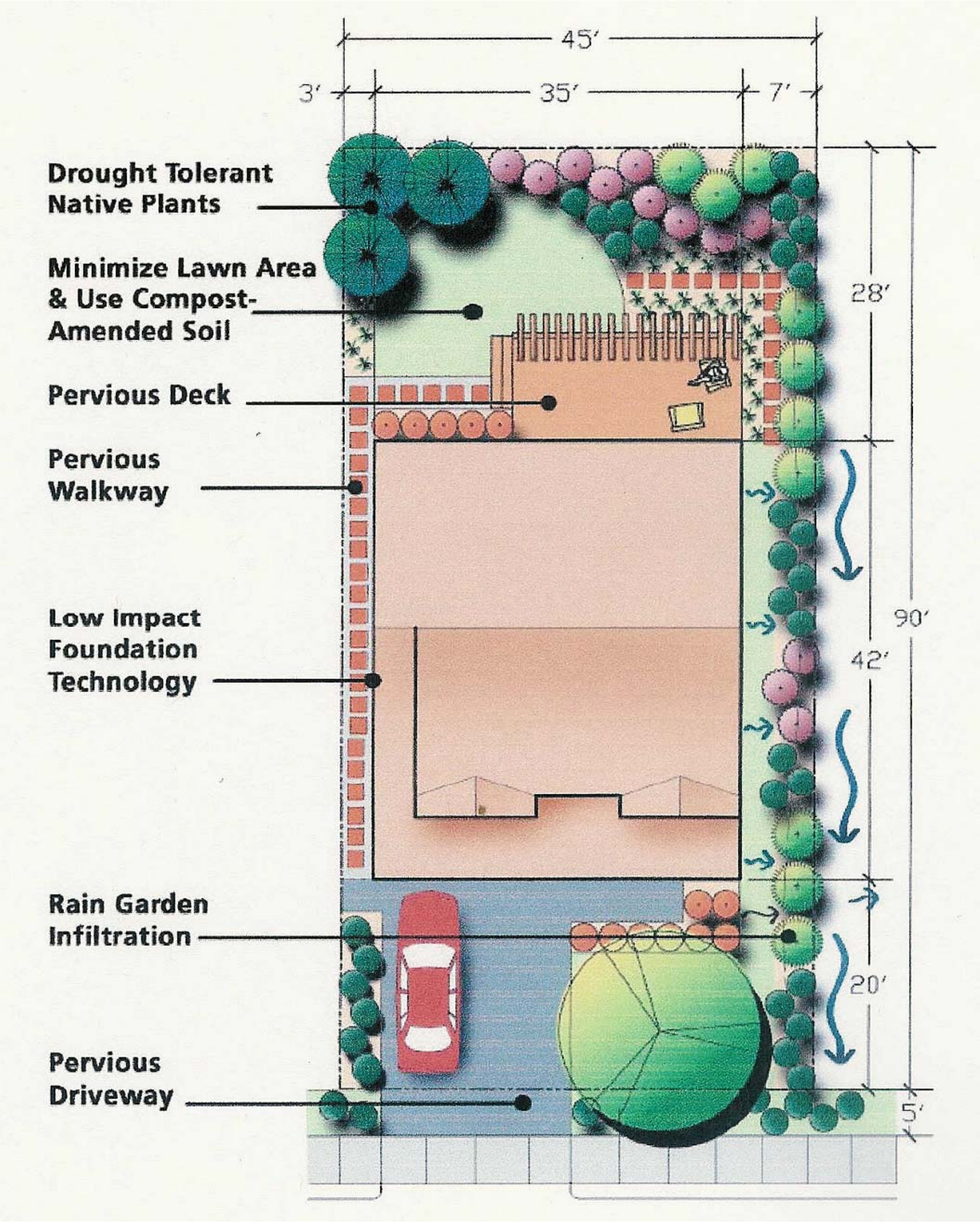


Figure 6.31. Use of LID Practices on a Medium- to High-Density Lot
Source: Puget Sound LID Technical Manual (2005)

6.5.2.1. Environmental Site Design Practice #6: Fit the Design to the Terrain

KEY BENEFITS	USING THIS PRACTICE
• Helps to preserve the natural hydrology and drainageways of a site • Reduces the need for grading and land disturbance • Provides a framework for site design and layout	• Develop roadway patterns to fit the site terrain. Locate buildings and impervious surfaces away from steep slopes, drainageways and floodplains

The layout of roadways and buildings on a site should generally conform to the landforms on a site. Natural drainageways and stream buffer areas should be preserved by designing road layouts around them. Buildings should be sited to utilize the natural grading and drainage system and avoid the unnecessary disturbance of vegetation and soils. All site layouts should be designed to conform with or "fit" the natural landforms and topography of a site. This helps to preserve the natural hydrology and drainageways on the site, as well as reduces the need for grading and disturbance of vegetation and soils. **Figure 6.32** illustrates the placement of roads and homes in a residential development.

Roadway patterns on a site should be chosen to provide access schemes which match the terrain. In rolling or hilly terrain, streets should be designed to follow natural contours to reduce clearing and grading. Street hierarchies with local streets branching from collectors in short loops and cul-de-sacs along ridgelines help to prevent the crossing of streams and drainageways as shown in **Figure 6.33** below. In flatter areas, a traditional grid pattern of streets or "fluid" grids which bend and may be interrupted by natural drainageways may be more appropriate (see **Figure 6.34** below). In either case, buildings and impervious surfaces should be kept off of steep slopes, away from natural drainageways, and out of floodplains and other lower lying areas. In addition, the major axis of buildings should be oriented parallel to existing contours.

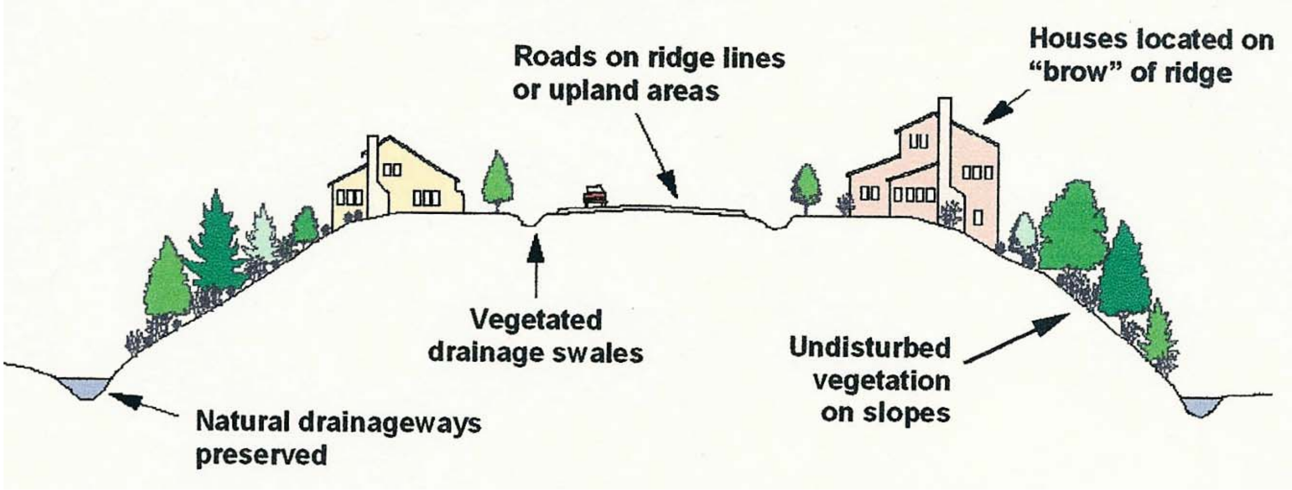


Figure 6.32. Preserving the Natural Topography of the Site
(Adapted from Sykes, 1989)

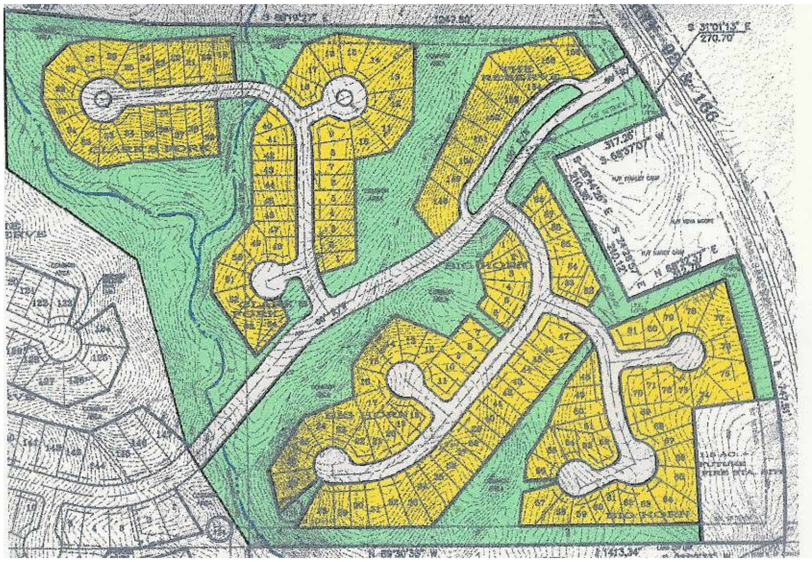


Figure 6.33. Subdivision Design for Hilly or Steep Terrain Uses Branching Streets from Collectors that Preserves Natural Drainageways and Stream Corridors
Source: ARC (2006)

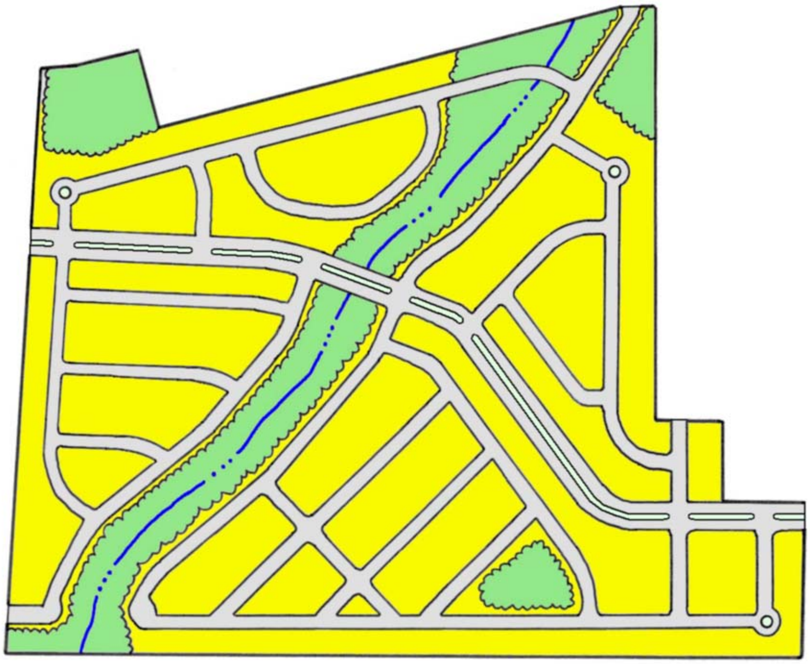


Figure 6.34. A Subdivision Design for Flat Terrain Uses a Fluid Grid Layout that is Interrupted by the Stream Corridor
Source: ARC (2006)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6

6.5.2.2. Environmental Site Design Practice #7: Locate Development in Less Sensitive Areas

KEY BENEFITS	USING THIS PRACTICE
• Areas with highly permeable soils can be used as nonstructural stormwater infiltration zones • Helps to preserve the natural hydrology and drainageways of a site • Makes most efficient use of natural site features for preventing and mitigating stormwater impacts • Provides a framework for site design and layout	• Use soil surveys to determine site soil types • Lay out the site design to minimize the hydrologic impact of structures and impervious surfaces • Leave areas of porous or highly erodible soils as undisturbed conservation areas

Healthy soils effectively cycle nutrients; store carbon as organic matter; minimize runoff and maximize water holding capacity; absorb excess nutrients, sediments and pollutants; provide a healthy rooting environment and habitat to a wide range of organisms; and maintain their structure and aggregation. Porous soils, such as sand and gravels, provide an opportunity for groundwater recharge of stormwater runoff and should be preserved as a potential stormwater management option. Preserving soil horizons saves money by reducing the need for soil restoration and surface drainage improvements. Unstable or easily erodible soils should be avoided due to their greater erosion potential. By limiting grading, sites can also reduce costs for construction machinery and transport of imported soils.

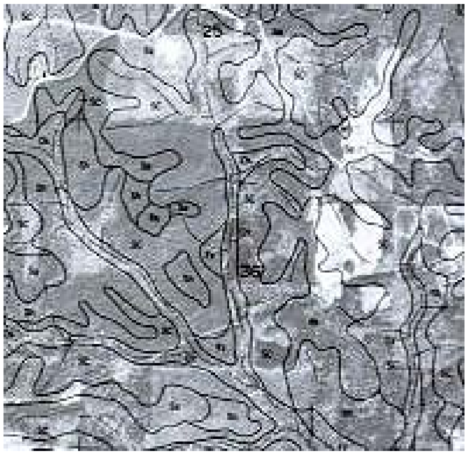


Figure 6.35. Soil Mapping Information Can Be Used To Guide Development
Source: USDA-NRCS

Soils on a development site should be mapped in order to preserve areas with porous soils, and to identify those areas with unstable or erodible soils as shown in the Soil Survey (see **Figure 6.35**). Soil surveys can provide a considerable amount of information relating to all relevant aspects of soils. General soil types should be delineated on concept site plans to guide site layout and the placement of buildings and impervious surfaces.

To minimize the hydrologic impacts on the existing site land cover, the area of development should be located in areas of the site that are less sensitive to disturbance or have a lower value in terms of hydrologic function and ecosystem services. In much the same way that a development should be designed to conform to terrain of the site, a site layout should also be designed so that the areas of development are placed in the locations of the site that minimize the hydrologic and ecologic impact of the project, using the following methods:

- Avoid developing on land designated as prime farmland, unique farmland, or farmland of statewide importance, in order to conserve the most productive farmland for use by future generations. Once converted to industrial and urban uses, this farmland is lost and cannot be regained.
- Given the choice, select sites on brownfields or greyfields for redevelopment and/or otherwise within existing communities where necessary infrastructure already exists.
- Locate buildings and impervious surfaces away from stream corridors, floodplains, wetlands and natural drainageways. Use buffers to preserve and protect riparian areas and corridors.
- Areas on a site with highly erodible or unstable soils should be avoided for land disturbing activities and buildings to prevent erosion and sedimentation problems as well as potential future structural problems. These areas should be left in an undisturbed and vegetated condition.
- Areas of the site with porous soils should left in an undisturbed condition, as much as is feasible, and/or used as stormwater runoff infiltration zones. Buildings and impervious surfaces should be located in areas with less permeable soils (**Figure 6.36**). These areas should ideally be incorporated into undisturbed natural or open space areas.

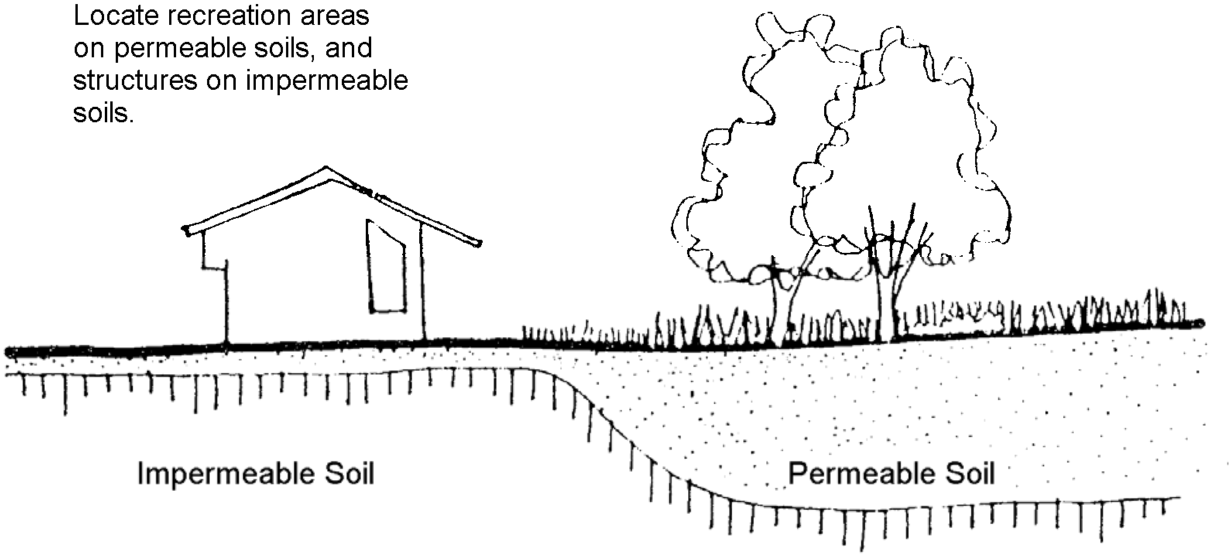


Figure 6.36. Avoid Building On or Disturbing Porous Soils
Source: Day and Crafton (1978)

Infiltration of stormwater into the soil reduces both the volume and peak discharge of runoff from a given rainfall event, and also provides for water quality treatment and groundwater recharge. Soils with maximum permeability (hydrologic soil group A and B soils such as sands and sandy loams) allow for the most infiltration of runoff into the subsoil.

Avoid land disturbing activities or construction on areas with steep slopes or unstable soils.

- Minimize the clearing of areas with dense tree canopy or thick vegetation, and ideally preserve them as natural conservation areas
- Ensure that natural drainageways and flow paths are preserved, where possible. Avoid the filling or grading of natural depressions and ponding areas.
- Design carefully around floodplains. Access to buildings and residences should be from the landward direction. Stream crossings should be as nearly perpendicular as possible (see **Figure 6.38** below).

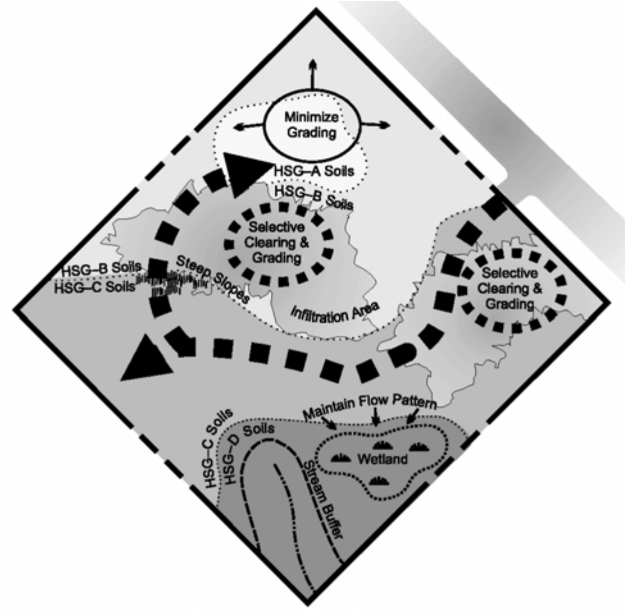


Figure 6.37. Guiding Development to Less Sensitive Areas of a Site
Source: Georgia Stormwater Management Manual (2001)

Figure 6.37 above shows a development site where the natural features have been mapped in order to delineate the hydrologically sensitive areas. Through careful site planning, sensitive areas can be set aside as natural open space areas (see Environmental Site Design Practice #9). In many cases, such areas can be used as buffer spaces between land uses on the site or between adjacent sites.

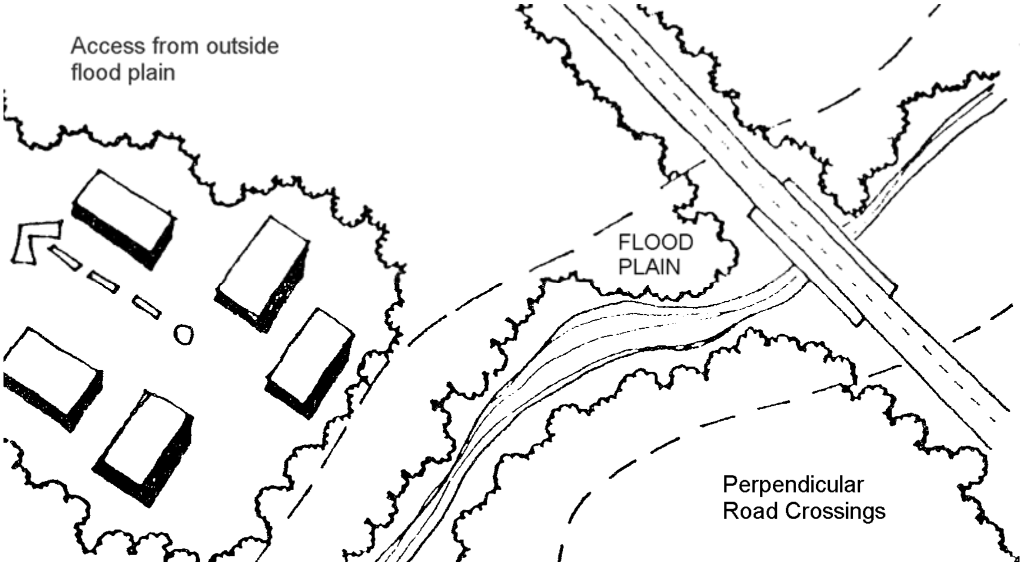


Figure 6.38. Design Carefully Around Floodplains
Source: Day and Crafton (1978)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.1: Limit development of soils designated as prime farmland, unique farmland, and farmland of statewide importance	0 (Prerequisite)
1.2: Protect floodplain functions	0 (Prerequisite)
1.3: Preserve wetlands	0 (Prerequisite)
1.4: Preserve threatened and endangered species	0 (Prerequisite)
1.5: Select brownfields or greyfields for redevelopment	5 - 10
1.6: Select sites within existing communities	6

6.5.2.3. Environmental Site Design Practice #8: Reduce the Limits of Clearing and Grading

KEY BENEFITS	USING THIS PRACTICE
• Preserves more undisturbed natural areas on a development site • Techniques can be used to help protect natural conservation areas and other site features	• Establish limits of disturbance for all development activities • Use site footprinting to minimize clearing and land disturbance

Clearing and grading of the site should be limited to the minimum amount needed for the development function, road access, and the necessary infrastructure (e.g., utilities, wastewater disposal, and stormwater management). Minimal disturbance methods should be used to limit the amount of clearing and grading that takes place on a development site, preserving more of the undisturbed vegetation, good soils, and natural hydrology of a site. Unnecessarily removing forest cover will decrease infiltration and, thus, increase runoff and the possibility of erosion and siltation (**Figure 6.39**). Vegetation plays an enormous role in regulating stream flow and maintaining water quality. Areas which contain high-quality, stable, or unique vegetation should be identified and preserved.

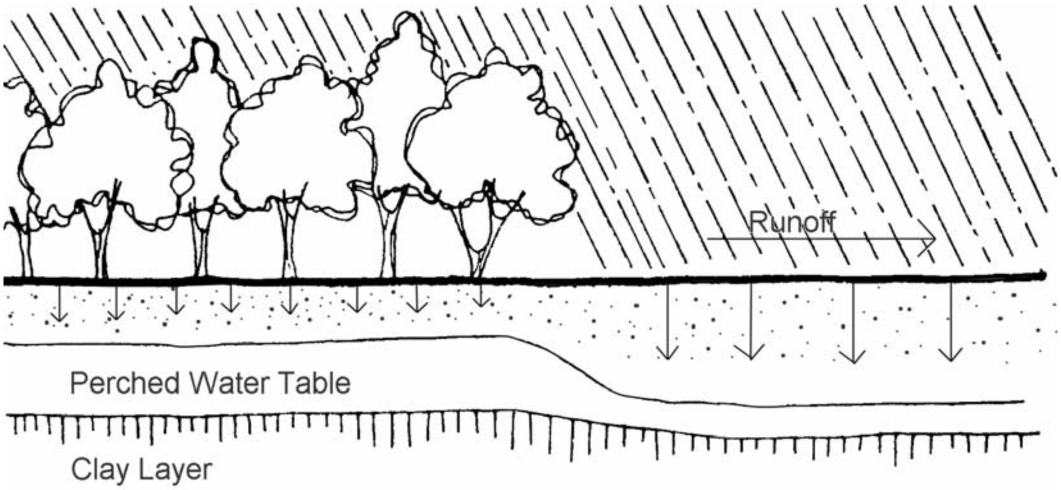


Figure 6.39.Clearing Vegetation Decreases Infiltration and Baseflow and Increases Runoff
Source: Day and Crafton (1978)

Appropriate methods include the following:

- Avoiding mass grading and establishing physically marked limits of disturbance (LOD) based on maximum disturbance zone radii/lengths. These maximum distances should reflect reasonable construction techniques and equipment needs together with the physical situation of the development site such as slopes or soils. LOD distances may vary by type of development, size of lot or site, and by the specific development feature involved.
- Using site "footprinting" which maps all of the limits of disturbance to identify the smallest possible land area on a site which requires clearing or land disturbance for building

footprints, construction access, and safety setbacks. Examples of site footprinting are illustrated in **Figures 6.40 and 6.41**.

- Fitting the site design to the terrain.
- Use alternative site designs that incorporate open-space or “cluster” developments.
- Using special procedures and equipment which reduce land disturbance.

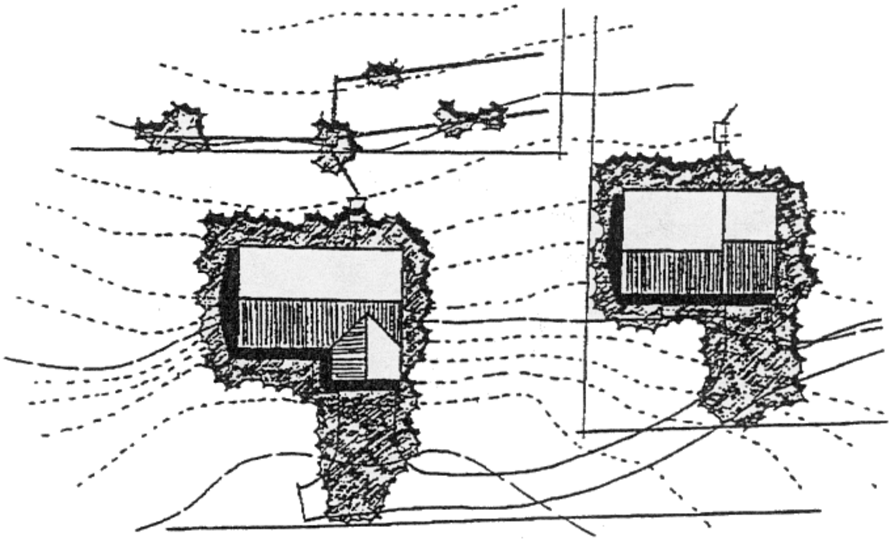


Figure 6.40. Establishing Limits of Clearing
Source: DDNREC (1997)

Figure 6.41. Example of Site Footprinting
Source: ARC (2006)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.8: Preserve plant communities native to the ecoregion	2 - 6

6.5.2.4. Environmental Site Design Practice #9: Use Open Space Development

KEY BENEFITS	USING THIS PRACTICE
• Can be used to help protect natural conservation areas and other site features • Can be used to preserve natural hydrology and drainageways and improve watershed protection • Reduces the need for grading and land disturbance • Reduces infrastructure needs and development costs • Increases community recreational space	• Use a site design which concentrates development and preserves open space and natural areas of the site
This practice reflects the CWP Better Site Design Principles #11 (Open Space Design), #15 (Open Space Management), and #21 (Conservation Incentives)	

Open space site designs (sometimes referred to as conservation development or cluster development) incorporate smaller lot sizes to reduce overall impervious cover while providing protection for open space and natural areas opportunities for on-site stormwater runoff reduction and treatment, and protection of local water resources. Open space development is typically applied to residential development. Where open space design is available as an option under local zoning codes, the localities typically relax minimum lot sizes, setbacks and frontage distances in order to maintain the same number of dwelling units at the site while achieving the conservation purposes.

The Department encourages localities to consider making open space development a by-right form of development, so that zoning variances or special use permits are unnecessary, and to provide incentives for developers to make greater use of this form of development. Incentives and flexibility in the form of density compensation, buffer averaging, and property tax reduction, among others, should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, compensatory mitigation consistent with locally adopted watershed plans should be encouraged. More detailed guidance regarding such options can be found in the discussion of the Center for Watershed Protection's Better Site Design Principle No. 21 (in CWP 1998a).

The ability to implement open space designs depends to a great extent on the base zoning density of the open space design. Flexibility sharply declines as the density of the base zone increases. Generally, high density residential zones (more than six dwelling units per acre) are not feasible for open space developments, simply due to the lack of space.

Open space developments have many benefits compared with conventional commercial developments or residential subdivisions: they can reduce impervious cover, stormwater pollution, construction costs, and the need for grading and landscaping, while providing for the conservation of good soils, high quality, stable or unique vegetation, wildlife habitat, and community open space. **Figure 6.42** and **Figure 6.43** below show examples of open space developments.

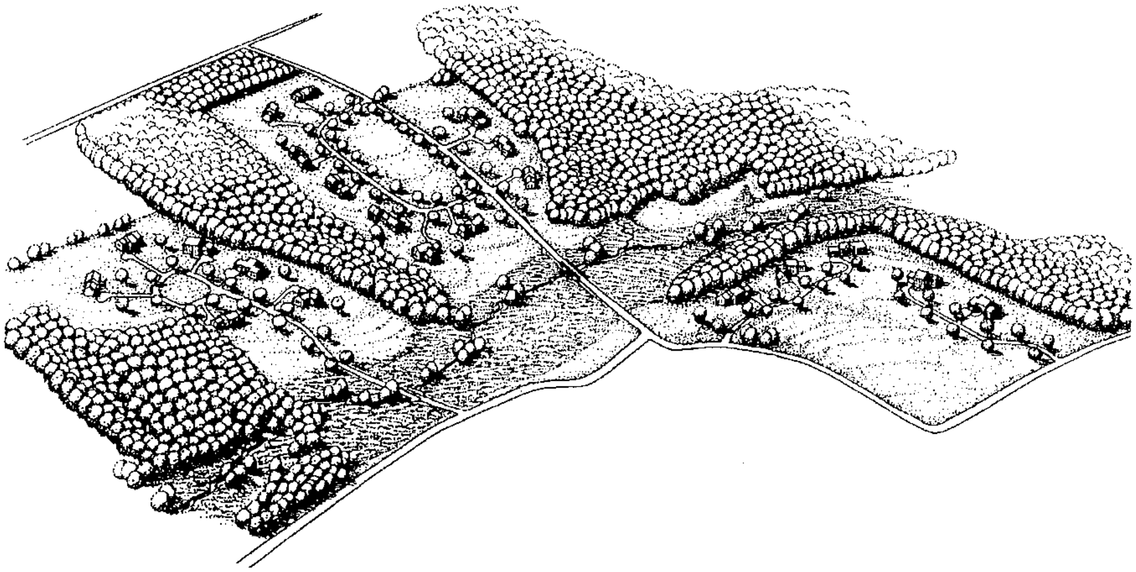


Figure 6.42. Open Space Subdivision Site Design Example
Source: DE DNREC (1997)

Figure 6.43. Aerial View of an Open Space Subdivision
Source: Chesapeake Bay Stormwater Training Partnership

Along with reduced imperviousness, open space designs provide a host of other environmental benefits lacking in most conventional designs. These developments reduce potential pressure to encroach on conservation and buffer areas because enough open space is usually reserved to accommodate these protection areas. As less land is cleared during the construction process, alteration of the natural hydrology and the potential for soil erosion are also greatly diminished. Perhaps most importantly, open space design typically results in 25 to 50 percent of the development site being placed in conservation areas that would not otherwise be protected.

Some measure of the value of open space design in reducing impervious cover can be gleaned from a series of "redesign" analyses (see **Table 6.9**). In each case, an existing conventional residential subdivision was "redesigned" using open space design principles. The resulting change in impervious cover was measured from the two plans. These studies suggest that open space designs can reduce impervious cover by 40-60 percent and stormwater runoff volume by 20-60+ percent, when compared to conventional subdivision designs, particularly if narrow streets can also be used at the site. The value of open space designs in reducing impervious cover is evident over most residential zones, although only minor reductions in impervious cover occur in areas which used very small lot size (1/8 acre lots and smaller) in the original zoning.

Table 6.9. Redesign Analyses Comparing Impervious Cover and Stormwater Runoff from Conventional and Open Space Subdivisions

Residential Subdivision Name	Conventional Zoning for the Subdivision	Impervious Cover at the Site			% Reduction in Stormwater Runoff (%)
		Conventional Design (%)	Open Space Design (%)	Net Change (%)	
Remlick Hall [1]	5 acre lots	5.4	3.7	-31	20
Duck Crossing [2]	3-4 acre lots	8.3	5.4	-35	23
Tharpe Knoll [3]	1 acre lots	13	7	-46	44
Chapel Run [3]	1/2 acre lots	29	17	-41	31
Pleasant Hill [3]	1/2 acre lots	26	11	-58	54
Prarie Crossing [4]	1/2 to 1/3 acre lots	20	18	-20	66
Rappahannock [2]	1/3 acre lots	27	20	-24	25
Buckingham Greene [3]	1/8 acre lots	23	21	-7	8
Belle-Hall [5]	High Density	35	20	-43	31
Sources: [1] Maurer, 1996; [2] CWP, 1998b; [3] DE DNREC, 1997; [4] Dreher, 1994; and [5] SCCCL, 1995.					

Source: CWP, 1998a

Decreased stormwater runoff translates to less stormwater pollution. Again, several redesign analyses have compared the stormwater pollution loads of conventional and open space developments using simple models (see **Table 6.10** below). Significant reductions in stormwater pollutant loadings generally occur when open space designs are used – comparable to what can be achieved if stormwater best management practices were installed at the conventional site.

Open space developments can also be significantly less expensive to build than conventional projects. Most of the cost savings are due to reduced infrastructure cost for roads and stormwater management controls and conveyances. The examples in **Table 6.11** below demonstrate infrastructure cost savings ranging from 11-66 percent.

Table 6.10. Redesign Analyses Comparing Stormwater Pollution Loads from Conventional and Open Space Subdivisions

Residential Subdivision	Change in Phosphorus Load (%)	Change in Nitrogen Load (%)	Other
Remlick Hall [1]	-42	-42	
Prarie Crossing [2]	-81	N/A	92% TSS reduction
Rappahannock [3]	-60	-45	
Belle-Hall [4]	-67	-69	
Sources: [1] Maurer, 1996; [2] Dreher, 1994; [3] CWP, 1998b; and [4] SCCCL, 1995			

Source: CWP, 1998a

Table 6.11. Projected Construct Cost Savings for Open Space Designs from Redesign Analyses

Residential Development	Construction Cost Savings (%)	Notes
Remlick Hall [1]	52	Includes costs for engineering, road construction, and obtaining water and sewer permits
Duck Crossing [2]	12	Includes roads, stormwater management, and reforestation
Tharpe Knoll [3]	56	Includes roads and stormwater management
Chapel Run [3]	64	Includes roads, stormwater management, and reforestation
Pleasant Hill [3]	43	Includes roads, stormwater management, and reforestation
Rappahannock [2]	20	Includes roads, stormwater management, and reforestation
Buckingham Greene [3]	63	Includes roads and stormwater management
Canton, Ohio [4]	66	Includes roads and stormwater management
Sources: [1] Maurer, 1996; [2] Dreher, 1994; [3] CWP, 1998b; and [4] NAHB, 1986		

Source: CWP, 1998a

While open space developments are frequently less expensive to build, developers find that these properties often command higher prices than those in more conventional developments. Several studies estimate that residential properties in open space developments garner premiums that are higher than conventional subdivisions and moreover, sell or lease at an increased rate (Zielinski, 2001). Open space development also reduces the heat island effect of urban areas, and the preserved vegetation can help to reduce heating and cooling costs, providing long-term economies. Many studies have shown that a well-designed and marketed open space development can be very desirable to home buyers. Some examples are presented in **Table 6.12** below.

Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements.

A 1992 survey of local open space design regulations conducted by Heraty revealed that the open space requirements were poorly defined in most communities. For example, less than a third of local cluster ordinances required that open space be consolidated. Only 10 percent required that a specified portion of the open space be maintained and managed in a natural state. Similarly, few communities clearly specify allowable uses for open space areas. Instead, most communities rely on community associations to manage open space and determine allowable uses.

Table 6.12. Examples of Successful Open Space Developments

Subdivision Name	Location	Percent Open Space	Notes
Farmview	Bucks County, PA	*	The fastest selling subdivision in its price range, with lots from 1/2 to 1/3 the size of competing projects (Arendt, et al., 1994)
Palmer Ranch	Sarasota, FL	36	93% of existing wetlands at the site were preserved. Accounted for 30% of the new home market in Sarasota in 1994 (Ewing, 1996).
Fields of St. Croix	Lake Elmo, MN	60	80% of home sites in the first phase were sold within 6 months (NAHB, 1997)
Westgreen	Leesburg, VA	39	Targeted to young professionals and empty-nesters. Every lot in Phase I sold during the first weekend (ULI, 1992)
* More than 23% was preserved as open space and 31% was preserved as productive farm land.			

Source: CWP, 1998a

Realistically, few community associations have the legal or financial resources to adequately manage open space, particularly if it is intended for active recreation. Furthermore, it is difficult for individual community associations to manage interconnected open spaces in a cohesive manner. The concern that homeowners lack the money, organization or technical ability to adequately maintain common areas is often cited as the reason for communities to prohibit or restrict open space designs.

However, open space managed in natural condition actually has minimal annual maintenance cost. This is one reason why communities should encourage designers to retain as much open space as possible in a natural condition. Communities should also explore more reliable methods to assure that the responsibility for open space management can be met within a development. The two primary options are to (1) create a community organization or (2) to shift the responsibility to a third party, such as a land trust or park, by means of a conservation easement. The latter technique is especially useful in developments that have high quality conservation areas retained in open space.

Communities that have cluster or open space ordinances should revisit them to ensure that open space is well planned and, where possible, connected. Clear performance criteria for open space consolidation, maintenance in natural condition, allowable uses, and future management should be carefully considered. More detailed guidance about managing open space can be found in the discussion of Principle No. 15 in CWP 1998a.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.12: Reduce urban heat island effects	3 - 5

6.5.2.5. Environmental Site Design Practice #10: Consider Creative Development Design

KEY BENEFITS	USING THIS PRACTICE
• Allows flexibility to developers to implement creative site designs which include environmental site design practices • May be useful for implementing an open space development	• Check with your local review authority to determine if the community supports Planned Unit Developments (PUDs) • Determine the type and nature of deviations allowed and other criteria for receiving PUD approval

Planned Unit Developments (PUDs) allow a developer or site designer the flexibility to design a residential, commercial, industrial, or mixed-use development in a fashion that best promotes effective stormwater management and the protection of environmentally sensitive areas. A Planned Unit Development (PUD) is a type of planning approval available in some communities which provides greater design flexibility by allowing deviations from the typical development standards required by the local zoning code with additional variances or zoning hearings. The intent is to encourage better designed projects through the relaxation of some development requirements, in exchange for providing greater benefits to the community. PUDs can be used to implement many of the other stormwater-related ESD practices covered in this Handbook and to create site designs that maximize natural nonstructural approaches to stormwater management. Examples of the types of zoning deviations which are often allowed through a PUD process include:

- Allowing uses not listed as permitted, conditional or accessory by the zoning district in which the property is located
- Modifying lot size and width requirements
- Reducing building setbacks and frontages from property lines (e.g., zero lot line configurations, as shown in **Figure 6.44**).
- Altering parking requirements
- Increasing building height limits

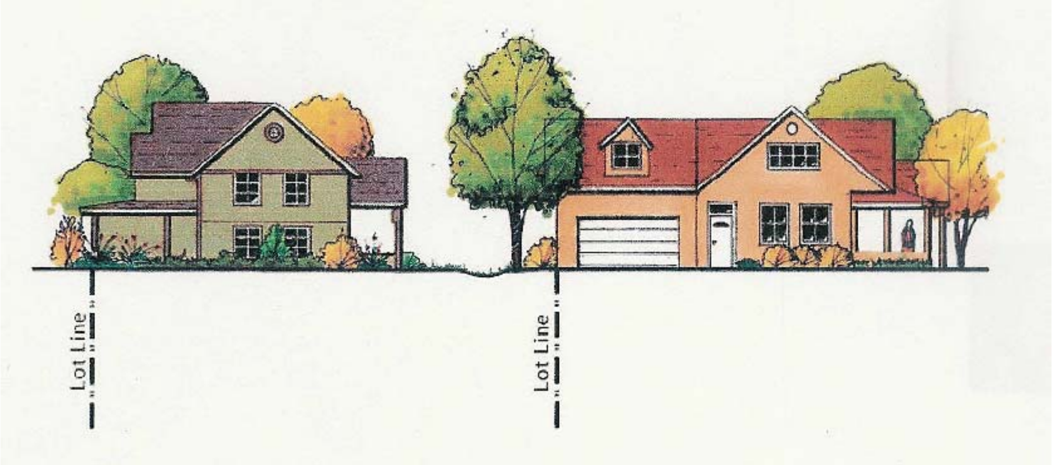


Figure 6.44. Zero Lot Line Configuration
Source: Puget Sound LID Technical Manual (2005)

Many of these changes are useful in reducing the amount of impervious cover on a development site (see Environmental Site Design Practices #12 through #17). A developer or site designer should consult their local review authority to determine whether the community supports PUD approvals. If so, the type and nature of deviations allowed from individual development requirements should be obtained from the review authority in addition to any other criteria that must be met to obtain a PUD approval.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
2.2: Use an integrated site development process	0 (Prerequisite)
4.4: Minimize soil disturbance in design and construction	6
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.7: Use native plants	1 – 4
4.8: Preserve plant communities native to the ecoregion	2 – 6
4.9: Restore plant communities native to the ecoregion	1 – 5
4.10: Use vegetation to minimize building heating requirements	2 – 4
4.11: Use vegetation to minimize building cooling requirements	3 - 5
4.12: Reduce urban heat island effects	3 - 5

6.5.3. Reducing Impervious Cover in Site Design

The level of impervious cover – i.e. rooftops, parking lots, roadways, sidewalks and other surfaces that do not allow rainfall to infiltrate into the soil – is an essential factor to consider in ESD for stormwater management. Site by site and watershed by watershed, increased impervious cover means increased stormwater generation and increased pollutant loadings.

Thus by reducing the area of total impervious surface on a site, a site designer can directly reduce the volume of stormwater runoff and associated pollutants that are generated. It can also reduce the size and cost of necessary infrastructure for stormwater drainage, conveyance, and control and treatment. Some of the ways that impervious cover can be reduced in a development include:

- Reduce Roadway Lengths and Widths
- Reduce Building Footprints
- Reduce the Parking Footprint
- Reduce Setbacks and Frontages
- Use Fewer or Alternative Cul-de-Sacs
- Create Parking Lot Stormwater Islands

Figure 6.45 shows examples employing several of these principles to reduce the overall imperviousness of the development. The next several pages cover these methods in more detail.

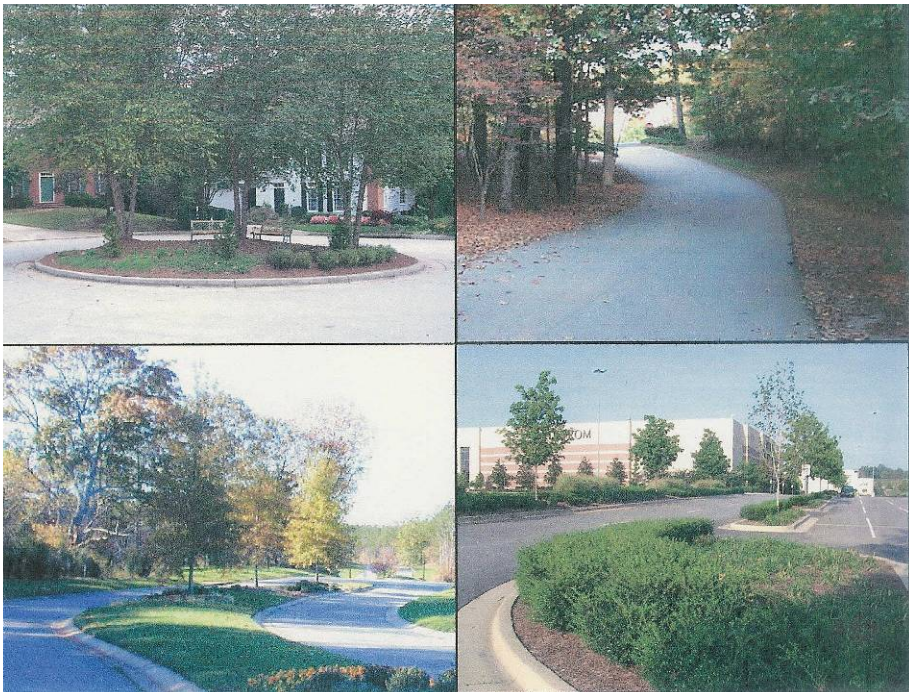


Figure 6.45. Example of Reducing Impervious Cover (clockwise from upper left): (a) Cul-de-sac with Vegetated Island; (b) Narrower Residential Street; (c) Vegetated Median in Roadway; and (d) "Green" Parking Lot with Vegetated Islands
Source: ARC (2001)

6.5.3.1. Environmental Site Design Practice #11: Reduce Roadway Lengths and Widths

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Reduces the costs associated with road construction and maintenance	• Consider different site and road layouts that reduce overall street length • Minimize street width by using narrower street designs that are a function of land use, density and traffic demand • Smaller side yard setbacks will reduce total street length
This practice reflects the CWP Better Site Design Principles #1 (Street Width), #2 (Street Length), and #3 (Right-of-Way Width)	

Figure 6.46. Narrow Residential Street with Swale Drainage
Source: Chesapeake Bay Stormwater Training Partnership

Roadway widths and lengths should be minimized on a development site where possible to reduce overall imperviousness, while still supporting expected traffic volume, on-street parking and access for emergency, maintenance and service vehicles. Furthermore, a wide right-of-way (ROW) is only needed when utilities and sidewalks are located some distance from the paved section of the roadway. While a wide ROW does not necessarily create more impervious cover, it can work against environmental site design for several reasons. First, it subjects a greater area to clearing during road construction. This may lead to needless loss of existing trees. Second, and more important, a wide ROW consumes land that may be better used for housing lots, making it more difficult to achieve a more compact site design. The right-of way in **Figure 6.46** above is just wide enough to account for the pavement and open channels. It is also narrower because there are no sidewalks and the utilities have been placed underground.

Consider the use of alternative road layouts (**Figure 6.47**) that increase the number of homes served per unit length, thus reducing the total linear length of roadways. This can significantly reduce overall imperviousness of a development site and associated runoff and pollutant generation. Reducing imperviousness also helps to reduce the urban heat island effect. Site designers are encouraged to analyze different site and roadway layouts to see if they can reduce overall street length. The length of local cul-de-sacs and cross streets should be shortened to a maximum of 200 ADT (average daily trips) to minimize traffic and road noise so that shorter setbacks may be employed.

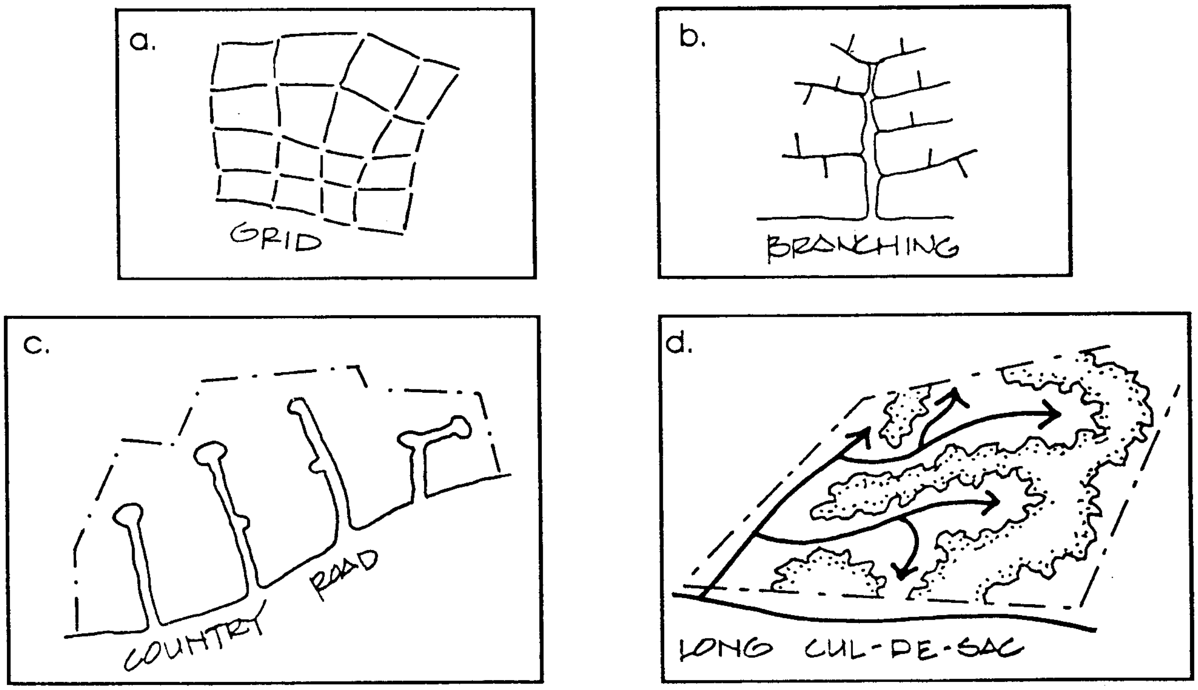


Figure 6.47. Alternative Street Layouts
Source: Center for Watershed Protection

Residential streets and private streets within commercial and other development should be designed for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency access. Many communities require minimum street widths that are much wider than needed to support travel lanes, on-street parking, and emergency access. Access streets in subdivisions often are wider than the collector and “higher order” streets that receive their traffic. Ironically, excessively wide streets encourage excessive speed as well.

Several time-honored sources of highway specifications such as the American Association of State Highway and Transportation Officials (AASHTO) and the Institute of Transportation Engineers (ITE) have established minimum pavement width and right-of-way width specifications which are unnecessarily large, especially when applied in zones of lower density where average lot size is large and traffic generation, even at build-out, is much less than traffic anticipated by such specifications. **Table 6.13** below illustrates the various national standards as compared to alternative standards developed by the Metropolitan Washington (DC) Council of

Governments. For comparison, **Table 6.14** below is a translation of the most recent VDOT subdivision street design standards (March, 2009) into the same criteria categories.

Table 6.13. Condensed Summary of National Residential Street Design Standards

Design Criteria	AASHTO	ITE	MWCOG
Residential Street Categories	1	3	4 depending on ADT
Minimum Street Width	26 ft. min.	< 2du = 22-27 ft. 2-6 du = 28-34 ft. < 6du = 36 ft.	< 100 ADT = 16 ft. 100-500 ADT = 20 ft. 0-6 du/ac = 32 ft.
Additional righty-of-way	24 ft.	24 ft.	8 to 26 ft.
Design speed, level terrain	30 mph	30 mph	15 to 25 mph
Curb and Gutter	Generally required	Generally required	Not required on collectors
Cul-de-Sac Radii	30 ft.	40 ft.	30 ft.
Turning Radii in Cul-de-Sac	20 ft.	25 ft.	17 ft.
AASHTO = American Association of State Highway and Transportation Officials ITE = Institute of Transportation Engineers MWCOG = Metropolitan Washington Council of Governments (1995) ADT = Average Daily Trips Du = Dwelling Units			

Table 6.14. VDOT Residential Street Design Standards

Design Criteria	**VDOT Curb & Gutter Street Section**			**VDOT Road & Ditch Street Section**			
	No Parking	Parking 1 Side	Parking Both Sides	No Parking	Parking 1 Side	Parking Both Sides	Min. Width of Shoulder
Minimum Street Width	<2K ADT: 24 ft. 2-4K ADT: 26 ft.	<2K ADT: 24 ft. 2-4K ADT: 31 ft.	<2K ADT: 29 ft. 2-4K ADT: 36 ft.	<2K ADT: 24 ft. 2-4K ADT: 26 ft.	<2K ADT: 24 ft. 2-4K ADT: 31 ft.	<2K ADT: 29 ft. 2-4K ADT: 36 ft.	<2K ADT: 6 ft. 2-4K ADT: 8 ft.
Additional righty-of-way	8' to 12' from back of curb. Right-of-Way shall extend a minimum of 1' beyond any feature to be maintained by VDOT.			Minimum 28' beyond edges of pavement. Right-of-Way shall extend a minimum of 1' beyond any feature to be maintained by VDOT.			
Design speed, level terrain	<2K ADT: 25 mph 2K-4K ADT: 30 mph			<2K ADT: 25 mph 2K-4K ADT: 30 mph			
Curb and Gutter	Not required on collector streets						
Cul-de-Sac Radii	Circular Type Turnaround: 45 ft. to edge of pavement or face of curb Concentric or Offset Cul de Sac (unpaved center): Unpaved ctr area = min. 30 ft./max. 120 ft.						
Turning Radii in Cul-de-Sac	Minimum 45' radius to accommodate school buses, intercity buses and single unit trucks. Auto-TURN® shall be used when designing for larger vehicles.						
ADT = Average Daily Trips							

Source: Adapted from VDOT Road Design Manual, Appendix B(1): March, 2009

Even AASHTO's minimum pavement width of 26 feet is sometimes exceeded. For the type of "first order" street system designed to service low density residential subdivisions, this width is excessively costly to construct, requires expensive real estate, and creates far more stormwater than otherwise would result. Because of the way in which so much development is configured, these streets are often times just networks of cul-de-sacs specifically designed to exclude through traffic. In most cases such streets will not receive significantly increased traffic as an area builds out. Consequently, traffic levels are not likely to increase much beyond the traffic generated by the homes lining the street.

Width reduction offers considerable potential benefit in terms of stormwater reduction. For the very smallest access street or lane (approximately 15 homes, with fewer than 100 vehicle trips per day), width can be decreased to 16 feet. Guidelines exist to increase width as the traffic increases (20 feet for 100-500 trips per day, 26 feet for 500-3,000 trips per day, and so forth). In conventional developments with conventional lots and house design, there is no need to provide on-street parking, although if tightly clustered configurations are used, on-street parking may be a desirable option and included in the design (add another 8-foot lane).

Figure 6.48 below shows different options for narrower street designs. Many times on-street parking can be reduced to one lane or eliminated on local access roads with less than 200 ADT on cul-de-sac streets and 400 ADT on two-way loops. One-way single-lane loop roads are another way to reduce the width of lower traffic streets.

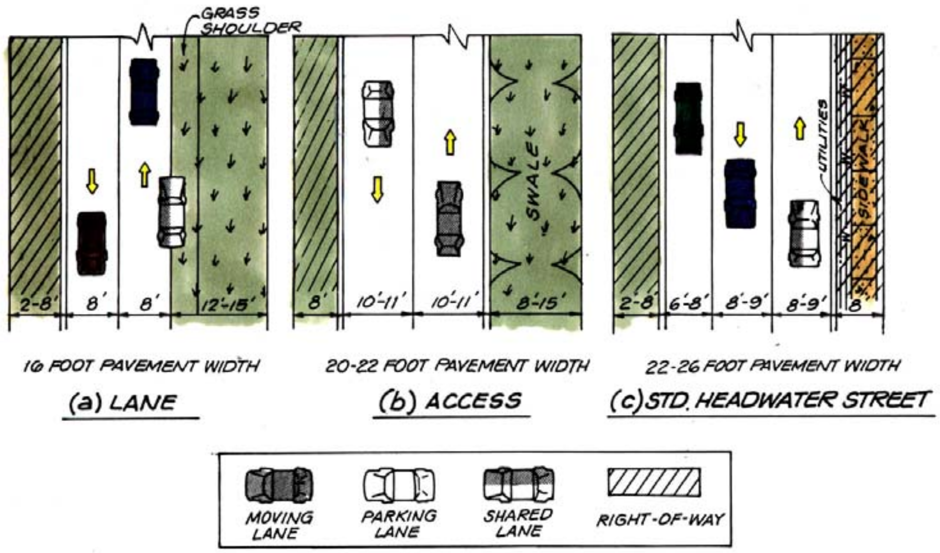


Figure 6.48. Potential Design Options for Narrower Street and Roadway Widths
Source: Chesapeake Bay Stormwater Training Partnership

Some communities currently require residential streets as wide as 32-40 feet and which provide two parking lanes and two moving lanes (**Figure 6.49** below). Local experience has shown that residential streets can have pavement widths as narrow as 22-26 feet, and still accommodate all access and parking needs (ITE, 1997). Even narrower access streets can be used when only a handful of homes are served. Significant cost savings occur in both road construction and maintenance. Narrower streets also help reduce traffic speeds in residential neighborhoods which, in turn, improve pedestrian safety. Snow stockpiles on narrow streets can be accommodated if parking is restricted to one side of the street or alternated between the sides. Alternatively, the right-of-way may be used for snow storage. Narrow snowplows are available.

Eight foot wide snowplow blades mounted on pick-up trucks are common. Some companies manufacture alternative snowplows on small Bobcat®-type machines.

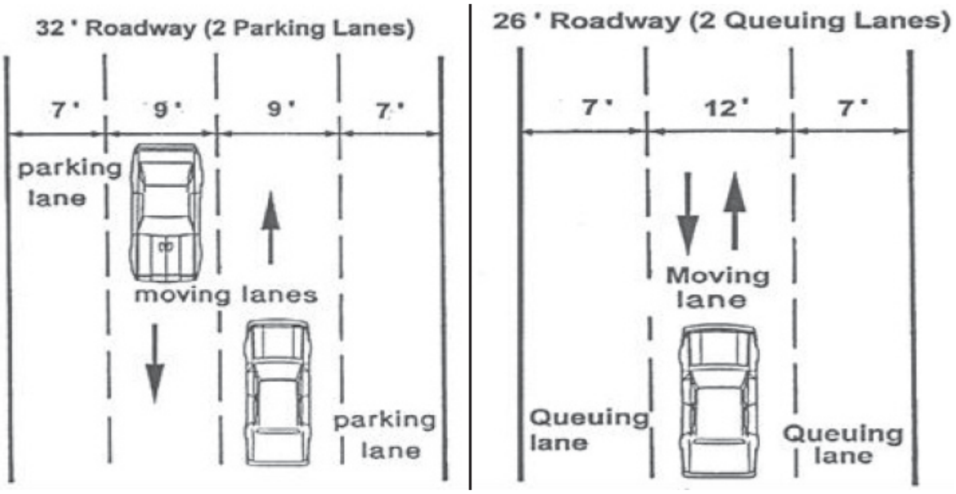


Figure 6.49. Traditional Street Width (left) and a Narrowed Street with "Queuing Lanes" (right). Source: MPCA (2006)

A narrower ROW can generally be accommodated on many residential streets without unduly compromising safety or utility access (see **Figure 6.50** and **Table 6.15** below). Some communities have recently narrowed ROWs for residential streets to 35-45 feet. This is done by redesigning each of the main components of the ROW. First, the *pavement width* is reduced on some streets. Second, *sidewalks* are either narrowed or restricted to one side of the street. Third, the *border width*, which separates the street from the sidewalk, is slightly relaxed. Last, *utilities* are installed underneath street pavement at the time of construction. When these design techniques are combined together, the width of most residential ROWs can be reduced to 10-25 feet. It should be noted that a narrow ROW may not be desirable if stormwater is conveyed by swales along the road (instead of curb and gutter).

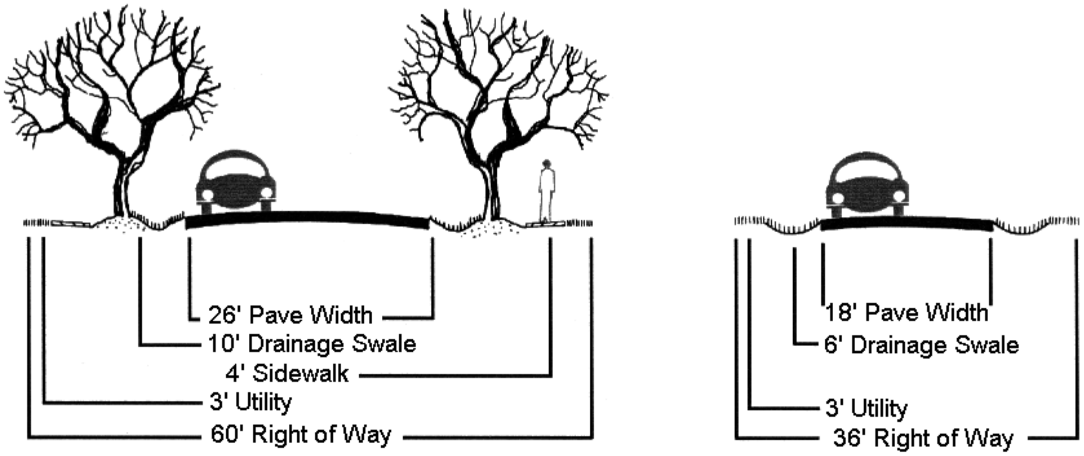


Figure 6.50. Design Options for Narrower Rights-of-Way on Residential Streets
(Source: VPI&SU, 2000)

Table 6.15. Examples of Narrower Right-of-Way Widths

Source	Right-of-Way Width	Pavement Width and Purpose
Portland, OR	35 feet 40 feet	20-foot residential street 26-foot residential street
Montgomery County, MD	20 feet 44 feet 46 - 60 feet	16-foot residential alley 20 foot residential street 26 foot residential street
ASCE, 1990 (Recommendations)	24 - 26 feet 42 - 46 feet	22 - 24 foot residential alley 26 foot residential street

Road length also is an important issue. Road length should first be addressed from a macro level planning perspective. Obviously overall dense patterns of development result in dramatically less road construction than low density patterns, holding net amount of development constant. High density development and vertical development contrast sharply with low density sprawl, which has proliferated in recent years and has required vast new highway systems throughout urban fringe zones.

Furthermore, if the critical mass of density is achieved, other forms of transportation such as transit may be enabled. Concepts such as Transit Oriented Development (TOD) has extremely important stormwater benefits as well, where flows of all types – from stormwater to traffic – can be managed much better. The Department encourages the Virginia Department of Transportation (VDOT) to continue to consider appropriate revisions in its standards for subdivision roads and streets – which govern design criteria in most Virginia communities – to minimize street size and imperviousness while still maintaining traffic and pedestrian safety.

More detailed guidance about minimizing street imperviousness can be found in the discussion of Principles No. 1 (Street Width), No. 2 (Street Length), and No. 3 (Right-of-Way Width) in CWP 1998a.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.2. Environmental Site Design Practice #12: Reduce the Impervious Footprints

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Can result in slowing/calming traffic in residential neighborhoods	• Use alternate or taller building designs to reduce the impervious footprint of buildings • Consolidate functions and buildings or segment facilities to reduce footprints of structures • Reduce directly-connected impervious areas
This practice reflects the CWP Better Site Design Principles #13 (Sidewalks) and #14 (Driveways)	

Building Footprints

The impervious footprint of commercial buildings and residences can be reduced by using alternate or taller buildings while maintaining the same floor to area ratio. Sidewalk and driveway lengths and widths should be minimized where possible to reduce overall imperviousness. Reducing imperviousness also helps to reduce the urban heat island effect.

In order to reduce the imperviousness associated with the footprint and rooftops of buildings and other structures, alternative and/or vertical (taller) building designs should be considered. Consolidate functions and buildings, as required, or segment facilities to reduce the footprint of individual structures. **Figure 6.51** shows the reduction in impervious footprint by using a taller building design.

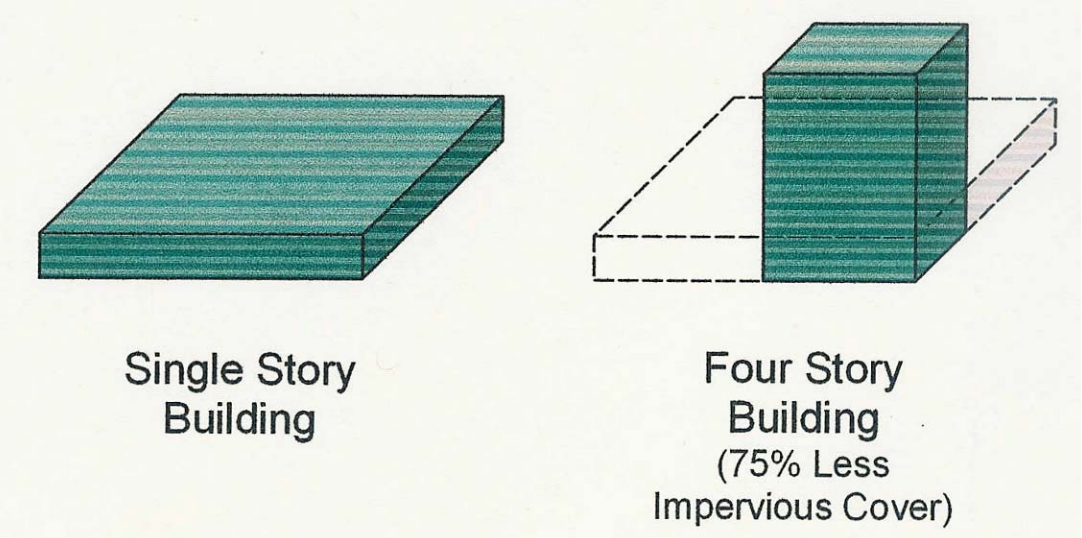


Figure 6.51. Building Up Rather Than Out Can Reduce the Amount of Impervious Cover on the Site. Source: ARC (2006)

Sidewalk Footprints

Many communities require sidewalks that are excessively wide or are located adjacent to the street where the pedestrians are at risk from vehicles. While sidewalk design requirements protect pedestrians, needless sidewalks can also increase the amount of site imperviousness, thereby preventing infiltration of stormwater runoff into the soil. In general, the placement and width of sidewalks can be modified without impairing travel access or minimizing pedestrian safety.

An environmental site design technique modifies the width and location of sidewalks to promote safer pedestrian mobility when linking pedestrian areas (**Figure 6.52**). Impervious cover is reduced when sidewalks are required on only one side of the street, reduced in width (to 3 or 4 feet) and are located away from the street. Sidewalks can also be disconnected so they drain to lawns or landscaping instead of the gutter and storm drain system. Slimmer sidewalks reduce and/or disconnect impervious cover, and thus reduce the generation of runoff. However, a minimum width of 4 feet should be provided, pursuant to the Americans with Disabilities Act. Other benefits include greater pedestrian safety, lower construction and maintenance costs, and reduced individual homeowner responsibility for snow clearance.

Figure 6.52. A Common Walkway Draining to Adjacent Vegetation and Linking Pedestrian Areas
Source: MPCA (2006)

Pedestrian safety is the usual reason for requiring sidewalks on both sides of a street. However, actual safety statistics show that having a sidewalk on only one side of the street provides approximately the same level of safety as providing sidewalks on both sides of the street (**Table 6.16** below).

Table 6.16. Survey of Pedestrian Accidents Related to the Presence of Sidewalks

Sidewalk Location	% of Accidents
No sidewalk present	83.5%
Pedestrian sidewalk only	0.9%
Multi-use sidewalk	0.6%
Sidewalk present on both sides of street	7.3%
Sidewalk present on at least one side of street	7.7%
Total	**100%**

Source: NHI (1996)

While safety is probably the most important issue governing pedestrians and the use of sidewalks, more and more governments, well-insured organizations, and professionals are being sued as a result of accidents involving pedestrians. It is true that taking simple and straightforward steps can reduce the occurrence of legal challenges and reduce the liability involved. The most important factor involving a government official or design professional in protecting themselves from legal challenges is the use of "ordinary care." Ordinary care means that design decisions are based on a basic level of care that can be expected of a reasonably experienced and prudent professional. Ordinary care is usually determined by using the "85 percentile rule." This simply means that designs are based on accommodating the behavior that can be expected of 85 percent of the travelers who use the facility in a reasonable manner (NHI, 1996). **Table 6.17** provides recommended design elements for sidewalks.

Table 6.17. Design Elements for User-Friendly, Safe and Legally Defensible Sidewalks

Sidewalk Design Element	Use, Safety, and Liability Considerations
4 feet minimum width	Allows users to walk side-by-side, helping to keep one user from walking in the street
Provide a buffer from traffic	Limits potential accidents and resulting lawsuits
Provide access to streets and destinations	Provides linkage between automobiles, transit and other destinations, avoids "dumping" pedestrians out at unsafe locations
Provide shade where possible	Makes walking more pleasant in the heat of summer
Design to avoid areas of standing or flowing water across the sidewalk	Standing or flowing water can freeze in the winter, creating a hazard and a potential liability situation
Design at the street level	Encourages sidewalk use and awareness of traffic situations
Limit the amount and strictly regulate vending machines (e.g., news stands, FedEx boxes, etc.)	These items take up valuable sidewalk space, potentially hinder sight distances, and can infringe on sidewalk area at critical locations, such as road crossings
Provide places to sit	Provides rest spots and places for people to stop, out of the way of traffic and congestion
Provide adequate and well-designed crossings	Helps minimize one of the major reasons for pedestrian accidents (i.e., darting out in front of on-coming traffic)

Source: Partially adapted from NHI, 1996

The Americans with Disabilities Act (ADA) does not specifically address sidewalks. However, it does require accessible routes. There must be at least one accessible route within the site boundary from public transportation stops, parking, and passenger loading zones. There must be at least one accessible route from public streets or sidewalks to the buildings or facilities they serve. Accessible routes must coincide with the routes for the general public *to the maximum extent feasible*. Sidewalks must be at least three feet wide (ADA Hotline, 1997; Dey, 1997).

Driveway Footprints

Driveways are linked very much to the configuration of a development and present another opportunity to practice environmental site design. Most local codes contain front yard setback requirements that dictate driveway length. In many communities, front yard setbacks for certain residential zoning categories may extend 50 or 100 feet or even longer. This increases driveway length well beyond what is needed for adequate parking and access to a garage. Furthermore, as lots have grown larger (sometimes much larger than one acre), minimum setback criteria typically are exceeded significantly. Houses often sit back considerable distances; driveways and total impervious cover increase significantly. As much as 20 percent of the impervious cover in a residential subdivision consists of driveways (Schueler, 1995).

As houses have grown larger and car-per-household ratios have increased, greater accommodation has been required for the automobile, which translates into increased impervious surface of different types. A 20-foot driveway fans out into a three-car garage. Turnaround aprons are increased in size accordingly. More aesthetic side-loading garages mean even longer driveways. The end result has been a substantial increase in the amount of impervious area created per person or per dwelling.

Shorter setbacks reduce the length and impervious cover for individual driveways. In addition, driveway width can be reduced from 20 feet to 18 feet, and more permeable driveway surfaces allowed (**Figure 6.53**). Another way to reduce impervious cover is to allow shared driveways (with enforceable maintenance agreements and easements) that provide street access for up to six homes (**Figure 6.54** below). Shorter driveways help reduce infrastructure costs for developers since they reduce the amount of paving or concrete needed. Another option, intrinsic to Traditional Neighborhood Design (TND), is the elimination of the driveway altogether, as garages open onto alleys – the new common driveways – with small aprons.

Figure 6.53. Alternative (Permeable) Driveway Surfaces
Source: ICPA

Figure 6.54 Example of a Shorter Driveway (left) and a Shared Driveway (right)
Source: MPCA (2006)

Minimize Clearing of Existing Vegetation

Last, but certainly not least among techniques to minimize building footprints is the concept of minimizing the amount of landscape that is cleared and will require maintenance following development. Ideally, clearing of vegetation and disturbance of soil is carefully limited to a prescribed distance from proposed structures and improvements (see **Section 6.5.2.3**, ESD Practice #8). At issue are construction phase impacts as well as long-term operation and maintenance of the development. The objective should be to maximize existing (hopefully natural/native) vegetation and to minimize creation of an artificial landscape that will perpetually require chemical nutrients and routine cutting/trimming.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.3. Environmental Site Design Practice #13: Reduce the Parking Footprints

<table>
<tr><th>KEY BENEFITS</th><th>USING THIS PRACTICE</th></tr>
<tr><td>• Reduces the amount of impervious cover and associated runoff and pollutants generated</td><td>• Reduce the number of parking spaces
• Minimize stall dimensions
• Consider parking structures and shared parking
• Use alternative porous surface for overflow areas</td></tr>
<tr><td colspan="2">This practice reflects the CWP Better Site Design Principles #6 (Parking Ratios), #7 (Parking Codes), #8 (Parking Lots), #9 (Structured Parking, and #10 (Parking Lot Runoff)</td></tr>
</table>

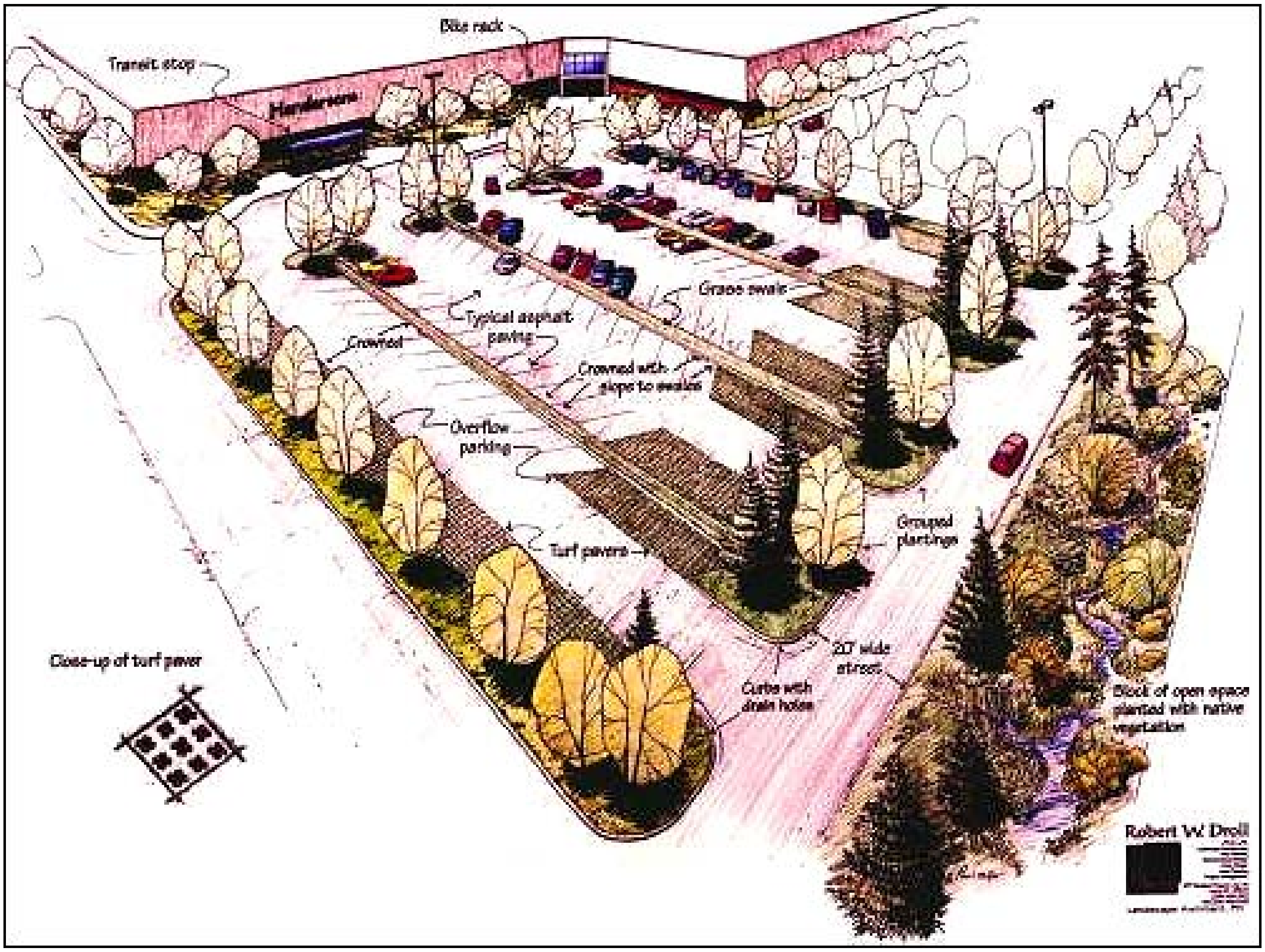


Figure 6.55. Multiple Stormwater Management Strategies Applied to Parking Lot
Source: Chesapeake Bay Stormwater Training Partnership

Stormwater management requirements can be met in many cases by applying environmental site design principles to parking lot design. Overall imperviousness associated with parking lots can be reduced by eliminating unneeded spaces, providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, using multi-storied parking decks, and using permeable pavers or pavement surfaces in overflow parking areas, where feasible, to reduce and treat stormwater runoff. Reducing imperviousness and replacing it with valuable green space also helps to reduce the urban heat island effect.

A complete discussion of all of the relevant parking/stormwater issues links to larger macro planning issues quite quickly. Stated simply, low density development sprawling into the countryside – widely scattered subdivisions, office parks and shopping centers along major roadways and at expressway interchanges – typically forces maximum reliance on the automobile for transportation. This means more trips will be generated on a per-resident or per-capita basis, so there is a need for more parking accommodations. By contrast, with Transit Oriented Design (TOD) or Traditional Neighborhood Design (TND), the total number of auto trips is reduced as the result of walking, biking or using available transit services, so parking needs are reduced. Furthermore, the mixture of uses as found in these neo-traditional TOD/ TND configurations also means that opportunity for creative “sharing” of spaces can be devised so that daytime spaces can be used for nighttime parking demand as well. This minimizes the suburban separation of uses with its vast zones of single-purpose parking lots. Additionally, this blending of uses and sharing of parking spaces can help to deflect the peak demand factor (i.e., the shopping mall at Christmas) that has driven so many municipal parking requirements. But there are also ESD techniques that can minimize parking-related imperviousness, even when more conventional modes of development are used.

For example, the aerial photo in **Figure 6.56** below shows a parking lot in Minneapolis, Minnesota. The University of Minnesota’s Metropolitan Design Center redesigned the lot to demonstrate how impervious area can be reduced while maintaining the same number of required parking spaces. **Figure 6.57** is a graphic of the parking lot as originally designed, showing that the drive aisles and several of the parking spaces in the lot *exceed* the city’s minimum parking requirements. The drive lanes are 28-feet wide. However, the city requires a minimum of 22 feet for two-way driving lanes and 20 feet for one-way lanes in parking lots with 90° parking stalls. The green spaces do not effectively capture stormwater runoff and the trees do not shade the parking lot.

Figure 6.58 shows the redesign. By reducing the interior driving lanes to 20-feet wide and increasing the percentage of compact spaces, green space can be increased to 22 percent. Effective use of the minimum parking space and aisle dimensions as permitted in the city’s zoning code allows the number of parking spaces to remain the same, while adding valuable green space to the parking lot.

Figure 6.56. Original Parking Lot. Source: Philadelphia Stormwater Manual

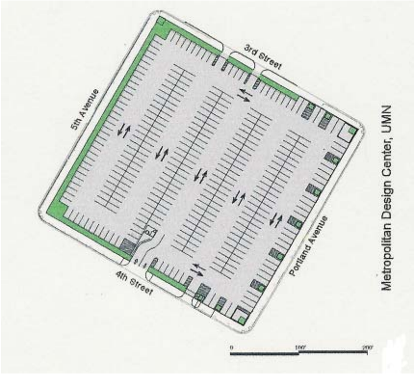


Figure 6.57. Original Design Source: Philadelphia Stormwater Manual

255 standard parking spaces
70 compact parking spaces
325 total parking spaces
Total green space: 6.5%

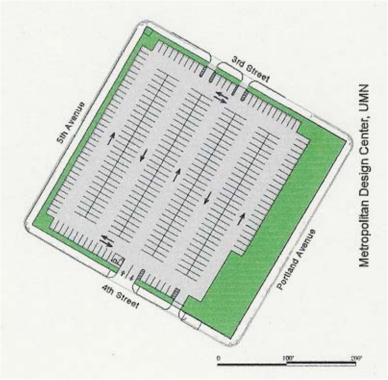


Figure 6.58. Redesigned Lot Source: Philadelphia Stormwater Manual

244 standard parking spaces
81 compact parking spaces
325 total parking spaces
Total green space: 22%

The bottom line is that smaller parking lots can sharply reduce impervious cover and provide more effective treatment of stormwater pollutants. In addition, smaller parking lots reduce both up front construction costs and long term operation and maintenance costs, as well as the size and cost of stormwater practices. Parking lot landscaping makes the lot more attractive and comfortable for customers, and promotes safety for both vehicles and pedestrians. In addition, trees and other landscaping help screen adjacent land uses, shade people and cars, reduce summertime temperatures and improve air quality and bird habitat. In many communities, parking lots are over-sized and under-designed. Local parking and landscaping codes can be modified to allow the following ESD techniques to be applied within parking lots:

- Minimize standard stall dimensions for regular spaces
- Provide compact car spaces
- Use of pervious pavement (asphalt, concrete, blocks, sand amendments)
- Incorporate efficient parking lanes
- Reduce minimum parking demand ratios for certain land uses
- Treat the parking demand ratio as a maximum limit (rather than a minimum, which can be increased arbitrarily)
- Create stormwater “islands” in traffic islands or landscaping areas to treat runoff using bioretention, filter strips or other practices
- Encourage shared parking arrangements
- Use structured parking

Parking Space Ratios

Many localities rely on parking ratio standards prepared by recognized agencies and authorities. The common practice is to set parking ratios to accommodate the highest hourly parking need during the peak season. The trend in recent years has been to increase these ratios, perhaps reflective of the general increase in land development and traffic and congestion and the concern on the part of most localities to err on the conservative side. In some cases, minimum parking requirements are actually exceeded by the developer interested in promoting business. Municipalities typically establish *minimum* parking ratios, but rarely establish *maximum* parking ratios (the maximum possible number of spaces *allowed to be built* at a project). This typically results in parking lot designs with far more spaces than are actually required, where the vast majority of parking spaces are unused most of the time. By determining average parking demand instead, a lower maximum number of parking spaces can be set to accommodate most of the demand. **Table 6.18** provides examples of conventional parking ratio requirements and compares them to average parking demand. **Figure 6.59** below shows the variation in parking space sizes across the nation.

Table 6.18. Conventional Minimum Parking Ratios

Land Use	**Parking Requirement**		**Actual Average Parking Demand**
	Typical Parking Ratio	**Typical Range**	
Single family homes	2 spaces per dwelling unit	1.5 – 2.5	1.11 spaces per dwelling unit
Shopping Centers	5 spaces per 1000 sq. ft. gross *floor* area (GFA)	4.0 – 6.5	3.97 per 1000 sq. ft. GFA
Convenience Store	3.3 spaces per 1000 sq. ft. GFA	2.0 – 10.0	--
Other Retail	4 spaces per 1000 sq. ft. GFA	--	--
Restaurant	1 space for 50 sq. ft. of gross *leasable* area	--	--
Industrial	1 space per 1000 sq. ft. GFA	0.5 – 2.0	1.48 per 1000 sq. ft. GFA
Professional Office	5 spaces per 1000 sq. ft. GFA	4.5 – 10.0	4.11 per 1000 sq. ft. GFA
Church	1 space per 5 seats	--	--
Golf Course	4 spaces per hole	--	--
GFA – Gross floor area of a building, not counting storage or utility spaces			

Source: Adapted from CWP (1998a) and Chesapeake Bay Stormwater Training Partnership

The first parking-related objective of ESD is to avoid inflated parking ratios. All parking requirements should be revisited, compared with neighboring municipalities, and compared with actual experience. In the ideal, a study of actual developments and their respective experiences should be undertaken. However, elaborate studies can be circumvented by quick phone calling and other creative ways to assess the local situation. Ratios such as the typical 5 spaces per 1,000 square feet of gross leasable floor area should be downwardly adjusted as much as possible. Depending upon the specific use involved, ratios driven by peak demand such as for shopping centers may be able to be further reduced if combined with special parking overflow provisions.

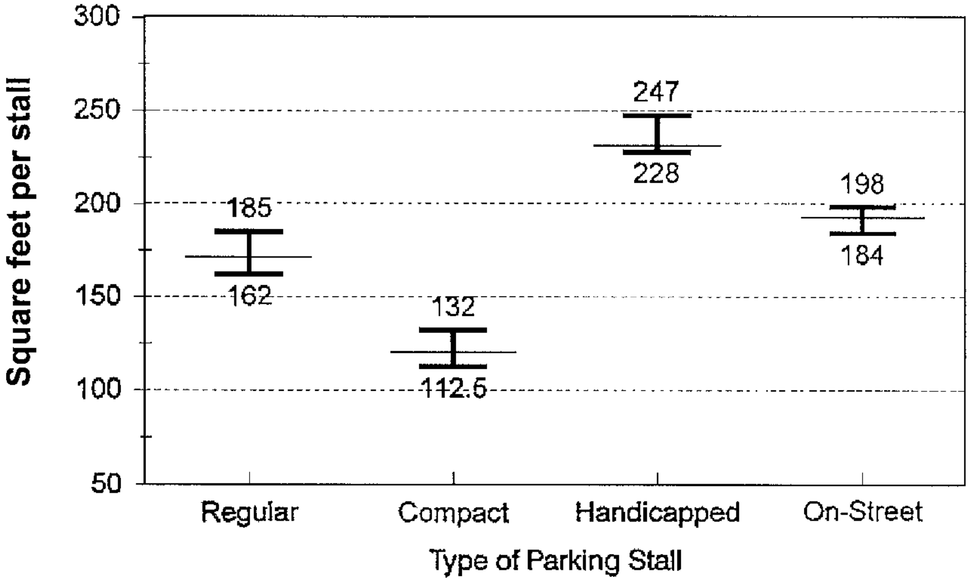


Figure 6.59. Variation in Parking Space Sizes Across the U.S.
Source: Schueler (1995)

However, it is important that adjustment of ratios is done with care. Some office parks, for example, are experiencing "employment intensification" which is certainly compatible with many growth management principles being espoused nationally. As companies grow, more employees typically are hired (downsizing excepted); and ratios of employees per square foot of work area increase. Therefore, cars usually increase, along with the demand for more parking.

In light of this, communities should re-evaluate their parking demand ratios based on local surveys of actual parking lot use rates for a mix of common land uses or activities. Localities should also make it clear that their parking ratios should be interpreted as the *maximum* number of spaces that can be built at a project, unless compelling data justify that more parking spaces are actually needed (based on actual parking demand studies). Reducing parking spaces to numbers reflecting actual use can also reduce construction costs significantly. Costs per space ranged from $1,200 to $1,500 in 1995 (Markowitz). Reducing a commercial parking ratio from 5 spaces to 4 spaces per 1,000 square feet of gross floor area could result in savings of tens of thousands of dollars, even then. Savings would likely be much greater today.

Parking Stall and Aisle Dimensions

Parking lots are the largest component of impervious cover in most commercial and industrial zones, but conventional design practices do little to reduce the paved area in parking lots. The size of a parking lot is driven by stall geometry, lot layout and parking ratios. A parking space is composed of five impervious components, of which the stall is only one part:

- The overhang at the edge of the stall (beyond the car)
- A narrow curb (or curb stop)
- The parking stall
- The parking aisle that allows access to the stall; and
- A share of the common impervious area (e.g., fire lanes, entrances, and traffic lanes)

In terms of parking stall design standards, parking stall size can be reduced without compromising performance of the parking lot. In most parking codes, stall size itself can range from 162 to 200 square feet. A standard dimension in years past has been approximately 10-by-20 feet, borne out of the large car era. Schueler, assuming a 9.5-by-19 foot space dimension further points out that with the typical overhang zone provided plus the appropriate share of the parking aisle, this parking space impervious area increases to 400 square feet, nearly twice the area of the parking stall itself (see **Figure 6.60** below).

With the downsizing of vehicles, even full size vehicles such as SUVs, a reasonable size adjustment to the parking stall would be 9-by-18 feet, nearly a 20 percent reduction in impervious area lot-by-lot, or even 7.5-by-15 feet for compact stalls (a reduction of nearly 50 percent), which comprise 40-50 percent of all cars on the road. A fixed percentage of these compact stalls should be specified (perhaps 20 to 35 percent of the total number of stalls, depending upon use, local experience, etc.).

Another component of the lot layout is the internal geometry or traffic pattern. The traffic flow of the parking lot design can be optimized to eliminate unneeded lanes (drive aisles). For example, two-way traffic aisles require greater widths than one-way aisles (for example, from 24 to 18 feet). One-way aisles used in conjunction with angled parking stalls can significantly reduce the overall size of the parking lot. Depending upon the size and configuration of the parking lot, total impervious area of the parking lot may decrease by as much as 10 percent.

Structured Parking

Most communities do not specify the type of parking structure to be built (e.g., surface lot or parking garage). The type of parking facility constructed in a given area is a reflection of the cost of land and construction expenses. In suburban and rural areas, where land is relatively inexpensive, surface parking costs much less than a parking garage. However, in highly urban areas with higher land costs, multi-deck garages may be more economical per car space than open lots. Also, if neo-traditional TND/TOD concepts are put into practice, densities can be increased sufficiently so that structured parking can make economic sense. Structured parking decks are one method to significantly reduce the overall impervious area footprint. **Figure 6.61** below shows a parking deck used for a commercial development.

Local governments should consider providing incentives (e.g., tax credits, stormwater waivers, or density, floor area, or height bonuses) to encourage the construction of multi-level, underground, and under-the-building parking structures. In this manner, developers can reduce the land cost chargeable to parking.

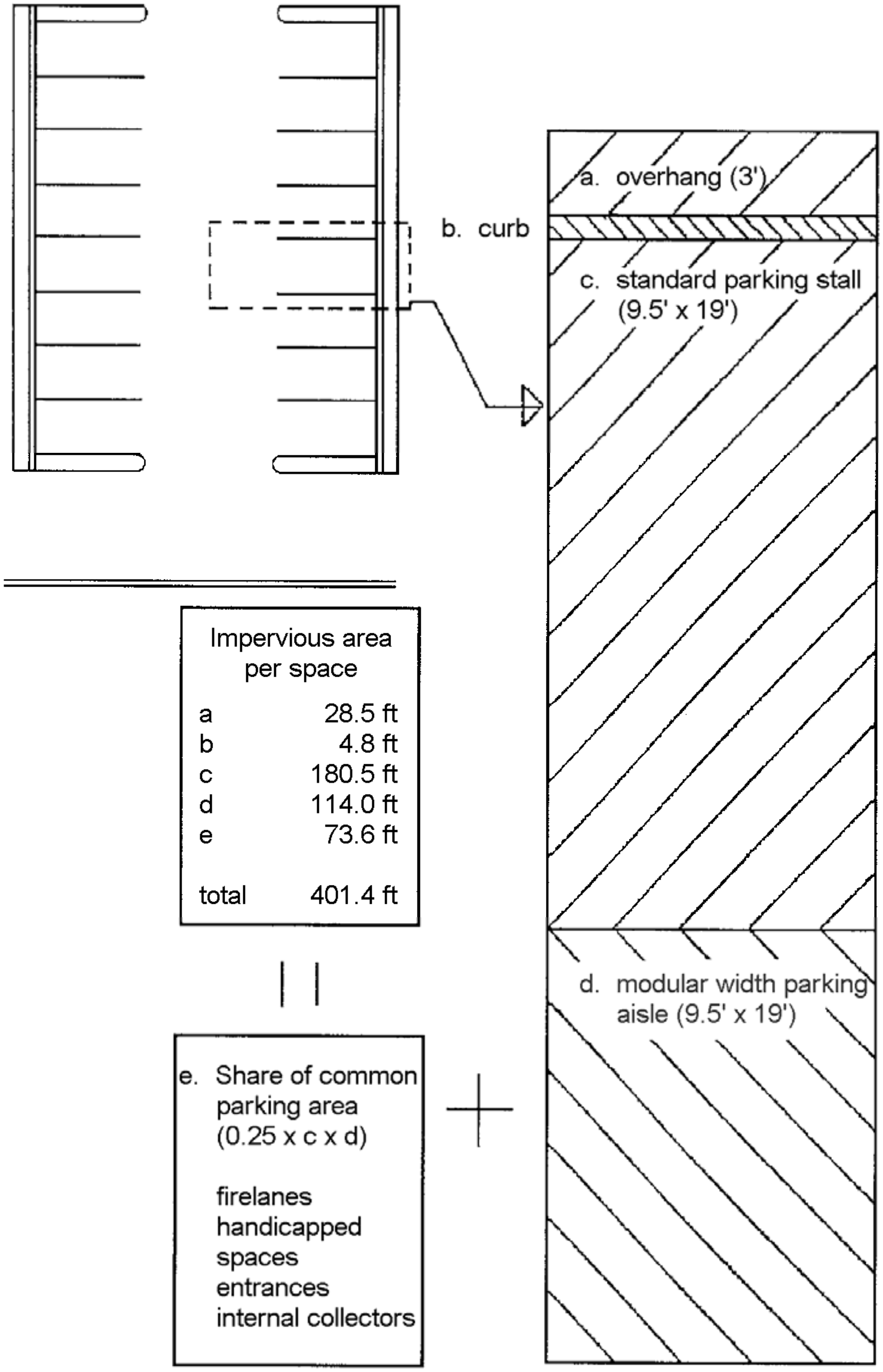


Figure 6.60. Parking Stall Dimension Analysis
(Source: Schueler, 1997)

Figure 6.61. Structured Parking at an Office Park Development
Source: ARC (2001)

Shared Parking Spaces

Depending on site conditions (i.e., proximity to mass transit or a mix of land uses), it is possible to reduce the number of parking spaces needed. Parking can be shared in mixed-use areas by creatively pairing uses wherever possible, especially when the adjoining parking demands occur and different times during the day or week (see **Table 6.19**). A shared parking arrangement could include usage of the same parking lot by an office space that experiences peak parking demand during weekdays with a church that experiences parking demands during the weekends and evenings.

Table 6.19. Land Uses with Different Peak Daily Operating Times

Land Uses with Daytime Peak Hours	Land Uses with Evening Peak Hours
Banks	Bowling Alleys
Business Offices	Hotels (without conference facilities)
Professional Offices	Theaters
Medical/Dental Clinics	Restaurants
Service Stores	Bars
Retail Stores	Night Clubs
Manufacturer/Wholesale	Auditoriums
Grade Schools/High Schools	Meeting Halls

Source: CWP (1998a)

Mass transit (light rail, transit buses, etc.) can lower parking demand directly by reducing the number of vehicles driven and, therefore, the number of vehicles that need to be parked. Furthermore, mass transit is a key strategy for reducing traffic congestion and air pollution.

Developers often don't even attempt such sharing because of the perception that officials would simply reject the concept. Municipalities should incorporate such sharing concepts into their requirements. There are straightforward guidelines which can be used to make sharing operate reasonably. Localities should even consider providing incentives for developers to use sharing options. Sharing is another effective way to reduce parking demand and impervious surfaces.

Alternate (More Permeable) Parking Area Surface Materials

A variety of other design-linked techniques should be evaluated, including altered approaches to spillover parking where pervious pavement approaches can be used. Gravel in these rarely used zones should be considered, or perhaps some version of grid pavers (several types are now available). Even grass may be a possible option. Pervious paving materials are usually less durable than asphalt, but they are appropriate for less traveled spillover areas.

Figures 6.62 and 6.63 below are examples of porous paver used at overflow parking areas. Alternative pavers can also capture and treat runoff from other site areas. However, porous pavement surfaces generally require proper installation and more maintenance than conventional asphalt or concrete. For more specific information using these alternative surfaces, see the Specification for *Permeable Pavement* on the Virginia Stormwater BMP Clearinghouse web site at: http://www.vwrrc.vt.edu/swc/ .

Construction costs for permeable pavement materials are generally higher than for conventional pavements. However, cost savings due to reduced curb and gutter and reduced stormwater management requirements can offset this initial cost difference. Similarly, reduced storm sewer and stormwater management facility maintenance requirements may offset the generally greater maintenance requirements associated with permeable pavement.

Figure 6.62. Grass Paver Surface Used for Parking
Source: ARC (2001)

Figure 6.63. Other Options for Permeable Surfaces in Fringe Parking Areas
Source: Cahill & Associates

Incorporation of Additional Parking Lot Stormwater Control Measures

Parking lots are significant sources of stormwater pollutants in the urban/suburban landscape, particularly in commercial areas. These large impervious areas also generate significant volumes of stormwater runoff, which typically carries the pollutants into nearby streams. *During the design stage*, parking lot layout and BMP choice are two linked and important considerations for an effective design. The most practical layout should be chosen for the lot. The BMPs used in the design should be located at the lowest point(s) of elevation of the parking lot. Whenever possible, plan to integrate bioretention areas, filter strips, and permeable paving materials into parking lots and required landscaping areas and traffic island. These practices will remove pollutants and infiltrate much of the runoff into the ground, rather than merely transferring it into local surface waters. The application of green parking techniques in various combinations can dramatically decrease times of concentration and detention times of a site. Reducing the volume of runoff discharged into receiving streams and stretching out the time during which it is discharged also helps to protect the structural and biological integrity of the receiving channels.

The two photos below (**Figure 6.64** below) show the parking lot of a public school in Portland, Oregon. The school used a better layout to increase the number of spaces available and to capture the runoff and treat and infiltrate it through vegetated infiltration beds (e.g., Virginia Stormwater Design Specification No. 10, Bioretention, or Virginia Stormwater Design Specification No. 11, Dry Swale). **Figure 6.65** below shows a grass channel receiving runoff from a parking area, and **Figure 6.66** below shows a more robust bioretention installation in a parking area median.

Figure 6.64. Glencoe Elementary School Parking Lot (Before and During Storm), Portland, Oregon
Source: Philadelphia Stormwater Manua

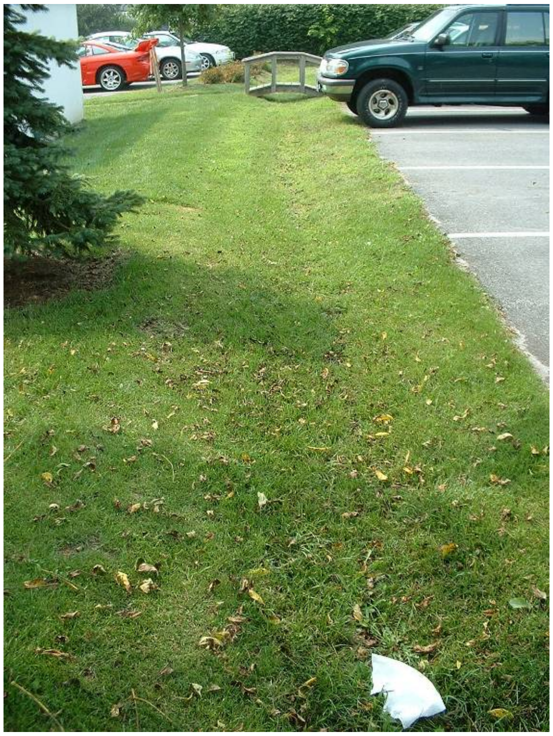


Figure 6.65. Grass Channel Receiving Parking Lot Runoff. Source: CWP

Figure 6.66. Bioretention in Parking Median.
Source: Center for Watershed Protection

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.12: Reduce urban heat island effects	3 - 5

6.5.3.4. Environmental Site Design Practice #14: Reduce Setbacks and Frontages

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated	• Reduce building and home front and side setbacks • Consider narrower frontages
This practice reflects the CWP Better Site Design Principle #12 (Setbacks and Frontages)	

Many subdivision codes have very strict requirements that govern the geometry of the lot. These include side yard setbacks, minimum lot frontages, and lot shape (see **Figure 6.67**). Although the precise requirements vary from locality to locality, most localities require structures, especially residences, to be set back specific distances from street and highway rights-of-way, which are typically somewhat landward of the edge of the street to begin with. Structures typically must be set back from lot lines on the side and rear as well, all of which effectively requires lots to be quite large. Similarly, yard requirements (front, side, and rear) often are comparably overstated. Typically, lot-by-lot street frontage requirements are excessive, making concentrated development configuration difficult or impossible. From this perspective, such setbacks must be viewed as contrary to the goals and objectives of ESD.These criteria constrain and, in some cases, prevent site planners from designing open space or cluster developments that can reduce impervious cover.

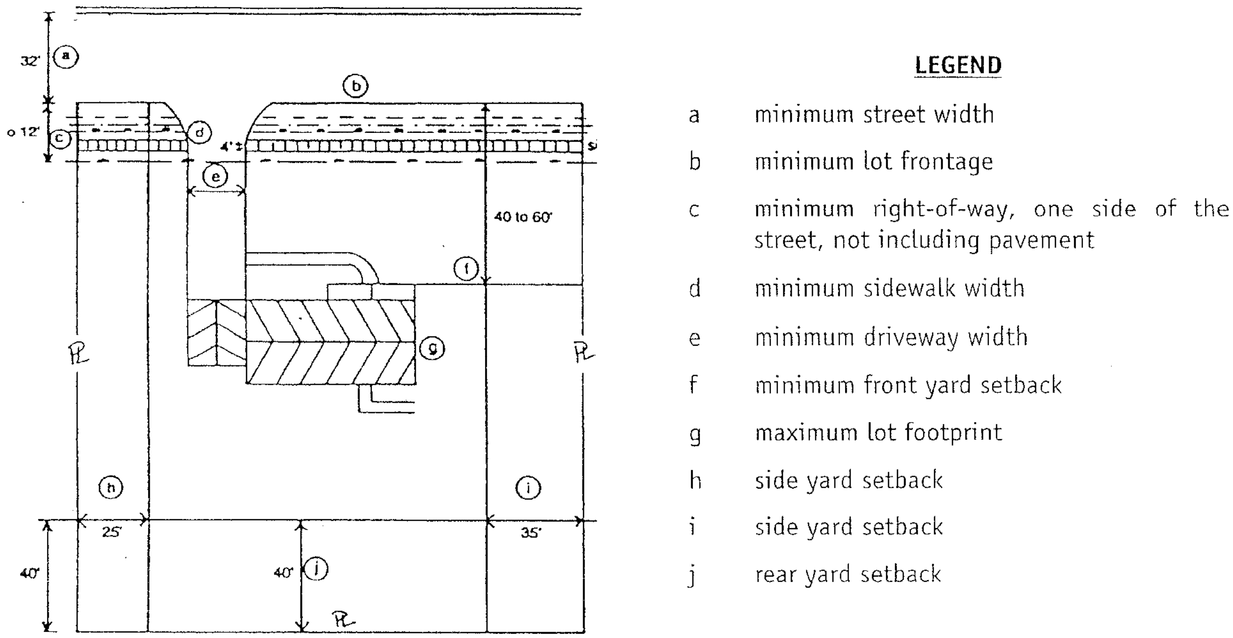


Figure 6.67. Setback Geometry of a Typical 1-Acre Lot
Source: Schueler (1995)

Setbacks and frontage distance requirements can increase impervious cover in the following ways:

- Front yard setbacks, which dictate how far houses must be from the street, can extend driveway length.
- Large side setbacks and frontage distances (usually larger as housing density increases) directly influence the road length needed to serve individual lots.

Smaller setbacks and frontage distances, which are often essential for open space designs, are typically not permitted or require a zoning variance, which may be difficult to obtain.

Setbacks and frontage widths have evolved over time and have been used in local jurisdictions to satisfy a variety of community goals. Often setback and frontage distances are used to ensure uniform appearance and equally-sized lots. Setbacks are often used for fire safety purposes (i.e., to prevent fire from spreading from forests to a house or from one house to another) and traffic concerns. Frontage distances are often set to provide for residential parking. The availability of on-street parking is largely determined by the street length serving each lot, which is set by minimum frontage distance.

Reduction in setbacks is integral to clustering and reducing imperviousness. Communities can reduce impervious cover by relaxing or reducing front and side yard setbacks and allowing for narrower frontage distances. Allowing for narrower side yard setbacks leads to narrower lot widths. With narrower lots, shorter roads are needed, which reduces overall imperviousness. Relaxing front yard setbacks leads to shorter front yards. This eliminates the need for long driveways, which are found in many conventional subdivisions. Flexible setback and frontage requirements allow developers to be creative in producing attractive and unique lots, more interesting neighborhood aesthetics, and more compact lots that provide sufficient room for personal living and recreation while still creating common open space areas. This can allow the flexibility to preserve open space on the development site.

Building and home setbacks should be shortened to reduce the amount of impervious cover from driveways and entry walks. A setback of 20 feet is more than sufficient to allow a car to park in a driveway without encroaching into the public right of way, and reduces driveway and walkway pavement by more than 30% compared with a setback of 30 feet (see **Figure 6.68** below). Reducing imperviousness also helps to reduce the urban heat island effect.

Further, reducing side yard setbacks and using narrower frontages can reduce total street length, especially important in cluster and open space designs. **Figure 6.69** below shows residential examples of reduced front and side yard setbacks and narrow frontages.

Flexible lot shapes and setback and frontage distances allow site designers to create attractive and unique lots that provide homeowners with enough space while allowing for the preservation of natural areas in a residential subdivision. **Figure 6.70** below illustrates various non-traditional lot designs. Market research and homeowner surveys have shown that, for the most part, flexible setbacks and frontage requirements can provide communities that are attractive to both homeowners and potential home buyers (ULI, 1992).

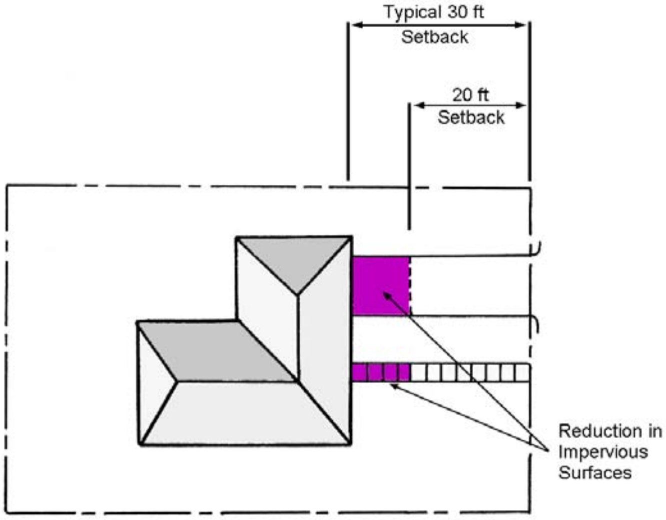


Figure 6.68. Reduced Impervious Cover by Using Smaller Setbacks
(Source: MPCA, 1989)

Figure 6.69. Examples of Reduced Frontages and Side Yard Setbacks
Source: ARC (2001)

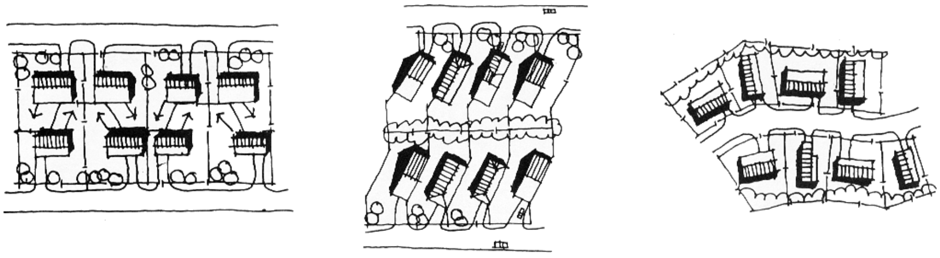

Zipper Lots Angled Z-Lots Alternative Lot Widths

Figure 6.70. Non-Traditional Lot Designs
(Source: ULI, 1992)

Parking

One concern of this approach is that by reducing overall street length, reduced frontages result in less on-street parking. However, a frontage distance of fifty feet allows for on-street parking of two cars for each lot. Parking concerns can usually be addressed through site design in most residential zones.

A common parking concern relates to ownership of extra cars, boats, or large recreational vehicles. In the unlikely event that additional parking demand cannot be met through site design, communities may consider providing a common (shared) overflow parking area in the neighborhood (this is often done at apartment developments). When many homeowners are expected to own RVs or boats, expanding existing driveways using permeable pavement surfaces could provide the needed parking area.

Safety

Safety considerations include fire protection and adequate sight distances for drivers. Fire protection concerns focus on the proximity of structures to each other. When front and side setbacks are reduced, homes are closer together. This has led to the concern that fire could spread easily from one home to another. However, with the development of fire-retardant materials and the use of fire walls, the need for large setbacks has been reduced.

Adequate sight distance is an important aspect of safe road design. Site designers tend to rely on state and local government street criteria (e.g., minimum horizontal and vertical curve criteria) and rarely consider site (and lot) specific conditions when developing road layouts. According to AASHTO (1994), potential sight distance impairments can be avoided if visual obstructions (e.g., garages, front porches, etc.) are placed 1.5 feet or more from the curb. That small distance is considerably less than the 30-feet front setback required by many communities.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.5. Environmental Site Design Practice #15: Use Fewer or Alternative Cul-de-Sacs

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated	• Consider alternative Cul-de-Sac designs
This practice reflects the CWP Better Site Design Principle #4 (Cul-de-Sacs)	

Cul-de-sacs are local access streets with a closed circular end that allows for vehicle turnarounds. Many of these cul-de-sacs can have a radius of more than 40 feet. From a stormwater perspective, cul-de-sacs create a huge bulb of impervious cover, increasing the amount of runoff. For this reason, reducing the size of cul-de-sacs through the use of alternative turnarounds or eliminating them altogether can reduce the amount of impervious cover created at a site.

Site designers should minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of a cul-de-sac should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should also be considered. Alternative turnarounds are designs for end-of-street vehicle turnarounds that replace cul-de-sacs and reduce the amount of impervious cover created in developments. Reducing imperviousness also helps to reduce the urban heat island effect.

Numerous alternatives create less impervious cover than the traditional 40-foot cul-de-sac. These alternatives include reducing cul-de-sacs to a 30-foot radius and creating hammerheads ("tees"), and loop roads (see **Figures 6.71**). Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. Fire trucks, service vehicles and school buses are often cited as needing large turning radii. However, some fire trucks are designed for smaller turning radii. In addition, many newer large service vehicles are designed with a tri-axle (requiring a smaller turning radius) and many school buses usually do not enter individual cul-de-sacs.

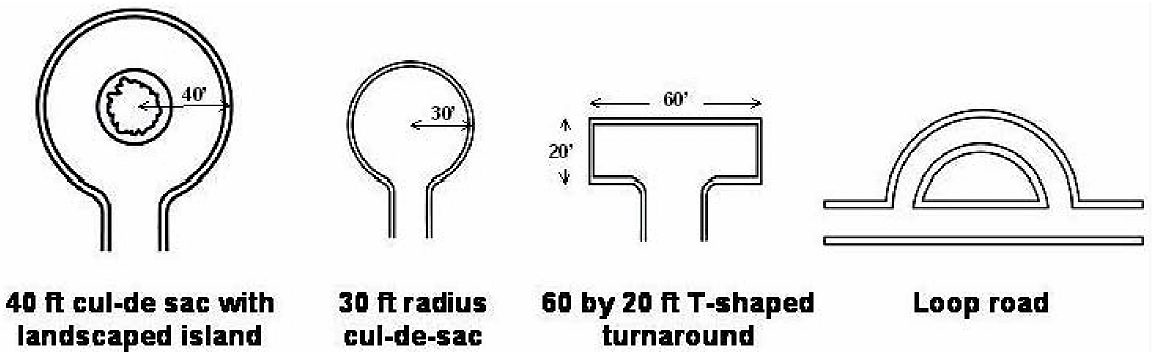


Figure 6.71. Four Turn-Around Options for Residential Streets
(Source: Schueler, 1995)

Another way to reduce the imperviousness of traditional cul-de-sacs is to creat a loop road, as shown in **Figure 6.72** below. Still another method is to create a pervious island or stormwater bioretention area in the middle of the cul-de-sac (**Figures 6.73 through 6.75** below).

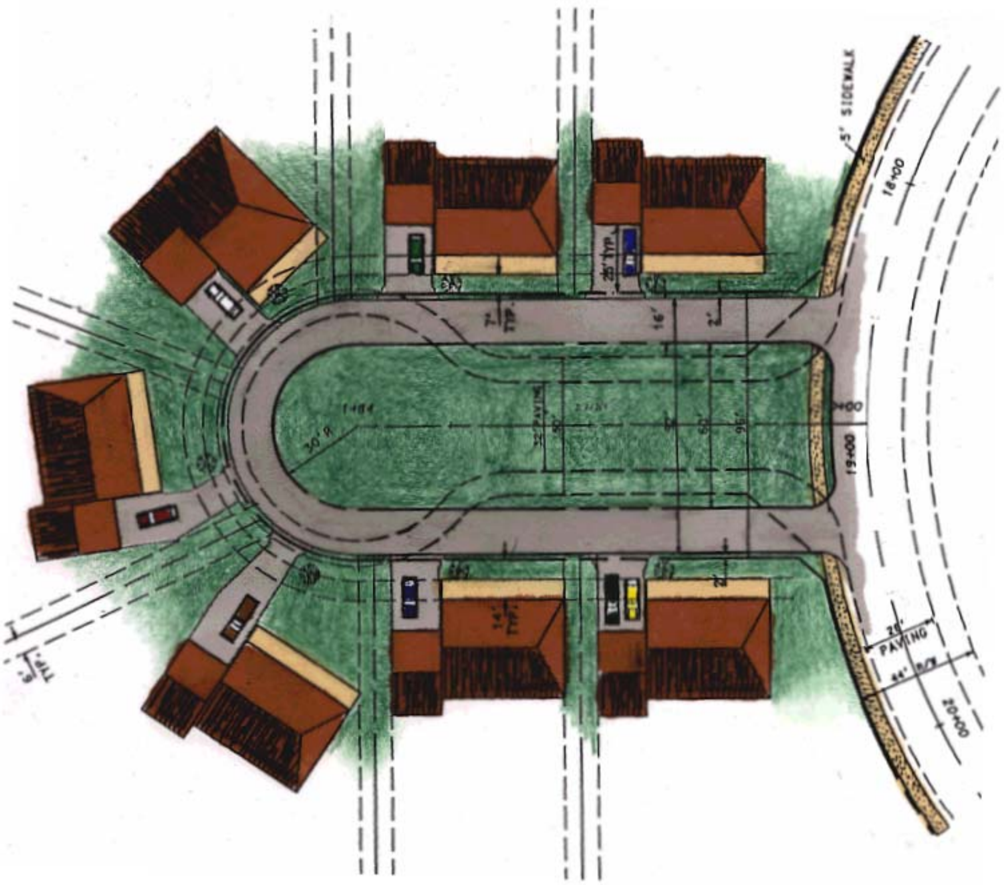


Figure 6.72. Use of a loop road to avoid creating a cul-de-sac.
Source: Chesapeake Bay Stormwater Training Partnership

Figure 6.73. Trees and vegetation planted in the landscaped Island of a cul-de-sac (left) and a loop road (right)
Source: MPCA (2006)

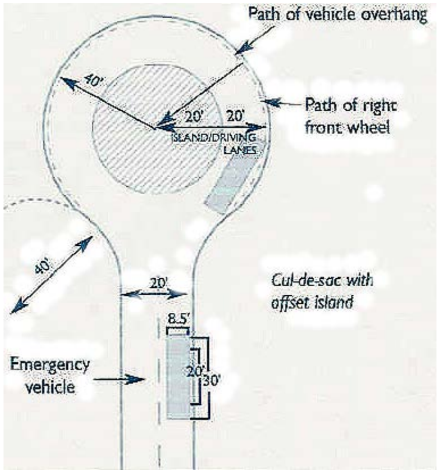


Figure 6.74. Alternative cul-de-sac design. Source: Connecticut Stormwater Quality Manual

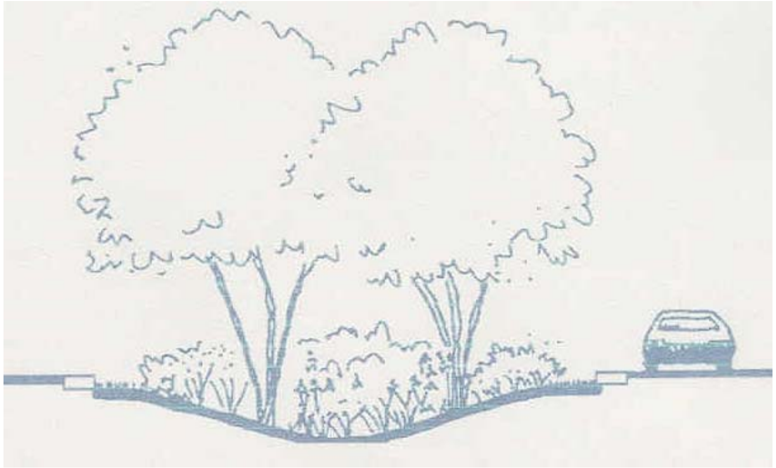


Figure 6.75. Recessed bioretention area in cul-de-sac Source: Connecticut Stormwater Quality Manual

Of course, another solution to the cul-de-sac problem is to apply site design strategies that avoid or minimize dead-end streets and cul-de-sacs altogether. Implementing alternative turnarounds will require addressing local regulations and marketing issues. Communities may have specific design criteria for cul-de-sacs and other alternative turnarounds that need to be modified.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.6. Environmental Site Design Practice #16: Create Parking Lot Stormwater "Islands"

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Provides an opportunity for the siting of structural control facilities • Trees in parking lots provide shading for cars and are more visually appealing	• Integrate porous areas such as landscaped islands, swales, filter strips and bioretention areas in a parking lot design

Provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands (**Figure 6.76**). Parking lots should be designed with landscaped stormwater management "islands" which reduce the overall impervious cover of the lot as well as provide for runoff treatment and control in stormwater facilities.

When possible, expanses of parking should be broken up with landscaped islands which include shade trees and shrubs. Fewer large islands will sustain healthy trees better than more numerous very small islands. The most effective solutions in designing for tree roots in parking lots use a long planting strip at least 8 feet wide, constructed with sub-surface drainage and compaction resistant soil.

Figure 6.76. Parking Lot Stormwater Island

Structural practices such as filter strips, dry swales and bioretention areas can be incorporated into parking lot islands. Runoff is directed into these landscaped areas and is temporarily detained. It then flows through or filters down through the bed of the facility and is infiltrated into the subsurface or collected for discharge into a stream or another stormwater facility. These facilities can be attractively integrated into landscaped areas and can be maintained by commercial landscaping firms. It is important to examine runoff volumes and velocities and ensure runoff enters bioretention facilities in a distributed manner and at non-erosive velocities. It is also important to ensure that bioretention facilities have proper pre-treatment. For detailed specifications of such practices, refer to the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.12: Reduce urban heat island effects	3 - 5

6.5.4. Using Natural Features and Runoff Reduction to Manage Stormwater

An ESD strategy seeks to maximize the use of pervious areas at the site to help filter and infiltrate runoff generated from impervious areas and to spread excess runoff from these surfaces over pervious areas. Most development sites have extensive areas of grass or landscaping where runoff can be treated close to the source where it is generated. Designers should carefully look at the site for pervious areas that might be used to disconnect or distribute runoff.

Traditional stormwater drainage design tends to ignore and replace natural drainage patterns and often results in overly efficient hydraulic conveyance systems. Structural stormwater controls are costly and often can require high levels of maintenance for optimal operation. Through use of natural site features and drainage systems, careful site design can reduce the need and size of structural conveyance systems and controls.

Almost all sites contain natural features which can be used to help manage and mitigate runoff from development. Features on a development site might include natural drainage patterns, depressions, permeable soils, wetlands, floodplains, and undisturbed vegetated areas that can be used to reduce runoff, provide infiltration and stormwater filtering of pollutants and sediment, recycle nutrients, and maximize on-site storage of stormwater. Site design should seek to utilize the natural and/or nonstructural drainage system and improve the effectiveness of natural systems rather than to ignore or replace them. These natural systems typically require low or no maintenance and will continue to function many years into the future.

Soils are the foundation for successful planting, and the water holding capacity of soils can significantly reduce the volume of runoff from a site. In addition to successful plant growth, soils can be engineered to improve water holding capacity. For example, tight soils can be amended with compost to recover soil porosity lost due to the soil’s natural materials, compaction as a result of past construction activities, soil disturbance, and on-going human traffic. The amendment process seeks to recover the porosity and bulk density of soils by incorporating soil (McDonald, 1999). The humus material of compost has a water holding capacity of up to 80 percent by weight. This quality is very significant when trying to decrease runoff and increase filtration.

On-site soils can be amended by incorporating compost into the soils or by laying a one to three inch “blanket” of compost on top of the soils. Fiber amendments can assist in maintaining soil structure even with heavy surface loads. The method chosen depends on site characteristics and the purpose it is intended to serve, such as promoting infiltration or reducing nutrient and sediment loading to surface waters. Some of the methods of incorporating natural features into an overall stormwater management site plan include the following practices:

- Manage stormwater outfalls to protect natural receiving waters
- Use buffers and undisturbed areas
- Use natural drainageways instead of storm sewers
- Use vegetated swales instead of curb and gutter
- Drain runoff to pervious areas
- Amend tight soils with compost

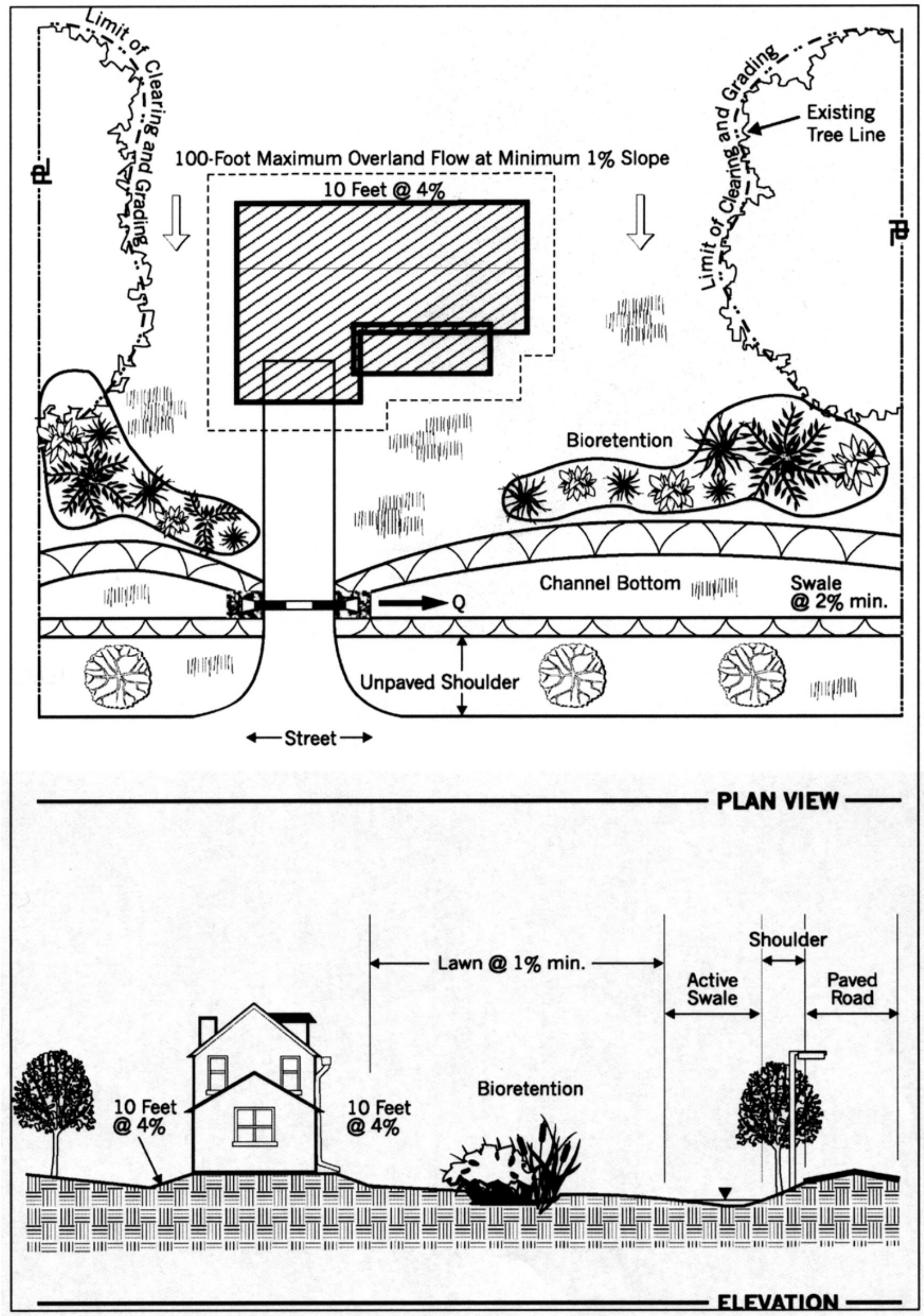


Figure 6.77. Residential Site Design Using Natural Features for Stormwater Management
(Source: Northern Shenandoah Valley Regional LID Manual, 2005)

The following pages cover each practice in more detail.

6.5.4.1. Environmental Site Design Practice #17: Use Buffers and Undisturbed Filter Areas

KEY BENEFITS	USING THIS PRACTICE
• Riparian buffers and undisturbed vegetated areas can be used to filter and infiltrate stormwater runoff • Natural depressions can provide inexpensive storage and detention of stormwater flows	• Direct runoff towards buffers and undisturbed areas using a level spreader to ensure sheet flow • Use natural depressions for runoff storage • Disconnect these areas from the flow from impervious areas

With proper design, undisturbed natural areas, such as forested conservation areas and riparian buffers, or vegetated filter strips, can be used to receive runoff in the form of sheet flow from upslope areas of the development site. Runoff can be directed towards grass filter strips, riparian buffers and other undisturbed natural areas delineated in the initial stages of site planning to infiltrate runoff, reduce runoff velocity and remove pollutants (see Stormwater Design Specification No. 2, Sheet Flow to Vegetated Filter Strip or Conserved Open Space). Natural depressions can be used to temporarily store (detain) and infiltrate water, particularly in areas with porous (hydrologic soil group A and B) soils. Vegetated filter strips may use existing vegetation or may be planted during the course of development.

The objective in utilizing natural areas for stormwater infiltration is to intercept runoff before it has become substantially concentrated and then distribute this flow evenly (as sheet flow) to the buffer or natural area. This can typically be accomplished using a level spreader, as seen in **Figure 6.78**. A mechanism for the bypass of higher flow events should be provided to reduce erosion or damage to a buffer or undisturbed natural area.

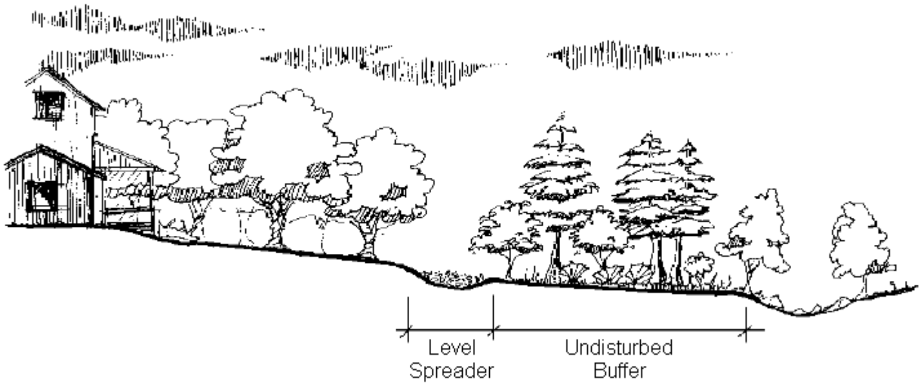


Figure 6.78. Using a Level Spreader with a Riparian Buffer
(Adapted from NCDENR, 1998)

Redirecting stormwater runoff from impervious surfaces to filter strips could also be categorized as “hydrologic disconnection” where the objective is to minimize stormwater conveyance through wide-scale distribution close to the point of generation. In these cases, sidewalks and driveways and other impervious features are designed to drain evenly onto adjacent pervious, presumably vegetated zones. Such zones may be lawn areas or planted groundcover, possibly even preexisting vegetation. In cases where contributing areas are relatively small in size and estimated flows are not great, provisions can be simple (e.g., roof drains discharging onto splash blocks). Carefully constructed berms can be placed around natural depressions and below undisturbed vegetated areas with porous soils to provide for additional runoff storage and/or infiltration of flows.

In the discussion here, Vegetated Filter Strips and Buffers are combined, although there are differences. One frequently cited difference is that filter strips often are created and planted, whereas buffers use existing vegetation. Another distinction is that filter strips ideally are located as close to the source of the runoff as possible, and are carefully integrated into the development landscape design (i.e., grassed filter strips often receive runoff from adjacent parking areas). In contrast, buffers are typically recommended as a technique to protect sensitive environmental features such as wetlands or stream corridors. Environmental site design includes proper buffering of these sensitive features from impact-generating uses.

Most filter strips have limited stormwater management capabilities and therefore, while still useful, are best suited for relatively low density development (i.e., flows generated by higher density development may be too intense). Also, their functions are maximized when only smaller storm events are treated (i.e., larger event flows should bypass the filter strip to prevent erosion). In many cases, filter strips are designed to treat up to the ½-inch rainfall, although both size of storm and density of development need to be taken into account. If designed properly, filter strips can be used to hold pre- to post-development runoff volumes constant. Practically speaking, this pre-to-post volume control is feasible only in relatively low density situations with the filter strip approach. Once runoff is concentrated and increases in rate and volume, the size of the required filter strip would need to be quite large – often impractically large – and provisions for managing the increased volume, such as use of berms, should be considered.

Another important aspect of quantity is peak rate control. Filter strips help to control peak rate as volume is controlled. As runoff passes through the filter strip and is infiltrated, peak rate is reduced. Although filter strips and buffers can infiltrate a certain amount of the runoff, they are often not adequate to satisfy peak rate criteria, especially when the contributing area is quite large. In these cases, they can be managed most effectively when used in conjunction with other ESD Practices and/or other stormwater control measures.

In terms of water quality, filter strips, when properly designed, are reasonably effective at reducing suspended solids and pollutants such as phosphorus that are bound to soil particles. The pollutants moving with infiltrated stormwater undergo physical, chemical, and biological removal processes. As stormwater moves through surface vegetation, resistance slows overland flow and promotes deposition of particulate pollutants (especially the larger particles). Pollutants are also removed through uptake by the vegetation itself. Plants absorb nutrients and even some metals. Over time, the sediment deposited, if not excessive, is incorporated into the soil mantle, aided by plant growth and decay. In low density applications and for small storm events, pollutant removal of non-soluble pollutants can be excellent. Specific design information and specifications on filter strips can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.3: Protect and restore riparian, wetland, and shoreline buffers	3 - 8
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.2. Environmental Site Design Practice #18: Use Creative Site Grading, Berming and Terracing (Terraforming)

KEY BENEFITS	USING THIS PRACTICE
• Creative site grading can be used to temporarily slow, capture or direct runoff to areas for infiltration • Natural depressions can provide inexpensive storage and detention of stormwater flows	• Reserve or define and create specific zones for infiltration • Use creative grading to direct flow there • Location should not interfere with use of the site or integrity of structures • Do not compact permeable soils
This practice reflects the CWP Better Site Design Principle #19 (Clearing and Grading)	

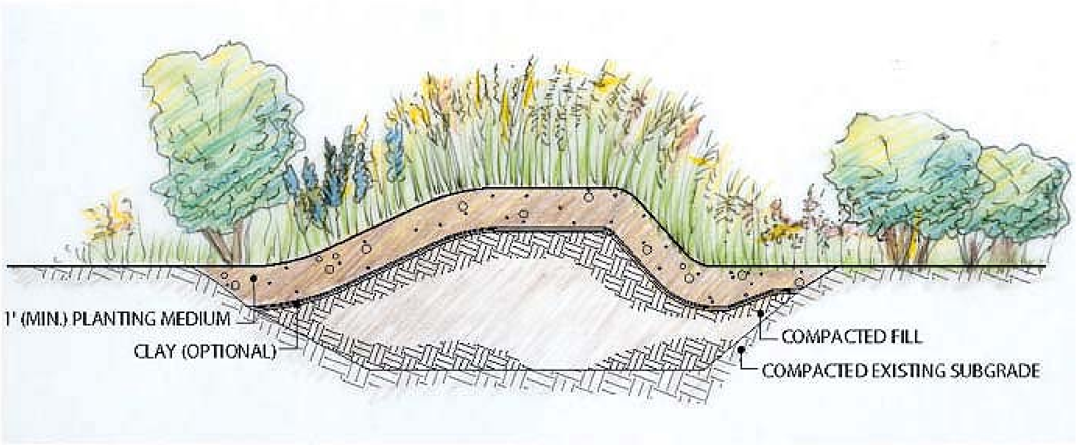


Figure 6.79. Components of a Berm Created for Stormwater Control
Source: Philadelphia Stormwater Manual

Many communities allow clearing and grading of an entire development site except for a few specially regulated areas such as jurisdictional wetlands, steep slopes, and floodplains. Very few communities restrict clearing and grading of buffers, open space and native vegetation during construction. As noted in the discussion of ESD Practice #1 (Preserve Undisturbed Natural Areas), sustainable design conserves as much of the site as is feasible in its natural state. Such conserved areas retain their natural hydrology and do not erode during construction. As a rule, clearing should be limited to the minimum area required for building and traffic footprints, construction access, and safety setbacks.

Terraforming is a term applied to a careful grading process designed to achieve specific objectives, such as infiltration rather than disposal of stormwater. Exact configurations resulting from this special grading may vary. For example, subtle, sometimes nearly imperceptible depressions or saucers can be integrated into the graded landscape to receive residential rooftop runoff or stormwater from the driveway or turnaround (see **Figures 6.80** below). Terraforming can be achieved at a micro-scale, replicated lot-by-lot, possibly replicating specific concepts throughout a development to facilitate both installation and ongoing maintenance (e.g., rear yard depressions, use of the driveway or elevated roadway to create subtle upslope dams, etc.).

Terraforming can be integrated effectively into larger scale site planning, such as at recreational areas or office parks, and can be independent of or integrated with BMPs such as bioretention or infiltration.

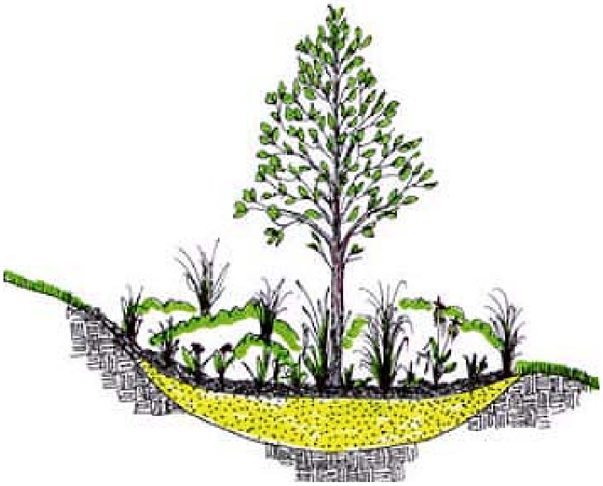


Figure 6.80. Berm Creates Small Bioretention Area.
Source: Philadelphia Stormwater Manual

A basic principle of environmental site design is to achieve an area-wide watershed build-out that minimizes total disturbance of natural vegetation and soil mantle to the extent possible. However, there are instances where the grading process can contribute to a positive solution, rather than resulting in environmental problems. Some communities have grading ordinances that prescribe maximum and minimum slopes for house lots. However, to maximize preservation of trees and other vegetation, some flexibility regarding slope criteria should be considered. For example, allowing a slightly steeper engineered slope in a limited area of the site than authorized by code may allow for preservation of more trees and native vegetation (see **Figure 6.81**).

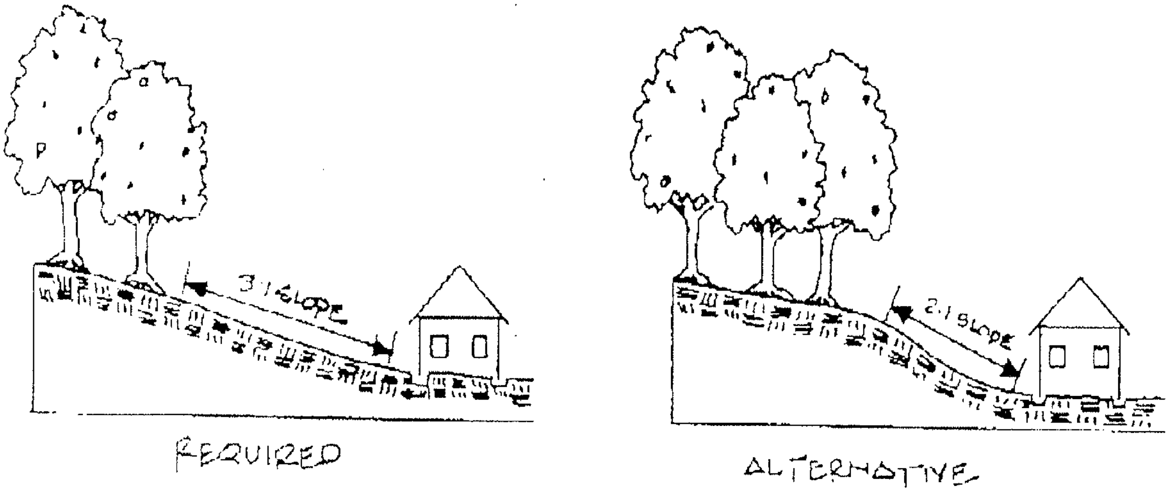


Figure 6.81. Allowing a Grading Variance Results in More Tree Protection
Source: CWP (1998a)

Disturbance of the natural vegetation and soil, if deemed necessary, can be accomplished carefully and with imagination so that natural processes can be exploited and enhanced to the maximum, and the full range of stormwater management objectives can be achieved. This particular technique, like so many others, is best used in conjunction with other techniques. Specific concepts range in scale and application from micro site-by-site terraformed saucers to creative use of subtle earthen berms placed in zones of existing vegetation.

In all cases, the objective is to achieve comprehensive stormwater management functions, including reduction of stormwater volumes, management of peak rates of discharge, and reduction of pollutant loadings. These objectives are accomplished as the runoff is collected and infiltrated through the soil mantle and the vegetative root zone, enabling a full range of physical, chemical, and biological processes to affect the stormwater.

However, because this technique is very reliant on the process of infiltration, all the factors constraining the use of infiltration-oriented BMPs come into play. Soil characteristics are critical. Tight soils with extremely poor permeability will suffer even worse compaction if graded and regraded, so they should not be considered for terraforming. Depth to bedrock and the seasonal high water table must be considered. Of course, berming in areas with existing vegetation and a developed root zone can be expected to provide better soil permeability.

Creative terraforming may not work in all developments. To the extent that concentrated development configurations are used, any lot-by-lot approach might be difficult to implement. Even in such settings there may be opportunities to use terraforming elsewhere on the site, such as in recreational open spaces. However, for those developments that have large lots with ample space for onsite stormwater management, the feasibility of terraforming should be considered.

Basic Criteria

Basic criteria or principles must be respected. In extremely heavy clayey soils, soil compaction may prevent infiltration. As with any infiltration-driven concept, avoid zones near structures, septic system drainfields, and so forth. Setback distances should vary with topography and other factors (e.g., infiltration downslope of basements requires less separation distance than infiltration upslope of basements). Furthermore, location of any terraformed areas should be evaluated from a user perspective. Ideally, the location should not interfere with but rather should enhance use of the site, such as sports playing fields. Usually this is not difficult to accomplish.

To the extent that this micro-scale site-by-site or grouped-site approach can be implemented, the terraforming concept is quite similar to designing for onsite septic system drainfields. The objective is to define and reserve specific areas of the site to accommodate these natural functions, whether the need be wastewater effluent management or stormwater management.

Berms

Berms are landscape features located along existing contours in moderately sloping areas. They are usually designed to intercept and direct runoff or to promote stormwater detention and infiltration. Berms and shallow depressions are suitable terraforming tools for both small and large projects. In most cases, berming is most effective when used in conjunction with other environmental site design principles and practices discussed in this chapter:

- A berm and depression can act as pre-treatment (e.g., a sediment forebay) before stormwater enters a a BMP such as a bioretention basin or infiltration facility.
- A berm placed downslope of such facilities can increase their detention capacity without additional excavation.
- A shallow depression can be created behind a berm to provide an small detention or infiltration area without the need for a more complex stormwater control measure.
- A berm can be placed across a slope to divert water to a nearby channel or BMP.
- A series of small berms and depressions can be placed along a slope to provide infiltration and detention while stabilizing the slope (see **Figure 6.82** below). However, as the slope increases, berms become more challenging to construct and the extent of natural area disruption increases.

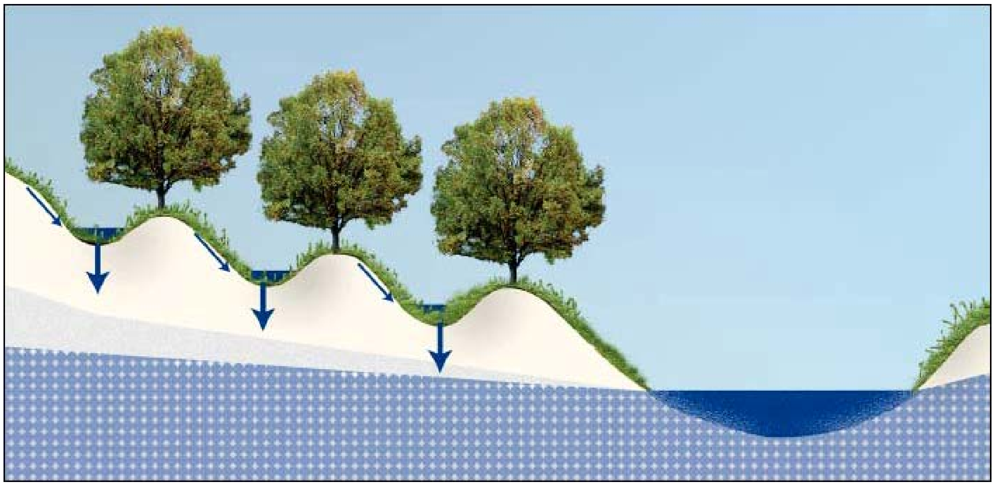


Figure 6.82. Successive Berms on Slope Create Multiple Bioretention Areas.
Source: Philadelphia Stormwater Manual

Conceptually, the fundamental work of the berm is to block the passage of runoff, retain it, and allow it to infiltrate naturally into vegetated areas upslope. In the ideal, a berm would simply be an impermeable wall, the top of which would assure sheet flow from larger storms onto vegetated areas downslope. It is critical that areas upslope be able to infiltrate stormwater and that areas downslope be able to handle overflow.

Although stormwater can be piped and conveyed down to the berm itself, the best use of berms includes level-spreading of runoff well upslope, allowing for sheet flow down to the berm itself.

This approach maximizes opportunity for recharge prior to the berm and minimizes the volume or runoff that must be retained and infiltrated thereafter.

When flooding is likely to occur (i.e., within a flood plain), a system of mounds or berms can be created to reduce the velocity of flood waters, creating a more gradual flooding process. If berms are placed correctly (see **Figure 6.83**), they can divert peak flows away from structures and trap sediments before runoff carries them into the stream. **Figure 6.84** illustrates several creative ways in which earth mounds may be incorporated into playground configurations as significant play features as well as flood diversions. Of course, flood routing must be performed to assure that creation of berms or mounds in the flood plain will not result in an increase of the flood elevation at downstream sites.

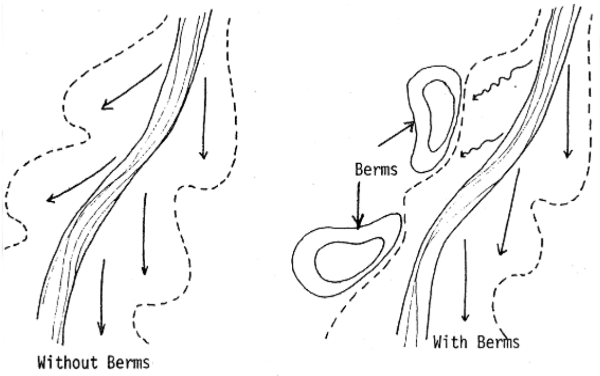


Figure 6.83. Berms Controlling Flood Flows
Source: Day and Crafton (1978)

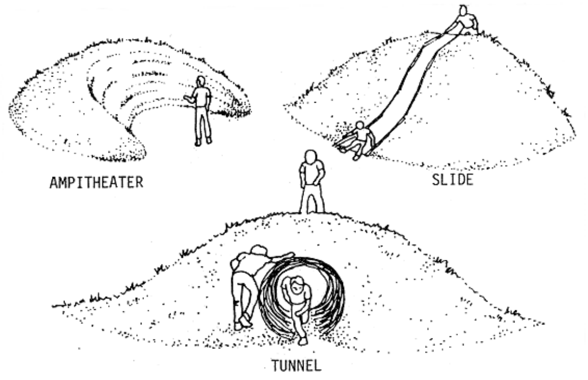


Figure 6.84. Creative Berm Configurations
Source: Day and Crafton (1978)

Berming includes both residential and nonresidential applications, ranging from individual lots to broader site-wide installations. Berms can be incorporated with individual driveways, lot-by-lot, in order to direct and infiltrate runoff from roads and driveways. Such berm systems may intersect a vegetated swale, with the berms extending along the contours into the respective lot and providing volume control as needed.

Berming can be carefully integrated into total site development by taking advantage of areas of existing vegetation. Larger volumes of stormwater can be directed to these natural areas, where volume control can be provided through placement of a berm. Depending upon the configuration of the development, some sort of level spreading device may be necessary to properly distribute the larger flows to the natural area. It is important to note that slope is a key determinant of whether this approach can be used. If large areas of relatively flat land with existing vegetation (ranging from dense forest to scrub growth) are available to receive stormwater runoff, then such an approach is ideal and can be accomplished with minimal difficulty. If the stormwater initially is evenly spread upslope of the area, sheet flow will be generated. Sheet flow not infiltrated from the larger storms will be detained by the berm. Once contained, this stormwater will be infiltrated, aided and abetted by the enhanced permeability of the vegetated floor of the natural area.

Berms may be designed to detain and contain storms of any size (see **Figure 6.85**). If the size of the bermed area is sufficient to detain the difference between pre-development and post-development flow for up to the 2-year storm (a reasonable recharge target), then larger storms will have to bypass the berm. In such cases, the berm itself becomes a level spreading device, and reinforcement of the berm may be necessary for structural stability. Here, the berm top and sides can be reinforced through use of "geowebs" or "geogrids" which significantly increase stability if significant erosive forces must be withstood. Of course, reinforcement increases the cost. Reinforcement may be also necessary when flows are substantial and slopes are considerable.

Figure 6.85. Berms Form a Basin to Detain Runoff from Larger Storms

Berm Design

Berms should be designed within the context of stormwater quality, channel protection, and flood protection requirements applicable to the site and as part of the stormwater management system for the site.

- Create a conceptual stormwater management plan for the entire site, and determine what portion of the sizing requirements berms and retentive grading will help to meet. Determine the general location of these features and the role they will play on the site. The ideal berm location is on moderately rolling terrain, rather than more severe slopes, where channelization upslope of the berm is not necessary in order to achieve storage volumes and where natural vegetation remains undisturbed up to the base of the berm.
- Placement of the berm must be accomplished carefully. The objective is to avoid significant disruption of the natural area, whether in mature forest, dense scrub growth, or meadow. Berm dimensions have an important bearing on the extent of disruption created. The berm

must be stable, but at the same time it should be no taller and no longer in base area than is absolutely necessary for stability. Only the minimum volume of fill material should be used for the berm.

- Create a conceptual design for the berm(s), including height of the berm and depth of the depression. Suggested starting design values for berms are 6-24 inches for berm height and 6-12 inches for ponding depth behind the berm. If more volume is needed that can be provided behind a 24-inch high berm, additional berms should be considered. The width of the top of the berm and the thickness of the berm itself should be a function of slope and stormwater volume to be handled. This must be evaluated on a case-by-case basis in order to guarantee structural stability.
- Berm slopes should not exceed a 3:1 (H:V) ratio. If the berm is to be mowed, the slope should not exceed a 4:1 ration in order to avoid "scalping" by the mower blade. If trees are to be planted on the berm, the slope should not exceed a ratio ranging from 5:1 to 7:1. The top of the berm should be level so as prevent concentrating (at lower spots) any overflow during larger storms.
- If the berm will be linked with a depression intended to promote infiltration, an soil infiltration test should be performed. If infiltration is feasible, determine the engineer's best estimate of saturated vertical infiltration rate, with an appropriate factor of safety. These test results should be included with site plans provided to the local plan review authority for approval.
- Estimate the amount of runoff reaching the system during the design storm and the maximum ponding depth or elevation at the berm. The design infiltration rate may be subtracted from stage at each time step in this calculation.
- Using the infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding will take to drain. The maximum drawdown time for the entire storage volume should not exceed 72 hours; a drawdown period of 24-48 hours is recommended, based on site conditions and owner preference. If routings indicate the stored water will not drain in the time allowed, adjust the berm height and depression depth until the time constraints are met. These routings should be included with the site plans provided to the local plan review authority for approval.
- Design an overflow or bypass mechanism for large storms, accounting for appropriate erosion protection. The contours of the site may allow water to flow around the edge of the berm, provided that erosion will not occur or sufficient protection is provided.
- To minimize cost, check the volume of cut and fill material and adjust the berm height and depression depth to more closely balance the two.
- Consider maintenance activities when choosing berm materials and shape (see **Figure 6.79** on page 108 above).

Berm Construction

Berm construction should first include channel excavation parallel to contours and then mounding of excavated material into berm formation at the lower edge of the channel (**Figure 6.86** below. Upslope of the berm itself, a broad flat cleared area is created. This approach readily provides a storage volume. If excavation volume and berm fill balances, this approach is quick and easy. However, excavation for channelization should be avoided, in order to minimize disruption and compaction of soils in the areas upslope of the berm where infiltration is so critical.

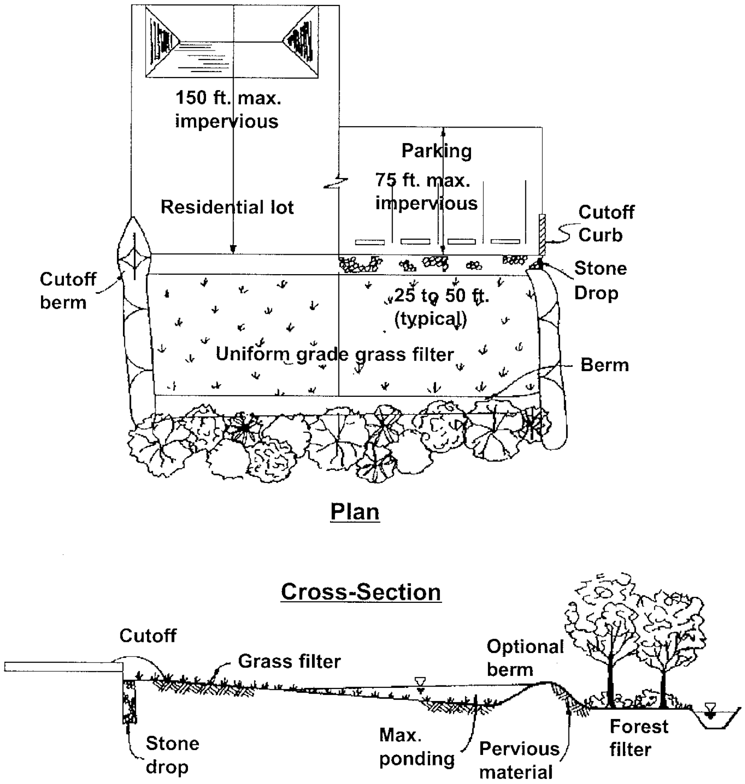


Figure 6.86. Example of a Filter Strip with "Terraforming" Berming

The following is additional guidance on the construction of berms:

- It is very important that areas where infiltration berms will be established must be clearly marked before any site work begins, to avoid soil disturbance and compaction during construction. Also, construction runoff must be directed away from the proposed infiltration berm location. Berm excavation and construction should not be done until other site grading is complete and the drainage area has been fully stabilized.
- Existing soil surfaces of any proposed infiltration area should be manually scarified, so the in-situ soils will not be compacted. Heavy equipment must not be used in the berm area.
- Topsoil should be stripped and stockpiled carefully and saved for replacement, using a small loader. It is important that organic material be stripped down to a solid mineral base in order to make sure that the interface between the berm fill material and the parent soil is tight.
- The excavated area should be backfilled as soon as the subgrade preparation is complete to avoid accumulation of debris. Place the berm granular fill, free of organic matter. Use appropriate construction equipment so as to prevent disturbance and compaction of up-slope areas as well as down-slope areas (protection up-slope areas is most critical). The berm should be created in 8-inch lifts, tamped lightly. The berm should be graded as fill is added and compacted consistent with applicable standards for fill material. Topsoil should be replaced following berm compaction.

- The surface ponding area at the base of the berm should be protected from compaction. If compaction occurs, the soil should be scarified to a depth of at least 8 inches.
- After allowing for settlement, final grading should be completed to within 2 inches of the proposed design elevations. The crest and base of the berm should be level along the contour.
- The top and downslope side should be stabilized with a non-erosive covering (e.g., erosion control netting or matting, etc.). When the side slopes are steeper than 5:1 (H:V), then the lip of the berm should be stabilized with a light-duty geoweb-type product. Then the surface should be seeded and planted with vegetation specified in the project plans and specifications. It is critical that the plant materials are appropriate for the soil, hydrologic, light and other site conditions. Native trees, shrubs and grasses are strongly recommended, but turf grass is acceptable. Although the plants will be subject to ponding, they may also be subject to drought, especially in areas that get a lot of sunlight or are in otherwise highly impervious areas.
- Mulch should be placed to prevent erosion and protect the new vegetation, manually grading the berm to its final elevations. Ideally, the area should be watered at the end of each day for two weeks following the completion of planting.

Berm Maintenance

- Periodically remove trash, debris and invasive plants from the area.
- If turfgrass is present, mow the grass to maintain a 2-4 inch height.
- Inspect periodically for erosion, and repair and stabilize eroded areas.

Economics of Terraforming

The economic benefits associated with minimizing clearing and grading and use of terraforming are two-fold. First, designing in sync with the terrain minimizes earthwork costs, often by thousands of dollars per acre. Second, through minimizing clearing, the volume of stormwater runoff generated on the site is reduced, resulting in lower stormwater management costs. As has been mentioned elsewhere, the cost of maintaining forests and open space is minimal compared to maintaining impervious surfaces and managed turf.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.8: Preserve plant communities native to the ecoregion	2 - 6
4.9: Restore plant communities native to the ecoregion	1 - 5
4.13: Reduce the risk of catastrophic wildfire	3

6.3.5.3. Environmental Site Design Practice #19: Use Natural Drainageways and Vegetated Swales Instead of Storm Sewers and Curb & Gutter

KEY BENEFITS	USING THIS PRACTICE
• Use of natural drainageways reduces the cost of constructing storm sewers or other conveyances, such as roadway curbs and gutters, and may reduce the need for land disturbance and grading • Natural drainage paths are less hydraulically efficient than man-made conveyances, resulting in longer travel times and lower peak discharges • Can be combined with buffer systems to allow for stormwater filtration and infiltration • Reduces the cost of road and storm sewer construction	• Preserve natural flow paths in the site design • Direct runoff to natural drainageways, ensuring that peak flows and velocities will not cause channel erosion • Use vegetated open channels (enhanced wet or dry swales or grass channels) in place of curb and gutter to convey and treat stormwater runoff
This practice reflects the CWP Better Site Design Principle # 5 (Vegetated Open Channels)	

Figure 6.87. Dry swale along a suburban connector street (no curb and gutter).
Source: Chesapeake Bay Stormwater Training Partnership

Where density, topography, soils and slopes permit, the natural drainageways of a site, or properly designed and constructed vegetated channels and swales, should be used to convey and treat stormwater runoff instead of constructing underground storm sewers, concrete open channels, or roadway curb and gutter structures. Streets, in particular, contribute higher loads of pollutants to urban stormwater than any other source in residential developments (Bannerman, et al., 1993 and Steuer, et al., 1997). Research has indicated that residential streets contribute a majority of the sediment, phosphorus, copper, zinc, and fecal coliform bacteria found in urban stormwater runoff. Some examples of these pollutant sources (see **Figure 6.88**) are as follows:

- Atmospheric pollutants settle or are washed onto the street during rain events
- Pavement fragments contribute to stormwater pollution
- Vehicles contribute emissions and tire and brake system particles and residues
- Snow collected at the street edge melts and contributes salts
- Leaves and pollen from trees are blown into the street
- Curb and gutter systems channel polluted stormwater directly into streams

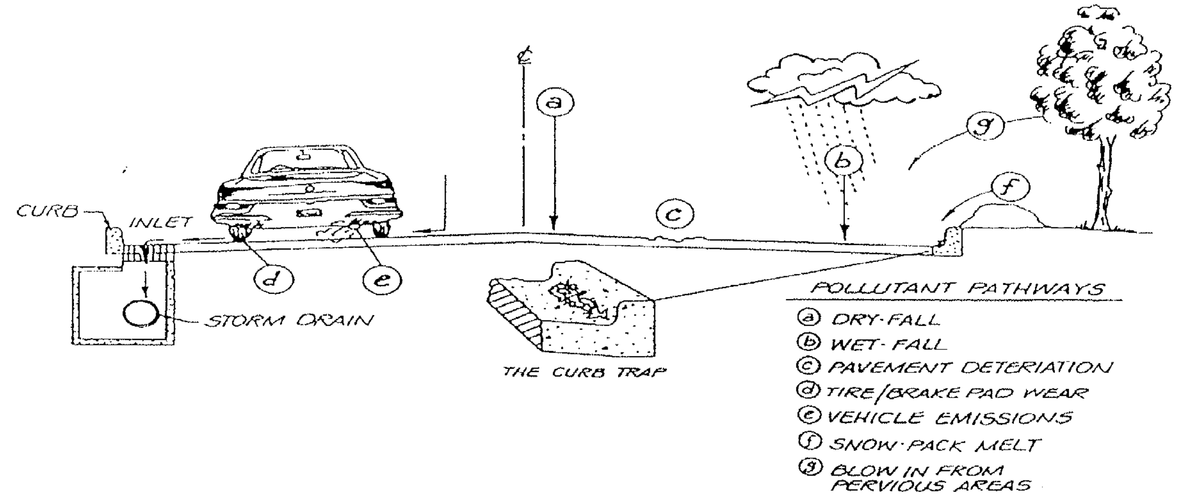


Figure 6.88. Street-Related Runoff Pollutant Pathways
Source: Schueler (1995)

Structural drainage systems and storm sewers are designed to be hydraulically efficient in removing stormwater from a site. However, these systems also tend to increase peak runoff discharges, flow velocities and the delivery of pollutants to downstream waters. A preferred alternative is the use of natural drainageways and vegetated swales (where slopes and soils permit) to carry stormwater flows to their natural outlets, particularly for low-density development and residential subdivisions. It is critical that natural drainageways be protected from higher post-development flows by ensuring that runoff volumes and velocities provide adequate residence times and non-erosive conditions and, as needed, by applying downstream channel protection methods (e.g., check dams and channel or outlet armor).

The conventional structural conveyance system in most cases provides no water quality management function and returns no stormwater back into the ground. Velocities and erosive forces of stormwater are actually worsened by such systems. Although vegetated swales vary in their intended objectives and design, the overall concept of a vegetated swale is to slow stormwater flows, capture some proportion of stormwater pollutants through biofiltration or bioretention, and hopefully infiltrate some portion of flow back into the ground.

Swales can act in two ways to affect stormwater flows. First, simple conveyance in a vegetated channel causes a decrease in the velocity of the flow. As the water passes over and through the vegetation, it encounters resistance. This resistance translates into increased times of concentration (slowing the flow) within the watershed, more temporary storage of stormwater on-site during the storm, and reduced peak discharge rates. The result can be a reduction in habitat destruction and streambank erosion that often is caused by peak flows of small storms, which comprise a majority of the rainfall events. Some of the flow will also infiltrate, depending on the design of the swale and the residence time.

Secondly, water quality can be affected by passage through vegetation. All the physical, chemical, and biological processes previously described can significantly reduce the pollutant loadings in stormwater. For example, total suspended solids are often reduced by settling, as a result of decreased flow velocity. Vegetation can also directly absorb nutrients and utilize them in growth.

Vegetated channels can be designed to meet a broad array of stormwater management objectives and to accommodate a variety of site specific situations. They are commonly used in single family residential areas with low to moderate impervious cover in place of curb and gutter systems as part of a drainage easement. They are also often used along roadsides, in the medians of highways, or in recessed areas of parking lots.

Where density, topography, soils, slope, and safety issues permit, vegetated open channels can be used in the street right-of-way to convey and treat stormwater runoff from roadways. Curb and gutter and storm drain systems allow for the quick transport of stormwater, which results in increased peak flow and flood volumes and reduced runoff infiltration. Curb and gutter systems also do not provide treatment of stormwater that is often polluted from vehicle emissions, pet waste, lawn runoff and litter.

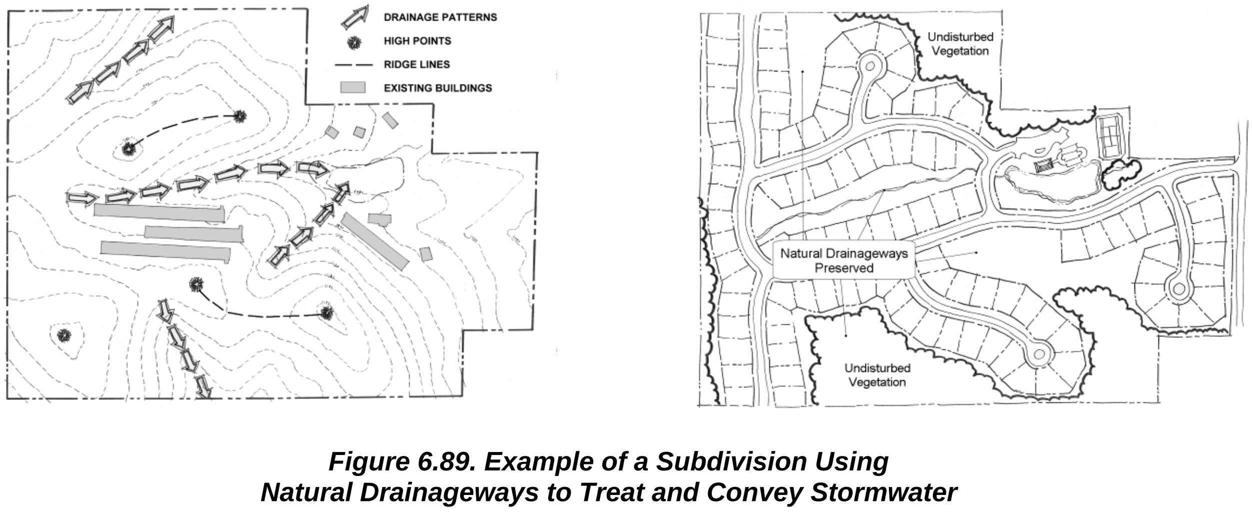


Figure 6.89. Example of a Subdivision Using Natural Drainageways to Treat and Convey Stormwater
Source: ARC (2001)

Open vegetated channels along a roadway (see **Figures 6.90** through **6.92** below) remove pollutants by allowing infiltration and filtering to occur, unlike curb and gutter systems which move water with virtually no treatment. Engineering techniques have advanced the roadside ditches of the past, which suffered from erosion, standing water and break up of the road edge. Grass channels and enhanced dry swales are two such alternatives and with proper installation under the right site conditions, they are excellent methods for treating stormwater on-site. In addition, open vegetated channels can be less expensive to install than curb and gutter systems. Further design information and specifications for grass channels and enhanced swales can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

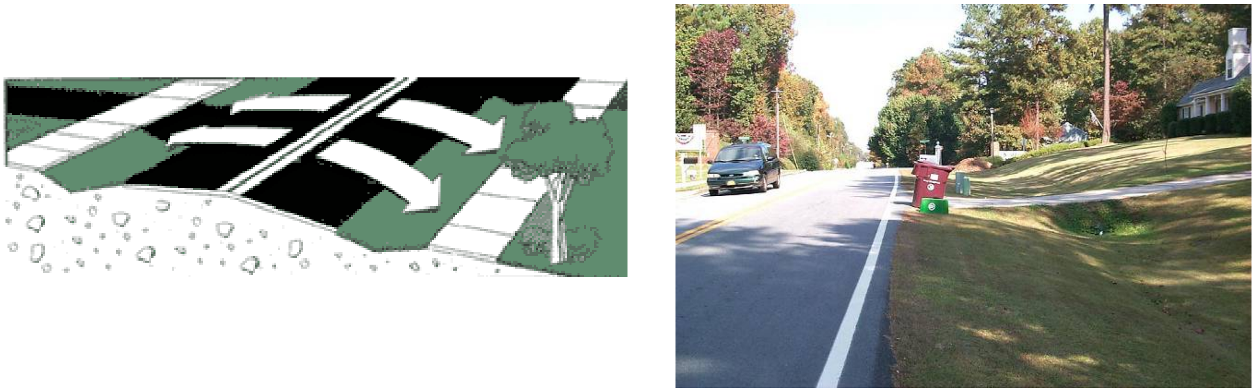


Figure 6.90. Using Vegetated Swales Instead of Curb and Gutter
Source: ARC (2001)

Figure 6.91. Grass Channel in Median.
Source: Center for Watershed Protection

Figure 6.92. Subdivision Street Swale Drain.
Source: Center for Watershed Protection

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.4. Environmental Site Design Practice #20: Drain Runoff to Pervious Areas

KEY BENEFITS	USING THIS PRACTICE
• Harvesting rooftop runoff keeps the water on-site for reuse and reduces domestic water and sewer costs • Sending runoff to pervious vegetated areas increases overland flow time and reduces peak flows • Vegetated areas can often filter and infiltrate stormwater runoff	• Minimize directly connected impervious areas and drain runoff as sheet flow to cisterns or pervious vegetated areas
This practice reflects the CWP Better Site Design Principle # 16 (Rooftop Runoff)	

Where possible, direct runoff from impervious areas (e.g., rooftops, roadways and parking lots) to cisterns for on-site reuse or to pervious areas such as yards, open channels or vegetated areas to provide for water quality treatment and infiltration. Avoid routing runoff directly to the roadway or structural stormwater conveyance system. Sending runoff over a pervious surface before it reaches an impervious surface can decrease the annual runoff volume from residential development sites by as much as 50 percent (Pitt, 1987). This grading and design technique can significantly reduce the annual pollutant load as well.

Stormwater quantity and quality benefits can be achieved by routing the runoff from impervious areas to pervious areas such as lawns, landscaping, filter strips and vegetated channels. Much like the use of undisturbed buffers and natural areas (Environmental Site Design Practice #17), revegetated areas such as lawns, engineered filter strips and vegetated channels can act as biofilters for stormwater runoff and provide for infiltration in porous soils (hydrologic group A and B). In this way, the runoff is “disconnected” from a hydraulically efficient structural conveyance such as a curb and gutter or storm drain system. Some of the methods for disconnecting impervious areas include:

- Designing roof drains to flow to infiltration trenches or vegetated areas
- Directing flow from paved areas such as driveways to stabilized vegetated areas (see **Figure 6.93** below)
- Breaking up flow directions from large paved surfaces
- Carefully locating impervious areas and grading landscaped areas to achieve sheet flow runoff to the vegetated pervious areas

For maximum benefit, runoff from impervious areas to vegetated areas must occur as sheet flow and vegetation must be stabilized. Specific design information and specifications for rainwater harvesting, sheet flow to vegetated filter strips and open space, and grass channels, dry swales, bioretention, and infiltration can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

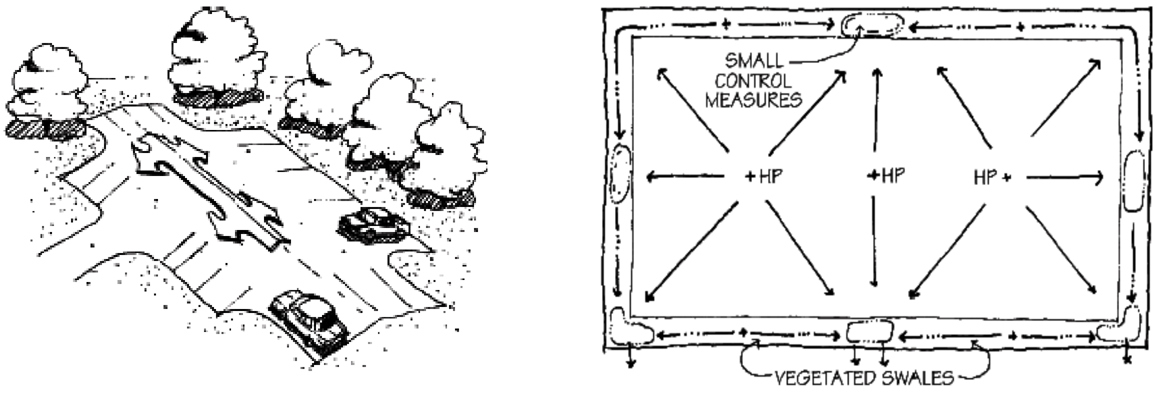


Figure 6.93. Using Vegetated Swales Instead of Curb and Gutter
Source: NC DENR (1998)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.5. Environmental Site Design Practice #21: Infiltrate Site Runoff or Capture It for Reuse

KEY BENEFITS	USING THIS PRACTICE
• Helps to preserve the natural hydrology of a site • Helps to recharge groundwater and thus maintain the baseflow of local streams • Removes pollutants that would otherwise be exported from the site • Lower runoff volumes leaving the site protects receiving waters from degradation • Capturing and/or reducing runoff volume on-site can reduce the amount and cost of drainage infrastructure for the site • Reusing captured runoff on-site (e.g., irrigating landscaping) can reduce owner costs for potable water	• Direct rooftop runoff to pervious areas such as yards, open channels, vegetated areas or infiltration practices or capture it in rain tanks or cisterns for reuse • May be used for roadway or parking impervious areas if adequate pre-treatment is provided • Use permeable pavement only in low traffic areas or for pedestrian walkways/plazas

Direct runoff from rooftop areas to pervious areas or use “vegetated roof” strategies to reduce rooftop runoff volumes and rates. Use infiltration trenches, basins, or leaching chambers to provide groundwater recharge, mimic existing hydrologic conditions, and reduce runoff and pollutant export. Permeable paving surfaces may also be used where site conditions are appropriate.

Capturing rainwater and rooftop runoff on-site provides an opportunity to not only reduce runoff volume discharging from the site, but also to use the water on-site, reducing the amount of potable water required for routine use. For example, roof downspouts discharging to rain tanks (**Figure 6.94**) can store water to be used for irrigating landscaped borders, washing vehicles, etc. Sophisticated capture systems can even be connected to the building’s plumbing for use in flushing toilets, bathing, etc. While not as adaptable to older buildings, such systems incorporated into new construction can achieve payback in just a few years. Vegetated roofs (**Figure 6.95**) actually store the water in the vegetation’s growing media, providing moisture to the plant materials that would otherwise need to be provided from potable sources.

Figure 6.94. Rain Barrel

Figure 6.95. Vegetated Roof

Surface disconnection spreads runoff from small parking lots, courtyards, driveways and sidewalks into adjacent pervious areas at the site where it is filtered and infiltrated into the soil. Most development sites have extensive areas of grass or landscaping where runoff can be treated close to the source where it is generated. In some cases, minor grading of the site may be needed to promote overland flow and vegetative filtering. Using infiltration trenches (**Figure 6.96**) and basins to filter runoff back into the ground helps to reduce the amount of stormwater runoff volume and associated pollutants that would otherwise be discharged from the development site. Rooftop runoff may be discharged directly to dry wells or infiltration chambers (**Figure 6.97**) or into perforated pipes spreading underground to provide moisture for a lawn (**Figure 6.98**).

Figure 6.96. Infiltration Trench

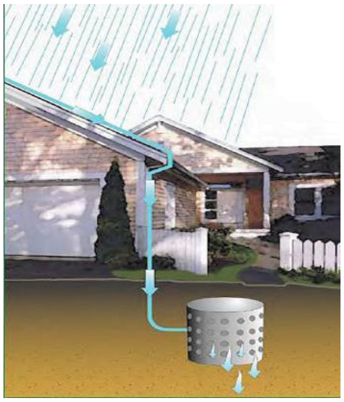
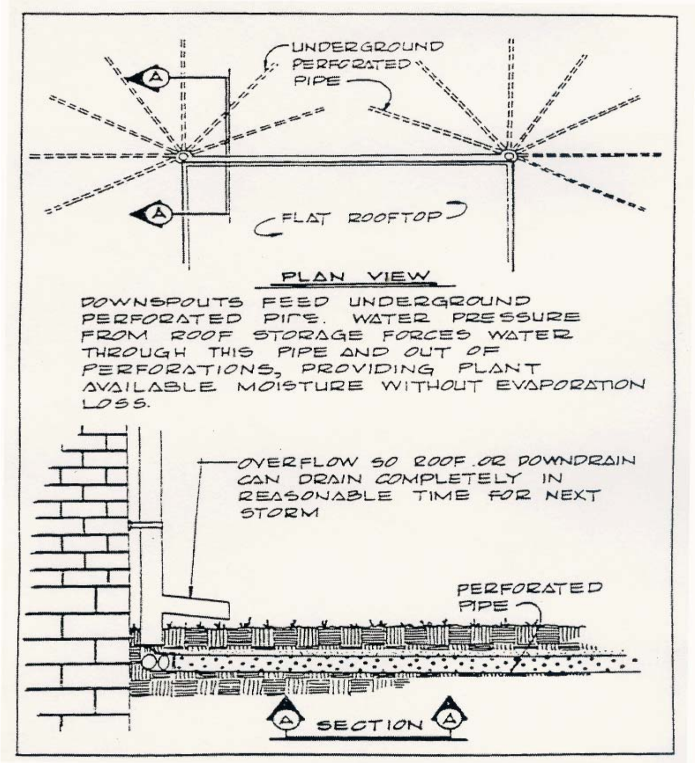


Figure 6.97. Dry Well



DOWNSPOUTS FEED UNDERGROUND PERFORATED PIPE. WATER PRESSURE FROM ROOF STORAGE FORCES WATER THROUGH THIS PIPE AND OUT OF PERFORATIONS, PROVIDING PLANT AVAILABLE MOISTURE WITHOUT EVAPORATION LOSS.

OVERFLOW SO ROOF OR DOWNDRAIN CAN DRAIN COMPLETELY IN REASONABLE TIME FOR NEXT STORM

Figure 6.98. Downspout Connected to Infiltration Trenches Spread Out to Provide Underground Moisture to Lawn. Source: Baltimore SWM Manual

Porous paving materials should be used only in low traffic areas or for pedestrian walkways, plazas, and outdoor playing surfaces (e.g., basketball and tennis courts) (**Figures 6.99** and **6.100**)

In order to employ infiltration practices, the site must have soils with moderate to high infiltration capacities and must have adequate depth to groundwater and underlying geology. Poor soils will inhibit or even preclude aggressive infiltration. However, site soils can be amended with compost and other appropriate materials to improve the infiltration capacity. Care must be taken to avoid infiltrating runoff from stormwater hotspots unless adequate pre-treatment is provided. Infiltration on sites developed in karst areas should be limited to micro- and small-scale infiltration practices. Large-scale infiltration practices will likely increase the risk of sinkhole formation.

Figure 6.99. Porous Asphalt Bike Path

Figure 6.100. Porous Asphalt Playing Court

For more specific information about using rainwater harvesting, vegetated roofs, infiltration devices, soil amendments, or permeable paving surfaces see the Specifications for these practices on the Virginia Stormwater BMP Clearinghouse web site at: http://www.vwrrc.vt.edu/swc/ .

Traditionally, landscaping and stormwater management have been treated separately in site planning. In recent years, engineers and landscape architects have discovered that integrating stormwater into landscaping features can improve the function and quality of both. The basic concept is to adjust the planting area to accept stormwater runoff from adjacent impervious areas and utilize plant species adapted to the modified runoff regime (**Table 6.20**). Excellent guidance on how to match plant species to stormwater conditions can be found in Cappiella et al. (2005).

Table 6.20. Environmental Factors to Consider When Integrating Stormwater and Landscaping

Factor	Problem Addressed
Duration and depth of inundation	Invasive plants
Frequency of inundation	Pollutants and toxins
Available moisture during dry weather	Soil compaction
Sediment loading	Susceptibility to erosion
Salt exposure	Browsers (deer and beavers)
Nutrient loading	Slope

Source: Adapted from Shaw and Schmidt (2003)

A landscaping area may provide full or partial stormwater treatment, depending on site conditions. An excellent example of the use of landscaping for full stormwater treatment is bioretention. Even small areas of impervious cover should be directed into landscaping areas since stormwater or melt water help to reduce irrigation needs.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.1: Reduce potable water use for landscape irrigation by 50 percent from the established baseline	0 (Prerequisite)
3.2: Reduce potable water use for landscape irrigation by 75 percent from the established baseline	2 - 5
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.6. Environmental Site Design Practice #22: Restore or Daylight Streams at Redevelopment Projects

KEY BENEFITS	USING THIS PRACTICE
• Restores historic drainage patterns and habitats • Provides better runoff attenuation • Helps reduce pollutant loads	• Daylighting should be considered whenever a culvert replacement is scheduled • Stream restoration should also be considered for degraded open streams • Consider runoff pre-treatment and erosion potential of the restored stream

Urban streams are arguably the most extensively degraded and disturbed aquatic systems in North America. Research over the last three decades has revealed that urban development has a profound impact on the hydrology, morphology, water quality and biodiversity of urban streams (Schueler, 1995). The quality of an urban stream depends on the interaction of many different physical and biological processes, each of which is strongly influenced by the degree of impervious cover present in its contributing watershed.

Urban stream degradation is a classic example of the difficulty in addressing long-term environmental change at the local level. Development is a gradual process that spans decades and occurs over a wide region of the landscape. However, it is composed of hundreds of individual development projects completed over a much shorter time-span, which transform just a few acres at a time. Consequently, the true scope of stream degradation may not be fully manifested at the watershed scale for many years.

When viewed from the air, headwater streams dominate the landscape (**Figure 6.101**). Their scale, proximity, and vulnerability to changes in land use make them an excellent choice for local water resources management.

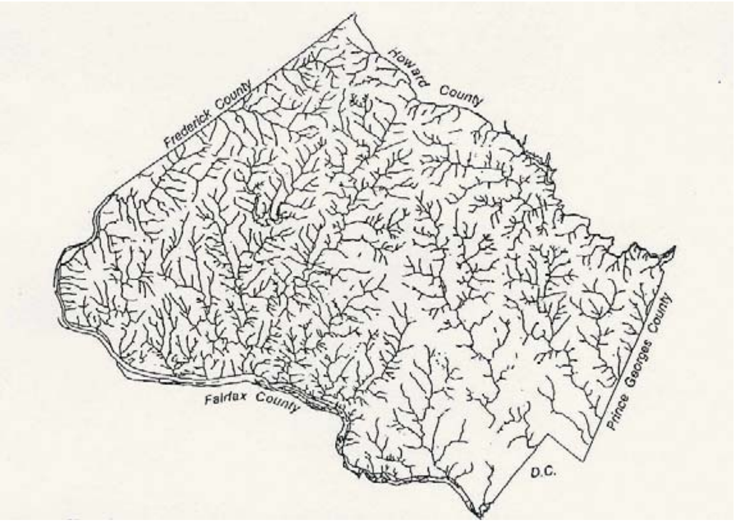


Figure 6.101. Headwater Streams in the Urban Landscape: Montgomery County, Maryland. Source: Schueler (1995)

The commitment to restore a degraded stream on a development or redevelopment site can result in improvements throughout the watershed, especially if done as part of a coordinated local stream system or watershed improvement plan. A restored stream channel connected integrally with its floodplain can be an important part of a design strategy that incorporates the natural drainage system into a sustainable stormwater management system for the site. **Figures 6.102** and **6.103** show before- and after-photos of two different stream restoration projects. These are examples of the kinds of outcomes that can be expected when natural stream channel design concepts are applied.

Figure 6.102. Waukegan Brook Restoration, Washington Park, Michigan
Source: Stormwater Magazine (July-August, 2009)

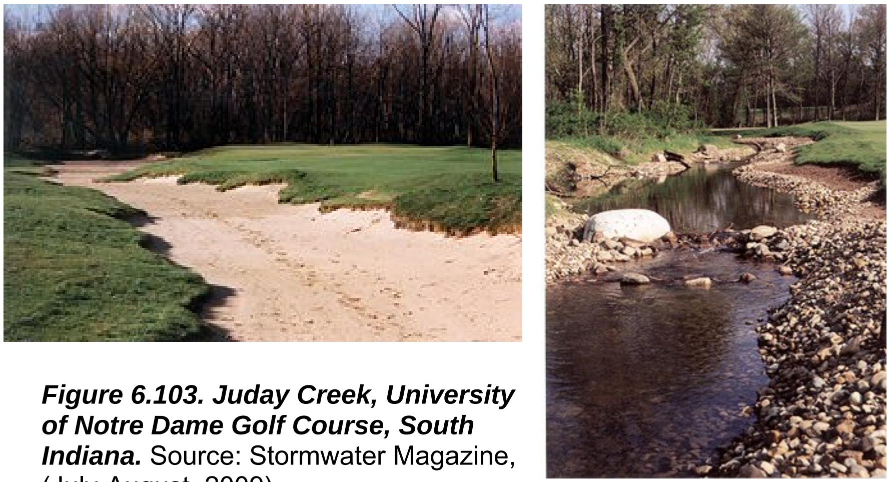


Figure 6.103. Juday Creek, University of Notre Dame Golf Course, South Indiana. Source: Stormwater Magazine, (July-August, 2009)

Where feasible and practical, daylight streams that have been paved or piped to reconnect the streams to the floodplain, restore natural habitats, better attenuate runoff, and help reduce pollutant loads. Daylighting confined streams restores the historic drainage pattern by removing the closed drainage system and constructing a stabilized, vegetated stream. Restored streams also provide educational and recreational opportunities and can help to revitalize neighborhoods. In many ways, paved or piped streams are a metaphor for the way we have "buried" our connection with nature. Daylighting these streams restores not only natural ecological processes, but it can restore a sense of place and the natural importance of water even in the most urban settings (Jessica Hall, Landscape Designer and stream advocate). Prior to taking this step, flooding potential must be carefully evaluated, as well as the potential impact on utilities and the risks associated with contaminated sites.

The following series of photos (**Figures 6.104** through **6.110**) display a stream daylighting project at the Dell, on the grounds of the University of Virginia (UVA).

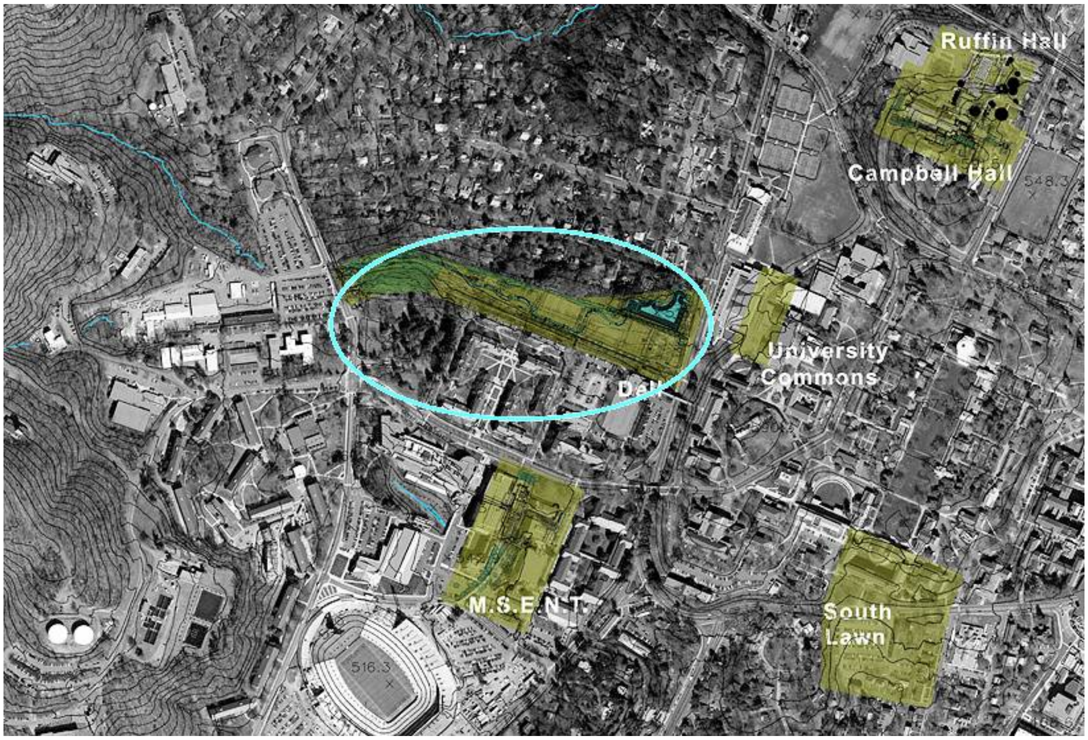


Figure 6.104. Location Map: University of Virginia Stream Daylighting Project (The Dell)
Source: Nelson Byrd Woltz Landscape Architects

Figure 6.105. The UVA Dell Project Site Before Restoration
Source: Nelson Byrd Woltz Landscape Architects

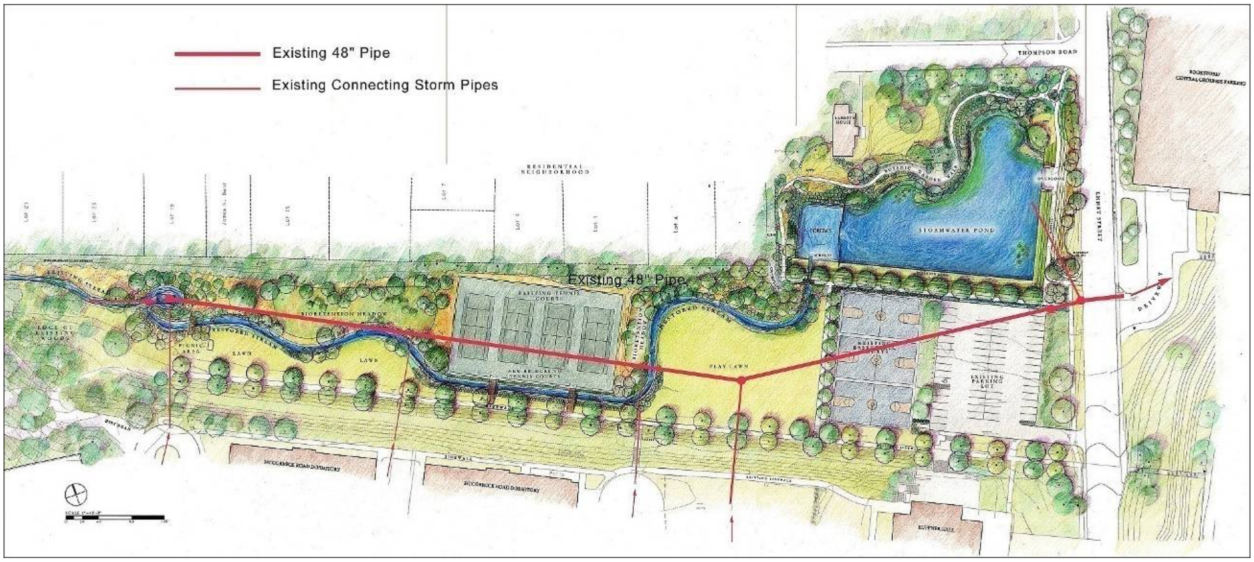


Figure 6.106. The UVA Dell Project Site. Location of the Piped Stream, Connecting Pipes, and the Daylighted Stream Configuration. Source: Nelson Byrd Woltz Landscape Architects

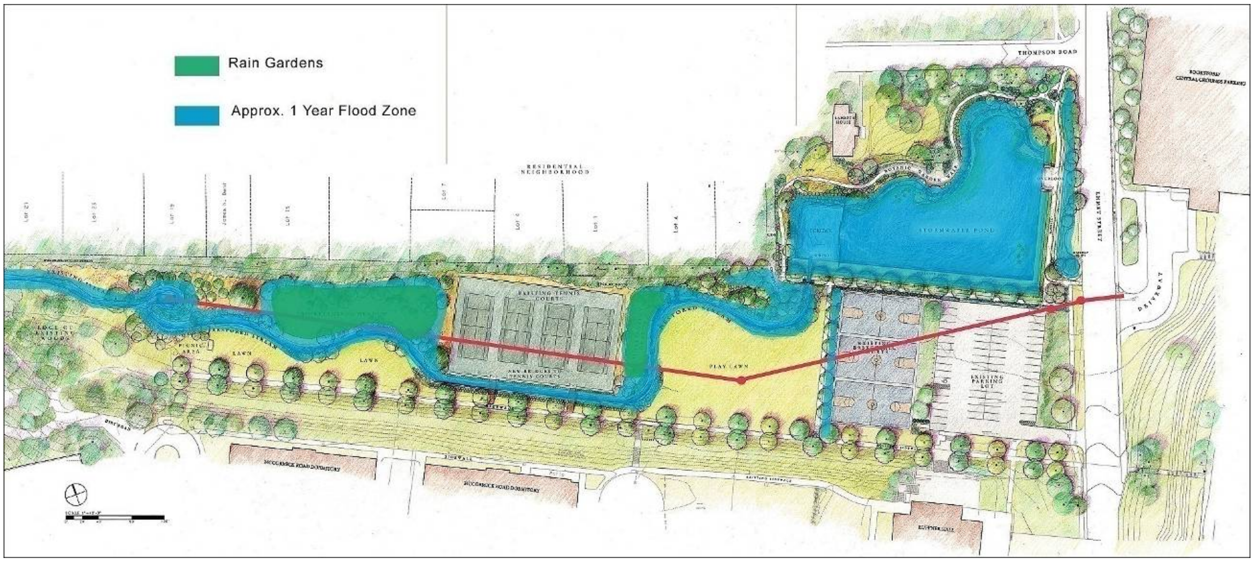


Figure 6.107. UVA Dell Project Site. Location of Rain Gardens and the 1-Year Flood Zone.
Source: Nelson Byrd Woltz Landscape Architects

Figure 6.108. UVA Dell Project Site. Location of Rain Gardens and the Maximum Flood Zone.
Source: Nelson Byrd Woltz Landscape Architects

Figure 6.109. UVA Dell Project Site. View of the Stream from Upstream of the Tennis Courts.
Source: Nelson Byrd Woltz Landscape Architects

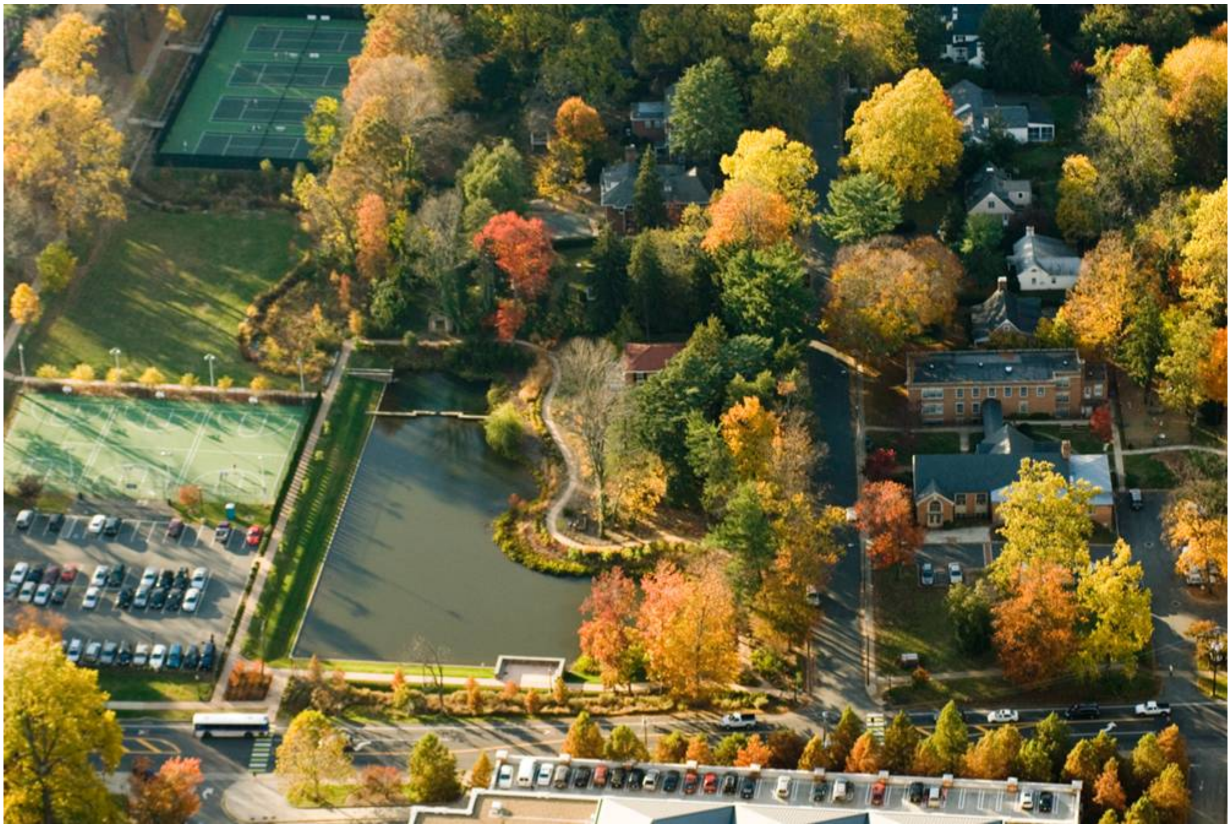


Figure 6.110. UVA Dell Project Site. Daylighted Stream Leading to Pond (lower center).
Source: Nelson Byrd Woltz Landscape Architects

For more in-depth guidance on stream restoration, including procedures to assess existing conditions, refer to the following resources:

- *The Virginia Stream Restoration & Stabilization Best Management Practices Guide*, at: http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/Publications.aspx
- *Stream Restoration: A Natural Channel Design Handbook*, at: http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf
- *Stream Restoration Design Handbook (2007)I,* by the USDA-NRCS
- *Restoring Streams in Cities: A Guide for Planners, Policy Makers, and Citizens (1998)*, by A. L. Riley and Luna Leopold

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.4: Rehabilitate lost streams, wetlands, and shorelines	2 - 5

6.6. OVERCOMING BARRIERS TO ENVIRONMENTAL SITE DESIGN

Despite the clear benefits of ESD techniques, it may be difficult to apply some of them in many communities across the state at the present time. The primary reason is that the geometry, location, and design of development projects is largely dictated by local subdivision codes and zoning ordinances. In some cases, these codes discourage or even prohibit ESD techniques. In other cases, development review authorities are hesitant to approve innovative ESD techniques because of fears they may create real or perceived problems. While potential barriers differ in every community, some frequently cited problems are that ESD techniques may:

- Restrict access for fire trucks and emergency vehicles
- Increase future municipal maintenance costs
- Drive up construction costs
- Make it more difficult to plow snow
- Generate future problems or complaints (e.g. inadequate parking, wet basements, etc.)
- Interfere with existing utilities

These real or perceived local problems must be directly addressed in order to gain widespread adoption of ESD techniques. Communities may also need to carefully reevaluate their local codes and ordinances to overcome barriers to ESD.

Effective methods for promoting code change are to (1) use Code and Ordinance Worksheets to evaluate potential conflicts within local development codes and (2) establish a local site planning roundtable to assist in identifying necessary code changes. Roundtables involve key stakeholders from the local government, development, and environmental communities that influence the development process. These approaches are discussed in detail in **Appendix 3-B** of **Chapter 3** of this Handbook.

6.7. ENVIRONMENTAL SITE DESIGN EXAMPLES

6.7.1. Example 1: Rural Residential Subdivision

Figure 6.111. Location Map for Remlick Hall Farm/Subdivision

This example, earlier documented in the Chesapeake Bay Foundation's publication ***A Better Way to Grow*** (1996), is located near the hamlet of Remlick, in rural Middlesex County, Virginia. The subdivision is situated on the banks of Lagrange Creek, a tributary of the Rappahannock River, which drains directly into the Chesapeake Bay. **Figure 6.111** is a location map.

Figure 6.112 is an aerial view of the original Remlick Hall Farm site before the development began. **Figure 6.113** is a site plan of the farm under the pre-development conditions.

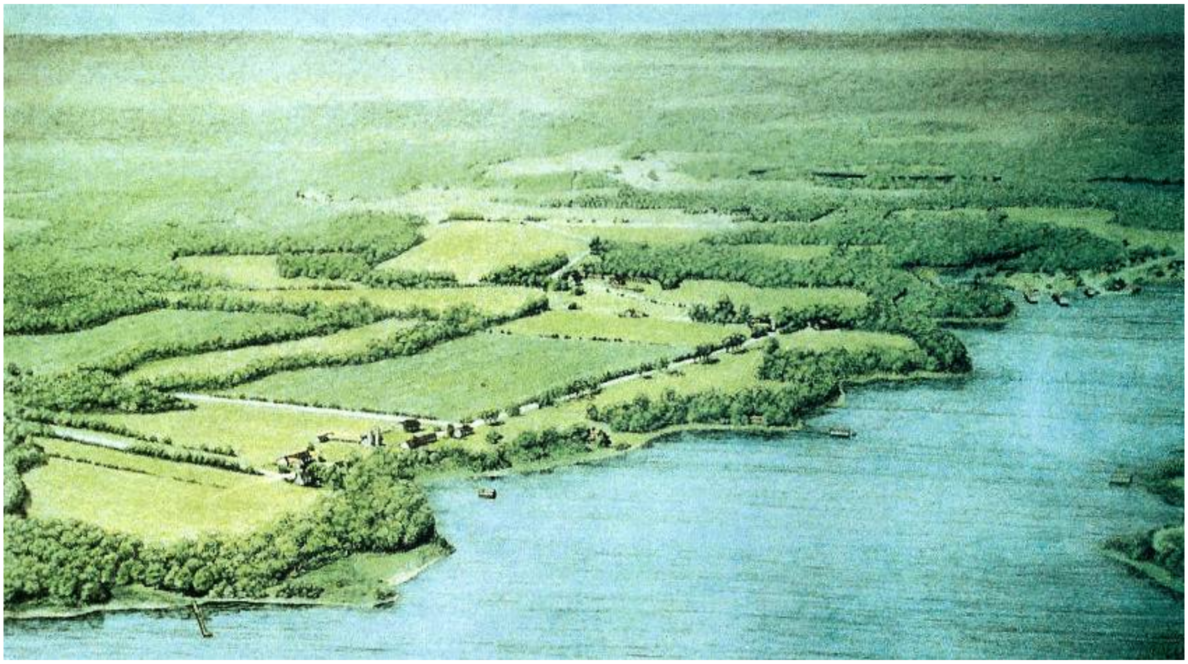


Figure 6.112. Aerial View of Remlick Hall Farm Prior to Development

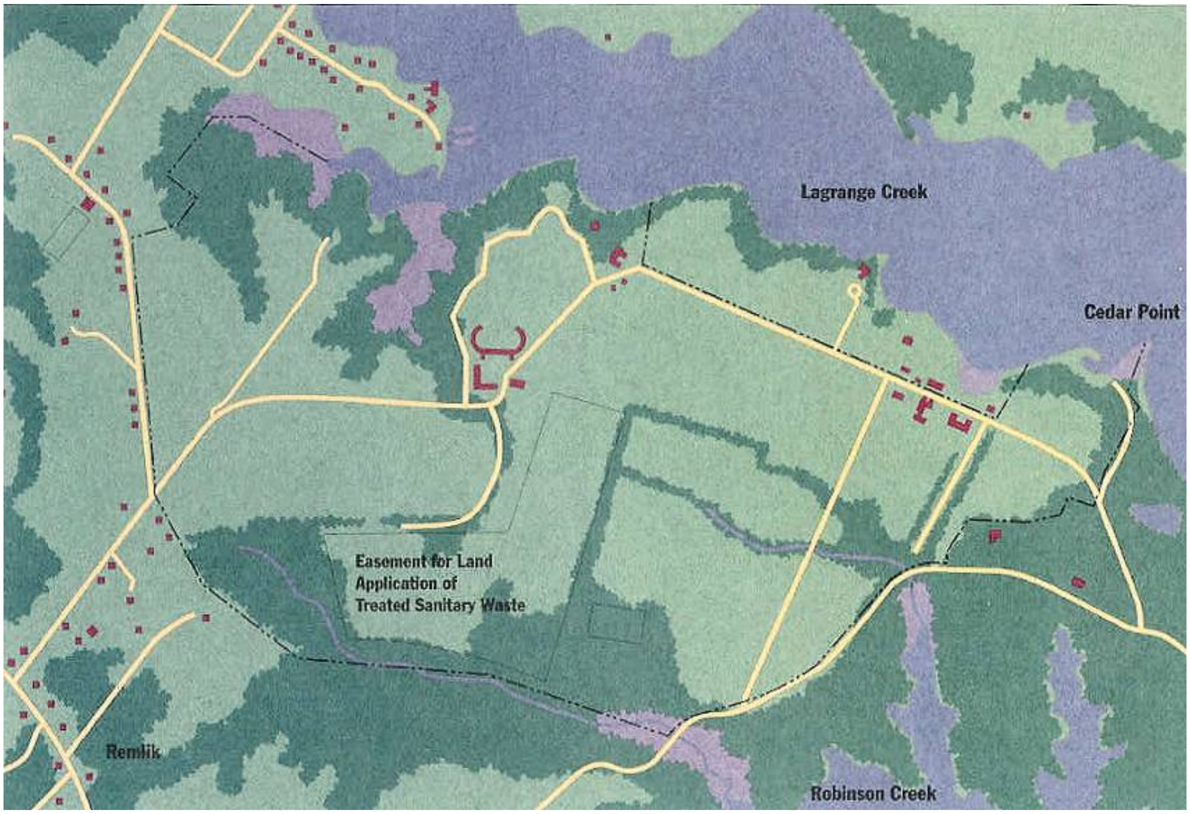


Figure 6.113. Site Plan of Remlick Hall Farm Prior to Development

The Remlick Hall property is a working farm. The farm produces grain crops and hay and also serves as a center for stabling and training horses. Located in the floodplain, the farmland on the property contains prime agricultural soil. Land in the center of the farm has been designated to be fertilized using treated sewage sludge from a nearby subdivision.

The farm and surrounding area is intended for agricultural and rural conservation, according to the Middlesex County comprehensive plan. The county's Low Density Rural Zoning District applies to the property. The zoning permits residential development at a maximum density of one home per 40,000 square feet, which is slightly less than an acre. A stated purpose of the zoning district is the protection of rural character and agricultural and forestry uses. In reality, however, typical development at this density assures the very elimination of the things it is intended to protect.

Clustering development is an effective way to allow development and also save farmland and open space in rural areas undergoing suburbanization. And as far as the Chesapeake Bay is concerned, farmland is preferable to developed land. Properly managed farmland minimizes polluted runoff and maintains the land's permeability to infiltrate stormwater.

The site plan in **Figure 6.114(a)** depicts a layout of residential lots typical of conventional subdivisions. It contains a total of 84 lots: 19 one-acre lots, 58 two- to four-acre lots, and seven lots five- to 15-acres in size. As is typical of conventional subdivisions, most, if not all, of the site is divided into lots. The limited open space that does remain consists of undevelopable land – wetlands and the sewage land application site, which by itself is too small to farm. **Figure 6.114(b)** is an aerial view of this site plan. Even with large lot development, note how much forest cover has been removed, when compared to the view in **Figure 6.112**.

This spread-out development pattern requires 20,250 linear feet of roadway at a VDOT standard width of 20 feet. This translates into 10.83 acres of new impervious surface area on-site for roads and driveways alone. Other hard surfaces and the roof tops associated with each new home contribute yet more impervious surface area, for a total of 26.3 acres. The polluted runoff shed by these surfaces, in combination with the individual septic systems serving the homes, is likely to pollute local waters above and below ground.

The site plan of the cluster subdivision alternative for Remlick Hall, depicted in **Figure 6.115(a)**, contains a total of 52 lots in three clusters. The two westernmost clusters together contain a total of 44 lots with a minimum size of 7,500 square feet, or slightly less than one-sixth of an acre. This lot size requires the use of shared septic facilities – one large drainfield serving a number of homes. The third cluster of homes is grouped near the existing complex of farm buildings and residences at the eastern end of the property. Eight high-end residences occupy lots of approximately one acre in this cluster. **Figure 6.115(b)** is an aerial view of this site plan. When compared to the view in **Figure 6.112**, note that virtually all of the forest cover is preserved.

The cluster plan preserves the rural character, field and shoreline vistas, and large acreages of forest and workable farmland for the enjoyment of all residents. It requires 9,750 linear feet of roadway, a 53 percent reduction in road length from the conventional plan alternative. The cluster plan saves $525,000 in development costs, largely due to the sizable reduction in road length over the conventional plan. Reduction in road length and width (from 20 feet wide to 18 feet) also pays off in less polluted runoff. The original CBF publication documents information regarding land use coverage, stormwater pollutants, and the construction costs of the two alternative plans.

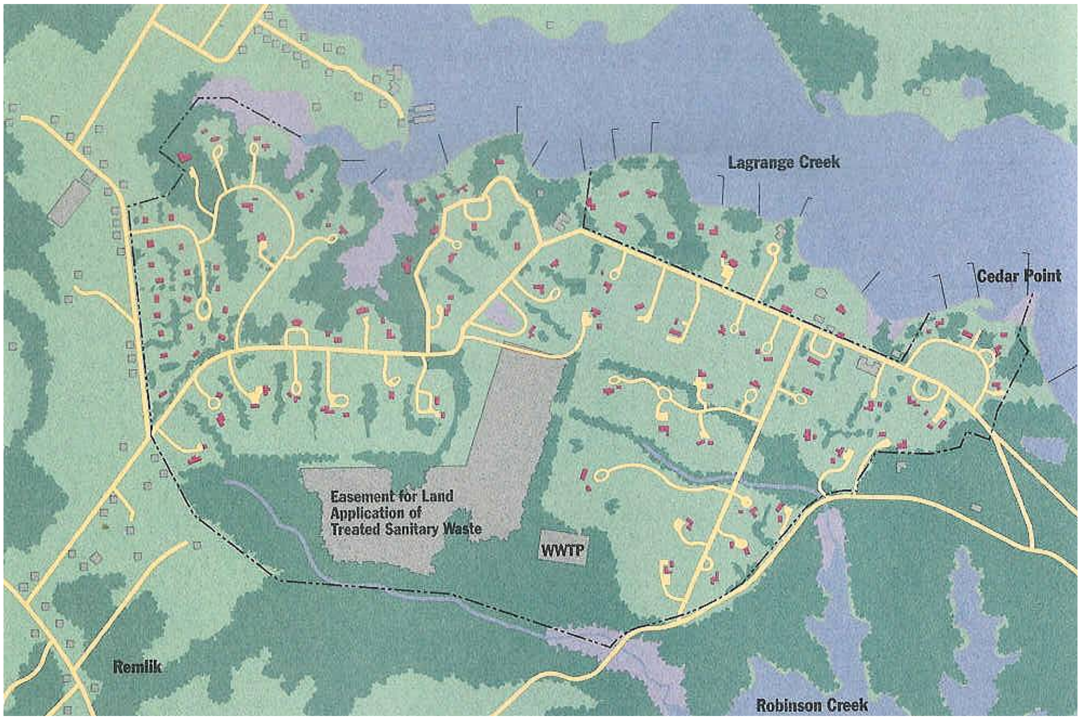
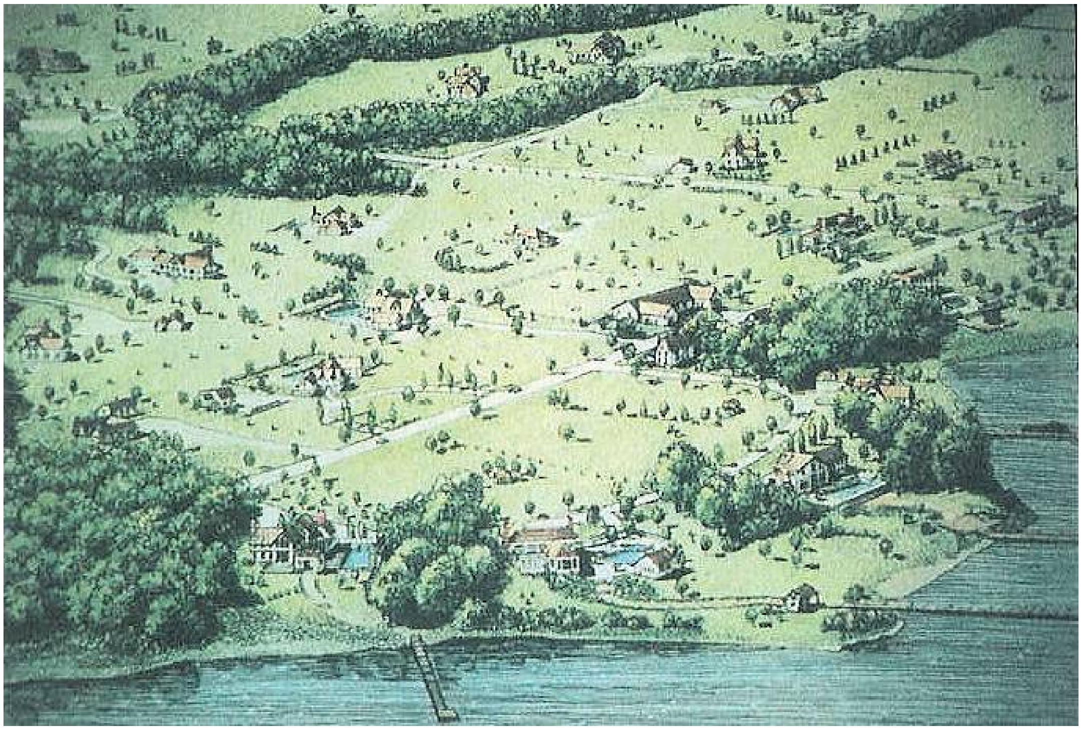


Figure 6.114. Site Plan and Aerial View of Conventional Subdivision Design for Remlick Hall



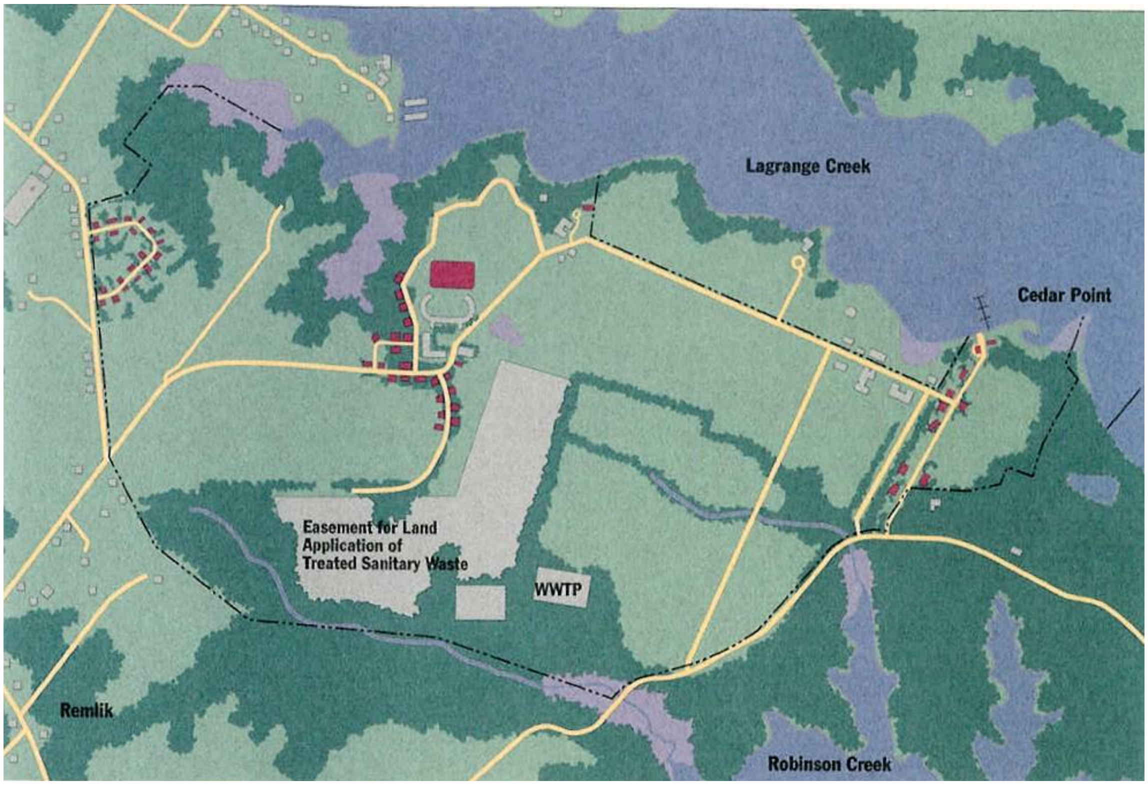


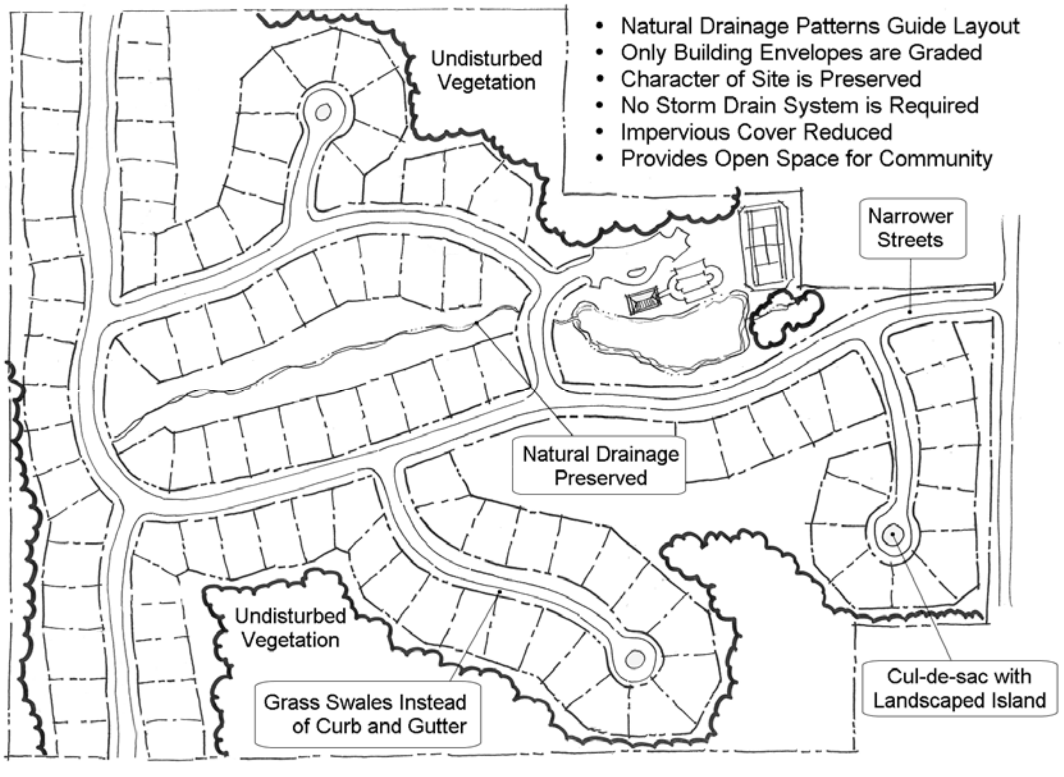
Figure 6.115. Site Plan and Aerial View of Clustering Subdivision Design for Remlick Hall

6.7.2. Example 2: Suburban Residential Subdivision A

A typical residential subdivision design on a parcel is shown in **Figure 6.116(a)**. The entire parcel except for the subdivision amenity area (clubhouse and tennis courts) is used for lots. The entire site is cleared and mass graded, and no attempt is made to fit the road layout to the existing topography. Because of the clearing and grading, all of the existing tree cover, vegetation and topsoil are removed, dramatically altering both the natural hydrology and drainage of the site. The wide residential streets create unnecessary impervious cover and a curb and gutter system that carries stormwater flows to the storm sewer system. No provision for non-structural stormwater treatment is provided on the subdivision site.

A residential subdivision employing stormwater ESD practices is presented in **Figure 6.116(b)**. This subdivision configuration preserves a quarter of the property as undisturbed open space and vegetation. The road layout is designed to fit the topography of the parcel, following the high points and ridgelines. The natural drainage patterns of the site are preserved and are utilized to provide natural stormwater treatment and conveyance. Narrower streets reduce impervious cover and grass channels provide for treatment and conveyance of roadway and driveway runoff. Landscaped islands at the ends of cul-de-sacs also reduce impervious cover and provide stormwater treatment functions. When constructing and building homes, only the building envelopes of the individual lots are cleared and graded, further preserving the natural hydrology of the site.

Figure 6.114. Comparison of a Traditional Residential Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)

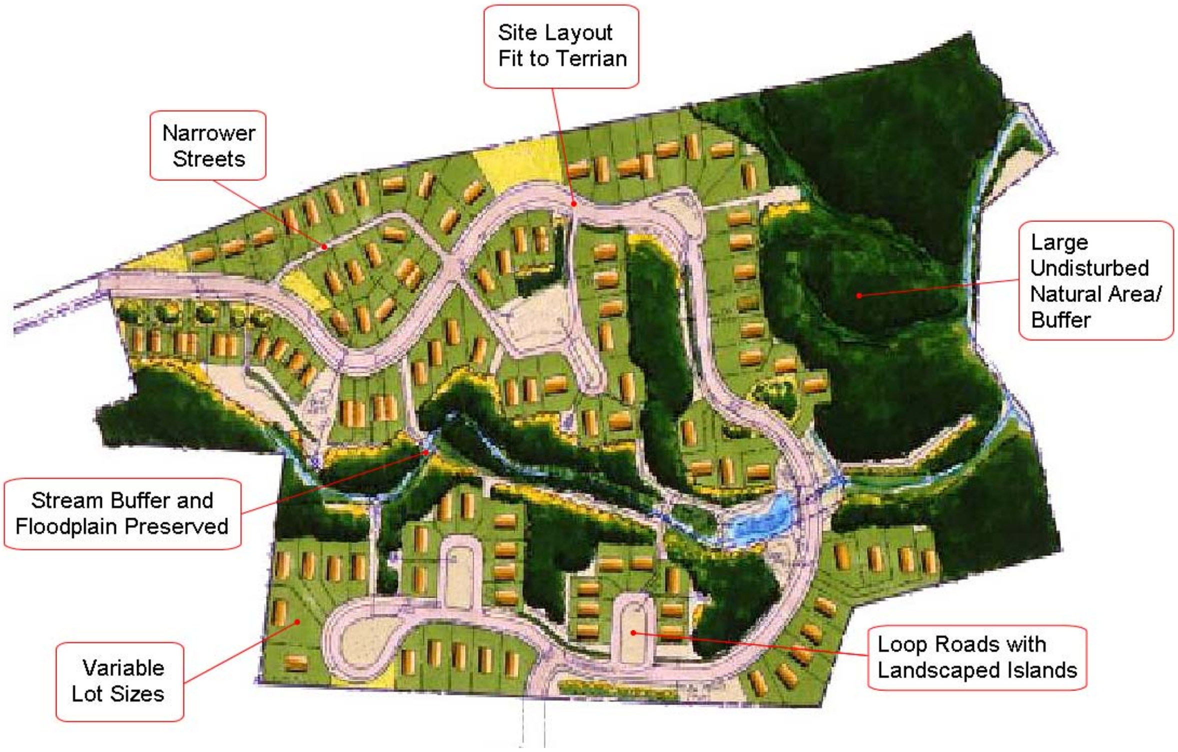


6.7.3. Example 3: Suburban Residential Subdivision B

Another typical residential subdivision design is shown in **Figure 6.117(a)**. Most of this site is cleared and mass graded, with the exception of a small riparian buffer along the large stream at the right boundary of the property. Almost no buffer was provided along the small stream that runs through the middle of the property. In fact, areas within the 100-year floodplain were cleared and filled for home sites. As is typical in many subdivision designs, this one has wide streets for on-street parking and large cul-de-sacs.

The ESD subdivision can be seen in **Figure 6.117(b)**. This subdivision layout was designed to conform to the natural terrain. The street pattern consists of a wider main thoroughfare that winds through the subdivision along the ridgeline. Narrower loop roads branch off of the main road and utilize landscaped islands. Large riparian buffers are preserved along both the small and large streams. The total undisturbed conservation area is close to one-third of the site.

Figure 6.117. Comparison of a Traditional Residential Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)



6.7.4. Example 4: Suburban Residential Subdivision C

Still another typical residential subdivision design is shown in **Figure 6.118(a)**. Virtually all of the site is cleared and mass graded. The ESD subdivision design shown in **Figure 6.118(b)** provides exactly the same number of lots, but they are smaller and arranged in conformance with the terrain, reducing the cleared area by 40% and the amount of impervious cover by half.

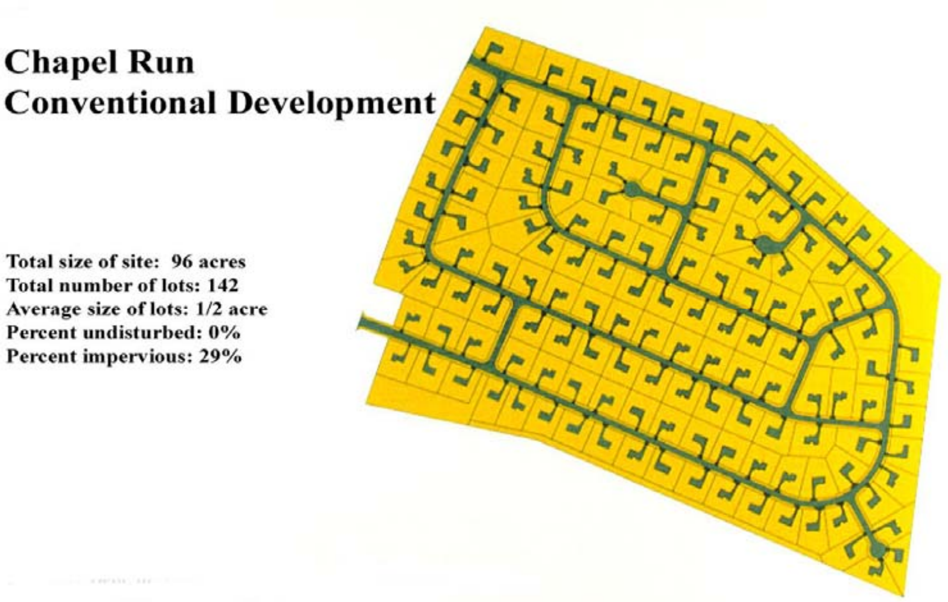
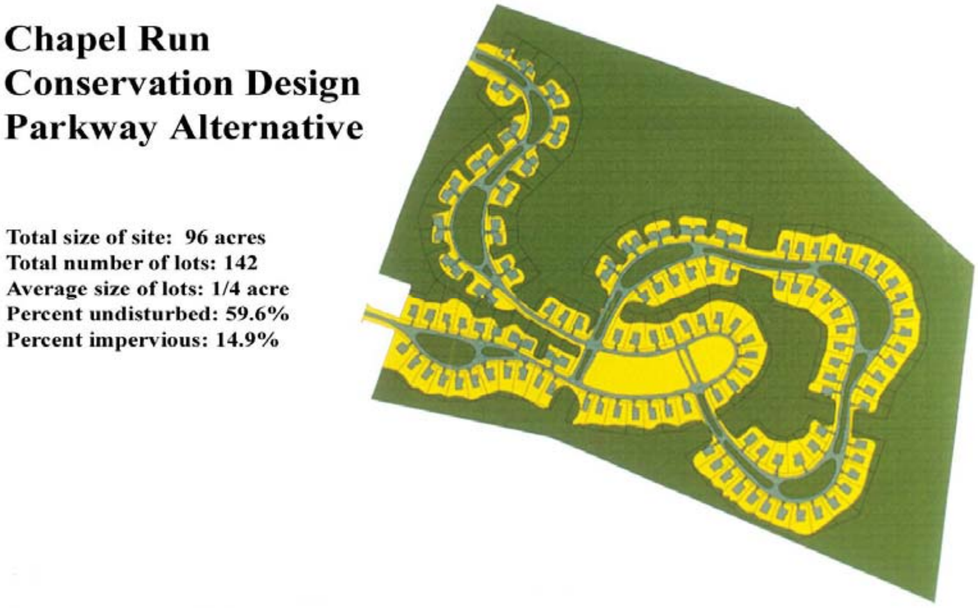


Figure 6.118. Comparison of a Traditional Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)
Source: Delaware Dept. of Natural Resources and Environmental Control



6.7.5. Example 5: Commercial Development Example

Figure 6.119(a) shows a typical commercial development containing a supermarket, drugstore, smaller shops and a restaurant on an out lot. The majority of the parcel is a concentrated parking lot area. The only pervious area is a small replanted vegetation area acting as a buffer between the shopping center and adjacent land uses. Stormwater quality and quantity control are provided by a wet extended detention pond in the corner of the parcel.

An ESD commercial development can be seen in **Figure 6.119(b)**. Here the retail buildings are dispersed on the property, providing more of an “urban village” feel with pedestrian access between the buildings. The parking is broken up, and bioretention areas for stormwater treatment are built into parking lot islands. A large bioretention area which serves as open green space is located at the main entrance to the shopping center. A larger undisturbed buffer has been preserved on the site. Because of the bioretention areas and buffer provide water quality treatment, only a dry extended detention basin is needed for water quantity control.

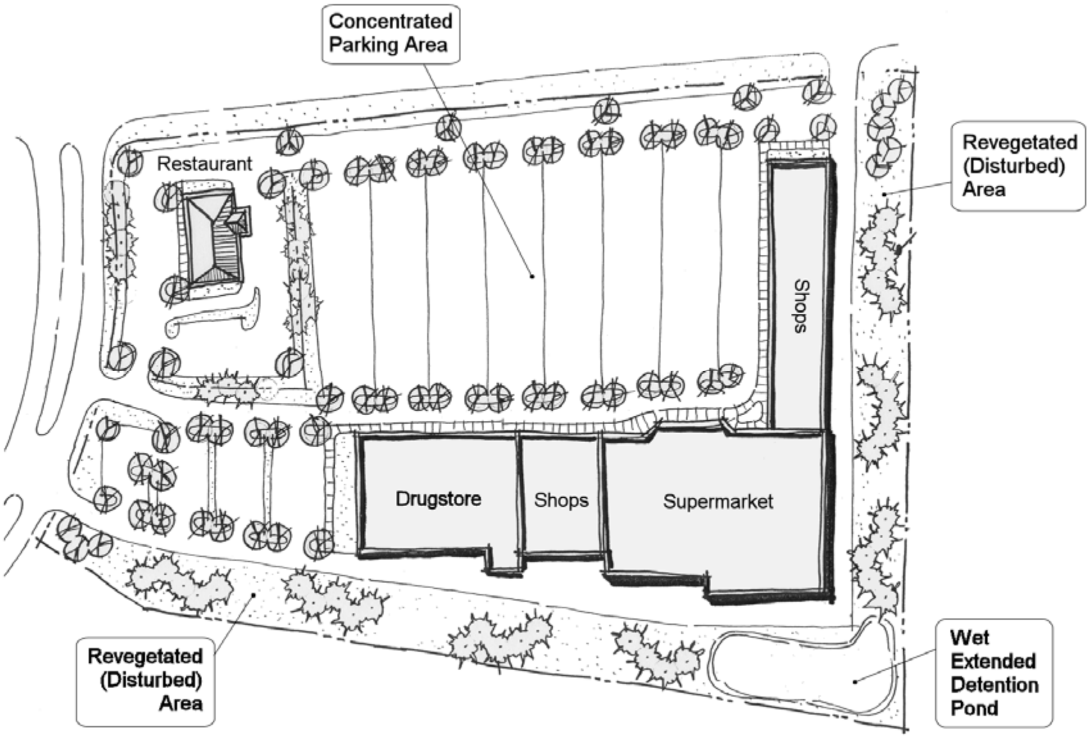
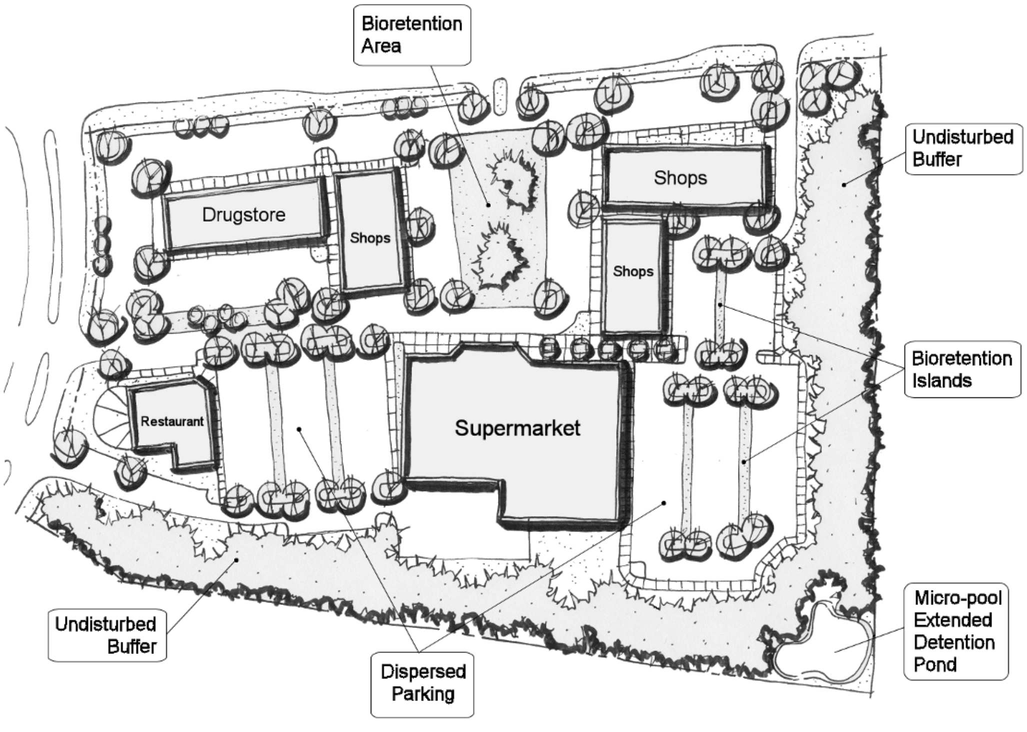


Figure 6.119. Comparison of a Traditional Commercial Development Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)



6.7.6. Example 6: Office Park Example

An office park with a conventional design is shown in **Figure 6.120(a)**. Here the site has been graded to fit the building layout and parking area. All of the vegetated areas of this site are replanted areas.

The ESD layout, presented in **Figure 6.120(b)**, preserves undisturbed vegetated buffers and open space areas on the site. Both the parking areas and buildings have been designed to fit the natural terrain of the site. In addition, a modular porous paver system is used for the overflow parking areas.

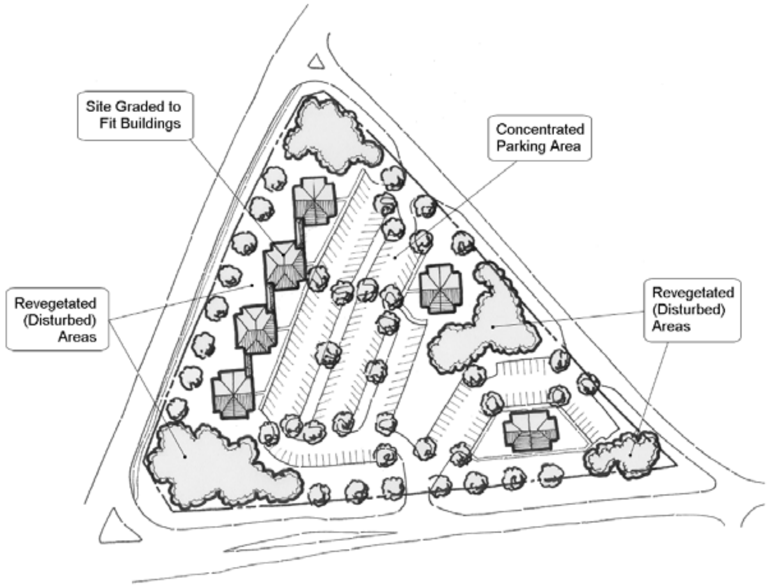
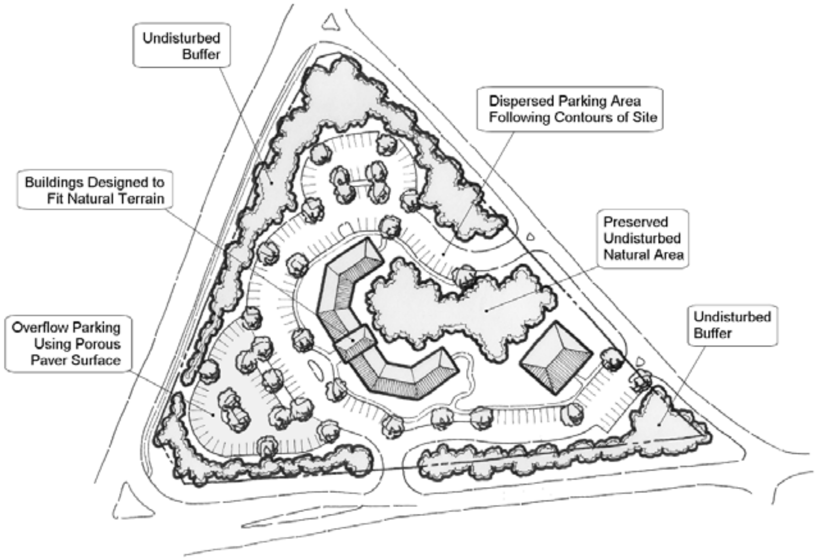


Figure 6.120. Comparison of a Traditional Office Park Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)



6.8. OTHER GOOD REFERENCE MATERIAL ON ENVIRONMENTAL SITE DESIGN

There are numerous sources of more specific information regarding Environmental Site Design. The earliest work on the specific topic was a publication by the Center for Watershed Protection entitled ***Better Site Design: A Handbook for Changing Development Rules in Your Community*** (August 1998), which is still available from the Center's website:

http://www.cwp.org/categoryblog/101-better-site-design-.html

The publication entitled ***Better Site Design: An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act*** is available from DEQ's website:

http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/Publications.aspx

For guidance regarding use of environmental design techniques for land development in rural areas, see the book ***Rural By Design*** (Randall Arendt et al., 1994). Perhaps the seminal work on the subject of accommodating man-made structures within the existing natural order in a manner that minimizes impact and cost is Ian McHarg's ***Design with Nature*** (1969).

6.9. PLANNING STORMWATER MANAGEMENT FOR SPECIAL SITE OR CLIMATIC CONDITIONS

Certain kinds of site or climatic conditions create unique challenges regarding site design and BMP selection. Among those are karst geologic conditions, conditions unique to sites near the coastline, sites classified as pollution hotspots, sites where extremely cold winter temperatures and precipitation exist, ultra-urban settings, and sites draining to waters that have exceptional classifications, such as pristine cold water trout streams or polluted waters subject to TMDL waste load allocations. The significance of these kinds of settings for site design is discussed below. The guidance for selecting BMPs in these kinds of settings is provided in **Chapter 8,** entitled **BMP Overview and Selection.**

6.9.1. Karst Geologic Conditions

Karst topography is commonplace in portions of Virginia west of the Blue Ridge, and in small, isolated areas in the Piedmont (see **Figure 6.121**). Karst is a dynamic landscape underlain by soluble bedrock such as limestone, dolomite, and marble. Prior to urbanization, much runoff reaches the epikarst through diffuse infiltration through fractured bedrock (see **Figure 6.122**), and is released slowly into the underlying network of caves. Characteristic karst landscape features include a pinnacled, highly irregular soil-rock interface (Denton, 2008), sinkholes, sinking and disappearing streams, caves, and large springs. Together, these features comprise an interconnected karst hydrological system that is easily contaminated and able to transmit large volumes of water over long distances in a short period of time, frequently passing beneath surface watershed boundaries (Veni et al, 2001; Zokaites, 1997).

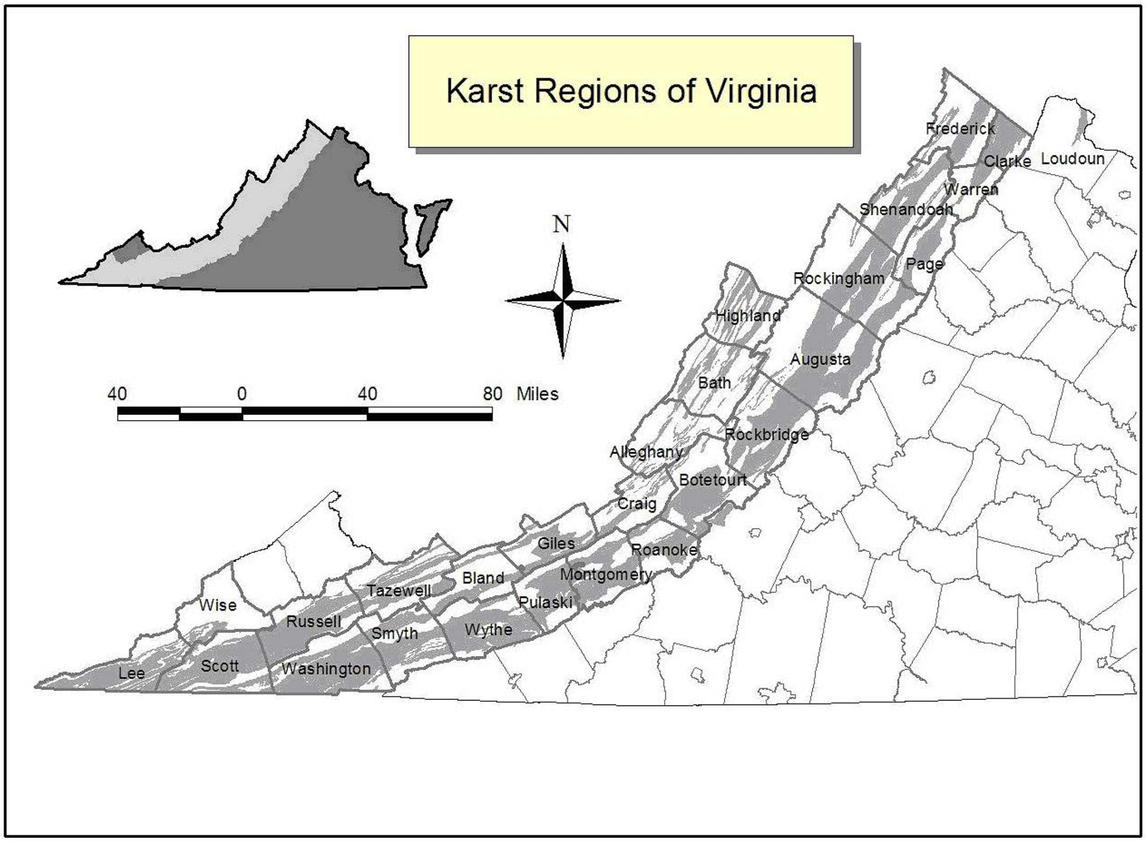


Figure 6.121. Karst Distribution in Virginia

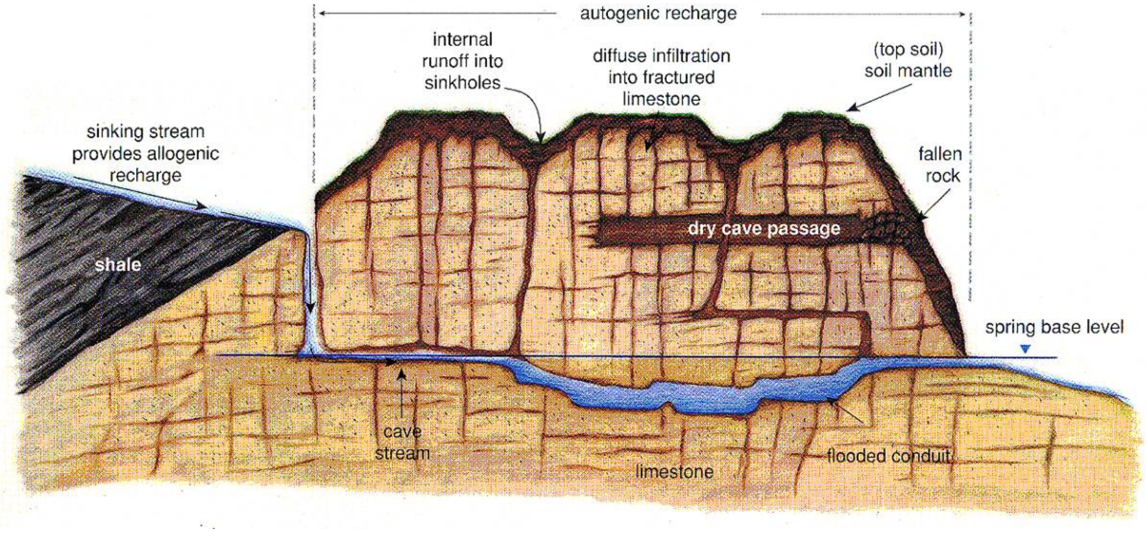


Figure 6.122. Profile Through Typical Karst Geology
Source: White et al. (1995)

The presence of active karst regions in the Ridge and Valley province of Virginia complicates the land development process and requires a unique approach to stormwater design. Some considerations include:

- Post-development runoff rates are greatly increased
- Highly variable subsurface conditions
- Surface/subsurface drainage patterns are poorly understood
- Unique rural development patterns exist in response to karst
- Much higher risk of groundwater contamination
- Risk of stimulating sinkhole formation
- Presence of endangered species

The following general principles should be considered in site layout and the design of stormwater systems in karst regions:

6.9.1.1. For Site Design

- Designers should perform the preliminary and detailed site investigations prior to site and stormwater design to fully understand subsurface conditions, assess karst vulnerability and define the actual drainage pattern present at the site. Any existing sinkholes should be surveyed and permanently recorded on the property deed. In addition, an easement, buffer or reserve area should be identified on the development plats for the project so that all future landowners are aware of the presence of active karst on their property.

- Minimize site disturbance and changes to the soil profile, including cuts, fills, excavation and drainage alteration.

- Sediment traps and basins should only be used as a last resort after all other E&S control options have been considered and rejected. In the rare instance they are employed, they should serve small drainage areas (2 acres or less), be located away from known karst features, and be equipped with impermeable liners to discourage subsidence.

- Minimize the amount of impervious cover created at the site so as to reduce the volume and velocity of stormwater runoff generated.

- Take advantage of topography when locating building pads and place foundations on sound bedrock.

6.9.1.2. For Stormwater Design

- Treat runoff as sheetflow in a series (treatment train) of small runoff reduction practices before it becomes concentrated. Practices should be designed to disperse flows over the broadest area possible to avoid ponding or soil saturation.

- Small scale LID-type practices work best in karst areas, although they should be shallow, closed and sometimes lined to prevent groundwater interaction. For example, micro-bioretention and infiltration practices are a key part of the treatment train. Distributed treatment is recommended over centralized stormwater facilities, which are defined as any practice that treats runoff from a contributing drainage area greater than 20,000 square feet of impervious cover, and/or has a surface ponding depth greater than three feet. Examples include wet ponds, dry extended detention ponds, and infiltration basins.

- The use of these centralized practices is strongly discouraged, even when liners are used. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed LID-type practices. In addition, distributed, disconnected LID practices eliminate the need to obtain an underground injection permit from the USEPA**.**

- Any discharge to karst features should only occur downstream of other BMP's and ensure that such discharges meet all relevant criteria of the Virginia Stormwater Management Regulations. The receiving feature should be identified on the permit registration as the receiving water. Developers should check with the Virginia Karst Office in the Virginia Department of Conservation and Recreation's Division of Natural Heritage to see if the resurgence location (where water entering the sinkhole returns to the surface at a spring) has been determined. If not, the developer is encouraged to coordinate with the Karst Office to perform dye trace investigations to locate the resurgence(s). Consistent with federal environmental regulations at 40 C.F.R. parts 144-148, some karst features receiving runoff may be considered class V injection wells and would have to be registered as such with EPA Region III. To ensure compliance in cases where stormwater runoff is discharged to a karst feature, DEQ recommends coordination with EPA Groundwater & Enforcement Branch (3WP22), U.S. EPA Region 3, 1650 Arch Street , Philadelphia, PA 19103, Phone: (215) 814-5427, Fax: (215) 814-2318.

For more detail regarding the effects of karst on site and stormwater design, see **Appendix 6-B** of this chapter, entitled *Stormwater Design Guidelines for Karst Terrain in Virginia*.

6.9.2. Coastal Plain/High Groundwater Table

Most stormwater practices were originally developed in the Piedmont physiographic region and have seldom been adapted for much different conditions in the coastal plain. Consequently, guidance for stormwater design is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, deeper groundwater table, low wetland density, and well drained soils.

By contrast, stormwater design in the coastal plain is strongly influenced by unique physical constraints, pollutants of concern and resource sensitivity of the coastal waters. Implementation of traditional stormwater practices in the coastal plain is constrained by physical factors such as flat terrain, high water table, altered drainage, extensive groundwater interactions, poorly-drained soils, and extensive wetland complexes. The significance of these constraints is described below:

Flat Terrain. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces the hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes for which the region is especially prone.

High Water Table. In much of the coastal plain, the water table exists within a few feet of the surface. This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater control practices.

Highly Altered Drainage. The headwater stream network in many coastal plain watersheds no longer exists as a natural system, with most zero order, first order and second order streams replaced by ditches, canals and roadway drainage systems.

Poorly Drained Soils. Portions of the coastal plain have soils that are poorly drained and frequently do not allow infiltration to occur and, as a result, coastal plain watersheds contain have a greater density of wetlands than any other physiographic region in the country (Dahl, 2006).

Very Well-Drained Soils. In other parts of the coastal plain, particularly near the coast line, soils are sandy and extremely permeable, with infiltration rates exceeding four inches per hour or more, providing a stronger risk of stormwater pollutants rapidly migrating into groundwater. This is a particular design concern, given the strong reliance in the coastal plain on groundwater for drinking water supply.

Drinking Water Wells and Septic Systems. A notable aspect of the coastal plain is a strong reliance on public or private wells to provide drinking water (USGS, 2006). As a result, *designers need to consider groundwater protection as a first priority* when they are considering how to dispose of stormwater. At the same time, development in the coastal plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to be careful in how they manage and dispose of stormwater so they do not reduce the effectiveness of adjacent septic systems.

Conversion of Croplands With Land Application. Land application of animal manure and domestic wastewater on croplands is a widespread practice across the coastal plain. When this farmland is converted to land development, there is a strong concern that infiltration through nutrient enriched soils may actually increase nutrient export from the site.

Pollutants of Concern. The key pollutants of concern in coastal plain watersheds are nitrogen, bacteria, and metals. These pollutants have greater ability to degrade the quality of unique coastal plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat, and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control.

Unique Development Patterns. The development patterns of coastal plain watersheds are also unique, with development concentrated around waterfronts, water features and golf courses rather than around an urban core. The demand for vacation rental, second homes and retirement properties also contributes to sprawl-type development.

Shoreline Buffers and Critical Areas. Chesapeake Bay Preservation Areas (CBPAs) in Virginia include special shoreline buffer and stormwater pollutant reduction requirements that strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within CBPAs must rely on stormwater micro-practices to comply with applicable requirements.

The Highway as the Receiving System. The stormwater conveyance system for much of the coastal plain is frequently tied to the highway ditch system, which is often the low point in the coastal plain drainage network. New upland developments often must get approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The requirement for developers to obtain both a local government and highway agency approval for their project can result in conflicting design requirements.

Sea Level Rise. Sea level is forecast to rise at least a foot over the next thirty to fifty years as a result of subsidence and climate change. This large change in average and storm elevations in the transition zone between tidal waters and the shoreline development a few feet above it has design implications for the choosing where to discharge treated stormwater.

Hurricanes and Flooding. Due to their location on the coast, coastal communities are subject to rainfall intensities that are 10-20 percent greater for the same design storm event compared to sites further inland. The flat terrain lacks enough hydraulic head to quickly move water out of the conveyance system (which may be further complicated by the backwater effects of tidal surges). Additionally, large tidal surges may cause significant flooding with no precipitation present.

Guidance for BMP selection based on a high groundwater table or the filtration rate of soils is provided in **Table 8.4** in **Chapter 8**.

6.9.2.1. General Stormwater Design Principles in the Coastal Plain

The following initial guiding principles are offered on the design of stormwater practices in the coastal plain:

- Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.
- Keep all other practices out of the riparian buffer area, except for the use of conservation filters at their outer boundary.
- Relax some design criteria to keep practice depths shallow and respect the water table.
- Emphasize design factors that can increase bacteria removal, not exacerbate bacteria problems.
- To maximize nitrogen removal, promote denitrification by creating anaerobic and aerobic zones adjacent to one another in either the vertical or lateral direction.
- Use plant species that reflect the native coastal plain plant community and, in particular, can survive well in a high salinity environment.
- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of in-line treatment in the swale and ditch system.

- Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to use site design to “raise the bridge” by increasing the vertical elevation of building pads at coastal plain development sites.

For more detail regarding the effects of coastal settings on site and stormwater design, see **Appendix 6-C** of this chapter, entitled *Stormwater Design in the Coastal Plain of Virginia*.

6.9.3. Pollution Hot Spots

Certain classes of business, municipal and industrial operations, if not carefully managed, produce higher concentrations of certain pollutants (e.g., nutrients, hydrocarbons, metals, chlorides, pesticides, bacteria, trash, etc.) than are normally found in urban runoff. Such facilities, commonly called pollution *Hotspots*, also present a greater potential risk for spills, leaks or illicit discharges. Hotspot facilities are required to obtain discharge permits and maintain a series of pollution control practices to prevent or minimize contact of pollutants with rainfall and runoff.

Examples of business, municipal and industrial activities that may be considered hotspots and need pollution prevention permits and plans include:

- Gasoline/fueling stations (**Figure 6.123**)
- Vehicle Repair Facilities
- Vehicle washing/steam cleaning sites
- Auto recycling facilities and junk yards
- Commercial laundry and dry cleaning
- Commercial nurseries
- Golf Courses
- Swimming Pools
- Heavy manufacturing/power generation
- Metal production, plating and engraving
- Toxic chemical manufacturing/storage
- Petroleum storage and refining facilities
- Airports and deicing facilities
- Marinas and ports
- Railroads and rail yards

CERCLA-designated superfund sites

- Hazardous waste handling, transfer and disposal facilities
- Recycling and solid waste handling and transfer facilities
- Composting facilities
- Landfills
- Incinerators
- Vehicle/equipment/fleet maintenance and parking areas
- Public works yards and material storage areas (**Figure 6.124**)
- Public Buildings (e.g., Schools, Libraries, Police and Fire Stations)
- Water/Wastewater Treatment Facilities

Figure 6.123. Gasoline Station

Figure 6.124. Public Works Yard

Hotspot facilities should be evaluated to identify their potential pollution-generating activities. There are typically six categories of pollution-generating activities that commonly contribute to stormwater problems (see **Figure 6.125**):

- Outdoor materials handling
- Physical plant maintenance
- Stormwater infrastructure
- Turf/landscape management
- Vehicle operations
- Waste management

Figure 6.125. Six Categories of Pollution-Generating Activities Assessed at Stormwater Hotspot Facilities

Training of personnel at the affected area is needed to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation. Both industrial and municipal operations must develop detailed stormwater pollution prevention plans (SWPPPs), train employees, and submit reports to regulators.

Stormwater management implications for hot spot sites are as follows:

- The main focus regarding potential pollutants must be on shelter (from the elements – see **Figure 6.126**) and containment of potential spills and illicit discharges (**Figure 6.127**)
- Certain stormwater control measures (e.g., infiltration) should be avoided
- The practices that are applied will typically require some sort of pre-treatment (e.g., a sand filter) before runoff is allowed to be discharged to a natural channel, a storm sewer or, most important, any type of infiltration practice.

Figure 6.126. Covered Chemical Storage

Figure 6.127. Wash Water Containment

Table 8.3 in **Chapter 8** is a matrix that indicates which control measures are appropriate for use at hotspot locations.

The following are excellent sources of information related to managing stormwater and pollution at hotspot-type settings:

- ***Issue Paper H: Potential Stormwater Hotspots, Pollution Prevention, Groundwater Concerns and Related Issues, version 3 (final)***, prepared by Emons & Oliver Resources and the Center for Watershed Protection for the Minnesota Pollution Control Agency, from which the document is available online at: http://www.pca.state.mn.us/publications/wq-strm8-14bf.pdf
- ***Urban Subwatershed Restoration Manual 9, Chapter 4: Hotspot Facility Management***, available from the Center for Watershed protection online at: http://www.cwp.org/Resource_Library/Center_Docs/municipal/USRM9.pdf
- ***Stormwater Management Manual for Western Washington, Volume IV: Source Control BMPs*** (February 2005 , Publication No. 05-10-32, which is a revised portion of Publication No. 91-75) available online from the Washington State Department of Ecology's Water Quality Program at: http://www.ecy.wa.gov/pubs/0510032.pdf
- ***Development Planning for Storm Water Management: A Manual for the Standard Urban Storm Water Mitigation Plan (SUSMP)***, available from the Los Angeles County (California) Department of Public Works online at: http://ladpw.org/wmd/npdes/SUSMP_MANUAL.pdf

6.9.4. Cold Winter Climate

In parts of Virginia, colder temperatures and longer lasting snow and ice events occur during the winter. Regions that have an average daily temperature of 35 degrees Fahrenheit or less during January, and that have a growing season less than 120 days, are especially vulnerable to the effects of cold weather. While Virginia's average growing season is rarely less than 160 days, the statewide average temperature for January is just above 35°F. This means that some areas are colder, illustrated by the typically bitterly cold temperatures of the northern Blue Ridge, which are more like January temperatures in Chicago.

Cold climates can present additional challenges to the selection, design and maintenance of stormwater management BMPs due to one or more of the factors listed in **Table 6.21** below. While there may be fewer runoff events during winter months, snow and ice may significantly impact the operation of some treatment practices during winter rain events and periods of snowmelt. Engineers and site designers in cold regions should be aware of these challenges and make provisions for them in their final designs.

Table 6.21. Cold Weather Challenges to BMP Selection and Design

Climatic Conditions	BMP Selection/Design Challenge
Cold Temperatures	• Pipe freezing • Permanent pool covered by ice • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities • Impacts of road salt/deicers/chlorides • Winter sanding impacts on facilities
Deep Frost Line	• Frost heaving • Reduced soil infiltration • Pipe freezing
Significant Snowfall	• High runoff volumes during snowmelt • High runoff during rain-on-snow • High pollutant loads during spring melt • Other impacts of road salt/deicers/chlorides • Snow management may affect BMP storage • Winter sanding impacts on facilities

Source: Adapted from Washington (State) Department of Ecology (2004)

The following describe in more detail some of the potential cold climate impacts:

Frost Heaving. Moisture in the soil expands when it freezes, causing the soil to rise or “heave.” This creates the potential for damage to structural components of BMPs, such as pipes or concrete infrastructure located within the soil. Another concern is that infiltration BMPs can cause frost heave damage to other structures, particularly roads. The water infiltrated into the soil matrix can flow under a permanent structure and then re-freeze. The sudden expansion associated with this freezing can cause damage to above-ground structures.

Pipe Freezing. Most treatment practices, with the exception of vegetative filter strips, rely on some form of inlet piping and may also have an outlet or underdrain pipe. Frozen pipes can crack due to ice expansion, creating a maintenance or replacement burden. In addition, pipe freezing reduces the hydraulic capacity of the system, thereby limiting pollutant removal and creating the potential for flooding (CWP, 1997).

Ice Formation on a Permanent Pool. The permanent pool of a wet pond serves several purposes. First, the water in the permanent pool slows down incoming runoff, allowing for increased settling of pollutants. In addition, the biological activity in the pool can act to remove nutrients, since growing algae, plants and bacteria require these nutrients for growth. In some systems, such as sand filters, a permanent pool acts as a pre-treatment measure, settling out larger sediment particles before full treatment by the BMP.

Ice cover on a permanent pool causes two problems. First, the treatment pool’s volume is reduced. Second, because the permanent pool is frozen, it acts as an impermeable surface.

Runoff entering an ice-covered pond can follow two possible routes, neither of which provides sufficient pollutant removal. In the first case, runoff is forced under the ice, causing scouring of bottom sediments. In the second case, runoff flows over the top of the ice, receiving little or no treatment. Sediment that settles on top of the ice can easily be re-suspended by subsequent runoff events (CWP, 1997).

Reduced Settling Velocities. Settling is the most important removal mechanism in many BMPs. As water becomes cooler, its viscosity increases, which reduces particle velocity by up to 50 percent and makes it more difficult for particles to settle out.

Reduced Biological Activity. Many stormwater treatment practices rely on biological mechanisms to help reduce pollutants, especially nutrients and organic matter. For example, wetland systems rely on plant uptake of nutrients and the activity of microbes at the soil/root zone interface to break down pollutants. During cold temperatures (below 40°F), photosynthetic and microbial activity is sharply reduced when plants are dormant during the non-growing season, limiting these pollutant removal pathways (CWP, 1997).

Reduced Oxygen Levels in Bottom Sediments. In cold regions, oxygen exchange between the air-water interface in ponds and lakes is restricted by ice cover. In addition, warmer water sinks to the bottom during ice cover, because it is denser than the cooler water near the surface. Although biological activity is limited in cooler temperatures, the decomposition that takes place does so at the bottom of wet ponds, sharply reducing oxygen concentrations in bottom sediments. In these anoxic conditions, positive ions retained in sediments can be released from bottom sediments, reducing the BMP’s ability to treat these nutrients or metals in runoff.

Reduced Soil Infiltration. The rate of infiltration in frozen soils is limited, especially when ice lenses form (CWP, 1997). There are two results of this reduced infiltration. First, BMPs that rely on infiltration to function can be ineffective when the soil is frozen. Second, runoff volume from snowmelt is elevated when the ground underneath the snow is frozen.

Increased Pollutant Loading During Winter or Spring Thaw Periods. Winter or spring melt events are important because of increased runoff volumes and pollutant loads. The snowpack contains high pollutant concentrations, due to the buildup of pollutants over a several-month period. Chloride loadings are highest in snowmelt events because of the use of deicing salts, such as sodium chloride and magnesium chloride. Excessive loadings can kill vegetation in swales and other vegetative BMPs. Research indicates roughly 65 percent of the annual sediment, organic, nutrient, and lead loads can be attributed to winter and spring melts.

Access Difficulties in Ice and Snow. Points of access to BMPs may be frozen shut, and BMPs and access ways may be buried under the snow.

Particular Maintenance Issues. Maintenance requirements of certain BMPS may increase during the winter months due to increased loading and debris. Pollutant loading typically increases due to leaf fall, snow plowing, sanding, salting, and accumulation of materials in snow piles. Unique cold climate pollutants include the following:

- Sand
- Salt
- Polycyclic Aromatic Hydrocarbons (PAHs) emitted from fireplaces and inefficient vehicles in the winter
- Cyanide included in deicing salt compounds to prevent clumping

BMPs that use filtration, settling, or trapping to remove contaminants require frequent inspection and maintenance. Regular maintenance of BMPs located in cold climates is suggested just prior to the first snowfall or road sanding, after the last snowfall, and during spring snowmelt to ensure the proper treatment of runoff.

Each of the individual stormwater control measure specifications on the Virginia Stormwater BMP Clearinghouse web site includes guidance for mitigating the potential effects of cold weather on treatment practice operation and performance. Furthermore, guidance for BMP selection based tolerance for winter conditions is provided in **Table 8.5** in **Chapter 8**. The following are excellent sources of more detailed information related to managing stormwater and pollution in cold climates:

- ***Issue Paper G:. Cold Climate Considerations for Surface Water Management***, prepared by Emons & Oliver Resources and the Center for Watershed Protection for the Minnesota Pollution Control Agency, from which the document is available online at: http://www.pca.state.mn.us/publications/wq-strm8-14be.pdf
- ***Stormwater BMP Design Supplement for Cold Climates***, by D. Caraco and R. Claytor, available online from the Center for Watershed Protection at: http://www.cwp.org/Resource_Library/Center_Docs/special/ELC_coldclimates.pdf
- ***Snow, Road Salt and the Chesapeake Bay***, available online from the Center for Watershed Protection at: http://www.cwp.org/Resource_Library/Special_Resource_Management/ColdClimate/snow_roadsalt_chesbay.pdf
- ***Stormwater Management Manual for Eastern Washington***, Publication No. 04-10-076, available online from the Washington State Department of Ecology at: http://www.ecy.wa.gov/pubs/0410076.pdf .
- ***New York State Stormwater Management Design Manual, Appendix I***, available online from the New York State Department of Environmental Conservation at: http://www.dec.ny.gov/docs/water_pdf/swdmappendixi.pdf

6.9.5. Cold-Water Fisheries and Other Sensitive Receiving Waters

Cold and cool water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. Waters of Virginia are classified in seven (7) classes in the Virginia Water Quality Standards (WQS, at 9 VAC 25-260 et seq.), administered by the State Water Control Board and the Department of Environmental Quality. Cold water fisheries fall into Classes V and VI. Class V streams are appropriate for stocking trout. Class VI streams accommodate natural trout populations. Both of these stream classes have stricter criteria for water temperature and dissolved oxygen than other classes of water in the state (9 VAC 25-260-60 and 9 VAC 25-260-70). This applies both to the typical conditions that apply to these stream classes as well as to the limit of variation in these criteria. Furthermore, § 9 VAC 25-260-370 B of the WQS describes the Virginia Department of Game and Inland Fisheries more discrete classification of trout waters and the distinctions between them. Finally, PART IX (§ 9 VAC 25-260-360 et seq.) of the WQS provides a Virginia map divided into regions and lists each named stream segment within each region, identifying for each the stream class and critical criteria that apply.

The design objective for the cold water (trout) streams is to maintain habitat quality by preventing stream warming, maintaining dissolved oxygen levels, maintaining natural recharge, preventing pollution, preventing bank and channel erosion, and preserving the natural riparian corridor. Techniques for accomplishing these objectives include the following:

- Minimizing impervious surfaces
- Minimizing surface areas of permanent pools
- Preserving existing forested areas
- Bypassing existing baseflow and/or spring flow
- Providing shade-producing landscaping

The elevated temperatures are also caused by reduced shading in developed riparian areas. Pavement and other impervious surfaces tend to absorb substantial amounts of heat in summer due to their dark coloring and typically a lack of shade. This heat is transferred to runoff passing over the surface, resulting in runoff that is dramatically warmer than natural groundwater inflow would have been under a natural hydrologic cycle. Some BMPs, such as swales, shallow ponds and large impoundments can also increase the temperature of runoff, as it is quickly warmed on hot summer days before being discharged. Traditional peak reduction outlet structures and simple spillway outlets do nothing to cool the water before discharge. Thus, their use in proximity to cold water streams should be limited. Alternative BMPs, such as buffers, infiltration or under-drained filters can be used, or, if ponds are required, under-drained outlet structures can provide effective cooling. Equally important to maintaining cool stream temperature is preservation and/or restoration of riparian trees and shrubs to provide shade, particularly for headwater streams that are the root of the local ecosystem and the base of its food chain.

Temperature changes can be stressful and even lethal to many coldwater organisms. A rise in water temperature of just a few degrees Celsius over ambient conditions can reduce or eliminate sensitive stream insects and fish species such as stoneflies, mayflies and trout (Schueler, 1987). Of note, the WQS state that temperature for Class V streams should be 21ºC and Class VI streams should be 20ºC. Furthermore the temperature may not be raised by a discharge event in excess of 2ºC for Class V streams or 0.5ºC for Class VI streams.

6.9.6. Waters Where TMDLs Have Been Established

The federal Clean Water Act and 9 VAC 25-870-10 of the Virginia Stormwater Management Regulations define *Total maximum daily load* or *TMDL* as “the sum of the individual wasteload allocations for point sources or load allocations (LAs) for nonpoint sources, natural background loading and a margin of safety. TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. The TMDL process provides for point versus nonpoint source trade-offs.”

Under the Clean Water Act, water quality standards, which consist of both narrative and numeric criteria, are established to protect the physical, chemical, and biological integrity of surface waters and maintain designated uses. Under the authority of section 303(d) of the Clean Water Act, water bodies that do not meet water quality standards are considered "impaired," and a "Total Maximum Daily Load" (TMDL) study must be conducted. This study computes the maximum pollutant load the water body can receive and still meet water quality standards, and it allocates this load to various point and nonpoint pollution sources, depending on what is causing the water quality impairment. Authorized states and tribes administer the TMDL program. In Virginia, the Department of Environmental Quality (DEQ) administers the TMDL program, as delegated from the EPA. The DEQ assists with developing TMDL implementation plans for waters with impairments due to nonpoint sources.

Currently, thousands of impaired waters are listed on state 303(d) lists. The Virginia 303(d) list of impaired waters can be found on the DEQ website at the following link:

http://www.deq.virginia.gov/wqa/ir2010.html

The most common sources of impairment associated with stormwater include sediment, pathogens (bacteria), nutrients, and metals (USEPA, 2007). However, stormwater and urban and suburban runoff are also significant contributors to impairments. For this reason, EPA and relevant state agencies are increasingly motivated to create a stronger link between TMDLs and stormwater permits, such as MS4, construction site, and industrial permits (USEPA, 2007; USEPA Region 5, 2007d, 2007e). With successive rounds of MS4 permits, permitted agencies will very likely need to apply more stringent stormwater criteria in impaired watersheds and/or provide a better match between particular pollutants of concern and selected BMPs.

Reflecting this point, section 9 VAC 25-870-54 E of the Virginia Stormwater Management Regulations, with the heading *Stormwater pollution prevention plan requirements*, states the following: "In addition to the above requirements, if a specific WLA for a pollutant has been established in a TMDL and is assigned to stormwater discharges from a construction activity, additional control measures must be identified and implemented by the operator so that discharges are consistent with the assumptions and requirements of the WLA in a State Water Control Board approved TMDL."

For the local stormwater manager, this will require an effort to tailor certain stormwater criteria, watershed plans and BMPs to help meet TMDL pollutant reduction benchmarks. However, it is important to understand that efforts to (1) conserve and protect open space and sensitive resources, (2) buffer stream systems, (3) reduce runoff volume and infiltrate it or hold it for use on-site, and (4) provide treatment of runoff through other kinds of stormwater management practices, can provide significant results in addressing various kinds of urban and suburban water quality impairments.

6.9.6.1. Strategies for Local Stormwater Managers to Address TMDLs Through Special Stormwater Criteria

Depending on the nature of the TMDL and the implementation plan, local stormwater criteria can help address TMDL requirements. The following three general approaches are discussed in order of decreasing sophistication. There are other approaches that can applied, and a local program may find that a hybrid of several approaches is most applicable:

- Site-Based Load Limits
- Surrogate Measures for Sources of Impairment
- Presumptive BMP Performance Standards

A. Site-Based Load Limits

Some pollutants that are the basis for TMDLs are understood well enough that site-based load calculations can be done for each development and redevelopment site. These pollutants generally include sediment, phosphorus, and nitrogen. In some areas, other pollutants, such as ammonia, fecal coliform bacteria, and other pollutants can be added to the list if adequate local or regional studies have been conducted (MPCA, 2006). If site-based load limits are to be used, the TMDL and local stormwater program should have the following characteristics:

- The TMDL allocates a load reduction target to urban/developed land (preferably separating out existing developed land from estimates of future developed land).
- The local program uses (or plans to use) a method, such as the Simple Method (CWP and MDE, 2000), that allows for the calculation of pollutant loads for a particular site development project.
- The local, regional, or state manual (or policy document) contains a method to assign pollutant removal performance values to various structural and nonstructural BMPs. Low-Impact Development (LID) credits are another positive factor so that LID practices can be incorporated.

The general process for calculating site-based load limits is as follows:

Step 1: Based on the wasteload allocation (WLA) and load allocation (LA) in the TMDL, develop a site-based load limit for the pollutant of concern. The local program must allocate the total load reduction goal for urban/developed land to existing and future urban/developed land within the impaired watershed. The program should consider having a more flexible standard for redevelopment projects because the standard will usually be more difficult to meet for these projects.

> *Example: Site-based load limit = 0.28 pounds/acre/year for total phosphorus* (*Hirschman et al. 2008*) *That is, if each newly developed site meets the standard of 0.28 pound/acre/year, the load reduction goal for new urban/developed land can be met. In this context, other measures—such as stormwater retrofits and restoration projects—might have to be applied for existing urban/developed land (see Step 5 below and Schueler et al. 2007*).

Step 2: For each development site, the applicant should calculate the post-development load for the pollutant of concern using a recognized model or method. Most use impervious cover as the main basis for calculating loads, although other land covers (e.g., managed turf) are also important contributing sources.

> *Example: Post-development total phosphorus load = 0.55 pound/acre/year*

Step 3: Next, the required load reduction is computed by comparing the post-development load to the site-based load limit, and an appropriate BMP is selected.

> *Example: Load reduction = post-development load – site-based load limit 0.55 – 0.28 = 0.27 pound/acre/year (load that must be removed to meet the load limit standard) Selected BMPs should be capable of removing the target load reduction. One way to determine this is to calculate the load leaving the BMP based on the expected effluent concentration and the effluent volume for the design storm (or on an annual basis).*

Step 4: Select a combination of structural and nonstructural BMPs that can be documented to meet the required load reduction. If the local program and/or TMDL implementation plan encourages LID, then these practices should be assigned load reduction credits.

If the entire load reduction cannot be achieved (or is impractical) on the particular site, the applicant might be eligible to implement equivalent off-site BMPs within the impaired watershed. These off-site BMP may be implemented by the applicant on developed land that is currently not served by stormwater BMPs. As and alternative, the applicant can pay an appropriate fee (fee in lieu) to the local program to implement stormwater retrofits within the impaired watershed. In either case, full on-site compliance is being “traded” to implement other BMPs that can help achieve TMDL goals.

The local program would have to apply this technique to a variety of local plans to gauge achievability and feasibility across a range of development scenarios. A good real-world example of this approach (although not specific to impaired watersheds) is Maine’s *Phosphorus Control in Lake Watersheds: A Guide to Evaluating New Development*, which can be found at:

http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps

B. Surrogate Measures for Sources of Impairment

If site-based load limits cannot be used because of the type of impairment (e.g., aquatic life) or limited data, surrogates that have a strong link to the cause of impairment can be used. For instance, various TMDLs have used impervious cover and stormwater flow as surrogates for stormwater impacts on aquatic life, stream channel stability, and habitat (USEPA, 2007). In these cases, the surrogates are relatively easy to measure and track through time. The TMDL might have a goal to reduce impervious cover and/or to apply BMP treatment to a certain percentage of impervious cover within the impaired watershed.

A local stormwater program could apply the surrogate approach through a tiered implementation strategy for new development and redevelopment:

- FIRST, minimize the creation of new impervious cover at the site through site design techniques. Preserve sensitive site features, such as riparian areas, wetlands, and important forest stands.
- SECOND, disconnect impervious cover by using LID and nonstructural BMPs.
- THIRD, install structural BMPs to reduce the impact of impervious cover on receiving waters.

C. Presumptive BMP Performance Standards

Perhaps the most widespread and simplest method to link TMDL goals with stormwater criteria is to presume that implementation of a certain suite of BMPs will lead to load reductions, and that monitoring and adaptive management can help adjust the appropriate template of BMPs over time (USEPA, 2007; USEPA Region 5, 2007d). This strategy acknowledges that data are often too limited to draw a conclusive link between particular pollutant sources and in-stream impairments. However, as more data becomes available and TMDL implementation strategies are refined, a more quantitative method, such as the two noted above, should be pursued.

There are a wide variety of “presumptive” BMPs that can be included in local stormwater criteria for an impaired watershed, and these should be adapted based on the pollutant(s) of concern:

- Stream/wetland/lake setbacks and buffers
- Site reforestation
- Soil enhancements
- Incentives for redevelopment

Requirements for runoff reduction:

- Implementation of LID
- Requirements for BMPs with filter media and/or vegetative cover
- Enhanced sizing and/or pre-treatment requirements
- Required BMPs at stormwater hotspots or particular land use categories (e.g., marinas, industrial operations)
- Contribution to stormwater retrofit projects within the watershed

The “providing channel protection” criterion is highly recommended for receiving waters that are impaired by sediment or sediment-related pollutants. Given the importance of channel erosion in the sediment budget of urban streams, it is critical to control erosive flows from development projects.

For more information on linking TMDLs to stormwater permits, see the following:

Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs, EPA 841-R-07-002, at:

http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/17_TMDLs_Stormwater_Sources.pdf

Total Maximum Daily Loads and National Pollutant Discharge Elimination System Stormwater Permits for Impaired Waterbodies: A Summary of State Practices, USEPA, at:

http://www.epa.gov/r5water/wshednps/pdf/state_practices_report_final_09_07.pdf

Incorporating Green Infrastructure Concepts into Total Maximum Daily Loads (TMDLs), USEPA at:

http://water.epa.gov/aboutow/owow/upload/tmdl_lid_final.pdf

For a comprehensive primer on stormwater retrofitting in existing urban/developed land, see: ***Urban Stormwater Retrofit Practices, Manual 3***, 2008, *Urban Subwatershed Restoration Manual Series*, Center for Watershed Protection, at:

http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series/89-manual-3-urban-stormwater-retrofit-practices-manual.html

To obtain even more information on creating a stronger link between stormwater criteria and TMDLs, refer to Chapter 4 of the Center for Watershed Protection's ***Post-Construction SWMP Program Guidance Manual*, at:**

http://www.cwp.org/documents/doc_details/200-managing-stormwater-in-your-community-a-guide-for-building-an-effective-post-construction-program.html?tmpl=component

6.9.7. Ultra Urban Settings

Accomplishing Environmental Site Design at ultra-urban development and redevelopment sites is challenging, since population is dense and space is extremely limited, land is expensive, soils are disturbed, and runoff volumes and pollutant loadings are great, and there is a wide range of potential pollutants. These sites do, however, present a great opportunity for making progress in stormwater management where it has not previously existed. Much of the opportunity is focused on BMP selection and design, as well as cohesive integration of the BMP treatment train into the development scheme. BMP selection for ultra-urban sites is addressed in **Section 8.6.1 and Table 8.3 of Chapter 8** of this Handbook. BMP designs aimed specifically at ultra-urban settings can be found in Attachment D of the *Baltimore City Stormwater Management Manual.* Such designs may be considered for approval by local plan review authorities as innovative/alternative designs, provided sufficient design/routing information is included.

6.10. REFERENCES

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Appendix 6-A

Site Plan Preparation and Submission as Part of the Land Development Process

Table of Contents

Appendix Section Headings

FIGURES

TABLES

6-A.1.0. INTRODUCTION

This Handbook discusses the selection, design and implementation of a wide range of stormwater control measures. To encourage and ensure that local stormwater guidelines and requirements are implemented, communities should implement a formal site plan preparation, submittal, and review procedure that facilitates open communication and understanding between the involved parties. As a practical matter, this process should fit reasonably into the normal site development process.

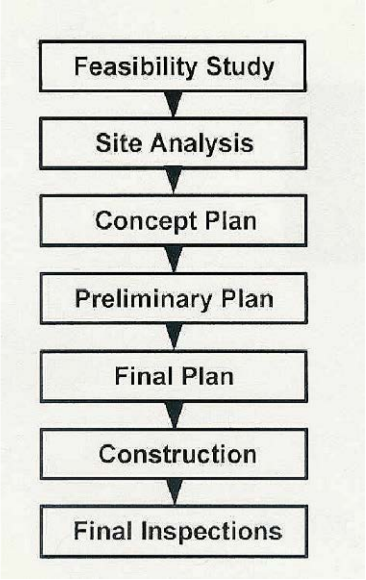

Figure 6-A.1. Typical Site Development Flow Chart

Figure 6-A.1 depicts a typical site development process from the perspective of the land developer. After an initial site visit the developer assesses the feasibility of the project. If the project is deemed workable, a survey is completed. The design team prepares a concept plan (often called a sketch plan) for consultation with the local review authority. A preliminary plan is then prepared and submitted for necessary reviews and approvals. Federal, state and local permits are applied for at various stages in the process.

After review by the local authority and possible public hearings, necessary revisions are made and a final construction plan is prepared. There may be several iterations between plan submittal and plan approval. Bonds are set and placed, contractors are hired, and construction of the project takes place. During and after construction numerous types of inspections take place. At the end of construction, there is a final inspection and a use and occupancy permit is issued for the structure itself.

Stormwater site planning and design is a subset of overall site development and must fit into the overall process if it is to be successful. **Table 6-A.1** on the next several pages shows how planning for the stormwater management system fits into the site development process from the perspective of the developer and site planner/engineer. For each step in the development process, the stormwater-related objectives are described, along with the key actions and major activities that are typically performed to meet those objectives.

Table 6-A.1. Stormwater Planning in the Site Development Process

Feasibility Study

Description:

A feasibility study is performed to determine the factors that may influence the decision to proceed with the site development, including the basic site characteristics, local and other governmental requirements, area information, surrounding developments, etc.

Stormwater-Related Objectives:

- Understand major site constraints and opportunities
- Understand local and other requirements

Key Actions:

- Initiate discussions with the local review authority
- Pre-consultation between the developer and the plan reviewer
- Determine local stormwater management requirements

Major Activities:

- Base map development
- Review of project requirements
- Review of local development and stormwater management requirements
- Review of local stormwater master plans or comprehensive land use plans
- Joint site visit with local review authority
- Collection of secondary source information
- Determination of other factors or constraints impacting feasibility

Site Analysis

Description:

A site analysis is used to gain an understanding of the constraints and opportunities associated with the site through identification, mapping and assessment of natural features and resources. Potential conservation and resource protection areas are identified at this stage.

Stormwater-Related Objectives:

- Identify key site physical, environmental, and other significant resources
- Develop preliminary vision for the stormwater management system

Key Actions:

- Site evaluation and delineation of natural feature/resource protection areas

Major Activities:

- Mapping of natural resources: soils, vegetation, streams, topography, slope, wetlands, floodplains, aquifers, etc.
- Identification of other key cultural, historic, archaeological, or scenic features, orientation and exposure
- Identification of adjacent land uses
- Identification of adjacent transportation and utility access
- Identification of natural feature protection and conservation areas

Table 6-B.1. continued

- Mapping of easements and utilities
- Integration of all layers – a map overlay
- Other constraints and opportunities

Concept Plan

Description:

A concept plan is used to provide both the developer and reviewer a preliminary look at the development and stormwater management concept. Based on the site analysis, a concept plan should take into account the constraints and resources available on the site. Several alternative "what if" concept plans can be created.

Stormwater-Related Objectives:

- Develop a concept for the stormwater management system
- Gain approval of the concept plan from the developer and local review authority

Key Actions:

- Develop a site layout concept using environmental site design techniques where possible
- Perform an initial runoff characterization based on the site layout concept
- Determine necessary site design and/or structural controls needed to meet stormwater management requirements

Major Activities:

- Prepare sketches of functional land uses including conservation areas
- Perform a "what if" analysis of different design concepts
- Conduct preliminary calculations based on applicable unified stormwater sizing criteria
- Use environmental site design concepts in the site layout concept
- Conduct a preliminary selection and siting of structural stormwater controls
- Identify the location of drainage/conveyance facilities

Preliminary and Final Plan

Description:

A preliminary site plan is created for local review, which includes roadways, building and parking locations, conservation areas, utilities, and stormwater management facilities. Following local approval, a final set of construction plans are developed.

Stormwater-Related Objectives:

- Assure soils and geotechnical issues are understood and resolved at this point
- Prepare preliminary and final stormwater management site plans
- Secure local and non-local permits

Key Actions:

- Perform runoff characterization based on the preliminary/final site plan
- Design structural stormwater controls and conveyance systems
- Perform a downstream analysis

Table 6-B.1. continued

Major Activities:

- Develop preliminary and final site layout plans
- Conduct calculations based on the applicable unified stormwater sizing criteria
- Select, site and design structural stormwater controls
- Design drainage and conveyance facilities
- Develop an erosion and sediment control plan and a site landscaping plan
- Apply for needed permits and waivers

Construction

Description:

During the construction stage, the site must be inspected regularly to ensure that all elements are being built according to plan, and that all resource or conservation areas are suitably protected during construction.

Stormwater-Related Objectives:

- Ensure that stormwater management facilities and site design practices are built as designed

Key Actions:

- Hold a pre-construction meeting at the site
- Inspect the site and stormwater management facilities during construction

Major Activities:

- Execute performance bonds
- Inspect during key phases or key installations
- Protect structural stormwater controls
- Protect conservation arease
- Control erosion and sedimentation
- Properly sequence construction

Final Inspection

Description:

After construction, the site must be inspected to ensure that all elements are completed according to plan. Long-term maintenance agreements should be executed.

Stormwater-Related Objectives:

- Ensure that stormwater management facilities and site design practices are built and operating as designed
- Ensure the long-term maintenance of structural stormwater controls and conveyances
- Ensure the long-term protection of conservation and resource protection areas

Key Actions:

- Conduct maintenance inspections
- Conduct a final inspection and submit record (as-built) drawings

Table 6-B.1. continued
Major Activities: • Conduct final site stabilization • Conduct an as-built survey • Execute maintenance agreements • Conduct a final site inspection • Obtain a use permit/certificate of occupancy

6-A.2.0. THE STORMWATER MANAGEMENT PLAN

It is important for the designer to effectively communicate the rationale, design, and maintenance requirements to several audiences including the facility owner, regulatory reviewers, and maintenance personnel. It is critical so that all parties fully understand the need for the specified BMPs and the how they are expected to function in the future, to foster agreement regarding their selection and approval of their design.

This communication is typically accomplished through development of a stormwater pollution prevention plan, or SWPPP, which is required by the General Virginia Stormwater Management Program (VSMP) Permit for Discharges of Stormwater from Construction Activities. The SWPPP is composed of three components:

- An Erosion and Sediment Control Plan for the *construction* process
- A Pollution Prevention Plan for the construction site/process (more of a source control plan)
- A (*post-construction*) stormwater management plan

The stormwater management plan is a comprehensive document that describes the potential water quality and quantity impacts associated with a development project both during and after construction. The stormwater management plan also identifies selected source controls and treatment practices to address the potential impacts, the engineering design of the control measures, and maintenance requirements that enable the proper performance of the selected practices over time. Finally, the stormwater management plan contains the technical information and analysis to allow a local plan review authority to determine whether a proposed new development or redevelopment project meets the local stormwater regulatory requirements. This Appendix discusses the typical contents of a stormwater management site plan and the recommended review and consultation checkpoints between the local government staff and the site developer/permittee.

The procedures and guidelines for the preparation of a stormwater management plan should, be explicitly stated in the local stormwater management ordinance. The ordinance, in turn, may refer to a design guidance document for additional detail. Ideally, stormwater management site plans are developed with open lines of communication between the developer (and the developer’s design consultants) and the plan reviewer. Stormwater management plans involve more than just the preparation of a document and maps. Beyond that, they should reflect the entire development process, from planning through construction and continuing after build-out via regular inspection and maintenance of the site's stormwater management system.

6-A.3.0. SITE PLANNING AND DESIGN PROCESS

The first step in addressing stormwater management begins with the site planning and design process. The kinds of projects for which stormwater management plans are required and those that are exempt from plan requirements are set forth in § 62.1-44,15:34 of the Code of Virginia.

The information presented in this Appendix presents an idealized model of the stormwater management and site planning process from the land developer's perspective. Those who follow these steps to develop an environmentally-friendly site plan and stormwater management plan are much more likely to receive a timely approval by the local plan approval authority. The Department encourages local governments to provide opportunities for collaboration, as described below, in the structure of the local program's administration and review process.

In order to most effectively address stormwater management objectives, consideration of stormwater runoff needs to be fully integrated into the site planning and design process. This involves a more comprehensive approach to site planning and a thorough understanding of the physical characteristics and resources of the site. The purpose of this Appendix is to provide a framework for involving effective and environmentally sensitive stormwater management planning *early* – during the feasibility study and in the site layout and planning and process – and to encourage a greater uniformity in stormwater management plan preparation.

When designing the stormwater management system for a site, a number of questions need to be answered by the site planners and design engineers, including:

- How can the site's stormwater management system be designed to most effectively meet the stormwater management minimum standards (and any additional needs or objectives)?
- What are the opportunities for using Environmental Site Design (ESD) practices to minimize the need for structural stormwater controls?
- What are the development site constraints that preclude the use of certain structural controls?
- What structural controls are most suitable and cost-effective for the site?

6-A.3.1. Principles of Stormwater Management Site Planning

The following principles should be considered in preparing a stormwater management plan for a development site:

1. The site design should utilize an integrated approach to deal with stormwater quantity, quality and streambank (channel) protection requirements. The stormwater management infrastructure for a site should be designed to integrate drainage and water quantity control, water quality protection, and downstream channel protection. Site design should be done in unison with the design and layout of stormwater infrastructure to attain stormwater management goals. Together, the combination of ESD practices (clustering, minimizing imperviousness, etc.)

and effective infrastructure layout and design can mitigate the worst stormwater impacts of most urban development while preserving stream integrity and aesthetic attractiveness.

2. The design should strive to protect and use existing site features, minimize land disturbance, and minimize the amount of impervious cover resulting from the proposed development. Chapter 6 discusses how to accomplish these objectives, including concepts of clustered and concentrated development, routing of drainage from impervious areas (i.e., disconnection), maximizing tree canopy over impervious features, and use of practices such as vegetated roofs, permeable pavements, and capturing rainwater (cisterns) for reuse on-site (irrigation, etc.).

3. Manage stormwater using a "systems" approach. Determine the level of control needed, using the following concepts to create a sensible, integrated management system (might include one or more "treatment trains"):

- **Stormwater management practices should strive to use the natural drainage system and require as little maintenance as possible.** Almost all sites contain natural features which can be used to help manage and mitigate runoff from development. Features on a development site might include the existing drainage network, depressions, permeable soils, wetlands, floodplains, and undisturbed vegetated areas that can be used to reduce runoff, provide infiltration and stormwater filtering of pollutants and sediment, recycle nutrients, and maximize on-site storage of stormwater. Site design should seek to improve the effectiveness of natural systems rather than to ignore or replace them. Furthermore, natural systems typically will continue to function for many years with little or no maintenance.
- **Structural stormwater controls should be implemented only after all site design and nonstructural options have been exhausted.** Operationally, economically, and aesthetically, stormwater-related ESD and the use of natural techniques offer significant benefits over structural stormwater controls. Therefore, all opportunities for using these methods should be explored before implementing structural stormwater controls such as wet ponds and sand filters.
- **Structural stormwater solutions should attempt to be multi-purpose and be aesthetically integrated into a site's design.** A structural stormwater facility need not be an afterthought or ugly nuisance on a development site. A parking lot, soccer field or city plaza can serve as a temporary storage facility for stormwater. In addition, water features such as ponds and lakes, when correctly designed and integrated into a site, can increase the aesthetic value of a development.

4. Consider operations and maintenance in the design of the stormwater management system and the individual practices chosen. Select and design practices so maintenance needs will be minimal. Design practices with convenient access for inspection and maintenance. Because a maintenance agreement will need to be executed with the local jurisdiction, prepare a document that includes a list of maintenance tasks and schedules that can be provided to appropriate post-construction property owner.

5. "One size does not fit all" in terms of stormwater management solutions. Although the basic problems of stormwater runoff and the necessity of managing it remain constant, each site, project, and watershed presents different challenges and opportunities. For instance, an infill development in a highly urbanized town center or downtown area will require a much different set of stormwater management solutions than a low-density residential subdivision in a largely undeveloped watershed. Therefore, local stormwater management needs to take into account differences between development sites, different types of development and land use, various watershed conditions and priorities, the nature of downstream lands and waters, and community desires and preferences.

6-A.3.2. Preparation of Stormwater Management Site Plans

A stormwater management site plan is a comprehensive report that contains the technical information and analysis to allow a local review authority to determine whether a proposed new development or redevelopment project meets the local stormwater regulatory requirements and/or the minimum stormwater management standards contained in this Handbook.

This section describes the typical contents and general procedure for preparing a stormwater management site plan. The level of detail involved in the plan will depend on the project size and the individual site and development characteristics. The preparation of a stormwater site plan ideally follows these steps:

- Pre-consultation Meeting and Joint Site Visit
- Review of Local Requirements
- Perform a Site Analysis
- Prepare a Stormwater Concept Plan
- Prepare a Preliminary Stormwater Site Plan
- Complete the Final Stormwater Site Plan

6-A.3.3. Pre-Consultation Meeting and Joint Site Visit

The most important action that can take place at the beginning of the development project is a pre-consultation meeting between the local review authority and the developer and his/her team to outline the stormwater management requirements and other regulations, and to assist the developer in assessing constraints, opportunities, and potential for stormwater design concepts.

This recommended step helps to establish a productive relationship for the entire development process. A joint site visit, if possible, can yield a conceptual outline of the stormwater management plan and strategies. By walking the site, the two parties can identify and anticipate problems, define general expectations and establish general boundaries of conservation areas and natural features to be protected. A major incentive for pre-consultation is that permitting and plan approval requirements will become clear at an early stage, increasing the likelihood that the approval process will proceed faster and more smoothly.

6-A.3.4. Review of Local Requirements

The site developer should be made familiar with the local stormwater management and development requirements and design criteria that apply to the site. These requirements may include:

- The minimum standards for stormwater management included in the Virginia Stormwater Management Regulations and the local stormwater management ordinance
- Design storm frequencies
- Conveyance design criteria
- Floodplain criteria
- Buffer/setback criteria
- Wetland provisions
- Watershed-based criteria
- Offset mitigation opportunities
- Erosion and sedimentation control requirements
- Maintenance requirements
- Need for physical site evaluations (infiltration tests, geotechnical evaluations, etc.)

Much of this guidance can be obtained at the pre-consultation meeting with the local review authority and should be detailed in various local ordinances (e.g., subdivision codes, stormwater and drainage codes, etc.). Current land use plans, comprehensive plans, zoning ordinances, road and utility plans, watershed or overlay districts, and public facility plans should all be consulted to determine the need for compliance with other local and state regulatory requirements.

Opportunities for special types of development (e.g., clustering) or special land use opportunities (e.g., conservation easements or tax incentives) should be investigated. There may also be opportunities to partner with a local community for the greenway development or other riparian corridor or open space enhancements.

6-A.3.5. Perform a Site Analysis and Inventory

Using approved field and mapping techniques, the site engineer should collect and review information on the existing site conditions, then document and map the following (9 VAC 25-870-55 B 8):

Analysis of Existing Conditions:

- Topography of the existing (pre-development) site showing drainage area or basin boundaries (ideally showing 2-foot contour intervals)
- All contributing drainage areas and existing drainage patterns, showing direction of flow and discharge points from the site
- Hydrologic analysis of runoff provided by off-site areas upstream of the project site
- Identification of intermittent and perennial streams, wetlands and other receiving waters, including karst features, into which stormwater may be discharged
- Soil types and underlying geologic formations (e.g., karst, etc.)

- Forest cover and other vegetative areas
- Current land use and land cover, including existing structures, roads, and locations of known utilities and easements
- Existing stormwater management facilities and conveyances
- Sufficient information regarding adjacent parcels to assess the impacts of stormwater runoff from the site
- Limits of clearing and grading and the proposed drainage patterns on the site
- Proposed buildings, roads, parking areas, utilities, and stormwater management facilities
- Proposed land use and land cover, with a tabulation of the percentage of surface area to be adapted to various land uses, including but not limited to planned locations of utilities, roads and easements
- Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions of the project site hydrology

Analysis of Post-Development Hydrology:

- Topography of the developed site conditions showing drainage area or basin boundaries (ideally showing 2-foot contour intervals)
- Total area of post-development impervious surfaces and other land cover areas for each sub-basin affected by the project
- Unified stormwater sizing criteria runoff calculations for water quality, channel protection, and overbank flooding protection for each sub-basin
- Location and boundaries of proposed natural feature protection areas
- Documentation and calculations for any applicable site design credits that are being used
- Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the proposed conditions of the project site hydrology

In addition, in order to effectively coordinate stormwater management planning with other relevant regulatory requirements, the site engineer should identify and map all previously unmapped natural and other pertinent features such as:

- Wetlands
- Critical habitat areas
- Boundaries of wooded areas
- Floodplain boundaries
- Utility easements
- Steep slopes
- Required buffers
- Proposed stream crossing locations
- Other required protection areas (e.g., wellhead protection or drainfield setbacks)

Some of this information may be available from previously performed studies or from the previous feasibility study. For example, if a development site requires a permit under the Erosion and Sediment Control Law, most of the resource protection features will likely have been mapped as part of the land disturbance activity plan. Other recommended site information to map or obtain includes utilities information, seasonal groundwater levels, and geologic mapping.

Individual map or geographic information system (GIS) layers can be designed to facilitate an analysis of the site through what is known as map overlay, or a composite analysis. Each layer (or group of related information layers) is placed on the map in such a way as to facilitate comparison and contrast with other layers. A composite layer is often developed to show all the layers at the same time (see **Figure 6-A.2**). This composite layer can be a useful tool for defining the best buildable areas and delineating and preserving natural feature conservation areas.

6-A.3.6. Prepare a Stormwater Concept Plan

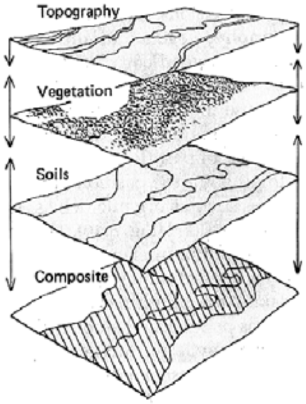

Figure 6-A.2. Composite GIS Analysis
(Source: Marsh, 1983)

Based upon the review of existing conditions and site analysis, the design engineer should develop a concept site layout plan for the project. During the concept plan stage the site designer will perform most of the layout of the site including the preliminary stormwater management system design and layout. The stormwater concept plan allows the design engineer to propose a potential site layout and gives the developer and local review authority a “first look” at the stormwater management system for the proposed development. The stormwater concept plan should be submitted to the local plan reviewer before detailed preliminary site plans are developed. The following steps should be followed in developing the stormwater concept plan:

(1) Use ESD approaches as applicable to develop the site layout, including:

- Preserving the natural feature conservation areas defined in the site analysis
- Fitting the development to the terrain and minimizing land disturbance
- Using various techniques to reduce impervious surface areas
- Preserving and using the natural drainage system, wherever possible

(2) Calculate preliminary estimates of the unified stormwater sizing criteria requirements for water quality, channel protection, overbank flooding protection and extreme flood protection based on the concept plan site layout.

(3) Determine the site design stormwater credits to be accounted for in the design of structural stormwater controls handling the water quality volume.

(4) Perform screening and preliminary selection of appropriate structural stormwater controls and identification of potential siting locations.

It is extremely important at this stage that stormwater design is integrated into the overall site design concept in order to (1) reduce the impacts of the development and (2) provide for the most cost-effective and environmentally sensitive design. The hydrology calculations for the site provide a key reference for the designer to use in planning a stormwater management system that, as much as is feasible, mimics the pre-development site hydrology.

For local review purposes, the stormwater concept plan should include the following elements:

(1) Applicant name, legal address, and contact information (i.e., telephone and FAX numbers and email address).

(2) Common address and legal description of the site

(3) Vicinity map

(4) Project narrative (see additional explanation below)

(5) Preliminary Calculations (see additional explanation below)

(6) Existing conditions and proposed site layout mapping and plans (recommended scale of 1” = 50’), which illustrate at a minimum:

- Existing and proposed topography (minimum of 2-foot contours recommended)
- Perennial and intermittent streams
- Mapping of predominant soils from USDA soil surveys, including the locations of bore hole investigations
- Boundaries of existing predominant vegetation and proposed limits of clearing and grading
- Location and boundaries of other natural feature protection and conservation areas such as wetlands, lakes, ponds, floodplains, Resource Protection Areas (RPAs), stream buffers and other setbacks (e.g., drinking water well setbacks, septic setbacks, etc.)
- Location of existing and proposed roads and roadway easements, buildings, parking areas and other impervious surfaces
- Existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
- Preliminary estimates of unified stormwater sizing criteria requirements
- Identification and calculation of stormwater site design credits
- Preliminary selection and location, size, and limits of disturbance of proposed structural stormwater controls (treatment practices, flood control facilities, stormwater diversion structures, etc.)
- Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
- Final landscaping plans for structural stormwater management practices and site revegetation
- Locations of pollution source controls
- Flow paths

- Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
- Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings

(7) Concept Design Drawings and Specifications

(8) Conceptual Erosion and Sediment Controls

(9) Supporting Documents and Studies

(10) Operations and Maintenance Plans

(11) Other Required Permits

(12) Identification of preliminary waiver requests

6-A.3.7. Project Narrative

Projects that require a stormwater management plan must include documentation that adequately describes the proposed improvements or alterations to the site. In particular, it is necessary to describe any alterations to surface waters, including wetlands and waterways, removal of vegetation, and land disturbing operations. The project scope and objective must identify, in summary, the potential water quality impacts to receiving waters during construction and the post-construction water quality and quantity impacts that may occur as a result of the intended use(s) of the property. In describing the project, alternative designs or construction methods should be evaluated to address the goal of impact minimization through the use of site design practices such as providing “green” parking areas, and preserving natural buffers or open spaces. The purpose of evaluating project alternatives is to achieve a final design that allows an appropriate, legal use of the property while minimizing impacts to surface water quality and stream system integrity caused by stormwater runoff.

The project narrative should consist of:

- **Project Description and Purpose.** Provide a general description of the project in adequate detail such that reviewers will have a sense of the proposed project and potential impacts. This section should describe existing and proposed conditions, including:
  - Natural and manmade features at the site including, at a minimum, wetlands, karst, watercourses, floodplains, and development (roads, buildings, and other structures)
  - Site topography, drainage patterns, flow paths, and ground cover
  - Impervious area and site runoff coefficients
  - Site soils as defined by USDA soil surveys including soil names, map unit, erodibility, permeability, slope, depth, texture, and soil structure
  - Stormwater discharges, including the quality of any existing or proposed stormwater discharges from the site and known sources of pollutants and sediment loadings

  - Critical areas, buffers, and setbacks established by the local, state, and federal regulatory authorities
  - Water quality classification of on-site and adjacent water bodies and identification of any on-site or adjacent water bodies included on the Virginia 303(d) list of impaired waters or having assigned waste load allocations in conformance with an established and EPA-approved TMDL

- **Potential Stormwater Impacts.** Describe the project's potential for stormwater impacts affecting water quality, peak flow, and groundwater recharge. The elements that should be included in this section are:
  - Description of all potential pollution sources such as erosive soils, steep slopes, vehicle fueling and/or washing, etc.
  - Identification of the types of anticipated stormwater pollutants and the relative or calculated load of each pollutant
  - A summary of calculated pre- and post-development peak flows
  - An analysis of potential downstream flooding and channel erosion

- **Critical On-site and Off-Site Resources.** Describe and identify the locations of on-site resources and off-site resources (typically downstream of the site) that could potentially be impacted by stormwater runoff. These resources may include:
  - Wells
  - Aquifers
  - Wetlands
  - Streams
  - Ponds
  - Karst
  - Public drinking water supplies
  - Neighboring land uses

- **Proposed Stormwater Management Practices.** Describe the proposed stormwater management practices and why they were selected for the project. Stormwater management practices that should be described in this section are:
  - Source controls and pollution prevention
  - Environmental site design
  - Runoff volume control practices
  - Stormwater treatment practices
  - Flood control and peak runoff attenuation management practices

- **Construction Schedule.** Describe the anticipated construction schedule, including the construction sequence and any proposed phasing of the project.

- **Long-term Operation and Maintenance.** Identify the mechanisms/entities, including the identification of financially responsible parties, through which the stormwater management facilities will be operated and maintained during and after construction activity.

6-A.3.8. Calculations

The stormwater management plan should include calculations to demonstrate that the proposed project satisfies the stormwater management objectives and treatment practice sizing criteria described in **Chapter 11** and applicable hydroligic and hydraulic procedures of **Chapter 11** of this Handbook.

- **Groundwater Recharge Volume (R_v).** If the locality where the development will take place has established a groundwater recharge requirement, calculate the required groundwater recharge volume to maintain pre-development annual groundwater recharge on the site after the site is developed. The R_v should be calculated using the procedures described in **Appendix A of Chapter 10** or otherwise established by the locality. The R_v calculation should include the average annual groundwater recharge (i.e., stormwater infiltration) provided by the proposed stormwater management practices.

- **Pollution Reduction.**
  - **Treatment Volume (T_V).** Calculate the design treatment volume to be treated by the proposed stormwater treatment practices using the procedures described in **Chapter 11** and in the individual BMP specifications provided on the Stormwater BMP Clearinghouse web site (http://www.vwrrc.vt.edu/swc/). Design calculations should demonstrate that the proposed stormwater treatment practices meet the required Treatment Volume (T_V), detention time, and other practice-specific design criteria.
  - **Water Quality Flow.** Where necessary, calculate the design water quality flow, which is the peak flow rate associated with the T_V. The water quality flow is used to size flow-based treatment practices (i.e., manufactured treatment systems such as catch basin inserts, media filters, and hydrodynamic structures). The peak flow rates associated with larger design storms should also be evaluated to ensure that stormwater treatment practices could safely convey large storm events while providing the minimum rates of pollutant removal established in this Handbook.
  - **Pollutant Loads.** At the discretion of the local plan review authority, estimate pollutant loads found in post-development runoff. The Virginia Runoff Reduction Method can be used to accomplish this.

- **Peak Flow Control (Stormwater Quantity).** For new development projects, calculations should be provided to demonstrate that post-development peak flows do not exceed the stream channel protection criteria set forth in 9 VAC 25-870-66 B. For redevelopment projects, the bank condition and sensitivity of receiving waters may justify a reduction in peak flows and runoff volume from the site. Achieving a reduction in runoff from a redevelopment project may often be feasible with proper planning and implementation of detention or infiltration practices.

  A number of methods and models are available to calculate peak stormwater discharge rates, as discussed in **Chapter 11**. The designer must determine the most appropriate method for the project. The following information should be submitted with all stormwater management plans:

- **Hydrologic and Hydraulic Design Calculations.** Calculate the post-development peak runoff rates, volumes, and velocities at the site limits. The calculations shall be based on the following 24-hour duration design storm events to satisfy the sizing criteria described in **Chapter 11** and **Appendix 11-E** of this Handbook:

    - Stream Channel Protection: 1-year frequency ("over-control" of the 1-year storm)
    - Protection from Frequent Flooding: 10-year frequency
    - Peak Runoff Attenuation: 10-year, 25-year, and 100-year frequency (or other specified storm event), *if required by the local review authority*
    - Emergency Outlet Sizing: Safely pass the 100-year frequency or larger storm

  Provide the following information for each of the above design storms for pre-development and post-development conditions:

    - Description of the design storm frequency, intensity, and duration
    - Watershed map with locations of design points and watershed area (acres) for runoff calculations
    - Time of concentration (and associated flow paths)
    - Imperviousness of the entire site and each watershed area
    - NRCS runoff curve numbers or volumetric runoff coefficients
    - Peak runoff rates, volumes, and velocities for each watershed area
    - Hydrograph routing calculations
    - Culvert capacities
    - Infiltration rates, where applicable
    - Dam breach analysis, where applicable
    - Documentation of sources for all computation methods and field test results

- **Downstream Analysis.** Improperly placed or sized detention may adversely affect downstream areas by delaying the timing of the peak flows from the site. Delayed peaks can coincide with the upstream peak flow that naturally occurs later as the discharge travels from the upper portions of the watershed. If the site is in the middle to lower third of a watershed and detention is proposed, provide calculations of existing and proposed discharges at any critical downstream points using hydrograph analysis. Critical downstream points may be currently flooded properties or roadways, for example. As general guidance, routing calculations should proceed downstream to a confluence point where the site drainage area represents 10 percent of the total drainage area or according to other locally established procedures.

- **Drainage Systems and Structures.** Provide design calculations for existing and proposed drainage systems and structures at the site. Based on the design storm for those structures, a hydrograph analysis should be used to analyze the storage and discharge for detention structures. Drainage system components should be designed according to the standards outlined in this Handbook, as well as other applicable local standards or requirements.

6-A.3.9. Prepare a Preliminary Stormwater Site Plan

The preliminary plan ensures that requirements and criteria are being complied with and that opportunities are being taken to minimize adverse impacts from the development. The preliminary stormwater management site plan should consist of maps, narrative, and supporting design calculations (hydrologic and hydraulic) and technical report data for the proposed stormwater management system, and should include the following sections:

(1) **Existing Conditions Hydrologic Analysis.** Provide an existing condition hydrologic analysis for stormwater runoff rates, volumes, and velocities, which includes:

- A topographic map of existing site conditions (minimum 2-foot contour interval recommended) with the basin boundaries indicated
- Acreage, soil types and land cover of areas for each sub-basin affected by the project
- All perennial and intermittent streams and other surface water features
- All 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
- Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology

(2) **Post-Development Hydrologic Analysis.** Provide a post-development hydrologic analysis for stormwater runoff rates, volumes, and velocities, which includes:

- A topographic map of developed site conditions (minimum 2-foot contour interval recommended) with the post-development basin boundaries indicated
- Total area of post-development impervious surfaces and other land cover areas for each sub-basin affected by the project
- Unified stormwater sizing criteria (**Chapter 10**) runoff calculations for groundwater recharge (where applicable locally), water quality, channel protection, overbank flooding protection and extreme flood protection for each sub-basin
- Location and boundaries of proposed natural feature protection and conservation areas
- Documentation and calculations for any applicable site design credits that are being used
- Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology

(3) Stormwater Management System. Provide drawings and design calculations for the proposed stormwater management system, including:

- A drawing or sketch of the stormwater management system including the location of nonstructural site design features and the placement of existing and proposed structural stormwater controls. This drawing should show design water surface elevations, storage volumes available from zero to maximum head, location of inlet and outlets, location of bypass and discharge systems, and all orifice/restrictor sizes.
- Narrative describing that appropriate and effective structural stormwater controls have been selected.

- Cross-section and profile drawings and design details for each of the structural stormwater controls in the system. This should include supporting calculations to show that the facility is designed according to the applicable design criteria.
- Hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms (should include stage-storage or outlet rating curves, and inflow and outflow hydrographs).
- Documentation and supporting calculations to show that the stormwater management system adequately meets the unified stormwater sizing criteria.
- Drawings, design calculations and elevations for all existing and proposed stormwater conveyance elements including stormwater drains, pipes, culverts, catch basins, channels, swales and areas of overland flow.

(4) **Downstream Analysis.** Provide the assumptions and calculations from a downstream peak flow analysis (when required) to show safe passage of post-development design flows downstream.

(5) **Geotechnical Analysis.** Any geotechnical report that may be required due to the presence of karst or other unique geological features should be provided in the preliminary site plan. This gives the local review authority the opportunity to collaborate on solutions early enough to avoid significant cost impacts. This is also a good phase for detailed consideration of site soils, especially if site soils may not be suitable for embankments, basin liners, bioretention media mixes, etc., and imported soils will be needed.

In calculating runoff volumes and discharge rates, consideration may need to be given to any planned future upstream land use changes. Depending on the site characteristics and given design criteria, upstream lands should be modeled as “existing condition” or “projected build-out/future condition” when sizing and designing on-site conveyances and stormwater controls.

6-A.3.10. BMP Operation and Maintenance

Stormwater management plans should include pertinent information regarding the routine and non-routine procedures necessary to maintain treatment practices, including vegetation, in effective operating conditions. **Chapter 9** of this Handbook contains operation and maintenance guidelines and recommendations for individual stormwater treatment practices, including sample inspection and maintenance checklists. Over time, post-construction documentation should be kept by the qualifying local program to demonstrate compliance with maintenance activities. Operation and maintenance elements that should be included in the stormwater management plan include:

- An BMP Maintenance Agreement(s) executed with the local jurisdiction
- Detailed inspection and maintenance checklists, identifying requirements/ tasks
- Inspection and maintenance schedules
- Parties legally and financially responsible for maintenance (name, address, and telephone number)
- As-built plans of completed structures (see **Section 3.7** of Chapter 3; **Section 3-E.1.3** of Appendix E of Chapter 3; and **Section 9.3.10** of Chapter 9 of this Handbook).

6-A.3.11. Complete the Final Stormwater Site Plan

The final stormwater management site plan adds further detail to the preliminary plan and reflects changes that are requested or required by the local review authority. The final stormwater site plan should include all of the revised elements of the preliminary plan. In addition, the following items must be included:

(1) Erosion and Sedimentation Control Plan: The proposed Erosion and Sedimentation Control Plan should, at a minimum, demonstrate the methods and designs to be utilized during construction and stabilization of the site following completion of construction activity. All proposed erosion and sediment control measures must comply with the Virginia Erosion and Sediment Control Law (§ 62.1-44.15:51 et seq., Code of Virginia), Virginia Erosion and Sediment Control Regulations (9 VAC 25-840-30)*, and the Virginia Erosion and Sediment Control Handbook*, 1992) and the local Erosion and Sediment Control ordinance.

- Erosion and sediment control measures must be included on the plans with sufficient detail to facilitate review of the design by regulatory officials, and proper construction of the measures.
- A description of the sequencing/phasing of construction and temporary stabilization measures must be included in the plans.
- If temporary E&S Control facilities are to be converted into permanent ("post-construction") BMPs, a description must be included regarding how and when to accomplish the conversion.

(2) Landscaping Plan

- Arrangement of planted areas, natural areas and other landscaped features on the site plan
- 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 the construction

(3) Operations and Maintenance Plan

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

(4) Evidence of Acquisition of Applicable Local and Non-local Permits

(5) Exception/Waiver Requests

Earlier conceptual designs and preliminary calculations should be refined for the completed design. The completed final stormwater site plan should be submitted to the local review authority for final approval prior to any construction activities on the development site.

6-A.3.12. Design Drawings and Specifications

Design drawings and specifications must be prepared by a professional engineer licensed to practice in the State of Virginia. The format of site plans and drawings should conform to the following:

- Drawings should be no larger than 24” x 36” and no smaller than 8-1/2” x 11”.
- Plans and documents should not be pieced together or submitted with handwritten markings. Blue line prints or photocopies of original plans are acceptable.
- A scale should be used that adequately presents the detail of the proposed improvements for the project. A maximum scale of 1” = 40’ is recommended, however larger scales up to 1” = 100’ may be used to represent overall site development plans or for conceptual plans. Profiles and cross-sections should be prepared at a maximum scale of 1” = 4’ vertical and 1”=40’ horizontal.
- Design details including cross-sections, elevation views, and profiles needed to allow the proper depiction of proposed controls for review and permitting as well as to facilitate the proper construction of these controls.
- Specifications, which clearly indicate the materials of construction, the specific stormwater control product designations (if applicable), the methods of installation, and reference to applicable material and construction standards.
- Plans should contain a title block that includes the project title, location, owner, assessor’s map and parcel number of the subject site(s), name of preparer, sheet number, date (with revision date, if applicable), and drawing scale.
- Legend defining all symbols depicted on the plans.
- A cover sheet with a sheet index for plan sets greater than two sheets. Multiple sheets should contain either match lines or provide an overlap of 1-inch with information on adjoining plan sheets.
- North arrow.
- Property boundary of the entire subject property and depicting the parcels, or portions thereof, of abutting land and roadways within one hundred (100) feet of the property boundary.
- Locus map of the site prepared at a scale of 1” = 1,000’ with a north arrow. The map should adequately show the subject site relative to major roads and natural features, if any, so the site can be easily found using the locus map for guidance.
- The seal of a licensed professional should be affixed to all original design plans, calculations, and reports prepared by them or under their direct supervision.

6-A.3.13. Supporting Documents and Studies

Information used in the design of construction and post-construction stormwater controls for the overall site development must be included (or referenced, if appropriate) with reports, plans, or calculations to support the designer’s results and conclusion. Pertinent information may include:

- Soil maps, borings/test pits
- Infiltration test results
- Groundwater impacts for proposed infiltration structures

- Reports on wetlands and other surface waters (including available information such as Maximum Contaminant Levels [MCLs], Total Maximum Daily Loads [TMDLs], 303(d) or 305(b) impaired waters listings, etc.)
- Water quality impacts to receiving waters
- Impacts on biological populations/ecological communities including fish, wildlife (vertebrates and invertebrates), and vegetation
- Flood study/calculations

6-A.3.14. Obtain Other Required Permits

Approval of a stormwater management plan does not relieve a property owner of the need to obtain other necessary permits or approvals from federal, state, and local regulatory agencies. The developer should obtain all applicable non-local environmental permits (e.g., §404 wetland permit, §401 water quality certification, VDOT entrance permit, VSMP General Permit for Stormwater Discharges from Construction Activities, etc.) or prior to or in conjunction with final plan submittal. In some cases, a non-local permitting authority may impose conditions that require the original concept plan to be changed. Developers and engineers should be aware that permit acquisition can be a long, time-consuming process. The stormwater management plan should include evidence of acquisition of all applicable federal, state, and local permits or approvals such as copies of permit registration certificates, local approval letters, etc.

Ideally, local governments should not issue a grading or building permit for any parcel or lot unless a stormwater management plan has been approved or officially waived. If requirements of federal, state, and local officials vary, the most stringent requirements should be followed.

6-A.4.0. REFERENCES

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual*. Prepared by AMEC, the Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and the Atlanta Regional Commission. Atlanta, Georgia.

Appendix 6-B

Stormwater Design Guidelines for Karst Terrain in Virginia

Adapted from CSN Technical Bulletin No. 1
Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed
(Ver. 2: June, 2009)
Developed by the CSN Karst Working Group

and

Technical Bulletin No. 2 (2000)
Hydrologic Modeling and Design in Karst
by the Virginia Department of Conservation and Recreation

Appendix 6-B
Stormwater Design Guidelines for Karst Terrain in Virginia

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6-B.1.0. INTRODUCTION

This Appendix has been prepared for engineers, plan reviewers, and public works officials to guide better stormwater decisions when land is developed in karst regions of Virginia. Until now, available local and state guidance on this topic has been uneven, sometimes conflicting and certainly not comprehensive. An informal working group of the Chesapeake Stormwater Network (CSN) developed the guidance from which this Appendix was adapted.

This Appendix can be incorporated directly or by reference into local and state land development codes, ordinances, regulations, permits, and engineering manuals that govern how stormwater is managed in karst terrain. The Appendix has been designed as an evolving document so that it can be updated over time to reflect new research, experience and project implementation.

Several important caveats apply to this guidance. First, the effect of land development on karst terrain is complex and hard to predict, and it requires professional analysis to reduce the risk of geological hazards, damage to infrastructure, and groundwater contamination. Second, this guidance was produced to respond to the recent growth pressures in many small communities in the Ridge and Valley region of Virginia. There is concern that past approaches to stormwater and land development in karst terrain have been inadequate to safeguard the public and the environment.

While communities that incorporate this guidance into their development review process can reduce the incidence of infrastructure damage and groundwater contamination, there is always some inherent risk when development occurs on this sensitive terrain. Consequently, the best local approach is to craft stronger local comprehensive land use plans that direct new growth away from karst areas to more appropriate locations (although it is recognized that this will be challenging for communities that are completely underlain by karst).

The following references are excellent sources of information for developers, local governments or citizens living or working in areas underlain by karst topography: *Living On Karst: A reference guide for landowners in limestone regions*, 1997, by the Cave Conservancy of the Virginias, and *Living With Karst: A Fragile Foundation*, by the American Geological Institute, 2001. Definitions of unfamiliar words, terms and acronyms in this Appendix can be found in this Handbook glossary, which is an Appendix of Chapter 1 of this Handbook.

6-B.2.0. WHY IS KARST TERRAIN DIFFERENT?

Two of Virginia's major tributaries B the Potomac and the James Rivers B flow through karst country. This band of karst terrain runs through the Bay watershed, and encompasses portions of Maryland, Pennsylvania, Virginia and West Virginia (**Figure 6-B.1** below). (A Virginia-specific map can be found in **Section 6.7.1** of this Chapter.) Karst in Virginia is a dynamic landscape characterized by sinkholes, springs, caves, and a pinnacled, highly irregular soil-rock interface that is a consequence of the presence of underlying carbonate rocks such as limestone, dolomite and marble (Denton, 2008).

Karst is often referred to as a dissolving landscape. However, karst rarely develops from bedrock dissolution on human timescales, except where salt or other evaporites occur in the subsurface. However, bedrock can dissolve over geologic time to result in hidden voids in the subsurface, susceptible to soil cover collapse into these voids. So when building in a karst environment, the watchword is to *live lightly on the land.*

The karst terrain in Virginia is distinct from some other regions (e.g., Florida) in that the bedrock is very ancient and, in many areas, is deeply buried by residual soils. Consequently, many sinkholes form due to the collapse of surface sediments, which is typically caused by the intrusion of stormwater from the surface into deep, underlying voids.

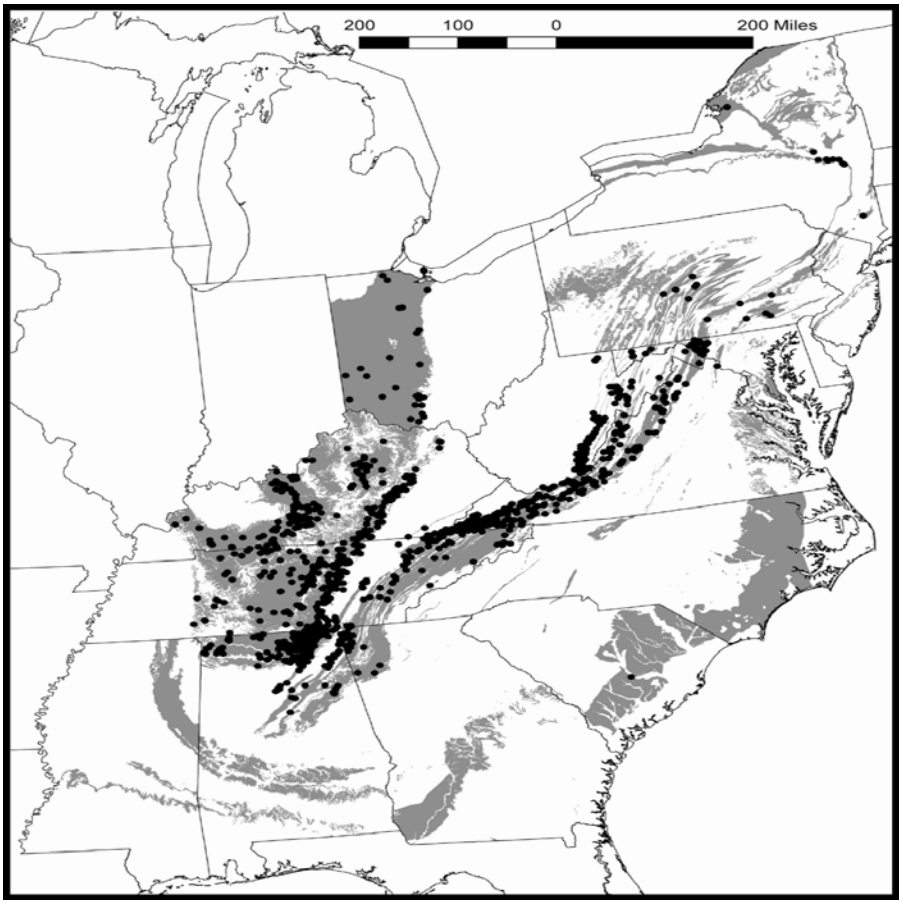

Figure 6-B.1. Karst Distribution in the Bay States
Note: grey = karst; black = caves (Source: Weary, 2005)

The presence of karst terrain within the Ridge and Valley Province (and select portions of the Piedmont Province) complicates the land development process and requires a unique approach to stormwater design. Significant cut and fill can aggravate karst issues. Some of the important considerations include the following.

Post Development Runoff Rates are Greatly Increased. In an undeveloped state, karst terrain produces about two-thirds less stormwater runoff than the Piedmont or Coastal plain (VA DCR, 1999). Even less runoff is produced if the site discharges into an existing sinkhole. As land is developed, however, the paved surfaces and compacted soils produce a much greater rate and volume of runoff. Three important consequences arise due to the increased runoff:

- More runoff is conveyed into a poorly defined surface drainage system that often lacks the capacity to handle it.
- More runoff greatly increases the risk of new sinkhole formation (e.g., collapse or subsidence), particularly if runoff is allowed to pond in the landscape. The increased risk for sinkholes may apply to the development site or to down-gradient off-site areas.
- Development-related changes that increase surface runoff could deprive the karst system of recharge, thereby causing a lowering of the water table and diminished spring flows. These changes can profoundly alter the hydrology of surface streams.

The implications of these risks are that highly distributed infiltration is preferred over focused infiltration, such as might occur in a large stormwater retention basin. Large basins and associated conveyances can be a problem in karst, but small ponds present much less risk. However, rain gardens and other small, distributed infiltration practices are best.

Highly Variable Subsurface Conditions. Karst terrain is notorious for its spatial variability, meaning that subsurface conditions and the consequent risk of sinkhole formation can change within a matter of yards across a development site. As a result, a sequence of karst feature analyses, geotechnical investigations and borings must be performed prior to site layout and the design of any stormwater practice to minimize the risk of a failure or other unintended consequences.

Surface/Subsurface Drainage Patterns are Poorly Understood. Drainage patterns are highly dynamic in karst terrain and involve a great deal of interaction between surface water and groundwater (see **Figures 6-B.2 and 6-B.3** below). Often, there is not a well-defined stream network that moves water to a downstream point. Furthermore, subsurface conduits commonly convey their flow in different directions than the overlying surface streams, in some cases crossing beneath topographical divides.

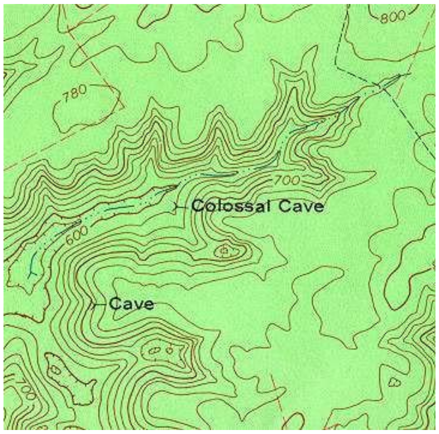

Figure 6-B.2. Typical Karst Topography

Figure 6-B.3. Typical Spring-Fed Stream

Site designers working in karst terrain face a confusing surface drainage pattern, full of losing streams, estravelles, turloughs, swallets and insurgences, which makes it hard to predict exact discharge points for runoff and groundwater. Therefore, designers need to think in three dimensions, rather than just two.

Lower Stream Density and More Karst Swales. Karst landscapes also have less perennial stream mileage per unit area than other physiographic regions. Consequently, many development sites in karst regions cannot discharge to the stream network within their property boundaries. This is a particular regulatory concern in Virginia, which requires that stormwater must discharge to an *adequate channel* (with defined bed and banks), a feature that may not be present at many sites in karst terrain (VA DCR, 1999).

Instead, much of the length of the headwater stream network in karst terrain is composed of karst swales, which appear as wide, shallow parabolic swales (Fennessey, 2003). Karst swales lack defined channels beds or banks, and may only briefly hold water during extreme storm events. Nevertheless, karst swales are an integral element of the natural drainage system and often exhibit significant infiltration capacity (SEA, 2000). The protection of natural karst swales is an important element of effective stormwater design in karst regions. However, soil and vegetation types common in karst swales, or other tell-tale signs, are rarely defined or delineated on soil or geology maps. Thus, where karst swales are suspected, their accurate delineation requires site-specific investigations by a professional geologist or soil scientist familiar with karst.

Rural Development Patterns and Growth Pressures. The karst region of Virginia has experienced primarily rapid, low-density growth in recent decades, and this trend is projected to continue in the future. The common rural development pattern involves large lot residential development and also many small lots or subdivisions constructed outside of water and sewer service areas. Consequently, many communities in karst terrain rely mainly on public or private wells to provide drinking water and septic systems to dispose of wastewater. Rural land development increases the demand on groundwater resources which, in times of drought, lowers the water table and causes wells to dry up. These problems are made worse when poorly designed stormwater management also reduces groundwater recharge within the same development.

Groundwater Contamination Risks. In karst terrain, contaminants in polluted runoff and spills often pass rapidly from the surface into groundwater, with little or no filtration or modification. In other cases, contaminants are “hung up” above the water table in the epikarst, releasing toxins into groundwater more gradually. The strong interaction between surface runoff and groundwater poses risks to the drinking water quality, upon which residents in karst terrain rely. Once an aquifer becomes contaminated, it is likely to be useless for a lifetime for consumption by humans and farm animals. As a result, designers need to consider groundwater protection as a first priority when they are considering how to dispose of stormwater, since there is always a risk that it will end up in the groundwater system.

Increased Sinkhole Formation **(Figures 6-B.4** and **6-B.5 below).** The increased rate of sinkhole formation caused by increased runoff from land development can result in damage to public infrastructure, roads and buildings. In addition, the existing drainage system may be further modified by land development, and then sinkholes may cause larger centralized stormwater practices to fail. Consequently, designers need to carefully assess the entire stormwater conveyance and treatment system at the site to minimize the risk of sinkhole formation. In most cases, this means installing a series of small, shallow runoff reduction practices across the site, rather than using the traditional pipe-to-pond approach.

Endangered Species. In some cases, development sites may have a subsurface discharge to caves, springs and surface streams that are home to rare, threatened or endangered species that are legally protected or otherwise merit special protection (e.g., cave-obligate aquatic and terrestrial invertebrates, bats and aquatic fauna in surface streams). Designers are required by federal law to screen for the presence of rare, threatened or endangered species to minimize project impact to habitat and ensure the project complies with the legal protections afforded under the Endangered Species Act. Designers should consult the Virginia Department of Conservation and Recreation's (DCR) Division of Natural Heritage for assistance with screening for threatened or endangered species.

Figure 6-B.4. A House Destroyed by a Sinkhole.

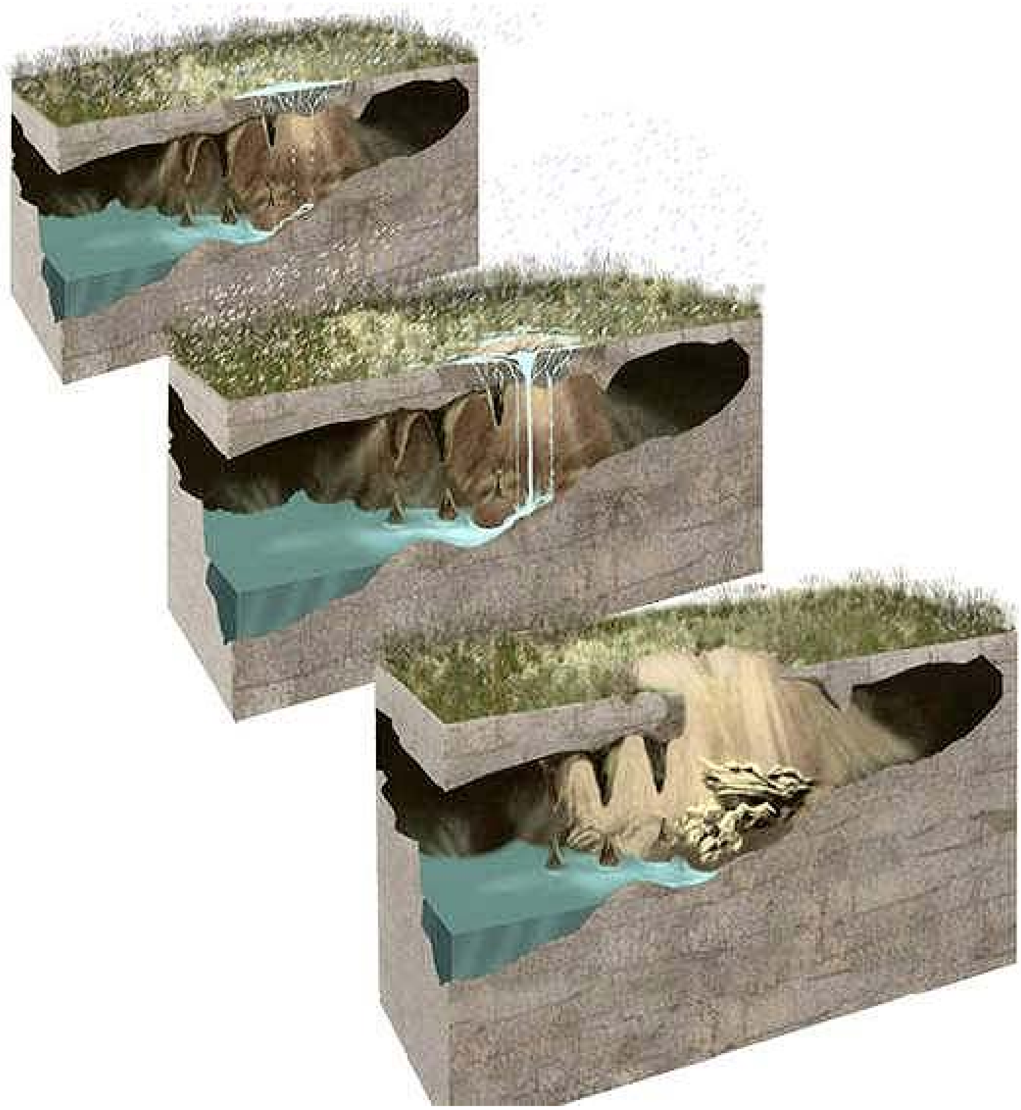

Figure 6-B.5. Schematic of Sinkhole Formation

6-B.3.0. A UNIFIED APPROACH FOR STORMWATER DESIGN IN KARST TERRAIN

This Appendix outlines a sequence of investigations to provide an adequate basis for stormwater design for any site underlain by limestone, dolomite and marble. These special studies are organized in the flow chart on the next page. The flow chart outlines a series of questions about the nature of the development. Based on the answers, designers can determine whether a special analysis is needed, and in which section of this Appendix they can find more information about it. The flow chart in **Figure 6-B.6** below was synthesized from several sources, including the Minnesota Stormwater Manual (2006), VA DCR (1999), CCDP (2007), MDE (2000) and PADEP (2006). It is important to note that flow chart is intended solely as a guide for stormwater management design; it is not meant to be used as a prescriptive process for local stormwater plan review.

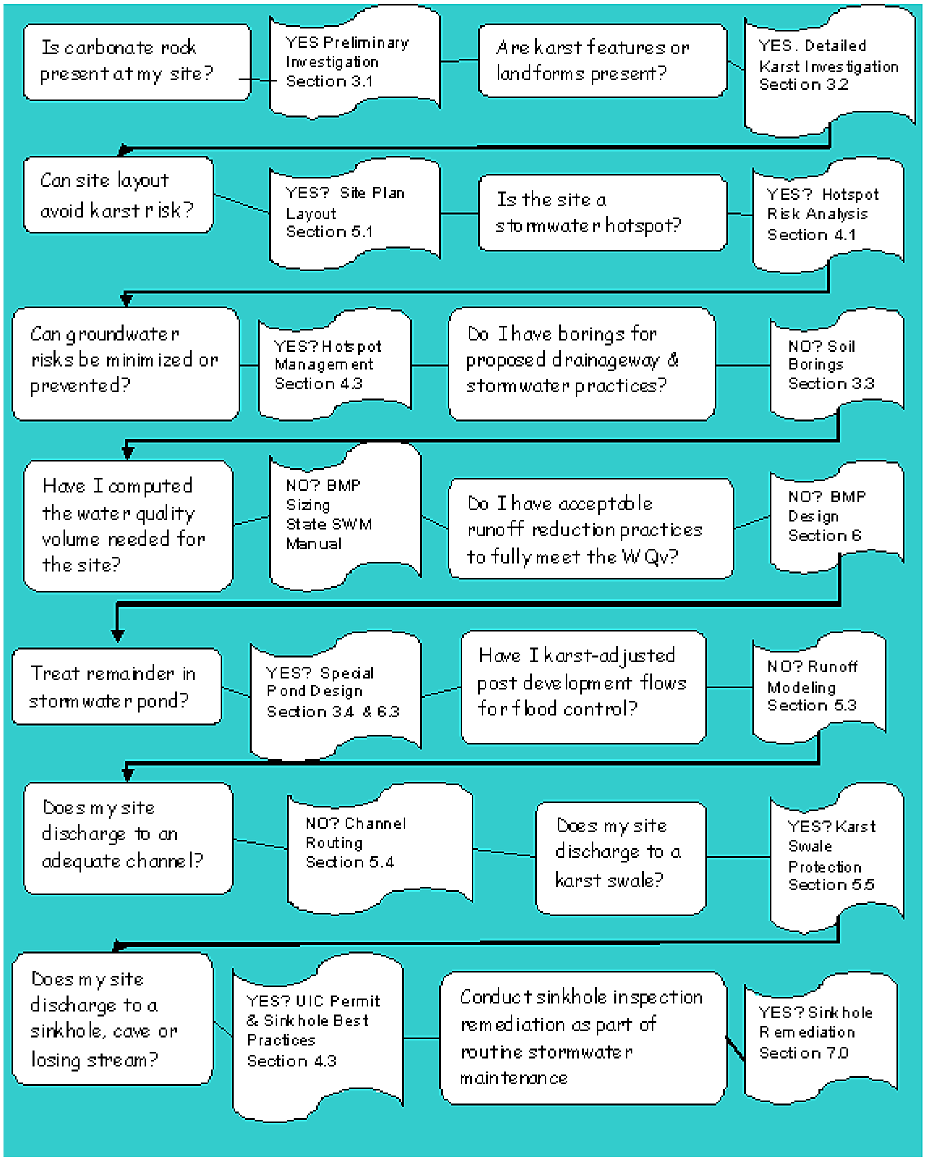

Figure 6-B.6 Flow Chart for Stormwater Design in Karst Terrain

6-B.4.0. PRELIMINARY AND DETAILED SITE INVESTIGATIONS FOR KARST

6-B.4.1. Introduction

Percolation of surface water can cause a migration of soil into solution cavities, forming "sinkholes" at the surface. Sinkholes cause instability of the land surface and must be given serious consideration in the development of erosion and sediment (E&S) control and stormwater management (SWM) plans. Sinkhole formation is often accelerated by construction activities that modify a site's hydrology or disturb existing soil and bedrock conditions. Ground failure in karst areas is most often caused by the alteration of drainage patterns, construction of impervious coverage, excessive grading, and the increased weight of site improvements.

An awareness of the limitations to site development posed by karst features can prevent problems, including damage to property, structures and life, and contamination of ground water. Appropriate site testing, planning, design, and remediation helps to prevent sinkhole formation during site development. Conventional methods of design and engineering may be inappropriate for karst areas. Often minor modifications in the approach to site testing and design can prevent persistent and costly post-development problems.

6-B.4.2. Preliminary Site Investigation

Site evaluation for karst features is usually carried out in two phases: (1) a *preliminary site investigation*, done prior to site design and development, and (2) a *site-specific investigation*, conducted once the decision is made to design a site plan and proceed with development.

Developers need to undertake a ***preliminary site investigation*** prior to conducting any design work for projects or building in areas known to be prone to karst. The level of investigation depends on the probability of karst being present and the local regulatory requirements. The purpose of the preliminary investigation is to identify areas of concern that may require additional investigation, and to review the preliminary site design in relationship to potential problem areas. The preliminary site investigation will often result in immediate changes to the site layout to avoid future problems.

Various methods are available to collect information about the bedrock and soil conditions at a proposed development site. The preliminary site investigation involves analysis of easily obtainable geological maps, topographic maps, soil surveys, and aerial photography.

Geologic maps contain information on the physical characteristics and distribution of the bedrock and/or unconsolidated surficial deposits in an area. Geologic features such as the strike and dip of strata, joints, fractures, folds, and faults are usually depicted. The orientation of strata and geologic structures generally controls the location and orientation of solution features in carbonate rock. Geologic contacts, faults, and certain fractures sets may be more prone to solution than others. The relationship between topography and the distribution of geologic units may reveal clues about the solubility of the specific rock units. Geologic maps are often available at various scales, the most common being 1:24,000. Digital geologic data may be available as well. Geologic maps can be obtained from the Virginia Department of Mines, Minerals and Energy, Division of Mineral Resources.

*Topographic map*s contain information about the relative positions and elevations of natural or man-made features of an area (e.g., buildings, roads, plains, hills, mountains, degree of relief, steepness of slopes and other physiographic features) related to the contours and configuration of the earth’s surface. Topographic maps are typically available at architectural/engineering supply, reprographic, and outdoor supply businesses. Topographic maps are also available at various scales, the most common being 1:24,000.

County soil surveys show the distribution of soil types or other soil mapping units in relation to the prominent physical and cultural features of the Earth’s surface. Soil surveys can be obtained from the local office of the U.S. Department of Agriculture of the local Soil and Water

Conservation District. USDA and Virginia Soil Survey soils maps commonly indicate sinkholes and other karst features, even if in cases where such features are too small to be visible on a 1:24,000 topographic map.

Aerial photographs provide a simple, quick method of site reconnaissance. Most localities have access to the 2002 and 2006-7 Virginia Geographic Information Network (VGIN) photographs at scales ranging from 1:100 for urban areas to 1:400 for rural areas. Google Earth is also a valuable tool for picking up landscape features that may not be visible on topographic maps. Inspection of photos can quickly reveal vegetation and moisture patterns that provide indirect evidence of the presence of cavernous bedrock. Piles of rock or small groups of brush or trees in otherwise open fields can indicate active sinkholes or rock pinnacles protruding above the ground surface. Circular and linear depressions associated with sinkholes, and linear solution features and bedrock exposures are often visible when viewed using stereo imagery. Inspecting photos taken on more than one date can be especially valuable in revealing changes that take place over time. Images defined at wavelengths other than visible light can be useful in detecting vegetative or moisture contrasts. Aerial photography is available from various state and federal agencies as well as from some private vendors.

LIDAR and other high resolution remote sensing data. Many Virginia localities have LIDAR (Light detecting and ranging) digital elevation maps with sub-meter vertical resolution. This data allows for very fine delineation of surface topographic features, including karst features such as sinkholes, as well as the watersheds draining to individual features.

The preliminary site investigation should also include screening for proximity to known caves. This can be accomplished through inquiries to DCR’s Division of Natural or by directly searching relevant state cave surveys.

The ***site-specific investigation*** includes collecting subsurface information at sites identified during the preliminary investigation as potential problem areas. During the site-specific investigation process, the experienced professional studies the site terrain in an effort to detect the signs of ground subsidence and to locate any obvious karst features, such as rock outcrops, sinkholes, springs, caves, etc. An on-site reconnaissance is an inexpensive, important step in finding potential site constraints.

Although many karst features are obvious to the eye, it is an advantage to conduct the site visit with an individual knowledgeable about karst geology. Prior to the site visit, field personnel should have reviewed the relevant resources described above to identify where problems might be found. It is important to review drainage patterns, vegetation changes, depressions, and bedrock outcrops to find evidence of ground subsidence. Sinkholes in subdued topography can often only be seen at close range. Disappearing streams are common in karst areas, and bedrock pinnacles that can be a problem in the subsurface will often protrude above the ground surface.

A simple and effective but often overlooked source of information during the site visit is an interview of the property owner. Often property owners can recount a history of problems with ground failure that may not be evident at the time of the site evaluation.

The product of the preliminary site investigation is usually a site map, which shows the location of any known or suspected karst features for later reference. These can be compared to other information collected to assess the potential risk of karst-related problems. It is important to understand that the while the presence of sinkholes or caves indicates the presence of karst, their absence does not necessarily mean that karst will not cause problems at the site (Hubbard 2004).

6-B.4.3. Detailed Site Investigation

Detailed site investigations are required in the design of all buildings, roads, stormwater conveyances and centralized stormwater facilities proposed within karst areas. The purpose of the investigation is to develop a **karst feature plan** that identifies the location and elevation of subsurface voids, cavities, fractures and discontinuities. The presence of any of these features could pose a danger to groundwater quality, a construction hazard, or an increased risk of sinkhole formation at a proposed centralized stormwater facility.

The scope of the geotechnical investigation should reflect the size and complexity of the development project. No single investigative approach works in every location. The sequence begins with a visual assessment of diagnostic karst features, and analysis of subsurface heterogeneity through geophysical investigation and/or excavation. Based on this information and the preliminary site plan, the number and pattern of test pits, test probes, soil borings, geophysical instruments or other observations needed to adequately characterize subsurface conditions can be determined by the geotechnical consultant and the requirements of the local reviewing authority. The following are some of the techniques that can be used in the detailed site investigation.

Test pit excavations are a simple, direct way to view the condition of soils that may reveal the potential for ground subsidence, and to inspect the condition and variability of the limestone bedrock surface where bedrock is sufficiently shallow. Soil texture is an important indicator of soil strength and, therefore, the ability of soils to bridge voids. An inspector should look for evidence of slumping soils, former topsoil horizons, and fill material (including surface boulders, organic debris, and other foreign objects) in the test pit. Voids in the soil or underlying bedrock can be revealed. The presence of organic soils at depth is an indicator of potentially active sinkhole sites. Leached or loose soils may also indicate areas of existing or potential ground subsidence. Observations of this type should be recorded in the soil log.

Test probes are performed by advancing a steel drill bit into the ground using an air-percussion-drilling rig. Probes can be installed rapidly and are an effective way to quickly test subsurface conditions. Penetration depths are usually less than 50 feet. During the installation of a test probe the inspector should be aware of the rate of advance of the drill bit, sudden loss of air pressure, soft zones, free-fall of the bit, and resistant zones. These observations can provide clues to the competency of the bedrock and the presence of cavities in soil or bedrock. The volume of fluid cement grout needed to backfill the probe hole can yield a measure of the size of subsurface voids encountered during drilling.

Soil borings can yield virtually complete and relatively undisturbed soil and rock samples. Borings may provide direct evidence of the presence and orientation of fractures, weathering, fracture fillings, and the vertical dimensions of cavities. They provide undisturbed samples that can be subjected to laboratory testing. However, it is possible that a set of borings could be located so that they miss key subsurface features and, therefore, do not accurately represent karst features under the surface. Soil borings can also create the conditions for surface collapses if they are not properly filled and sealed.

Use of a split inner core barrel in rock coring provides the most meaningful results, because this method collects a relatively undisturbed sample in the core barrel. Losses of drilling fluid can indicate the presence of soil or rock cavities. As with test probes, the volume of fluid cement grout placed to seal the drill hole can also yield a measure of the size of openings in the subsurface.

Once the general character of the surface cover is understood, borings are used to reveal its characteristics at specific locations at the site where construction is planned. The extreme spatial variability in subsurface conditions cannot be over-emphasized, with major differences seen a few feet away. Therefore, the consultant should obtain borings:

- Into suspected zones of bedrock solution;
- Adjacent to sinkholes or related karst features at the site;
- Along known zones of bedrock solution, or along known zones of geologic weakness, such as faults or fracture traces, including alignment of sinkholes;
- Adjacent to bedrock outcrop areas;
- Within the planned boundaries of any centralized stormwater facility;
- Through surficial materials to determine depth to bedrock; and
- Near any areas identified as anomalies from prior geophysical or subsurface studies.

The number and depth of borings at the site will depend entirely on the results of the subsurface investigations, the experience of the geotechnical consultant and the requirements of the local review authority. All borings or excavations should include the following:

- Descriptions, logged data and samples over the entire depth of the boring;
- Descriptions of any stains, odors, or other indications of environmental degradation;
- A minimum laboratory analysis of two soil samples representative of the material penetrated, including potential limiting horizons, with the results compared to field descriptions;
  - Minimum identified characteristics should include color, mineral composition, grain size, shape, sorting and degree of saturation;
- Any indications of water saturation should be carefully logged to include both perched and ground water table levels, and descriptions of soils that are mottled and gleyed. Note that groundwater levels in karst terrain can change dramatically in a short period of time and will not always leave evidence of mottling or gleying;
- Water levels in all borings should be fully open to a total depth that reflects seasonal variations in water level fluctuations; and
- A record of the estimates of soil engineering characteristics, including “N” or the estimated unconfined compressive strength, from a standard penetration test.

At the locations of centralized stormwater management facilities, the density of soil borings must result in a representative sampling over the area of the proposed facility. In general, a minimum of five borings must be taken for each centralized stormwater facility (or five per acre, whichever is greater), with at least one on the centerline of the proposed embankment and the reminder within the proposed impoundment area. For carbonate rocks, borings should extend at least 20 feet below the bottom elevation of the proposed centralized stormwater facility. Where refusal is encountered, the boring may either be extended by rock coring or moving to an adjacent location within 10 linear feet of the original boring site, in order to attain the 20 foot minimum depth. Upon completion, the boring should be backfilled with an impermeable plugging material such as grout mixed with bentonite, particularly when the boring intercepts subsurface voids.

Geophysical methods can serve as a rapid reconnaissance tool to detect physical anomalies in the subsurface that may be caused by karst features. Geophysical evaluations are often preferred over exclusive soil borings. There are many different techniques to reveal the nature of subsurface conditions in karst terrain, including:

- Electric resistivity tomography
- Seismic refraction
- Gravity surveys
- Electromagnetic (EM) inductance/conductivity surveys

These methods are especially suited to surveying linear corridors, and they are non-disruptive to the land. Geophysical data are often useful for extrapolating between locations where different sampling methods are used. Generally it is advisable to apply more than one geophysical technique, owing to the variability in physical properties of karst terrain. Geophysical methods require an experienced professional to interpret the data collected. The properties of weathered limestone, including a highly variable bedrock surface and soils with high clay content, often hinders the depth of penetration and resolution of geophysical signals, which can compromise the effectiveness of geophysical surveys. Despite these limitations, geophysics can sometimes provide a cost-effective, relatively rapid means of determining the potential for problems with karst features, including the location of shallow bedrock and significant cavities in the soil or bedrock. Geophysical anomalies should be targeted for additional direct testing procedures.

Electric resistivity tomography (see **Figure 6-B.7** below) has proven to be a particularly useful technique to identify subsurface anomalies at a scale that impacts stormwater design. This method allows high resolution imaging of features in the shallow subsurface. These surveys provide a qualitative evaluation of the site area and may identify “suspect areas” to be further evaluated by borings. The use of these surveys may reduce the total number of soil borings by narrowing down the locations of suspect areas at the site.

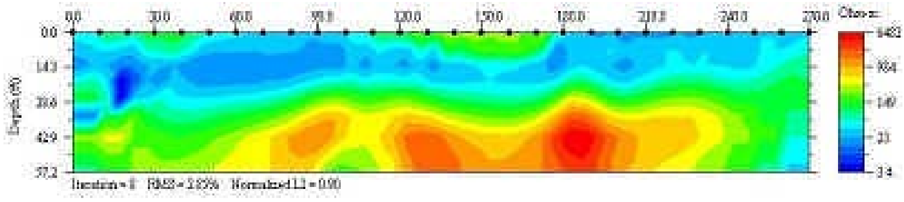

Figure 6-B.7. An Electric Resistivity Tomography Printout

Dye tracing. If karst features are expected to receive additional runoff after land development, it is advisable to conduct dye tracing to determine the flow direction of water entering the subsurface and the distance the water travels within the subsurface feature. Stormwater designers should retain the services of a qualified karst hydrologist or hydro-geologist to perform the trace. Also, designers are advised to coordinate with state natural resource agencies prior to initiating a trace to acquire pre-existing information on karst hydrology in the area and avoid potential cross-contamination with dyes from other investigations. Lastly, designers should notify local emergency response staff prior to introducing dye into the aquifer.

6-B.4.4. Specific Site Data To Be Obtained

Site and stormwater designers should retain the services of a qualified consultant experienced in working in karst landscapes. The investigation should determine the nature and thickness of subsurface materials including the depth to bedrock and the water table in area of the site where construction is planned. The investigation is an iterative process that may need to be expanded until the desired amount of detailed knowledge of the site is collected and fully understood. Pertinent site data to be obtained includes the following:

- The locations and descriptions of sinkholes, closed depressions, grikes and solution-enlarged voids. Note the dimensions of sinkholes, voids, and closed depressions (approximate depth, width, length). Descriptions of closed depressions should include other notes, such as cover collapse, open throat, bedrock or soil throat, ponding, rock collapse, rock fill, or other types of improvements.
- Bedrock characteristics (e.g., type, geologic contacts, faults, geologic structure).
- Overlying soil characteristics (type, thickness, spatial variability, mapped unit, geologic parent/history, infiltration rate, depth to seasonally high water table).
- Identification/verification of geological contacts if present, especially between karst and non-karst formations.
- A photo-geologic fracture trace map.
- The locations of bedrock outcrop areas.
- The locations of cave openings.
- The locations of springs.
- The locations of perennial, intermittent and ephemeral streams and their flow behavior and surface or subsurface discharge points (e.g., losing or gaining streams), channels and surface drainage network.
- The locations of site-scale watershed or drainage area boundaries based on large scale site topography (i.e., one foot or less contour intervals).

- The locations of public and private wells, at a minimum, within 1/4-mile of the site. However, to be thorough, wells within up to 10 miles (reflective of the direction of subsurface flow and the distance of the discharge’s flow) of the site should be located because they could very well be at risk.
- The layout of proposed buildings, roads, and stormwater management structures (and estimated locations and areas of site impervious and turf cover).
- The existing stormwater flow pattern.

The record of findings during this phase of the investigation includes logs of test pits, probes and borings, notes about evidence of cavities in soil and rock, loss of air pressure or drilling fluid during drilling, and the condition of soil and bedrock determined from samples collected. If unstable subsurface conditions are encountered, a decision can be made to (1) remediate the instability prior to construction or (2) to modify the site layout to avoid problem area(s).

6-B.4.5. Plan Submission

Consultants should identify and locate karst features, including suspected areas of ground subsidence, and submit these with both the development and stormwater management plan for the proposed site. Any existing sinkholes should be surveyed and permanently recorded on the property deed. Where these exist, an easement, buffer or reserve area should be identified on the development plat for the project so that all future landowners are aware of the presence of sinkholes on their property.

These findings should be compared to the proposed layout of site facilities and the site plan adjusted, wherever feasible, so that facilities are sited to avoid suspected areas of potential ground subsidence or sinkholes. Ideally, the site plan should minimize major site disturbance, especially cuts and fills. The amount of impervious cover on the site should be minimized to reduce stormwater runoff. Wells and septic systems should be located sensibly.

Alteration of drainage patterns should also be avoided, or at least minimized, to protect existing flow paths (such as karst swales). Where relocation of facilities is not practical, remedial measures and design standards can be employed to minimize the likelihood of failure. Remedial sealing of voids in the soil or bedrock and/or compaction of soil and rock voids may be viable measures in some areas.

At least one subsurface cross-section should be submitted with the stormwater plan, showing confining layers and depth to bedrock and the water table, if encountered. The cross-section should extend through the center-line of the proposed centralized stormwater facility, using actual geophysical and boring data. A sketch map or construction drawing indicating the location and dimension of the proposed facility should be included for reference to the identified subsurface conditions.

6-B.5.0. ASSESS FUTURE RISK OF GROUNDWATER CONTAMINATION

6-B.5.1. Designation of Stormwater Hotspots

Another key task in karst terrain is to assess whether the proposed operation or activity being built has a significant risk of becoming a future stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. **Table 6-B.1** presents a list of potential land uses or operations that may be designated as stormwater hotspots. It is important to understand that the actual hotspot generating area may only occupy a portion of the entire drainage area, and that some "clean" areas (such as rooftops or buffer areas) can be diverted away to another infiltration or runoff reduction practice. Communities should carefully review development proposals to determine if any future operation, on all or part of the site, should be designated as a stormwater hotspot. Also, it is important to note that practices that qualify as "injection wells" (see **Section 6-B.5.3** below) create potentially severe hotspot risks for groundwater resources and drinking water contamination.

Table 6-B.1. Potential Stormwater Hotspot and Site Design Responses

Potential Stormwater Hotspot Operation [1]	**SWPP Required?**	**Restricted Infiltration**	**No Infiltration**
Facilities w/NPDES Industrial permits	Yes	■	■
Public works yard	Yes		●
Ports, shipyards and boat/ship repair facilities	Yes		●
Railroads and railroad equipment storage	Yes		●
Auto and metal recyclers/scrap yards	Yes		●
Petroleum storage facilities	Yes		●
Highway maintenance facilities	Yes		●
Wastewater, solid waste, composting facilities	Yes		●
Industrial machinery and equipment	Yes	●	
Trucks and trailers	Yes	●	
Aircraft maintenance areas	Yes		●
Fleet storage areas	Yes		●
Parking lots (40 or more parking spaces)	No	●	
Gas stations	No		●
Highways (2500 ADT)	No	●	
Construction business (paving, heavy equipment storage and maintenance)	No	●	
Retail/wholesale vehicle/ equipment dealers	No	●	
Convenience stores/fast food restaurants	No	●	
Vehicle maintenance facilities	No		●
Car washes (unless discharged to sanitary sewer)	No		●
Nurseries and garden centers	No	●	
Golf courses	No	●	

Key: ■ Depends on facility ● Definitely restricted

The shaded Area highlights commercial facilities or operations not technically required to have NPDES permits, but can be designated as potential stormwater hotspots by the local review authority, as part of their local stormwater management ordinance.

[1] For a full list of potential stormwater hotspots, consult Schueler et al (2004).

Designation of a site as a hotspot influences how much runoff must be treated and whether it can be infiltrated or discharged to a sinkhole. A range of stormwater treatment and pollution prevention practices can be applied to prevent contamination of surface runoff or groundwater, particularly when the hotspot discharges to a community drinking water supply or wellhead protection area. Depending on the severity of the hotspot discharge, one or more of the management strategies outlined in **Section 5.2** of this Appendix may be required by the local review authority.

6-B.5.2. Management Strategies for Stormwater Hotspots in Karst Areas

As shown in **Table 6-B.1**, if a future operation at a proposed development project is designated as a stormwater hotspot, then one or more of the following management actions are required.

- **Stormwater Pollution Prevention Plan (SWPPP)**. This plan is required as part of an industrial, municipal, or general construction stormwater permit. It outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site. Other facilities or operations are not technically required to have NPDES permits (shown in the shaded areas of **Table 6-B.1** above), but can be designated in the local stormwater management ordinance as potential stormwater hotspots. An addendum should be included in the stormwater management plan for each designated hotspot facility to provide details regarding the pollution prevention practices and employee training measures that will be used to reduce contact of pollutants with rainfall or snowmelt.
- **Restricted Infiltration**. A minimum of 50% of the total Treatment Volume (T_v) must be treated by a filtering or bioretention practice ***prior*** to any infiltration. Runoff from portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an appropriate stormwater practice.
- **Infiltration Prohibition.** If a site is classified as a potentially severe hotspot, the risk of groundwater contamination is so great that infiltration of stormwater must be ***prohibited*.** In these cases, an alternative stormwater management practice, such as a closed bioretention facility, a sand filter, or a constructed wetland must be used to filter the entire T_v before it is discharged to surface water or reaches the groundwater.

6-B.5.3. Underground Injection Control Permits

The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program. The UIC regulations are intended to protect underground sources of drinking water from potential contamination. Depending on their design, some stormwater infiltration practices and ***all*** improved sinkholes can be potentially regulated as “Class V” underground injection wells. In Virginia, the UIC Program is administered by the USEPA, Region III (Philadelphia). Where the EPA administers the UIC program, Class V wells are “rule- authorized”, meaning that they do not require a permit, but the operator must contact the agency to provide an inventory of their well. Consult **Section 11** of this Appendix for more specific contact information.

Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. By definition, a well is “any bored, drilled, or driven shaft, or dug hole that is ***deeper than its widest surface dimension***, or an improved sinkhole, or a subsurface fluid distribution system.”

In karst terrain, improved sinkholes are the most common type of Class V well that will be encountered, although some infiltration practices may also qualify. Injection wells located in karst topography create a significant risk of groundwater contamination.

Federal regulations require all owners and operators of Class V wells to submit information to the appropriate state or federal authority. This includes the facility name and location, the name and address of a legal contact, ownership of the property, the nature and type of injection well(s), and the operating status of the injection well. Additional information on Class V well requirements can be accessed online at:

http://water.epa.gov/type/groundwater/uic/class5/regulations.cfm

The applicable regulatory authority then reviews this inventory data and may (1) determine the injection is authorized, (2) require more information, (3) issue a UIC permit with best management practice requirements, or (4) order the well closed. Given the risk of groundwater contamination, the locations of public and private wells should be identified, at a minimum, within 1/4-mile of the site. However, to be thorough, wells within up to 10 miles of the site (reflective of the direction of subsurface flow and the distance of the discharge's flow) should be located because they could very well be at risk.

Class V well requirements are primarily triggered by two conditions in karst terrain. The first and most serious condition is when increased post-development runoff is directed to an ***"improved sinkhole."*** The EPA defines an "improved sinkhole" as a naturally occurring karst depression or other natural crevice, which has been modified by a man-made structure to direct fluids into the subsurface. The EPA defines man-made structures to include pipes, swales, ditches, excavations, drains, graded slopes, or any other device that is intended to channel fluids toward or into a sinkhole

In Virginia, this definition would also include directing increased stormwater runoff volumes into an existing sinkhole from new upland development. The act of directing increased stormwater runoff from developed land into a sinkhole or other karst feature constitutes a "modification" and as such, becomes a de facto *improved* sinkhole requiring that the developer or owner obtain an EPA authorization and provide the required inventory of the facility. This is even true if the improved sinkhole is downstream of stormwater treatment practices, either on the site of off-site. Discharges to improved sinkholes on adjacent downstream properties are only allowed when appropriate legal agreements are made with the owner(s) of the property where the improved sinkhole is located. Since guidance on this matter is thin (i.e., what is the reasonable proximity between a discharge and a receiving sinkhole to result in the sinkhole being declared "improved?"), when in doubt, the developer should coordinate with the EPA and let the EPA make the call.

The second situation where a UIC authorization may be required is for certain "dug-out" stormwater practices that infiltrate runoff into the subsurface, or have a subsurface fluid distribution system. The specifications for the stormwater practices referred to in this Appendix have been created to avoid classification as Class V injection wells. The new Virginia stormwater management BMP design specifications include criteria regarding minimum geometric dimensions, surface pre-treatment, soil filtering, and design of "closed practices" that have filter fabric or under drains which daylight to the surface. These design specifications can be found on the Virginia Stormwater BMP Clearinghouse web site at:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

6-B.5.4. Stormwater Discharges to Improved Sinkholes

Under some circumstances, post-development stormwater must be discharged into an existing sinkhole or other karst feature. This may occur where significant portions of a site are internally drained and/or the majority of a site is underlain by karst. In other cases, it may be desirable to maintain pre-development flows to the existing sinkhole in order to maintain the subsurface hydrology. In either case, the following rules apply:

- The design goals are (1) to prevent *increased* runoff volumes from discharging to the sinkhole, but (2) to maintain the discharge at the level of the pre-development runoff volume, in order to maintain groundwater recharge.
- The applicant should ensure that known carcinogens, neurotoxins, drinking water pollutants and substances otherwise known to harmful to the health of humans, livestock and poultry will not be funneled underground into an aquifer.
- The sinkhole or karst feature receiving post-development stormwater runoff must be registered as a Class V Injection Well.
- The designer should conduct a survey to identify public or private drinking water wells within, at a minimum, 1,500 feet of the improved sinkhole. However, to be thorough, wells within up to 10 miles of the site (reflective of the direction of subsurface flow and the distance of the discharge's flow) should be located because they could very well be at risk.
- As such, the designer must notify the USEPA Region III office and must submit data on any drinking water wells identified in the survey. Keep in mind that an underground injection well authorization will be extremely difficult to obtain if the proposed land use or operation at the site is designated as a severe stormwater hotspot.
- DEQ strongly recommends that a dye trace be performed to understand in what direction and how far additional stormwater flows will move through the groundwater, particularly if drinking water wells are located nearby.
- The designer should maintain both the quality and quantity of runoff at pre-development levels prior to discharge into an existing sinkhole. Operationally, this means that the designer must treat the full Treatment Volume (produced by 1 inch of rainfall) in an acceptable runoff reduction practice before discharging to a sinkhole.
- A commitment to the operation and maintenance of stormwater practices (e.g., a maintenance agreement) must be included as a condition of the required underground injection authorization issued by the USEPA, Region III.

6-B.6.0. GENERAL STORMWATER DESIGN PRINCIPLES IN KARST AREAS

The following are general principles that should be considered in site layout and the design of stormwater management systems.

6-B.6.1. Site Design

Site design and construction procedures can be important in reducing the risk of sinkhole development. Sinkholes most often form in areas where storm-water runoff is concentrated, where bearing loads are concentrated, and where ground water is pumped out in large volumes. When development is proposed, consideration should be given to the following general guidelines to minimize the risk of ground failure:

- Designers should perform the preliminary and detailed site investigations prior to beginning site and stormwater design to fully understand the subsurface conditions, assess karst vulnerability, and define the actual drainage pattern present at the site.
- Any existing sinkholes and karst swales should be surveyed and permanently recorded on the property deed or plat. In addition, an easement, buffer or reserve area should be identified on the development plat for the project so that all future landowners are aware of the presence of these features.
- Minimize site disturbance and changes to soil profile, including cuts, fills, excavation and drainage alteration, near karst features.
- Require notification procedures on the design plans for both erosion and sediment control and stormwater management.
- Increase setbacks from building and other infrastructure.
- Minimize the amount of impervious cover created at the site so as to reduce the volume and velocity of stormwater runoff generated.
- Employ storm-water management measures that minimize flow velocities and ponding to avoid erosion of over-saturated of soils.
- Take advantage of subsurface conditions when locating building pads and place foundations on sound bedrock. To ensure this, take soil borings at key locations near buildings, roads, conveyances and at centralized stormwater management facilities. The number and depth of borings depends on the karst feature plans and local requirements.
- The location of new or replacement septic systems near improved sinkholes may be regulated by the local public health authority associated with the Virginia Department of Health. It is typically recommended that septic systems should be located at least 100 feet away from the base of an existing or remediated sinkhole.
- Designers should place a high priority on preserving as much of the length of natural karst swales present on the site as is feasible, in order to increase infiltration and accommodate flows from extreme storms

6-B.6.2. Erosion and Sediment Control Principles for Karst Areas

The selection, design, and implementation of E&S Control practices in karst areas should be guided by the following objectives and should incorporate the following design elements:

- The site should be designed to take maximum advantage of topography. Modifications of site topography should be minimized.
- Changes to the existing soil profile, including cuts, fills, and excavations, should be minimized.

- Where practical, drainage facilities should consist of embankments at or above grade. Excavation into the existing soil profile to construct swales and basins should be minimized to the degree possible.
- Temporary and final grading of the site should provide for drainage of storm-water runoff away from structures.
- All SWM facilities, including grassed waterways, diversions and lined waterways, should be designed to disperse the flows across the broadest channel area possible. This reduces the level of soil saturation and reduces the potential for soil movement. Shallow trapezoidal channel cross-sections are preferred over parabolic or V-shaped channels.
- Sediment traps and basins should only be used as a last resort for sediment control in karst areas, after all other erosion and sediment control options have been considered and determined to be inadequate. In the rare instance they are employed, they should serve small drainage areas (2 acres or less) and be located away from known karst features. The ESC plan should attempt to minimize drainage area sizes and therefore the need for basins or large traps.
- Vegetative cover should be established as rapidly as possible over exposed areas of soil. Construction scheduling should strive to minimize the time that soil excavations are open and non-vegetated. This reduces the time that the site is exposed to periods of concentrated flows as well as preventing excessive drying of soils.
- Utility trenches should be back-filled with in-situ soils or low permeability fill material, in order to discourage sub-surface water flow along the trench. Clay dams should be used at intervals along the trench excavation to impede subsurface flow along the trench. Trench backfill should be compacted to prevent future settlement and ponding. Backfill densities for open areas should exceed 90% of ASTM D-1557 maxima. Densities for areas supporting structures such as roadways should equal or exceed 95% ASTM D-1557 maxima.
- All underground piping should be waterproof and have water-tight fittings to minimize underground leaks. Leaks weaken and erode soils around underground conduits. The piping should be designed to withstand some limited displacement due to the probable ground settling and/or downward migration of trench bedding material into solution features.

6-B.6.3. Response to/Remediation of Sinkholes Occurring During Construction

It is possible for sinkholes to form during construction of a project (**Figure 6-B.8**). Sinkholes that occur during construction should be repaired immediately to prevent their enlargement and associated adverse impacts.

When sinkholes occur during construction, the site superintendant should take the following steps:

- Report the occurrence to the local plan approving authority within twenty-four (24) hours of discovery.
- Halt construction activities in the immediate area of the sinkhole until it is stabilized. Secure the sinkhole area.
- Direct the surface water away from the sinkhole area, if possible, to a suitable storm drainage system.

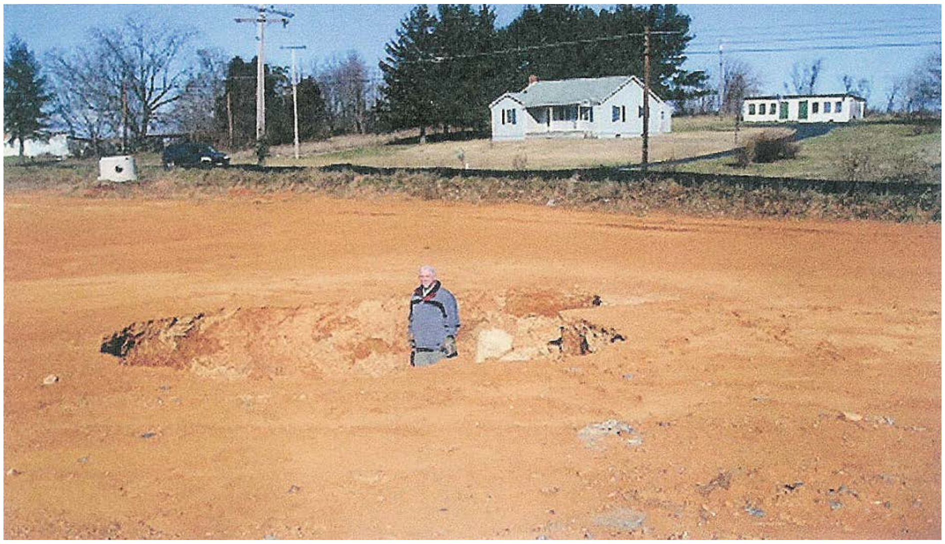

Figure 6-B.8. Sinkhole at a Construction Site

- Communicate the proposed remediation plan to the local plan approving authority. Some jurisdictions may have local requirements for notification and review as well.
- Repair any damage to E&S Control measures and restore ground cover and landscaping.
- In those cases where the hazard cannot be repaired without adversely affecting the E&S Control design, the applicant should submit contact the local plan approving authority for approval of changes to the plan.

The type of repair chosen for any sinkhole depends on its location, the extent and size of the void, and the type of infrastructure planned for the sinkhole area. Sinkhole sealing methods can include the use of available on-site materials, dry or wet grout, filter material, and geotextiles (see **Figure 6-B.9** below). General recommendations and references are available from Karst Program staff of the DCR Division of Natural Heritage, upon request.

All sinkhole remediation activities should be under the direct supervision of a geologist or geotechnical engineer with experience in limestone investigations and remediation practices. A certified professional should perform all borings. Also see related information in **Section 6-C.8.0** of this Appendix.

6-B.6.4. Stormwater Design Principles for Karst Areas

The following are important stormwater management design principles for karst areas:

- Treat runoff as sheet flow in a series of small runoff reduction practices before it becomes concentrated. Practices should be designed to disperse flows over the broadest area possible to avoid ponding, concentration or soil saturation.

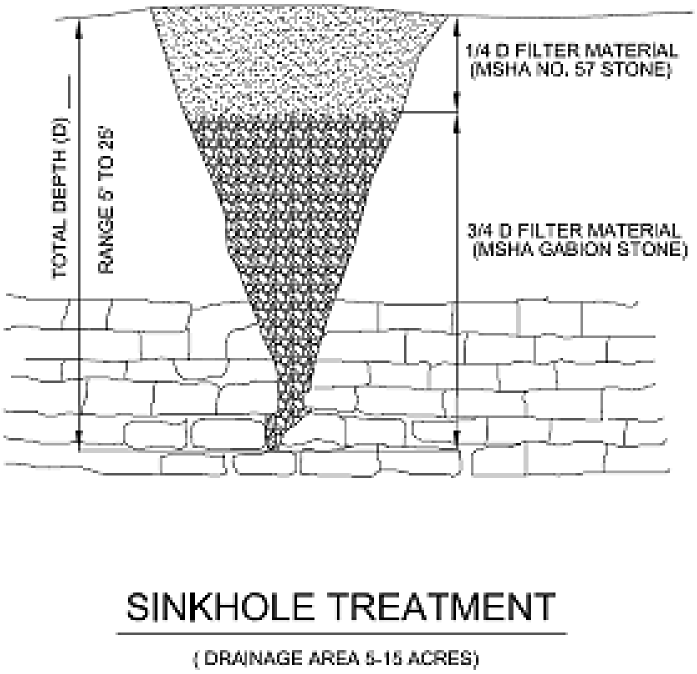

Figure 6-B.9. Typical Sinkhole Remediation (Similar to a Bioretention Cross-Section)
Source: MDE (2000)

- Small-scale low impact design (LID) types of practices work well in karst areas, although they should be shallow and sometimes use perforated under drains to prevent groundwater interaction. For example, micro-bioretention and infiltration practices can be a key part of the treatment train.
- Distributed treatment is recommended over centralized stormwater facilities, which are defined as any practice that treats runoff from a contributing drainage area greater than 20,000 square feet of impervious cover and/or has a surface ponding depth greater than 3 feet (e.g., wet ponds, extended detention (ED) ponds, and infiltration basins).
- The use of centralized stormwater practices with large drainage areas is strongly discouraged even when liners are used. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed LID practices. In addition, distributed LID practices generally eliminate the need to obtain an underground injection well authorization from the EPA.
- Designers should refer to the list of preferred and acceptable stormwater practices as outlined in **Table 6-B.2** and discussed further in **Section 7** below.
- Designers must address both the flooding and water quality aspects of post-development stormwater runoff. In most localities, the sequence of stormwater practices should have the capacity to safely convey or bypass the 2- and 10-year design storm, following the methods outlined in **Section 6.5** below.
- Designers should maintain both the quality and quantity of runoff at pre-development levels and minimize rerouting of stormwater from existing drainage.
- As a general rule, the stormwater system should avoid large contributing drainage areas, deep excavation, or pools of standing water.

  - In fact, use of larger ponds is highly discouraged in karst areas – especially wet ponds.
  - Temporary detention water depths should not exceed six feet.
  - Liners are required for ponds (see **Table 6-B.6** later in this document), with the thickness and material based on the proximity to bedrock or groundwater access.
  - Where ponds are employed, a rigid maintenance protocol with routine inspections is necessary, with immediate remediation of sinkholes that occur within basins.
- The potential hotspot status of the proposed development should be evaluated prior to design. If the site is likely to be designated as a stormwater hotspot, full water quality treatment must be provided prior to any discharge to groundwater.
- When existing or new sinkholes are determined to require remediation, the repair will use appropriate techniques [reference WVDEP (2004), MDE (2000) or CCDP (2007)]. These techniques are related to the size of the sinkhole, and are summarized in **Section 8** below.

Table 6-B.2. Stormwater Practice Selection in Karst Regions

Stormwater Practice	**Suitability in Karst Regions**	**Bay-wide Design Spec #** [4]	**UIC Permit?**	**Design and** ***Implementation Notes***
Closed Bioretention	Preferred	**9**	No	
Urban Bioretention [1]	Preferred	**9a**	No	
Rainwater Harvesting	Preferred	**6**	No	
Vegetated Roofs	Preferred	**5**	No	
Shallow Dry Swale	Preferred	**10**	No	Lined w/ underdrains
Filtering Practices	Preferred	**12**	No	Water-tight
Sheet Flow to a Filter Strip or Conserved Open Space	Adequate	**2**	No	Flow to karst swales
Grass Channel	Adequate	**3**	No	Compost amendments
Soil Compost Amendments	Adequate	**4**	No	
Small Scale Infiltration [2]	Adequate	**8**	No	Not at stormwater hotspots
Micro-bioretention	Adequate	**9**	No	Closed systems
Permeable Pavers	Adequate	**7**	No	
Constructed Wetlands	Adequate	**13**	Maybe	Use liner and linear cells
Rooftop Disconnection	Preferred	**1**	No	15 feet foundation setback
Wet Ponds	Discouraged	**14**	Maybe	Liner required
Dry ED Ponds	Discouraged	**15**	Maybe	Liner required
Open Bioretention	Discouraged	**9**	No	
Wet Swale	Prohibited	**13a**	No	Infeasible
Large Scale Infiltration[3]	Prohibited	**8**	Maybe	Use small-scale instead

[1] Closed, above-ground facilities with no groundwater interaction.

[2] See definitions and design requirements for micro- and small- scale infiltration in **Table 6-C.4**.

[3] Contributing drainage area of 20,000 sf of impervious cover or more.

[4] The most current version of the Virginia Stormwater Design Specifications can be downloaded from the Virginia Stormwater BMP Clearinghouse web site at http://www.vwrrc.vt.edu/swc/ .

6-B.6.5. Recommended Procedures for Conveying Runoff from Larger Storms

Karst areas often have no natural defined channels in or near small or moderate sized development sites. Instead, pre-development runoff typically flows in natural parabolic type swales (karst swales) across adjoining properties. New stormwater conveyance structures in karst areas should be designed in a manner that dissipates overland flow over the largest area possible. Every attempt should be made to avoid concentrated flows and ponding. Grass channels can be effective storm-water-diversion structures in karst areas. Particularly effective are waterway designs that are shallow and broad, providing maximum bottom width and wetted perimeter to disperse flow over the greatest area.

When developing a karst site, the peak storm runoff rate to these waterways must be restricted to the existing karst-adjusted peak runoff rate (see **Section 6.6** below) or the pre-development rate for good pasture (or better yet, forest cover), whichever is less. This is calculated by reducing the allowable peak flow rate resulting from the 24-hour storm events with return periods of 1-year, 2-years, and 10-years to levels that are less than or equal to the peak flow rates from the site for those storms, assuming the site was in a good pasture (or better yet, good forested) condition. This is typically achieved by multiplying the good pasture (or better yet, good forested) peak flow rate by a reduction factor [i.e., the runoff volume from the site when the site was in a good pasture condition (or, better yet, in a good forest condition) divided by the runoff volume from the site in its proposed condition].

6-B.6.6. Stormwater Modeling in Karst Areas

Karst loss is a term given to the loss of surface runoff into bedrock strata in areas underlain by limestone geologic formations. Unlike other calculation factors, such as curve numbers (which deal with characteristics of the land surface), a karst loss factor is intended to depict projected losses into bedrock.

The determination of karst potential in any given area may be simplified by the observation of noticeable indicators such as caves, crevices, limestone outcrops, sink holes, ponds that appear to lack sufficient contributing area, and disappearing streams. In other cases, karst infiltration areas may be difficult to identify, since definitive karst features are not always obvious. Generally, a lack of natural drainageway erosion or inadequately sized drainageways (in comparison to the size of the contributing area) may be clues to karst loss. Other observations may include undersized drainage conduits that never run full.

By accounting for karst loss through hydrologic modeling, the site designer can more accurately simulate actual conditions in deriving runoff rates. Mapping of a geographic area (when limited in size) may be productive in defining a karst loss zone (an area underlain by karst bedrock). However, the delineation of such zones is simply a method for *estimating* karst loss, not an accurate representation of the actual site-specific rate of karst loss. Accurate karst loss modeling requires an extensive field investigation at each site under consideration to obtain comprehensive information about subsurface strata. In many cases the cost to fully model a site is prohibitive. Therefore, as an alternative, karst runoff loss estimations may be comparatively simple but still reasonably accurate.

The premise behind karst runoff loss estimation and adjustment is to better approximate actual site conditions, which produce lower peak rates of runoff than those than would occur on a similar site where karst is not present. Typically, adjustment for karst loss is recommended only when analyzing *pre-development* site conditions. This is because once development occurs, karst features may become more obliterated from extensive site grading activity. Also, the addition of impervious cover and the construction of a surface drainage system may offset karst losses that may have existed prior to development.

Karst adjustment for post-development site conditions is typically *not* recommended, except for portions of the site that remained substantially undisturbed and uncompacted, during and subsequent to development. Furthermore, any runoff from the site draining to sinkholes subsequent to development must meet water quality and quantity standards. In any event, the adjustment factors shown in **Table 6-B.3** below apply only to pre-development runoff, and should never be used for post-development runoff computations.

Projecting karst loss in hydrologic modeling of limestone requires some specific examination (field inspection) of the subject area, along with a geologic examination of the underlying strata, in order to predict the extent of the karst loss zone. Many urban development sites of limited size will fall exclusively inside or outside of a karst loss zone. In such cases, the watershed does not need to be split into karst and non-karst areas.

Many of the traditional NRCS hydrologic models over-predict pre-development runoff from karst terrain, as a result of the high initial abstraction that occurs in karst areas, as well as the fact that concentrated storm flows are often rapidly converted to subsurface flows (Laughland, 2007). In general, over-predictions are more likely to occur when modeling the smaller storms and less likely to occur when modeling larger storm events, such as the 100-year storm. Consequently, designers must carefully modify their NRCS hydrologic and hydraulic computations to reflect the lower pre-development peak discharge rates. It is important to understand that more hydrologic monitoring and modeling research is needed to get predictions that are more reliable.

The following method for estimating stormwater runoff losses in karst settings is adapted from Laughland (2007), only one of many methods that can be used (some much more detailed than this). This method provides the multiplier factors (shown in **Table 6-B.3** below) used to adjust TR-55 and TR-20 pre-development rates, as follows.

1. Delineate the contributing drainage area or watershed to be studied.
2. Define any sinkhole areas within the contributing drainage area where surface drainage has no means of escaping offsite, other than downward through the karst strata (i.e. cracks, sinks, etc.). These areas can be assumed to contribute no surface discharge and can be subtracted from the contributing drainage area from Step 1.
3. Determine the amount of the contributing drainage area (from Step 2) underlain by karst strata (in percent).
4. Calculate the peak rate of runoff from the contributing drainage area using standard hydrologic methods, and reduce the calculated value by multiplying by the *Karst Loss Modification Value* (**Table 6-B.3**), based on the percent karst (% Karst) calculated in Step 3.

Table 6-B.3. Multipliers for Adjusting Predevelopment Runoff Quantities for Karst Impact

% of Drainage Area in Karst	Design Storm Return Frequency		
	2-year Storm	10-year Storm	100-year Storm
100	0.33	0.43	0.50
90	0.35	0.46	0.56
80	0.38	0.51	0.62
70	0.47	0.58	0.68
60	0.55	0.66	0.74
50	0.64	0.73	0.80
40	0.73	0.80	0.85
30	0.82	0.86	0.89
20	0.91	0.92	0.93
10	1.00	0.98	0.97
0	1.00	1.00	1.00

Source: Laughland,(2007) and VA DCR (1999)

Table 6-B.3 (developed using the *PSU-IV Program* by G. Aron et al) provides modifiers based on the percentage of the contributing drainage area that is underlain by karst strata. The modifiers are used to adjust the peak rate of runoff calculated using standard modeling techniques. For example, the calculated 2-year peak discharge of 12 cubic feet per second (cfs) from a drainage area that has been determined to be underlain by 80% karst zone (with no observed sinkhole areas) would be reduced as follows:

$$12 \text{ cfs} \times 0.38 = 4.5 \text{ cfs}$$

This represents a peak rate reduction of 62%. Note that as the storm frequency decreases (i.e. 2-year frequency to 10-year frequency storm), the multiplier may decrease and have less affect on the result. This is due to the fact that karst typically exerts less of an influence as the rainfall rate increases and underground voids fill with water. However, the change in infiltration capacity with storm frequency will vary between sites. Some sites may actually experience karst gain (a surcharge) in response to large flood events.

Other potential methods that can be used to model karst include applying a *TYPE I* rainfall distribution to a karst area that actually has a *TYPE II* rainfall distribution, or manipulating the Runoff Curve Number (RCN) or *Initial Abstraction* (Ia) values (when using NRCS methodology). However, each method of manipulation has both advantages and disadvantages in accurately representing the impacts of karst topography on runoff rates. However, more hydrologic monitoring and modeling research is needed to get predictions that are more reliable.

Local stormwater review authorities and state regulations may require management of different design storms for quantity control, including the following:

- Runoff reduction or detention of the 1-year storm event for downstream channel protection;
- Detention of the 10-year storm for safe conveyance; and
- Detention or floodplain control to manage the 100-year storm event.

Karst Surcharge. Sinkhole surcharge is a topic that is not frequently addressed in karst modeling methods. In this phenomenon, the opposite condition than that expected from karst loss occurs.

Rather than dampening the runoff peak, there can be depressed surface areas, or sinkholes, that experience surcharge (flooding) during rainfall events. This is due to the connectivity of the underground conveyance network. These natural runoff detention areas may or may not be significant in the overall hydrology of a watershed, but they may exert substantial impact on small sites, subjecting development in the area to inundation. A shift of detention catchment to other on-site or off-site karst areas is also possible when on-site development activity fills a sinkhole. Karst is unpredictable, and changes on the land surface may also result in subsurface hydrologic modifications. Due to the complexity of karst, sinkholes or surface depressions should *never* be filled unless a comprehensive valuation of the feature is completed first.

Additional guidance may be provided in the future to help identify the extent of karst loss.

6-B.6.7. Karst Swale Protection (KSP) for Stormwater Management

SEA(2000) proposed a Treatment Volume credit for protection of natural drainageways present on a karst development site. They define a karst swale protection area as being centered on the drainage-way or swale with a maximum width of 300 feet and a minimum width of 50 feet. However, the local review authority has some discretion to opt for a smaller width at small sites where natural land forms define an appropriate alternate width.

The credit is taken in the water quality or runoff reduction equation by reducing the area of site impervious cover draining to the karst swale by twice the KSP area. However, the maximum KSP credit may not to exceed 50% of the site impervious area. The rationale for the high credit is that the KSP area has proportionally higher infiltration capability than more upland areas at the site (Fennessey, 2003). SEA (2000) also recommends the following restrictions on the karst swale credit:

- The KSP area must be located on the development site.
- It is good practice to combine a KSP with an adjacent filter strip to accept off-site stormwater runoff.
- KSP areas must remain in an undisturbed condition during and after construction activity. There can be no construction activity within these areas, including temporary access roads or storage of equipment and materials. Temporary access for the construction of utilities crossing the KSP area may be permitted at the municipal engineer’s discretion, if the alignment of the crossing is perpendicular to the karst swale.
- KSP areas should be placed in a conservation easement or permanently preserved through a similarly enforceable agreement with the municipality.
- The limits of the undisturbed KSP area and conservation easement must be shown on all construction plans.

6-B.7.0. DESIGN CRITERIA FOR SPECIFIC STORMWATER CONTROL MEASURES

Stormwater management facilities are particularly vulnerable to collapse in karst areas because most are designed to concentrate and detain surface water runoff. Ponding and associated soil saturation occur where surface-runoff is concentrated. Saturation of fine-grained soils that develop on weathered limestone can cause a reduction in soil strength and erosion into bedrock voids.

One preventive strategy is to provide a pre-treatment method that does not use the detention of stormwater to settle out or filter pollutants. Consider manufactured water quality BMPs which can serve as pre-treatment devices or even spill containment BMPs for commercial/industrial development in karst areas. These structures will not eliminate the potential for karst collapse, but they do provide water quality treatment that helps to minimize the potential for the contamination of groundwater.

This section describes recommended design adaptations for stormwater practices installed in karst terrain. With reference to **Table 6-B.2** above**,** the base design specification for each practice can be found at the Virginia Stormwater BMP Clearinghouse web site at:

http://www.vwrrc.vt.edu/swc/.

6-B.7.1. Preferred Practices

Vegetated Roofs. Vegetated Roofs (Virginia Stormwater Design Specification No. 5 -- see **Figure 6-B.10** below) are a preferred treatment option in karst terrain for commercial, institutional and industrial sites. However, they may have somewhat limited application, given the forms and intensity of development in the Ridge and Valley Province. The overflow from the Vegetated Roof should extend at least 15 feet away from the building foundation.

Figure 6-B.10. Vegetated Roof

Rainwater Harvesting. Rainwater Harvesting (Virginia Stormwater Design Specification No. 6 – see **Figure 6-B.11** below) is a preferred practice in karst terrain, as long as the surface of the roof is not designated as a stormwater hotspot (based on the roofing material). Rainwater harvesting is also well-suited to provide an alternative water source in rural communities. Recommended design adaptations for karst areas are as follows:

Figure 6-B.11. Cistern to Harvest Rainwater

- Above ground tank designs are preferred to below ground tanks
- Tanks should be combined with automated irrigation, front-yard bioretention or other secondary practices to maximize their runoff reduction rates.
- The overflow from the rain tank should extend at least 15 feet away from the building foundation.

Bioretention (closed). Since bioretention (Virginia Stormwater Design Specification No. 9 – see **Figure 6-B.12** below) requires shallow ponding and treats runoff through a prepared soil media, it is generally appropriate for karst regions, provided that the following design modifications are made to reduce the risk of sinkhole formation or groundwater contamination:

Figure 6-B.12. Small Rain Garden

- Bioretention facilities in karst areas should be wide and shallow.
    - The minimum depth of the filter bed may be relaxed to 18 inches if the geotechnical investigation indicates that further excavation is likely to increase karst vulnerability.
    - Maximum depth of the filter bed should be 3 feet.

  - To reduce the vertical footprint, (1) to limit surface ponding to from 6 to 9 inches, and (2) save additional depth by shifting to turf rather than a mulch cover.
- If bedrock is within 3 feet of the bottom invert of a proposed bioretention area, it should be equipped with an underdrain to convey treated runoff to an appropriate discharge point. If groundwater contamination is a strong concern, the bottom of the facility should be lined with an impermeable filter fabric.
  - It is important to (1) maintain at least a 0.5% slope in the underdrain to ensure positive drainage, and (2) connect the underdrain to the ditch or conveyance system.
  - Add a sump stone layer below the underdrain to increase runoff volume reduction.
- The scale of the bioretention application is extremely important in karst terrain. Larger bioretention designs that rely on exfiltration of treated runoff into underlying soils are not recommended in karst regions.
- The Department recommends that the contributing area to individual bioretention areas be kept to less than 20,000 square feet of impervious cover. These micro-bioretention and small-scale bioretention practices are preferred over larger bioretention basins.
- The mix of plant species selected should reflect native plant communities present within the same physiographic region or eco-region, in order to be more tolerant of drought conditions.
- The standard setbacks from buildings, structures and roadways should be as described in **Table 6-B.4** below.

Table 6-B.4. The Three Design Scales for Bioretention Practices

Design Factor	Micro Bioretention (Rain Garden)	Small-Scale Bioretention	Bioretention Basins
Impervious Area Treated	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 200,000 sq. ft.
Type of Inflow	Sheetflow or roof leader	Shallow concentrated flow	Concentrated flow
Runoff Reduction Sizing	Minimum 0.1 inches over CDA	Minimum 0.3 inches over the CDA	Remaining T_v up to the full Cp_v
Observation Well/ Cleanout Pipes	No	No	Yes
Type of Pre-treatment	External (leaf screens, etc)	Filter strip or grass channel	Pre-treatment cell
Recommended Max. Filter Depth	Max 3 Foot Depth	Max 5 Foot Depth	Max. 6-foot depth
Media Source	Mixed On site	Obtained from an Approved Vendor	
Hydraulic Head Required	Nominal 1 to 3 feet	Moderate 1 to 5 feet	Moderate 2 to 6 feet
Building Setbacks	15 ft. down-gradient 25 ft. up-gradient	15 ft. down-gradient 50 ft. up-gradient	25 ft. down-gradient 100 ft. upgradient

Urban Bioretention (closed). Three forms of bioretention for highly urban areas (Virginia Stormwater Design Specification No. 9, Appendix A –**Figure 6-B.13**) can work acceptably within karst terrain. They are (1) stormwater curb extensions, (2) expanded tree planters, and (3) foundation planters, since each of these variants is enclosed in a concrete shell and does not interact with groundwater. Designers should consider the above-ground design variants, since they reduce excavation and also incorporate the general karst design modifications for regular bioretention described above.

Figure 6-B.13. Urban Bioretention

Dry Swale (closed). Shallow Dry Swales (Virginia Stormwater Design Specification No. 10 – see **Figure 6-B.14** below) work well in karst terrain when they use impermeable filter fabric liners and underdrains. Recommended design adaptations for karst areas are as follows:

- Try to locate Dry Swales in the pre-development flow paths.
- The invert of the Dry Swale must be located at least 2 feet above bedrock layers or pinnacles.
- If a Dry Swale facility is located in an area of sinkhole formation, standard setbacks to buildings and roads should be increased.
- The minimum depth of the filter bed may be relaxed to 18 inches or even less, if hydraulic head or water table conditions are problematic.
- A minimum underdrain slope of 0.5% slope must be maintained to ensure positive drainage and the underdrain must be connected to an adequate channel or discharge to a karst swale protection area.

Figure 6-B.14. Dry Swale

Filtering Practices. Stormwater filters (Virginia Stormwater Design Specification No. 12 – see **Figure 6-B.15**) are a good option in karst terrain, since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination. They are highly recommended for the treatment of hotspot runoff. Recommended design adaptations for karst areas are as follows:

- Construction inspection should certify that the filter bottoms are closed and water tight.
- The bottom invert of the sand filter should be at least 2 feet above bedrock.
- The minimum depth of the sand filter bed may be reduced to from 18 to 24 inches.

Figure 6-B.15. Sand Filter

6-C.7.2. Adequate Practices

Rooftop Disconnection (Figure 6-B.16). Rooftop disconnection is an acceptable practice for most residential lots with areas of less than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. (See Virginia Stormwater Design Specification No. 1 for the four primary micro-practice options.) The discharge point from the disconnection should extend at least 15 feet from any building foundations There should be at least 40 feet of disconnect if the discharge ultimately flows back onto an impervious surface or into a storm drainage system.

Figure 6-B.16. Rooftop Disconnection

Sheet Flow to Vegetated Filter Strips and Conserved Open Space. The use of conservation filter strips (Virginia Stormwater Design Specification No. 2 – see **Figure 6-B.17** below) is acceptable in karst areas, particularly when stormwater runoff discharges to the outer boundary of a karst swale protection area.

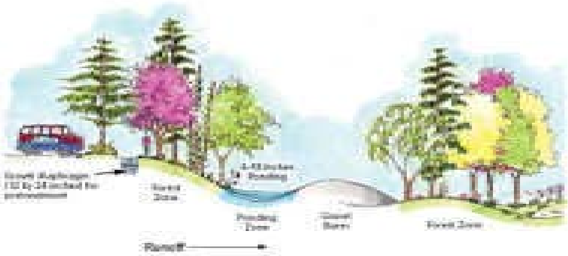

Figure 6-B.17. Sheet Flow to Filter Strips or Conserved Open Space

Conservation filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 20,000 square feet). Some communities use wide grass filter strips to treat runoff in the roadway shoulder. Depending on flow conditions (i.e., sheet or concentrated), the strip must have a gravel diaphragm, pervious berm or engineered level spreader conforming to the new requirements outlined in this design specification, to help spread the runoff across the surface of the receiving filter area. Ideally, vegetation in the filter area should be native meadow or forest cover. Each individual filter strip should have a maximum area of 1/2-acre.

***Grass Channel*.** Grass Channels (Virginia Stormwater Design Specification No. 3 – see **Figure 6-B.18**) are an acceptable practice in karst terrain of Virginia, as long as they do not receive hotspot runoff. The following design adaptations apply to Grass Channels in karst terrain.

- Soil compost amendments can be incorporated into the bottom of a Grass Channel to improve its runoff reduction capability.
- Check dams are generally discouraged for Grass Channels in karst terrain, since they pond too much water. However, flow spreaders that are flush with ground surface may be useful in spreading flows more evenly across the channel width.
- The minimum depth to the bedrock layer may be 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The Grass Channel may have off-line cells and should be connected to an adequate discharge point.

Figure 6-B.18. Grass Channel

Soil Compost Amendments. The incorporation of Soil Compost Amendments (Virginia Stormwater Design Specification No. 4) requires no special adaptations in karst terrain, but the designer should take soil tests to ensure that soil pH is adjusted to conform to pre-existing soil conditions.

Micro- and Small Scale Infiltration. The karst region is an acceptable environment for micro-infiltration and small-scale infiltration practices (see Virginia Stormwater Design Specification No. 8 – see **Figure 6-B.19** below). For definitions and design requirements, See **Table 6-B.5** below. Designers may choose to infiltrate less than the full Treatment Volume in a single practice (and use another runoff reduction practice to pre-treat or filter runoff before it reaches the infiltration facility.

Figure 6-B.19. Small-Scale Infiltration Trench

Table 6-B.5. The Three Design Scales for Infiltration Practices

Design Factor	Micro Infiltration	Small-Scale Infiltration	Large Scale Infiltration
Impervious Area Treated	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.
Typical Practices	Dry Well, French Drain, Paver Blocks	Infiltration Trench Permeable Paving	Infiltration Trench Infiltration Basin
Runoff Reduction Sizing	Minimum 0.1 inches over the CDA	Minimum 0.3 inches over the CDA	Remaining T_v up to the full Cp_v
Minimum Soil Infiltration Rate	0.5 inches per hour	1.0 inches per hour	1.0 inches per hour
Design Infililtraton Rate	50% of the measured rate for the soils in place		
Observation Well	No	Yes	Yes
Type of Pre-treatment	External (leaf screens, etc)	Filter strip or grass channel	Pre-treatment cell
Depth to Width	Max. 3 ft. deep Min. 10 ft. wide	Max. 5 ft. deep Min. 15 ft. wide	Max. 6 ft. deep Max. 20 ft. wide
Required Borings	One per practice	Two per practice	One per 500 sq. ft. of infiltration area
Building Setbacks	15 ft. down-gradient 25 ft. up-gradient	15 ft. down-gradient 50 ft. up-gradient	25 ft. down-gradient 100 ft. up-gradient

Some design modifications for small-scale infiltration in karst terrain include the following:

- The maximum CDA to the facility is 20,000 square feet.
- Designers should maximize the surface area of the infiltration practice and keep the depth of infiltration to less than 24 inches and the width wider than the depth.
- Soil borings must indicate that at least 3 feet of vertical separation exists between the bottom invert of the infiltration facility and the bedrock layer.
- Where soils are marginal, underdrains may be used.

- Setbacks to roads and buildings should be 15 feet down-gradient and 25 feet up-gradient.
- In many cases, bioretention is preferred over infiltration for stormwater management in karst areas.
- Infiltration is prohibited in karst areas if the contributing drainage area is classified as a severe stormwater hotspot.

Permeable Pavement. Permeable Pavement (Virginia Stormwater Design Specification No. 7 – **Figure 6-B.20** below) are an acceptable option in karst terrain if geotechnical investigations have eliminated concerns about the potential for sinkhole formation and groundwater contamination.

- Full infiltration from Permeable Pavement (i.e., the Level 2 design) is not recommended for large-scale pavement applications and is prohibited if the site (1) is designated as a severe stormwater hotspot, or (2) discharges to areas known to recharge to aquifers that are used for water supply.
- Permeable Pavement is acceptable when it is designed with an impermeable bottom liner and an underdrain. A minimum 0.5% underdrain slope must be maintained to ensure positive drainage.
- Carbonate rock should be used in the reservoir layer in order to provide extra water quality buffering capacity.

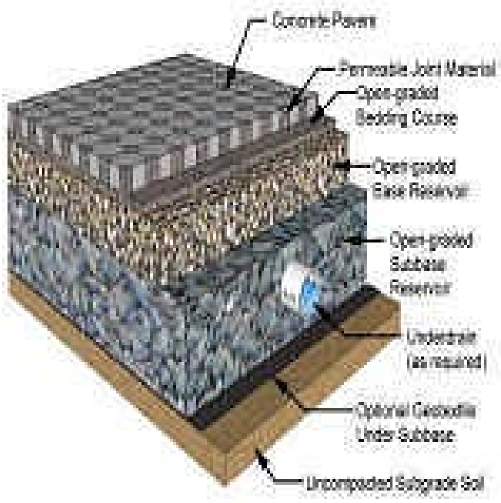

Figure 6-B.20. Profile Through Permeable Pavement

Constructed Wetlands (lined). Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain during the planning stage to assess this risk. If Constructed Wetlands ((Virginia Stormwater Design Specification No. 13 – see **Figure 6-B.21** below) are employed, the designer should do the following:

- Use an impermeable liner and maintain at least 3 feet of vertical separation from the bottom of the wetland to the underlying bedrock.
- Shallow, linear and multiple cell wetland configurations are preferred.

Figure 6-B.21. Constructed Wetland

- Regenerative conveyance systems are worth testing (with sand and organic lenses).
- Ideally, constructed wetlands should be installed draining to or in close proximity to karst swale protection areas.
- Deeper basin configurations (e.g., the pond/wetland system and the extended detention wetland) have limited application in karst terrain.

6-B.7.3. Discouraged Practices

Dry Extended Detention (ED) Ponds and Wet Ponds. The use of either Wet Ponds (Virginia Stormwater Design Specification No. 14) dry or ED Ponds (Virginia Stormwater Design Specification No. 15) is highly restricted in karst terrain because of frequent and recurring failures due to sinkhole formation.

The sealing of the solution channels in bedrock beneath stormwater basins can reduce seepage and soil displacement into underlying voids. Traditional sealing methods include compaction, clay blankets, bentonite treatment and flexible membrane liners. Methods traditionally used to reduce or eliminate excessive seepage from an impounded area may have limited success in limestone areas.

Sinkholes undermine the beneficial effects of basins on water quality by allowing introduction of untreated surface runoff directly to ground water. Thus, sinkholes "short-circuit" the hydraulic benefits of basins by allowing outlet structures to be bypassed.

Stormwater management basin sites can be evaluated and facilities designed and retrofitted to guard against sinkhole formation and improve water quality treatment performance. If a basin is used in a karst area, the following criteria should be applied:

- Minimize the amount of impervious cover on the site, in order to be able to minimize the size of the basin.

- Investigate soils and bedrock below the basin for the presence of voids. Repair existing voids and/or perform preventative grouting of the basin substrate.
- A minimum of 6 feet of unconsolidated soil material exists between the bottom of the basin and the top of the bedrock layer.
- Basin profiles should be broad and flat to allow the maximum dispersion of detained flow.
- Basin bottoms should be smooth, to avoid ponding.
- A liner is installed that meets the requirements outlined in **Table 6-B.6** below.
- Maximum temporary or permanent water elevations within basins do not exceed 6 feet.
- Inlet and outlet structures should be designed to provide diffuse discharge of water; avoid concentration of flows. Underdrains are preferred, in order to provide gradual discharge of water and avoid prolonged ponding of water.
- Maintenance inspections must be conducted at least annually (ideally, twice a year) to detect sinkhole formation. Sinkholes that develop should be reported immediately to local and state officials (see **Section 8.1**) and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority (see **Section 8**).

6-B.7.4. Prohibited Practices

Wet Swale. Wet Swales (Virginia Stormwater Design Specification No. 11), which are essentially linear wetlands, will often not work in karst terrain since the water table rarely reaches the land surface. (NOTE: In the Shenandoah Valley, numerous areas underlain by marl soils exist, indicating that many natural wet swales do exist in certain karst areas in Virginia. These areas result from the prolonged elevation of the water table above the land surface. If the soils are marly, a wet swale *may* be appropriate.)

Table 6-B.6. Required Groundwater Protection Liners for Ponds in Karst Terrain

Pond Position	Liner Material
The pond is excavated with at least 3 feet above bedrock	24 inches of soil with a maximum hydraulic conductivity of 1 x 10^{-5} cm/sec.
The pond is excavated within 3 feet of Bedrock	24 inches of clay [1] with a maximum hydraulic conductivity of 1 x 10^{-6} cm/sec.
The pond is excavated near bedrock within a wellhead protection area, in a recharge area for a domestic well or spring, or in an area with a high fracture density or significant geophysical anomalies	A synthetic liner with a minimum thickness of 60 mil
[1] Clay properties as follows: Plasticity Index of Clay = Not less than 15% (ASTM D-423/424) Liquid Limit of Clay = Not less than 30% (ASTM D-2216) Clay Particles Passing = Not less than 30% (ASTM D-422) Clay Compaction = 95% of standard proctor density (ASTM D-2216)	

Source: WVDEP (2006) and VA DCR (1999)

Large-Scale Infiltration. Large-scale Infiltration (see Virginia Stormwater Design Specification No. 8) is defined as individual practices that infiltrate runoff from a contributing drainage area with 20,000 to 100,000 square feet of impervious cover. These practices ***should not be used*** in karst terrain due to concerns about sinkhole formation and groundwater contamination. Micro-infiltration and small scale infiltration or bioretention are preferred stormwater management alternatives in karst terrain.

6-B.8.0. SINKHOLE REMEDIATION IN STORMWATER CONTROL MEASURES

Since karst terrain is so dynamic, there is always some risk that sinkholes will be created in the conveyance system or with E&S Control or Stormwater Management practices. This section outlines a four-step process of sinkhole remediation, involving notification, investigation, stabilization and final grading. This process has been loosely adapted from CCDP (2007). The choice of sinkhole remediation techniques is contingent on the scope of the perceived problem, the nature of contributing land uses, and the cost and availability of equipment and materials.

6-B.8.1. Sinkhole Notification

The existence of a new sinkhole within a temporary erosion control practice, road right of way or stormwater management practice must be reported to the local stormwater review authority within 24 hours or on the next business day. In the meantime, halt construction activities in the immediate area of the sinkhole and secure the area until it is stabilized. A plan for investigation and stabilization must be coordinated with the local regulatory authority, and repairs must commence immediately after receiving design approval. Until repairs are completed, a temporary berm must be constructed to divert surface flow away from the sinkhole. Having a registered professional engineer provide certify documentation of sinkhole repairs will provide assurance to the local review authority that the repairs are correctly designed and completed.

6-B.8.2. Sinkhole Investigation

The investigation phase should determine the areal extent and depth of the new sinkhole, as well as the depth of bedrock pinnacles upon which sinkhole stabilization will be founded. The investigation may involve visual inspection, excavation, borings and/or geophysical studies, as described below.

Visual inspection is generally used for smaller sinkholes (i.e., less than 10 feet in diameter) where the bedrock throat of a sinkhole is entirely visible from the ground surface.

Excavation by backhoe is commonly used for small to moderate-sized sinkholes (i.e., up to 20 feet in diameter) when the throat of the sinkhole is not visible from the ground surface. Track hoes, clam shells or other excavating equipment are typically used when soil depths exceed about 20 feet. The equipment is used to remove soil and fill from the sinkhole until the bedrock pinnacles and/or throat of the sinkhole are clearly visible.

As a safety measure prior to bringing in heavy equipment, a geophysical resistivity survey should be conducted in an attempt to determine if any very large subsurface voids exist. There are numerous documented instances of large equipment being swallowed by collapse of what appeared at the surface to be a small hole, but in the subsurface was actually a very large void.

Soil borings may be taken using augers, coring devices, air track or other boring equipment at larger sinkholes, particularly when more extensive sinkhole development is anticipated and/or critical foundation structures are at risk (e.g., bridge abutments, major roads, load bearing structures, etc.). This investigation involves a program of closely spaced borings to determine the location and depth of bedrock pinnacles, cavities and sinkhole throats.

Geophysical studies may be needed in conjunction with more intrusive methods to further delineate the scope of sinkhole dimensions, using techniques such as electromagnetic terrain conductivity, seismic refraction, or resistivity.

6-B.8.3. Sinkhole Stabilization

Stabilize reverse-graded backfilling, grouting, or subsurface engineering structures, as follows:

- ***Reverse-graded backfilling*** **(Figure 6-B.22** below**)** is generally applied to small and moderately-sized sinkholes. Once the throat of the sinkhole is fully excavated, it is filled with clean, interlocking rock material. The stone diameter of the initial fill layer must generally be one-half the diameter of the throat or cutter width. Once the initial fill layer is placed, progressively smaller diameter clean rock fill is layered above, up to or near the ground surface. Compaction of each layer of rock fill is essential. In general, at least three gradation sizes of fill are needed for adequate stabilization.
- ***Grouting*** **(Figure 6-B.23)** is generally discouraged, unless it is combined with the graded filter within moderate to large sinkholes. Borings are placed in the ground adjacent to the sinkhole and a concrete (grout) mix is injected by pressure or gravity into the subsurface until the throat is sealed. Grouting may be used to remediate small diameter voids, such as test borings or abandoned wells.

Figure 6-B.22. Sinkhole Remediation

Figure 6-B.23. Grouting a Sinkhole

Engineered ***subsurface structures*** are used on larger sinkholes or where concentrated load-bearing structures are present. The technique involves creating a bridge between bedrock pinnacles to form a stable base, above which appropriate fill and construction may be completed.

The type of repair chosen for any sinkhole depends on its location, the extent and size of the void, and the type of infrastructure planned for the sinkhole area. Sinkhole sealing methods can include the use of available on-site materials, dry or wet grout, filter material, and geotextiles. A good general engineering specification for sinkhole repair is included in Virginia Department of Transportation *Instructional and Informational Memorandum 228: Sinkholes – Guidelines for the Discharge of Stormwater at Sinkholes*:

(http://www.virginiadot.org/business/resources/IIM228.pdf)

6-B.8.4. Final Grading

In order to provide permanent stabilization and prevent groundwater contamination, final grading at the repaired sinkhole must be completed to avoid excess infiltration from the ground surface. The final grading should include placement of low permeability topsoil or clay and a vegetative cover. A positive grade should also be maintained away from the sinkhole to avoid local ponding or infiltration. However, this is not always possible if the sinkhole forms within the stormwater conveyance system or a centralized pond.

6-B.9.0. ACKNOWLEDGEMENTS

An informal working group of karst experts, stormwater practitioners and state and federal regulators, organized by the Chesapeake Stormwater Network, reviewed and contributed to the technical bulletin from which this Appendix was adapted. Special thanks are extended to Chris Anderson (Page County, VA), Twila Carr, Alana Hartman and Sherry Wilkins (West Virginia DEP), Bob Denton (Potomac Environmental Services) Tom Devilbiss (Carroll County, MD), Mike Eller (EPA Region 3), Jim Lawrence (VA Tech), Wil Orndorff (Virginia DCR), Michael Schwartz (Freshwater Institute), and Wayne Webb (Winchester, VA).

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6-B.11.0. KARST-RELATED RESOURCES FOR VIRGINIA

6-B.11.1. Virginia Resources

USGS Geologic Quadrangles. http://www.usgs.gov/pubprod/

Virginia Department of Conservation and Recreation Karst Program:

- Conservation sites for Virginia's Significant Caves
- Karst Hydrology Atlas
- Statewide Karst Bedrock Coverage
- Access available to areas of interest by request; contact Karst Program staff at 540-394-2552.

Virginia DCR Karst Program Staff:
Wil Orndorff
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8 Radford Street, Suite 201
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(540) 394-2552 (v)
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Virginia Cave Board
Virginia Division of Natural Heritage
Department of Conservation and Recreation
217 Governor Street, 3rd Floor
Richmond, VA 23219
http://www.dcr.virginia.gov/natural_heritage/cavehome.shtml
phone: (804) 786-7951
fax: (804) 371-2674
larry.smith@dcr.virginia.gov

Virginia Department of Mines, Minerals and Energy, Division of Mineral Resources:

- https://www.dmme.virginia.gov/commerce/
- Geologic Quadrangle Maps and Digital Data
- Karst Feature Maps
- Publications 44, 83, and 167
- Local Karst Maps
- Publications 102 (Clarke County) and 070 (Giles County)

Virginia DEQ Ground Water Characterization Program:
http://www.deq.virginia.gov/gwcharacterization/
Joel P. Maynard (Valley and Ridge contact)
4411 Early Road
P.O. Box 3000
Harrisonburg, VA 22801
Phone: (540) 574-7864
jpmaynard@deq.virginia.gov

6-B.11.2. Regional and National Resources

Digital Engineering Aspects of Karst Map: A GIS Version of Davies, W.E., Simpson, J.H., Ohlmacher, G.C., Kirk, W.S., and Newton, E.G. 1984. *Engineering Aspects of Ka*rst: U.S. Geological Survey, National Atlas of the United States of America, Scale 1:7,500,000.

http://pubs.usgs.gov/of/2004/1352/

Preliminary Map of Potentially Karstic Carbonate Rocks in the Central and Southern Appalachian States. 2008. D.J. Weary. Scale 1:250,000.

http://pubs.usgs.gov/of/2008/1154/

Geologic Framework of the Northern Shenandoah Valley Carbonate Aquifer System (in progress). Harlow, G., D. Nelms, M. Kozar. Scale 1:24,000.

http://geology.er.usgs.gov/eespteam/Karst/tasks/Shenandoah/shenandoah.htm

Digital Geologic Map and Database of the Frederick 30 x 60 Minute Quadrangle, Maryland, Virginia, and West Virginia. 2002. Scott Southworth, David K. Brezinski, Avery Ala Drake, Jr., William C. Burton, Randall C. Orndorff, and Albert J. Froelich. U.S. Geological Survey Open-File Report 02-437. Scale 1:100,000. Also includes 1:24,000 maps of certain quadrangles.

http://pubs.usgs.gov/of/2002/of02-437/

6-B.11.3. Other Karst Resources

Karst Environmental Education and Protection (KEEP): http://keepinc.org.

Karst Information Portal: www.karstportal.org.

National Cave and Karst Research Institute, 1400 Commerce Drive, Box 4, Carlsbad , NM 88220, USA. Email: gveni@nckri.org. Phone: (575) 887-5517.

Appendix 6-C

Stormwater Design in the Coastal Plain of Virginia

Adapted from CSN Technical Bulletin No. 2
Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed
(Ver. 1.0: May 1, 2009)
Developed by the CSN Coastal Plain Working Group

Appendix 6-C

Stormwater Design in the Coastal Plain of Virginia

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6-C.1.0. WHY THE COASTAL PLAIN IS DIFFERENT?

Most stormwater practices were originally developed in the Piedmont physiographic region and have not been adapted for much different conditions in the coastal plain. Consequently, much of the available stormwater design guidance is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, deeper groundwater table, low wetland density, and well drained soils.

By contrast, stormwater design in the mid-Atlantic coastal plain is strongly influenced by unique physical constraints, pollutants of concern and resource sensitivity of the coastal waters. Implementation of traditional stormwater practices in the coastal plain is severely constrained by physical factors such as flat terrain, high water table, altered drainage, extensive groundwater interactions, poorly-drained soils and extensive wetland complexes. The significance of these constraints is described below.

Flat Terrain. The most notable feature of the coastal plain is its uniformly flat terrain which creates several watershed planning and site design challenges. The low relief makes it possible to develop land without regard to topography. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces the hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes for which the region is especially prone.

High Water Table. In much of the coastal plain, the water table exists within a few feet of the surface (**Figure 6-C.1**). This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater control practices.

Figure 6-C.1. Coastal Plain Water Table
Source: Chesapeake Bay Stormwater Training Partnership (CBSTP)

Highly Altered Drainage. The coastal plain stream network has been severely altered by 300 years of ditching, channelization, agricultural drainage and mosquito control. The headwater stream network in many coastal plain watersheds no longer exists as a natural system, with most zero order, first order, and second order streams replaced by ditches, canals and roadway drainage.

Poorly Drained Soils. Portions of the coastal plain have soils that are poorly drained and frequently do not allow infiltration to occur. As a result, the coastal plain watersheds contain extensive wetland complexes and have a greater density of wetlands than any other physiographic region in the country (Dahl, 2006). Wetland cover exceeds 25% of many coastal plain watersheds, which exceeds the national average of 7% (Dahl, 2006).

Very Well-Drained Soils. In other parts of the coastal plain, particularly near the coast line, soils are sandy and extremely permeable, with infiltration rates exceeding four inches per hour or more. While these soils are exceptionally good for infiltrating stormwater runoff and promoting recharge, there is a stronger risk of stormwater pollutants rapidly migrating into groundwater. This is a particular design concern, given the strong reliance on groundwater for drinking water supply (discussed next).

Drinking Water Wells, Septic Systems. A notable aspect of the coastal plain is a strong reliance on public or private wells to provide drinking water (USGS, 2006). As a result, ***designers need to consider groundwater protection as a first priority*** when they are considering how to dispose of stormwater. At the same time, development in the coastal plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to be careful in how they manage and dispose of stormwater, so they do not reduce the effectiveness of adjacent septic systems.

Conversion of Croplands with Land Application**.** Land application of animal manure and domestic wastewater on croplands is a widespread practice across the coastal plain. When this farmland is converted to land development, there is a strong concern that infiltration through nutrient enriched soils may actually increase nutrient export from the site.

Pollutants of Concern- Watershed managers in the Piedmont have historically focused on phosphorus control, which is frequently a limiting nutrient for fresh waters but seldom for coastal waters. By contrast, the key pollutants of concern in coastal plain watersheds are nitrogen, bacteria and metals. These pollutants have greater ability to degrade the quality of unique coastal plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control. The design and engineering of stormwater practices need to be greatly modified to achieve greater reductions in nitrogen, bacteria and metals to improve coastal water quality.

Unique Development Patterns. The development patterns of coastal plain watersheds are also unique, with development concentrated around waterfronts, water features and golf courses rather than around an urban core. The demand for vacation rental, second home and retirement properties also contributes to sprawl-type development.

Shoreline Buffers and Critical Areas. Virginia has special land use criteria for locally designated coastline and river-edge resource lands in the coastal plain, known as the Chesapeake Bay Preservation Areas (CBPAs). They regulations applicable to CBPAs strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within CBPAs must rely on micro-scale stormwater control practices to comply with the special state and local requirements.

The Highway as the Receiving System. The stormwater conveyance system for much of the coastal plain is frequently tied to the highway ditch system, which is often the low point in the coastal plain drainage network. New upland developments often must get approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The prominence of the highway drainage network in the coastal plain has several implications, the greatest of these is that designers have to obtain both a local government and VDOT approval for their project, which often results in conflicting design requirements.

Sea Level Rise. Another unique aspect of the tidal waters of the coastal plain is the forecasted rise in sea level over the next 30 to 50 years as a result of land subsidence and climate change. The consensus (conservative) predictions are for sea level in the Chesapeake Bay to rise at least a foot in the coming decades, and perhaps two feet by the end of the century. This large change in average and storm elevations in the transition zone between tidal waters and the shoreline development only a few feet above it has design implications for the choosing where to discharge treated stormwater.

Hurricanes and Flooding**.** Coastal communities face unique challenges when it comes to handling flooding events. First, due to their location on the coast, they are subject to rainfall intensities that are 10% to 20% greater for the same design storm event compared to sites further inland. Second, the flat terrain lacks enough hydraulic head to quickly move water out of the conveyance system (which may be further complicated by backwater effects of tidal surges). Additionally, large tidal surges may cause significant flooding with no precipitation present (see **Figure 6-C.2** below).

6-C.2.0. GENERAL COASTAL PLAIN STORMWATER DESIGN PRINCIPLES

The following initial guiding principles are offered on the design of stormwater practices in the coastal plain:

- Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.
- Exploit opportunities for upland runoff reduction prior to using end of channel/pipe practices such as wet ponds, and incorporate essential coastal plain design features within any ponds employed.
- Keep all stormwater practices out of the riparian buffer area, except for the use of conservation filters at their outer boundary.

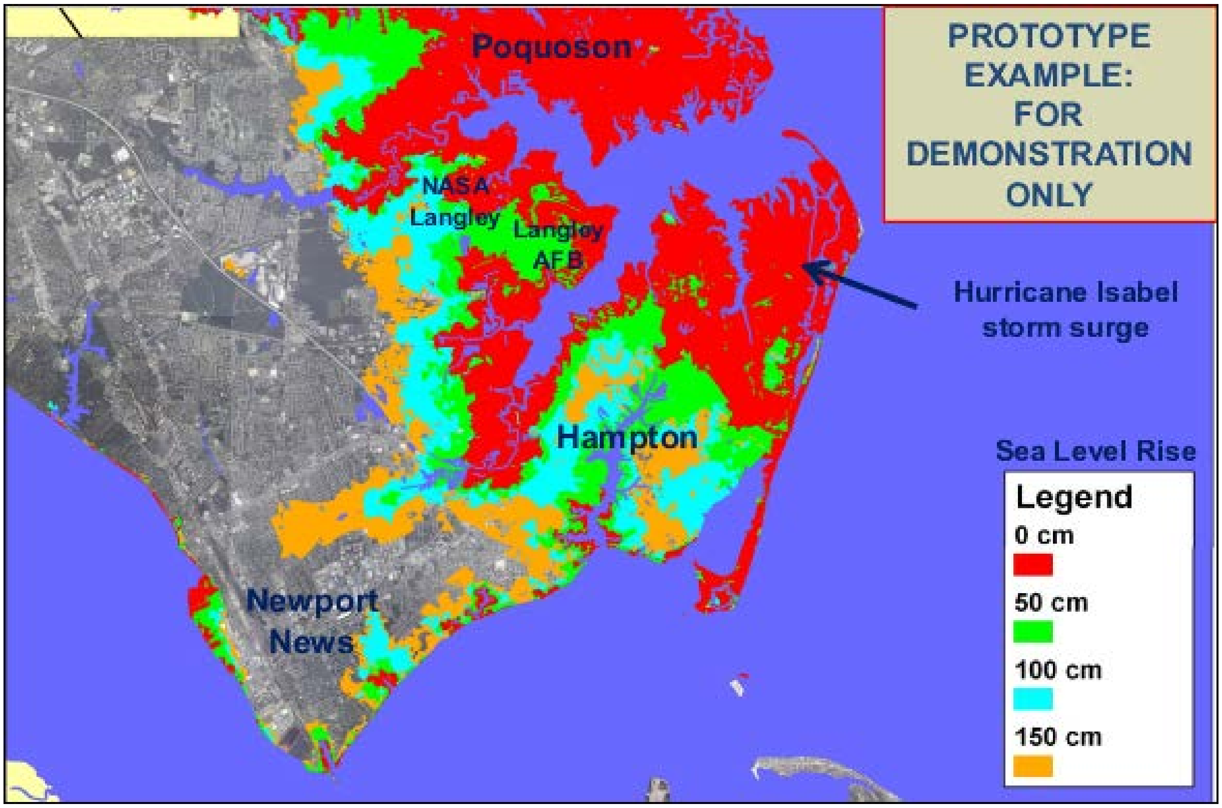

Figure 6-C.2. Hurricane Flood Prediction Model with Reference to Potential Sea Level Rise

Source: Virginia Institute of Marine Science and Noblis, Inc.

- Relax some design criteria to keep practice depths shallow and respect the water table.
- Emphasize design factors that can increase bacteria removal (and certainly not exacerbate bacteria problems).
- Promote de-nitrification to maximize nitrogen removal, by creating adjacent anaerobic and aerobic zones adjacent to one another in either the vertical or lateral direction.
- Use plant species that reflect the native coastal plain plant community and, in particular, can survive well in a high salinity environment.
- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of in-line treatment in the swale and ditch system.
- Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to utilize site design to “raise the bridge” by increasing the vertical elevation of building pads at coastal plain development sites.

6-C.3.0. SIZING STORMWATER PRACTICES IN THE COASTAL PLAIN

The following factors influence the sizing of stormwater practices in the coastal plain.

6-C.3.1. Higher Coastal Plain Nutrient Concentrations on Stormwater Runoff

A recent data analysis indicates there is a strong statistical difference in the nutrient concentrations between the coastal plain and piedmont physiographic regions in Virginia. Hirschman et al (2008) analyzed more than 753 storm events and found that median event concentrations of nutrients are 15% to 25% higher in the coastal plain, as compared to the piedmont (see **Table 6-C.1**). The reason for the higher nutrient concentrations is unclear, but it may be related to the greater stormwater-groundwater interaction that occurs, along with possible soil nutrient enrichment due to land application and septic system leachate.

Table 6-C.1. Comparison of Nutrient Storm Event Mean Concentrations in the Virginia Piedmont versus Coastal Plain (N=753 storm events)

Nutrients	Coastal Plain	Piedmont
Total Nitrogen [1]	2.13 mg/l	1.70 mg/l
Total Phosphorus	0.27 mg/l	0.22 mg/l
[1] The EMC for residential TN in Coastal plain is 2.96 mg/l		

Source: Appendix G of Hirschman et al 2008

6-C.3.2. Greater Water Quality Storm Events

Rainfall intensities are consistently greater in the coastal plain than in the piedmont. Rainfall Frequency Spectrum Analyses (RFSA) were conducted at numerous weather stations in Maryland to statistically determine the 90% storm event that defines the water quality volume (MDE, 2000). The analysis determined that while the 90% storm was 1.0 inch or less in the Piedmont stations and further west, it ranged from 1.1 to 1.2 inches in the coastal plain, with the greatest values near the coast.

Virginia had the Center for Watershed Protection conduct RFSAs at five locations around the Commonwealth (Abingdon, Lynchburg, near Harrisonburg, Richmond, and Reagan International Airport in Northern Virginia) in order to determine the variation in rainfall and establish a 90th percentile rainfall event for regulatory purposes. However, the study neglected to include a Tidewater location. The average result was 1.14 inches of rainfall. The Department decided to round that number down to the 1-inch rainfall and establish that as the statewide water quality design storm event. However, pursuant to the Virginia Stormwater Management Act, local governments are authorized to establish more stringent regulatory criteria. For example, a locality with a higher 90th percentile storm event (e.g., 1.2 inches) could establish that as the local water quality storm event, based on a localized or regional RFSA. The Virginia Runoff Reduction Method spreadsheet could be adapted to reflect the local rainfall amount.

6-C.3.3. Channel Protection Exemption?

Another key issue, subject to some debate, relates to whether a channel protection volume is needed to protect coastal plain stream channels from erosion. The 2000 *Maryland Stormwater Design Manual* contained two specific exemptions from channel protection for portions of the coastal plain: (a) the entire Eastern Shore of Maryland and (b) any direct discharges or outfalls to tidal waters. The Virginia Stormwater Management Regulations do not contain any specific exemptions for the coastal plain, and the stormwater regulations proposed by the Delaware Department of Natural Resources and Environmental Control *require* channel protection for coastal plain streams. While the tidal outfall exemption is reasonable, ***the growing body of geomorphic research on coastal plain streams strongly suggests that they should not automatically be exempted from channel protection***.

6-C.3.4. The Prevalence of Wet Ponds

Figure 6-C.3. Wet Pond

Wet ponds (**Figure 6-C.3**) are extremely popular in coastal plain communities, since excavated sediments can be used for fill elsewhere in the site, and the pond can also be used to temporarily store floodwater from larger design storm events. According to a major survey by Law (2008), wet ponds were the most common stormwater practice used in the coastal plain, with 81% of communities reporting their use. In some tidewater communities with high water tables, such as Newport News, VA, wet ponds treat 80% of the total land area to which stormwater practices are applied.

Since most coastal wet ponds are excavated well below the water table, they are strongly influenced by groundwater. Recent research profiled in **Section 6.0** of this Appendix indicates that coastal plain “dug-out wet ponds” have diminished nutrient removal capability (particularly for nitrogen) and extremely low rates of annual runoff volume reduction. In addition, under certain conditions, coastal plain wet ponds can create stagnant water nuisance conditions (including harmful algal blooms, mosquito breeding, etc.). Field studies have also revealed that many coastal plain wet ponds are frequently installed without the design features necessary to ensure their effective function.

6-C.3.5. Comparative Reduction of Runoff, Nitrogen and Bacteria

As noted earlier, the pollutants of concern in the coastal plain tend to be slightly different, which has a strong influence on the selection of stormwater practices. **Table 6-C.2** presents the most recent estimates of the runoff volume reduction, nitrogen removal and bacterial removal rates for the 15 classes of non-proprietary stormwater control practices approved by the Department. As can be seen, there is significant variability in the capability of different classes of stormwater control practices to reduce runoff and provide nitrogen or bacteria reduction. It is worth noting that while there a wide range of studies examining nitrogen EMC reduction rates of BMPs, relatively few have been conducted in the coastal plain. The situation is even worse for bacteria, where the actual data on *f. coli* or *e. coli* removal is sparse for all physiographic regions (Schueler, 2000 and 2007).

Table 6-C.2 Comparative Runoff Reduction, Nitrogen and Bacteria Removal

Practice	Annual Runoff Reduction (%) [1]	Nitrogen EMC Removal (%) [2]	Bacteria Removal [3]
Constructed Wetland	0	25 to 55 [4]	60
Bioretention	40 to 80	40 to 50	40*
Rain Tank/Cistern	15 to 45 [5]	0	NA
Wet Swale	0	25 to 35	0
Dry Swale	40 to 60	25 to 35	25*
Rooftop Disconnection	25 to 50	0	NA [6]
Permeable Pavers	45 to 75	25	ND [7]
Filter Strips	25 to 50	15	20*
Sand Filters	0	30 to 45	40
Infiltration	50 to 90	15	40*
Urban Bioretention	40	40	40*
Compost Amendments	25 to 50	0	NA
Green Roofs	45 to 60	0	NA
Wet Ponds	0	30 to 40	70
Dry ED Ponds	0 to 15	10	35
Grass Channel	10 to 20	20	-25

[1] Annual average runoff reduction as reported in Hirschman et al (2008)

[2] Change in stormwater event mean concentration (EMC) as it flows through the practice, as reported In CWP (2008). Total mass reduction is product of EMC reduction and runoff reduction.

[3] Bacteria removal rates as reported by Schueler et al, 2007. An asterisk denotes where monitoring Data is limited, and estimates should be considered extremely provisional.

[4] Where a range of numbers are shown in the cell, this refers to the Level 1/Level 2 design features as outlined in Hirschman et al. (2008).

[5] Runoff reduction can be increased if rain tanks are coupled with a secondary runoff reduction Practice (rain garden, filter path or front-yard retention).

[6] NA indicates the practice is not designed for bacterial removal or is located far up in treatment pathway such that bacteria source areas are largely absent (e.g., green roofs and cisterns)

[7] ND means no data is available.

In some cases, practices such as grass channels or ditches have been found to have low or negative rates for bacteria removal (Mallin et al, 2001). Given the limited bacteria data, the numbers shown in **Table 6-C.2** should be considered provisional, and designers should maximize the following design factors to enhance bacteria removal (adapted from Schueler, 2000):

- Create high light conditions to promote UV in areas of standing water.
- Design to prevent re-suspension of bottom sediments in treatment systems.

- Choose vegetation other than turf around ponds and wetlands to make access more difficult for geese and waterfowl.
- Use shallow wetlands and benches to create natural micro-predators for bacteria. However, at least a portion of the wetland area should be deep enough to avoid freezing in winter. Furthermore, the wetland surface should be exposed enough to result in high enough water temperatures in the summer to become anaerobic.
- Add a layer of organic matter into sand filter media.
- Avoid the use of grass channels (dry or wet swales are preferred).
- Maximize infiltration and filtration of runoff through soils.
- Maintain specified setbacks to prevent interaction of stormwater and septic drainfields and, if possible, connect household waste discharges to the local sanitary sewer and wastewater treatment plant.
- Use Vegetated Filter Strips at the edge of riparian buffer areas.
- Address all bacteria source areas.

6-C.3.6. Hotspot Concerns in the Coastal Plain

Stormwater hotspots are operations or activities that are known to produce higher concentrations of runoff pollutants and/or have a greater risk for spills, leaks or illicit discharges. Given that many portions of the coastal plain rely on groundwater as a primary source of drinking water, it is important to take steps to minimize the risk of groundwater contamination by polluted stormwater. A list of potential land uses or operations that may be designated as a stormwater hotspot is provided in the Virginia Stormwater Design Specification No. 8 (Infiltration).

Communities should carefully review development proposals to determine if any future activity on all or a portion of the site is likely to be designated as a stormwater hotspot. If so, stormwater treatment and pollution prevention practices must then be implemented at the hotspot to prevent contamination of surface or groundwater, particularly if it discharges to a drinking water source. Depending on the toxicity of the hotspot discharge, one or more of the following management strategies may be required:

- ***Stormwater Pollution Prevention Plan (SWPPP).*** This plan is required as part of an industrial, municipal, or general construction stormwater permit, and it outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site.
- ***Restricted Infiltration.*** A minimum of 50% of the total Treatment Volume must be treated by a filtering or bioretention practice prior to allowing any infiltration to occur. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an acceptable stormwater control practice.
- ***Infiltration Prohibition.*** The risk of groundwater contamination from spills, leaks or discharges is so great at hotspot sites that infiltration of stormwater runoff is ***prohibited.*** In these cases, an alternative stormwater control practice such as a closed bioretention area, sand filter or constructed wetland must be used to filter runoff before it reaches surface or groundwater.

6-C.3.7. Altered Drainage Systems

When designing stormwater management systems in the Coastal Plain, it is important to recognize that the original drainage patterns in a given watershed may have been significantly altered through stream channelization and/or the creation of constructed storm drainage systems (**Figure 6-C.4**). Thus, not only is much of the original surface storage lost, but the drainage network is much more hydraulically "efficient," as compared to a more natural wetland/stream system. In addition, most constructed drainage systems have been designed to prevent crop damage from standing water, not as conveyance systems based on a specific storm frequency. For example, it has been estimated that the typical constructed drainage channel in Delaware's Coastal Plain only has the capacity to convey the runoff from a 1-year to 2-year storm event under *pre-development conditions*. Further exacerbating this situation is the fact that there is typically no defined floodplain in the lower coastal plain to contain flows that exceed the capacity of these drainage channels.

Figure 6-C.4. Channelized Section of Four Mile Run, Fairfax County, VA.

Since local jurisdictions have not traditionally treated these constructed channels the same as natural streams, they often do not have floodplain ordinances or other controls in place to prevent potential impacts to adjacent properties under historic development patterns. Therefore, watersheds having a large percentage of altered drainage systems may require relatively stringent over-management techniques if adequate runoff reduction methods are not feasible. In cases where regulatory floodplains have not been established, one option for new development would be to provide adequate lot-free open space adjacent to altered drainage systems to accommodate out-of-bank flooding occurrences. Although it may not be feasible to extend the limits of this open space to accommodate the 100-year storm event, it seems reasonable to accommodate at least the 10-year storm in order to minimize the impacts of more frequent flooding events.

6-C.3.8. Discharges to Wetlands

Recent research has clearly shown that, even at extremely low levels of land development, direct and indirect stormwater discharges can have a deleterious impact on sensitive streams and wetlands (Wright et al 2007, Cappiella et al 2006). Consequently, a greater level of protection is needed to safeguard these important ecosystems from stormwater discharges, as follows:

- Define a series of sensitive wetland types that merit special protection (e.g., bogs, fens and others – see Wright et al, 2007).
- Explicitly prohibit the use of natural wetlands to provide stormwater treatment of any kind.
- Require full runoff volume reduction up to the amount of the Channel Protection Volume prior to discharge to a sensitive wetland down-gradient from the development site.
- Require modeling and monitoring analyses to confirm that no changes occur in the post-development hydroperiod in sensitive wetlands, which is operationally defined as no more than 6 inches of additional water level fluctuation for a 1-inch rainfall event.

6-C.4.0. APPLICABLE STORMWATER TREATMENT PRACTICES

This section evaluates the comparative applicability of the range of potential non-proprietary stormwater control practices, and classifies them as preferred, acceptable or restricted, as shown in **Table 6-C.3**.

Table 6-C.3. Comparison of the Applicability of Stormwater Practices for Coastal Plain

Stormwater Control Practice	Suitability for the Coastal Plain	Virginia Design Spec No.	Design and Implementation Notes
Rooftop Disconnection	Preferred	**1**	Via front-yard bioretention
Sheet Flow to Vegetated Filter Strips and Conserved Open Space	Preferred	**2**	Conservation filters to stream or shoreline buffers
Rainwater Harvesting	Preferred	**6**	Use above-ground tanks
Shallow Dry Swale	Preferred	**10**	Relaxed filter bed and water table depths; conduct soil nutrient testing
Wet Swale	Preferred	**11**	Can use on-line and off-line cells
Constructed Wetland	Preferred	**13**	Use shallow, linear, multiple-cell designs
Permeable Pavement	Acceptable	**7**	Use an underdrain when the infiltration rate is low or the water table is high
Shallow Bioretention	Acceptable	**9**	Relaxed filter bed and water table depths; conduct soil nutrient testing
Soil Compost Amendments	Acceptable	**4**	For B.C, and D soils, must be at least 2 feet above the water table
Green Roofs	Acceptable	**5**	Use coastal vegetation species selection
Small Scale Infiltration	Acceptable	**8**	Use wide and shallow designs; max. contributing drainage area is 20,000 sq. ft. of impervious cover
Urban Bioretention	Acceptable	**9a**	Use curb extensions, foundation planters and tree pits
Filtering Practices	Acceptable	**12**	Perimeter or non-structural sand filters are the most practical options
Wet Pond	Acceptable	**14**	See **Section 6** of this Appendix
Grass Channel	Restricted	**3**	Achieves poor bacteria removal
Large Scale Infiltration	Restricted	**8**	Depends on the soil infiltration rate and the nutrient composition in the soil
Dry Ext. Detention Pond	Restricted	**15**	Constrained by min. hydraulic head rqmts

6-C.5.0. SPECIFIC COASTAL PLAIN DESIGN CRITERIA FOR STORMWATER CONTROL PRACTICES

The ensuing discussion highlights some possible design adaptation for the coastal plain, and should be considered a starting point and not an ending point

6-C.5.1. Criteria for *Preferred* Stormwater Control Measures

These stormwater practices possess two properties: (1) they are widely feasible at most development sites in the coastal plain (with some design adaptations), and (2) they have a high rate of runoff volume reduction and/or a strong capability to remove pollutants of concern in the coastal plain (e.g., nitrogen, bacteria, etc.).

Rooftop Disconnection. Rooftop disconnection is strongly recommended for all residential lots with areas of less than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. (See Virginia Stormwater Design Specification No. 1 for the four primary micro-practice options.) The disconnection corridor should have a minimum slope of 1% and 2 feet of vertical separation to the water table.

Sheet Flow to Vegetated Filter Strips and Conserved Open Space. The use of conservation filter strips is highly recommended in the coastal plain, particularly when runoff discharges to the outer boundary of the shoreline, stream or wetland buffer, either as sheet flow or a concentrated discharge. Grass filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). However, in both cases the water table must be at lest 18 inches below the ground surface, Depending on surface flow conditions, the filter strip must have a gravel diaphragm, a pervious berm or an engineered level spreader conforming to the new requirements outlined in Virginia Stormwater Design Specification No. 2.

Rainwater Harvesting (Virginia Stormwater Design Specification No. 6)**.**

- In the coastal plain, above ground tank designs are preferred to below ground tanks**.**
- Tanks should be combined with automated irrigation, front yard bioretention or other secondary practices to maximize runoff volume reduction.

Permeable Pavement. Experience in North Carolina has shown that properly designed and installed Permeable Pavement systems (Virginia Stormwater Design Specification No. 7) can work effectively in the demanding conditions of the coastal plain, as long as underlying soils are moderately to highly permeable.

- Designers should avoid the use of non-underdrain permeable pavement systems at stormwater hotspot facilities and in areas known to provide groundwater recharge to any aquifer used as a water supply.
- Designers should ensure that the vertical distance from the bottom of the permeable pavement system to the top of the water table is at least 2 feet.

- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure positive drainage.
- In order to avoid clogging, avoid using permeable pavement if the site will be exposed to blowing sand (i.e., near coastal sand dunes).

Bioretention. Either the Level 1 (underdrain) or Level 2 (infiltration) design can be used for bioretention, depending on soil permeability and local water table conditions. The following design adaptations can help make bioretention work better in the coastal plain:

- A linear approach to bioretention – using multiple cells leading to the ditch system – helps conserve hydraulic head.
- The minimum depth of the filter bed can be relaxed to from 18 to 20 inches if hydraulic head or high water table issues exist.
- Bioretention media should be secured from an approved vendor to ensure nutrient content of the soil and compost are within acceptable limits. The use of on-site soils in the coastal plain is discouraged due to their probable nutrient enrichment, unless soil tests have been performed and show otherwise.
- To reduce the vertical footprint, (1) to limit surface ponding to from 6 to 9 inches, and (2) save additional depth by shifting to turf rather than a mulch cover.
- The minimum depth from the bottom of the bioretention practice to the seasonally high groundwater table may be as little as 1 foot, as long as the bioretention area is equipped with a large diameter underdrain (e.g., 6 inches in diameter) that is only partially efficient at dewatering the bioretention bed.
- It is important to maintain a slope of at least 0.5% for the underdrain to ensure positive drainage, and connect the underdrain to a ditch or the conveyance system.
- The mix of plant species selected should reflect native coastal plain plant communities and should be more wet-footed and salt tolerant than for typical Piedmont applications. See Virginia Stormwater Design Specification No. 9 for a list of plant species suitable for use in coastal bioretention practices.

Dry Swale. Dry Swales (Virginia Stormwater Design Specification No. 10) work well at many coastal plain sites, but they require several design adaptations to improve their feasibility and performance, consistent with the following:

- The minimum depth of the filter bed may be relaxed to from 18 to 20 inches, if hydraulic head or high water table conditions issues exist.
- The minimum depth to the seasonally high water table can be reduced to one foot, as long as the Dry Swale area is equipped with an underdrain
- It is important to maintain a slope of at least 0.5% for the underdrain to ensure positive drainage, and connect the underdrain to a ditch or the conveyance system.
- Designers should not try to apply Dry Swales to marginal sites, where wet swales or linear wetlands would work better (e.g., where the groundwater table is less than 30 inches below the swale invert).

Wet Swales. Wet Swales (Virginia Stormwater Design Specification No. 11), essentially linear wetlands consisting of a series of on-line or off-line storage cells, work well in areas with a high water table. Designers should design cells such that underlying soils are typically saturated but do not cause standing water between storm events. It may also be advisable to incorporate sand or compost into the surface soils to promote a better growing environment. Wet swales should be planted with native wet-footed species, such as sedges or wet meadows. Wet swales are not recommended in residential areas due to concerns about mosquito breeding.

Constructed Wetlands. Constructed Wetlands (Virginia Stormwater Design Specification No. 13) are an ideal stormwater control measure for the flat terrain, low hydraulic head and high water table conditions found at many coastal plain development sites. The following design adaptations can make them more effective:

- Shallow, linear and multiple-cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the extended detention wetland have *limited application* in the coastal plain.
- It is acceptable to excavate up to 6 inches below the seasonally high groundwater table to provide the requisite hydrology for wetland planting zones, and up to 3 feet below the water table for micropools, forebays and other deep pool features.
- The volume below the seasonably high water table is acceptable for the Treatment Volume, as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path, microtopography, etc.).
- Plant selection should focus on native species that are wet-footed and can tolerate some salinity.
- A greater range of coastal plain tree species can tolerate periodic inundation, so designers should consider creating forested wetlands, using species such as Atlantic White Cedar, Bald Cypress and Swamp Tupelo.
- The use of flashboard risers is recommended to control or adjust water elevations in wetlands constructed on flat terrain.
- The regenerative conveyance system is particularly suited for coastal plain situations where there is a significant drop in elevation from the channel to the outfall location (see Virginia Stormwater Design Specification No. 11: Wet Swale).

6-C.5.2. Criteria for *Acceptable* Stormwater Control Measures

This group of stormwater control measures can work at many sites in the coastal plain, but they either require major design adaptations or have a low-to-moderate capability to reduce the coastal pollutants of concern.

Soil Compost Amendments. Designers should evaluate drainage and water table elevations to ensure the entire depth of incorporated Soil Compost Amendments (Virginia Stormwater Design Specification No. 4) will not become saturated (i.e., maintain a minimum separation depth of 2 feet from the seasonally high groundwater table). Compost amendments are most cost effective when used to boost the runoff reduction capability of grass filter strips, grass channels and areas receiving runoff from rooftop disconnections.

Vegetated Roofs. Vegetated Roofs (Virginia Stormwater Design Specification No. 5) may be used in the coastal plain, but their effectiveness is somewhat limited since rooftops are not a major runoff source area for nutrients or bacteria, the key coastal plain pollutants of concern. Designers should consult with a qualified botanist or landscape architect to choose the most appropriate plant material, such as indigenous varieties of grass and *sedum* species, that can tolerate drought and salt spray.

***Small-Scale Infiltration*.** The **c**oastal plain is an acceptable environment for micro-infiltration and small-scale infiltration practices (Virginia Stormwater Design Specification No. 8), particularly if designers choose to infiltrate less than the full Treatment Volume in a single practice (and use secondary practices to achieve the remaining runoff reduction or treat the remaining volume). Some other design modifications for small scale infiltration in the coastal plain include the following:

- Designers should maximize the surface area of the infiltration practice, and keep the depth of infiltration to less than 24 inches.
- Where soils are extremely permeable (more than 4 inches per hour), shallow bioretention is a preferred alternative.
- Where soils are more impermeable (i.e., marine clays with permeability of less than 0.5 inches/hour), designers should probably shift to the use of bioretention *with underdrains*.
- The minimum depth to the water table should be kept to at least 2 feet.

Urban Bioretention. Three forms of bioretention for highly urban areas can work acceptably within the coastal plain – (1) stormwater curb extensions, (2) expanded tree planters, and (3) foundation planters – particularly when above-ground design variants are used (see Appendix A of Virginia Stormwater Design Specification No. 9). The general coastal plain design modifications for regular bioretention should also be consulted (see Virginia Stormwater Design Specification No. 9).

***Filtering Practices*.** The flat terrain, low hydraulic head and high groundwater table of the coastal plain make several of the filter designs (Virginia Stormwater Design Specification No. 12) difficult to implement. However, the perimeter sand filter and the non-structural sand filter have the least hydraulic head requirements and can work effectively at many small coastal plain sites, when the following design adaptations are made:

- The combined depth of the underdrain and sand filter bed may be reduced to from 24 to 30 inches.
- Designers may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells.
- The minimum depth to the seasonally high water table may be reduced to 12 inches, as long as the filter is equipped with a large diameter underdrain (e.g., 6 inches in diameter) that can de-water the bed if the groundwater mounds up.
- It is important for the underdrain to (1) have at least a 0.5% slope to ensure positive drainage and (2) be connected to the ditch or stormwater drainage system.

***Wet Ponds*.** A major research review, which is provided in **Section 6** of this Appendix, was conducted to verify the performance of Wet Ponds (Virginia Stormwater Design Specification No. 14) in the coastal plain. The following are the key findings:

- Expected nutrient removal rates are slightly reduced in the coastal plain, due to the influence of groundwater.
- Certain design features are essential to achieving optimal nutrient removal rates (e.g., multiple cells, benches, flow path, etc.).
- Additional design features (e.g., pond landscaping, bubblers/floating islands, etc.) could improve pollutant removal functions.
- Wet ponds could produce and or export harmful algal blooms if they interact with brackish groundwater or surface waters.

Consequently, special design recommendations are proposed for coastal plain wet ponds, as outlined in **Table 6-C.4** below. Where land is available, shallow constructed wetlands are a preferred over wet ponds in coastal plain environments with high water tables.

Table 6-C.4. Level 1 and 2 Wet Pond Design Guidance: Coastal Plain

Level 1 Design (RR:0 [1]; TP:45; TN:20)	Level 2 Design (RR:0; TP:65; TN:30)
T_v = (1.0) (Rv) (A) / 12	T_v = 1.5 (Rv) (A) / 12
Single pond cell (with a forebay)	Wet extended detention [2] or multiple-cell design [3]
Flow path = 1:1 or more [4]	Flow path = 1.5:1 or more
Standard aquatic benches	Wetlands comprise more than 10% of pond area
Turf in pond buffers	Pond landscaping to discourage geese
No internal pond mechanisms	Aeration (preferably bubblers that extend to or near the bottom or are on floating islands
Maintenance access to the forebay/riser	Maintenance access to the forebay/riser

[1] Runoff reduction can be computed for wet ponds designed for water reuse and upland irrigation
[2] Extended Detention provided to meet the water quality volume
[3] At least three internal cells including the forebay
[4] In the case of multiple inlets, the flow path is measured for the dominant inlets (that compromise 80% or more of total pond inflow)

6-C.5.3. *Restricted* Stormwater Control Measures

The last group of stormwater management practices has limited feasibility in the coastal plain and or poor removal capability for the pollutants of concern. In most cases, these practices are not recommended to function as the primary stormwater control at coastal plain development sites.

Grass Channel. Although Grass Channels (Virginia Stormwater Design Specification No. 3) work reasonably well in the flat terrain and low hydraulic head conditions of many coastal plain sites, they have very poor nutrient and bacteria removal rates. A Grass Channel should not be used as a stand-alone system. Dry Swales or Wet Swales are a much superior option to the Grass Channel, unless the soils are in the highly permeable Hydrologic Soil Group “A”. In these situations, apply the following criteria:

- The minimum depth to the seasonally high water table may be reduced to 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The Grass Channel may have off-line cells and should be connected to the ditch or other stormwater drainage system.

Large-Scale Infiltration**.** Large scale Infiltration, defined as individual Infiltration practices that serve a contributing drainage area of from 20,000 to 100,000 square feet of impervious cover, can work well in coastal plain sites where soils have an infiltration rate between 0.5 to 4.0 inches per hour. Where soils are extremely permeable (more than 4 inches per hour), a two-cell system (consisting of a shallow bioretention or filtering practice draining to the infiltration practice) should be used to provide for pollutant filtering prior to introduction into groundwater. Infiltration (Virginia Stormwater Design Specification No. 8) should *not* be used if the site is a designated stormwater hotspot.

Extended Detention Ponds**.** The lack of sufficient hydraulic head and the high groundwater table at many coastal plain sites severely constrain the application of Extended Detention (ED) Ponds (Virginia Stormwater Design Specification No. 15). Excavating ED ponds below the water table creates unacceptable conditions within the basin. No credit for the Treatment Volume may be taken for the water volume below the seasonally high water table. In general, ***shallow constructed wetlands are a superior option to ED ponds for the coastal plain environment****.*

6-C.6.0. TECHNICAL UPDATE ON COASTAL PLAIN WET POND RESEARCH AND IMPLICATIONS FOR DESIGN

The information in this section is an outgrowth from a Tidewater Virginia workshop on stormwater Wet Pond design held on March 22-23, 2009, where there was considerable debate about the original recommendation to restrict credit for the Treatment Volume (T_V) only to the pool storage volume that is above the seasonably high water table. The technical documentation for the proposed restriction, as initially drafted, would have restricted the feasibility of the most widely-used stormwater control measure in the Tidewater area of Virginia. Workshop participants requested that this groundwater-limited restriction be reconsidered. In that context, this section summarizes recent Wet Pond research and presents the basis for refined design and sizing criteria for Wet Ponds used in the coastal plain.

6-C.6.1. Review of Existing Research on Coastal Plain Wet Ponds

Several recent studies and reviews have explored the performance of wet pond performance in coastal plain conditions, particularly as performance is affected by the influence of groundwater (Mallin et al, 2002, Drescher et al, 2007, Harper and Baker, 2007, DeLorenzo and Fulton, 2009, Hirschman and Woodworth, 2009). These studies expand on the original review of the influence of groundwater on Wet Ponds developed by Schueler (2001). **Table 6-C.5** below summarizes the nine coastal plain Wet Pond pollutant removal performance studies, all of which had some groundwater interaction.

The basic findings from this review include the following:

- It was not possible to statistically compare the population of Wet Ponds in the *National Stormwater Pollutant Removal Database* that are influenced by groundwater with those that are not. The primary reasons relate to small sample size, the variability in the degree of coastal plain groundwater interaction, and considerable differences in design, sizing and residence time among the individual wet ponds studied. Nevertheless, it is evident that the groundwater influence in coastal plain Wet Ponds constrains the maximum degree of nutrient removal they can provide, as compared Wet Ponds in other physiographic regions Virginia where groundwater does not have so much influence.

Table 6-C.5. Review of Coastal Plain Wet Pond Nutrient Removal Performance

Study [3]	**Location**	**Name**	**TP**	**TN**
Mallin, 2002	Wilmington NC	Ann McCrary	23 [2]	(-3.5)
Mallin 2002		Silver Stream	58	40
Mallin, 2002		Echo Farms	(-35)	(-41)
Gain, 1996 [1]	Orlando, FL	FDOT	30	16
Kantrowitz 1995 [1]	Florida	St Joes	40	23
McCann 1995 [1]	Orlando, FL	Greenwood	62	(-11)
Rushton, 1997 [1]	Tampa Bay, FL	TB Detention	57-62	16-33
Messersmith 2007	South Carolina	5 cell pond	70	40
Messersmith, 2007	South Carolina	1 cell pond	(-2)	(-5)
Virginia LEVEL 1 [4] Criteria			**50**	**30**
Virginia LEVEL 2 Criteria			**75**	**40**

[1] As reported in the CWP *National Stormwater Pollutant Removal Database (2008)*

[2] The removal measured as the monthly concentration entering and leaving pond (N=29)

[3] Due to differences in pond design, sizing and stormwater monitoring protocols, the nine studies cannot be either directly compared to each other or aggregated to compute an overall average

[4] Nutrient event mean concentration (EMC) reduction rates reported in the Virginia Wet Pond Design Specification (No. 14)

- The analysis of individual coastal plain studies shows that Wet Pond performance clearly falls into one of two general groups. The first group consists of relatively standard Wet Pond designs that do not appear to be capable of meeting either Virginia Level 1 or Level 2 performance criteria for N and P removal (see the shaded cells in **Table 6-C.5** above). As a group, these Wet Ponds have low or even negative nutrient removal rates.

- The second group of Wet Ponds performed much better and could generally meet the Level 1 removal rates and, sometimes, the Level 2 removal rates. This group of Wet Ponds incorporated much more sophisticated design features and geometry. For example, the Silver Stream pond had a length-to-width ratio of nearly 18:1, two cells, a 2-foot depth, and extensive macrophyte and wetland cover (Mallin et al, 2002). Similarly, the Greenwood pond was composed of three cells, was oversized (1.25 inches of storage), contained extensive wetland benches and aeration fountains, and provided for water reuse (McCann, 1995). The Tampa Bay pond was retrofitted to increase detention time from 1 to 7 days, and included wet extended detention and wetland design elements (Rushton, 1997). The last top performer was a five-cell Wet Pond in South Carolina, with a very long residence time and extensive wetland elements (Messersmith, 2007).

- Another important study was conducted by Harper and Barker (2007). They examined the relationship between detention time and nutrient removal in a population of 19 Florida Wet Ponds and urban lakes with average residence times ranging from 1 to 500 days. All of these ponds and lakes were presumed to have a high degree of groundwater interaction. Harper and Barker found a strong statistical relationship between detention time and mass removal rate, with r^2 in the range of 0.8 to 0.9. In general, the curves show a sharp increase in nutrient removal during the first 5 to 15 days, followed by a more gradual increase with longer detention times. After 100 days of detention time, the removal rate for phosphorus and nitrogen was 75% and 42%, respectively.

- The Harper detention time equation was used to define the expected Treatment Volumes for the proposed Virginia Level 1 and 2 Wet Pond sizing criteria (i.e., 1.0 inch and 1.5 inches, respectively). The resulting detention times were then inserted into the Florida nutrient mass removal equations to obtain a prediction of nutrient removal rates under the proposed Virginia design criteria, as shown in **Table 6-C.6**. Since the Harper detention time equation was developed using Florida ponds, it is not recommended as a hard rule for setting a minimum detention time for ponds in Virginia. However, it does provide additional evidence that groundwater-influenced wet ponds sized according to the new Virginia design specifications have limits on their maximum expected nutrient removal rates. Specifically, the proposed pond sizing criteria appear capable of surpassing Level 1 phosphorus removal rates (50%), but cannot achieve the Level 2 rate of 75%. In the case of nitrogen, the proposed sizing criteria can only meet Level 1 nitrogen removal rates (30%) when ponds are sized to Level 2 design (e.g., 1.5 inches).

Table 6-C.6. Predicted Nutrient Removal Based on Harper Pond Equation

VA DEQ Wet Pond Criteria	Wet Pond Sizing Criteria	Annual Detention Time [1]	Predicted P Mass Removal (%) [2]	Predicted N Mass Removal (%) [3]
Level 1	$T_V = (1.0) (Rv) (A) / 12$	9 days	55	10
Level 2	$T_V = (1.5) (Rv) (A) / 12$	13.5 days	58	33
[1] page 5.34 [2] page 5.38 [3] page 5.39				

Source: Equations in Harper and Barker (2007)

- Harper and Baker (2007) also address the issue of pond stratification and depth, which is at the heart of the groundwater-T_v exclusion debate. The authors are unambiguous on this point – the depth of a coastal plain Wet Pond (including the depth below groundwater) by itself is not a particularly useful design parameter. This conclusion is also reinforced by an independent study of Florida ponds by Ceilla and Everham (2008).

- The authors note that the key pond design issue is actually the trophic state of the pond. This determines the depth of the anoxic zone, which increases nutrient release from the sediments. The trophic state is a measure of the degree of eutrophication in a pond which, in turn, is a function of the pond's nutrient input and residence time. Residence time is expressed as the pond pool volume divided by the annual runoff input from its catchment. Thus, pool depth is not always a reliable indicator of a longer detention time. Indeed, based on prior limnological research, there may be cases where a deeper pond could have a longer detention time (and be less eutrophic) than a shallow pond.

- Based on Florida pond and lake data, Harper and Barker (2007) present an equation to estimate the depth of the anoxic zone (see Page 6.48 of their work). When this equation is solved for typical trophic data reported by Drescher et al (2007) for South Carolina coastal Wet Ponds (pond chlorophyll-*a* of 40 ug/l; pond TP of 0.10 mg/l; pond TN of 1.0 mg/l; and an assumed Secchi depth of 1 foot), it implies a typical anoxic zone for coastal plain Wet Ponds of about 1 foot.

- Several other recent studies have shed light on the behavior of coastal plain Wet Ponds. The first is a comprehensive review by Drescher et al (2007) that describes a baseline study of 112 South Carolina Wet Ponds, and a review of data from other coastal plain states. The baseline study indicated that while dissolved oxygen (DO) was low in the coastal ponds, it was generally greater than 4.0 mg/l in 80% of 110 ponds evaluated. The coastal ponds were eutrophic to hyper-eutrophic with respect to chlorophyll-*a* concentrations (32% of ponds had chlorophyll-*a* > 40 ug/l). A majority of hyper-eutrophic Wet Ponds (chlorophyll-*a* > 60 ug/l) contained harmful algal blooms (HABs). In many cases, the limiting nutrient within coastal Wet Ponds was nitrogen rather than phosphorus, particularly when groundwater was brackish or the pond was tidally influenced.

- The HAB issue was further evaluated by DeLorenzo and Fulton (2009) who documented the presence of a wide range of HABs in coastal Wet Ponds, including blue green algae blooms (*cyanobacteria*), dinoflagellate blooms such as *Pfiesteria*, and "red tides," and raphidophytes. While the presence of algal blooms indicates that Wet Ponds are working to reduce nutrients, HABs can release toxins that can kill fish, contaminate shellfish and, in some cases, affect human health. HABs are most pronounced in Wet Ponds that have brackish groundwater and/or are directly connected to tidal waters [where salinity is > 5 parts per thousand (ppt)]. DeLorenzo and Fulton (2009) note several examples where HABs in hyper-eutrophic Wet Ponds were exported to adjacent tidal waters.

- Another set of studies evaluated the condition of large populations of Wet Ponds as they were actually installed and maintained in coastal plain conditions (Hirschman and Woodworth, 2009, and North and South Carolina studies summarized in Drescher at al, 2007). Most of the Wet Ponds were built according to pre-2000 design standards. Field evaluations indicated that a large fraction of the Virginia, North Carolina and South Carolina Wet Ponds fail to meet minimum design recommendations/guidelines with respect to forebay installation, minimum length-to width-ratio, and aquatic benches, and that many were encountering functional problems relating to a lack of maintenance (sediment deposition, excessive plant growth, trees on the embankment, etc.).

- In both South Carolina and Virginia, the worst performing Wet Ponds were in commercial areas rather than residential areas, which may reflect the fact that they were squeezed into the sites and had small contributing drainage areas. Indeed, anecdotal evidence from several designers at the March 2009 Stormwater Charette Design Workshop in Tidewater Virginia indicated that shallow Wet Ponds with small contributing drainage areas frequently produced the most nuisance conditions and maintenance problems.

6-C.6.2. Implications for Coastal Plain Wet Pond Design

Wet Ponds can be considered an *acceptable* stormwater practice for use in the coastal plain where the water table is within 4 feet of the land surface. However, *Constructed Wetlands are a preferred alternative when space is available*.

Adjustments to Nutrient Removal. The numerous lines of evidence reviewed indicate that standard designs of coastal plain wet ponds *cannot* achieve the desired nutrient removal rates in the current Virginia Stormwater Design Specification for Wet Ponds, based on design criteria, detention times, the influence of groundwater, and other factors. Therefore, slightly lower nutrient removal rates are proposed for coastal plain Wet Ponds to reflect the real world performance data for phosphorus and nitrogen removal. Specifically, Level 1 and 2 total removal rates for TP are now proposed to be 45% and 65% respectively, and Level 1 and 2 TN removal rates are reduced to 20% and 30%, respectively. These slightly lower removal rates are supported by recent pond research and the detention time relationships.

Essential Design Elements. The research validates the importance of incorporating specific Wet Pond design elements (e.g., forebays, minimum flow path, expanded wetland cover and multi-cell construction) to achieve desired nutrient removal performance. Given their importance in promoting nutrient removal, these factors are considered essential minimum design features for all Wet Ponds, as shown in **Table 6-C.4** above. Two additional design elements are recommended to distinguish Level 2 from Level 1 ponds, based on comments from designers and local stormwater managers. The first relates to pond landscaping to discourage geese. The second involves the use of internal mechanical devices to increase aeration and/or nutrient reduction..

Remove Pool Depth Restrictions. The research suggests that there is no technical basis for reducing the Treatment Volume to account for groundwater inputs, even when the water table is high, once the overall nutrient removal rates are adjusted. Reliable removal can be achieved by groundwater-influenced ponds, if they achieve the detention time associated with the Treatment Volume sizing and contain the requisite internal design features to promote nutrient removal. There is some indication that, on average, about 1 foot wet pond pool depth will be anoxic in the summer, which is accounted for in the slightly reduced maximum nutrient removal rates.

Restrictions on Brackish Ponds. Wet Ponds are discouraged in cases where groundwater input to the pond is brackish or is hydraulically connected to tidal waters [where salinity is > 5 parts per thousand (ppt)]. Given the potential for strong association of HABs with hyper-eutrophic Wet Ponds, it may not be wise to allow ponds to intersect the water table when (1) it is brackish and (2) there are other nutrient sources in the contributing drainage area (e.g., golf courses, septic systems, land application of biosolids).

Pocket Ponds. Another issue relates to Wet Ponds with small contributing drainage areas that are solely supplied by runoff and groundwater, frequently resulting in nuisance conditions and fluctuating water levels. There is virtually no data on these “pocket ponds” that are often installed on small commercial sites. Rather than mandating an arbitrary minimum drainage area, it is recommended instead that these pocket ponds must meet the minimum design and geometry requirements for all ponds (i.e., having a sediment forebay cell, aquatic benches, maximum side-slopes of 5W:1H, and a length-to-width ratio of 1:1).

In addition, the pond water balance evaluation must demonstrate that the pond will not draw down more than 2 feet during a 30-day summer drought, using the pond drawdown equation in (Equation 14.1 in Virginia Stormwater Design Specification No. 14: Wet Pond). Designers should strictly adhere to the same design requirements that apply to other Wet Ponds, which should greatly reduce the number of nuisance ponds that are forced into too-small sites (i.e., by reducing or eliminating essential pond design elements).

Increasing Runoff Reduction for Water Re-Use Ponds. Several designers noted that the guidance neglected the possibility of achieving runoff volume reduction from ponds through water re-use (i.e., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds, and accepted computational methods are available (Wanielista and Yousef, 1993 and McDaniel and Wanielista, 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water re-use, as long as acceptable modeling data is provided for documentation.

Benchmarking Sediment Deposition in Coastal Ponds. To facilitate maintenance, the contractor must mark and geo-reference on the as-built drawing the actual constructed depth of three areas within the permanent pool (forebay, mid-pond and outflow). This simple action will enable future inspectors to determine pond sediment deposition rates and schedule sediment cleanouts, as needed.

6-C.7.0. ACKNOWLEDGEMENTS

This Appendix was produced to customize and adapt stormwater design guidance for the demanding conditions of the coastal plain of Virginia, and has been reviewed by a wide range of Tidewater engineers and planners. The Chesapeake Stormwater Network, who developed the Technical Bulletin from which this Appendix has been adapted, acknowledges the assistance of Greg Hoffman, Sadie Drescher, Dave Hirschman and Laurel Woodworth of the Center for Watershed Protection, Joe Battiata of the Williamsburg Environmental Group, Jenifer Tribo of the Hampton Roads Planning District Commission, Randy Greer from the Delaware Department

of Natural Resources and Environmental Control, and the many individuals who provided feedback at a March 2009 workshop on Coastal Stormwater Management.

Support was provided from the Center for Watershed Protection, through a CITEET grant from NOAA.

For more in-depth guidance related to managing stormwater in a coastal setting, see the Georgia Department of Natural Resources' *Coastal Stormwater Supplement to the Georgia Stormwater Management Manual,* prepared by the Center for Watershed Management (http://www.cwp.org/Resource_Library/Center_Docs/SW/georgia_css.pdf).

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Appendix 6-D

The Sustainable Sites Initiative

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Leadership in Energy and Environmental Design (LEED®) and the Sustainable Sites Initiative (SSI). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. The SSI point credit system was designed by the American Society of Landscape Architects (ASLA) and the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b). This Appendix provides a more thorough discussion of the site planning process and design considerations as related to SSI credits. It is anticipated that SSI credits may eventually be blended into LEED credits. However, DEQ is not affiliated with any of the creators of LEED or SSI, and any information on applicable points suggested here is based only on perceived compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through LEED or SSI resources.**

6-D.1.0. THE SUSTAINABLE SITES INITIATIVE™ (SSI)

Environmental site design is intrinsically associated with the concept of sustainability and the emerging *sustainable site design* movement, reflected in the 2009 release of the Sustainable Sites Initiative™ (SSI), an interdisciplinary partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b).

The Sustainable Sites Initiative has spent several years developing guidelines for sustainable land practices that are grounded in rigorous science and can be applied on a site-by-site basis nationwide. These voluntary guidelines – *The Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009* – acknowledge that different regions of the country will have different requirements and therefore include performance levels appropriate to each region as needed. The benchmarks are meant to guide, measure and recognize sustainable landscape design practices on a site-by-site basis. They may also inform larger scale projects or planning efforts, although they are not intended to be a tool for regional planning.

By aligning land development and management practices with the functions of healthy ecosystems, the SSI believes that developers, property owners, site managers, and others can restore or enhance the ecosystem services provided by their built landscapes. Moreover, adopting such sustainable practices not only helps the environment but also enhances human health and well-being and is economically cost-effective.

For the Initiative's purposes, "sustainability" is defined as *design, construction, operations, and maintenance practices that meet the needs of the present without compromising the ability of future generations to meet their own needs*. This definition embraces the definition of sustainable development first put forward in a 1987 report of the United Nations World Commission on Environment and Development entitled *Our Common Future*. As Dr. Gro Harlem Brundtland, former Prime Minister of Norway once said, "The environment is where we all live; and development is what we all do in attempting to improve our lot within that abode. The two are inseparable." Also, as a Native American proverb states, "We do not inherit the earth from our ancestors, we borrow it from our grandchildren."

The impetus for creating the guidelines came from the recognition that although buildings have national standards for "green" construction, little existed for the space beyond the building envelope. Modeled after the LEED® (Leadership in Energy and Environmental Design) Green Building Rating System® of the U.S. Green Building Council, the Initiative's rating system gives credits for the sustainable use of water, the conservation of soils, wise choices of vegetation and materials, and design that supports human health and well-being. The U.S. Green Building Council anticipates incorporating the Sustainable Sites benchmarks into future revisions of its LEED rating system.

The term "ecosystem services" describes the goods and services provided by healthy ecosystems – the pollination of crops by bees, bats, or birds, for example, or the flood protection provided by wetlands, or the filtration of air and water by vegetation and soils. Ecosystem services provide benefits to humankind and other organisms but are not generally reflected in our current economic accounting (see **Figure 6-D.1**). Nature doesn't submit an invoice for them, so humans often underestimate or ignore their value when making land-use decisions. However, efforts to determine the monetary value of ecosystem services have placed that figure at an estimated global average of $33 trillion annually– nearly twice the value of the global gross national product of $18 trillion, both figures in 1997 dollars (Costanza et al., 1997).

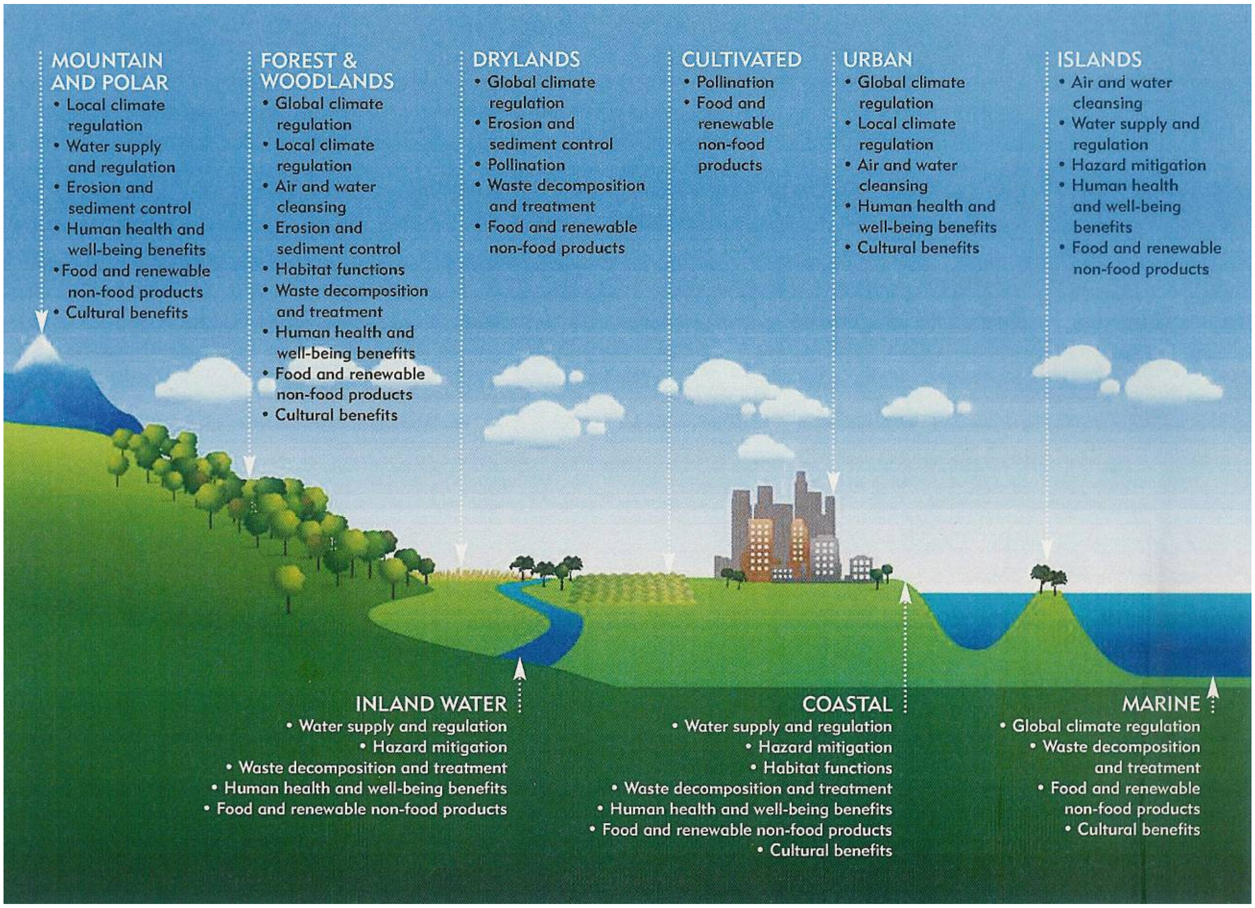

Figure 6-D.1. Various Ecosystem Services. *No type of ecosystem has a monopoly on the goods and services it can provide. The services shown here represent only a few of the many services available from each source type. With sustainable practices, built landscapes can provide many of these same natural services.* Source: ASLA et al. (2009a)

The SSI's committees and staff have distilled the potential ecosystem services that a sustainable site can strive to protect or regenerate to the following list:

- ***Global Climate Regulation.*** Maintaining balance of atmospheric gases at historic levels, creating breathable air, and sequestering greenhouse gases.
- ***Local Climate Regulation.*** Regulating local temperature, precipitation, and humidity through shading, evapotranspiration, and windbreaks.
- ***Air and Water Cleansing.*** Removing and reducing pollutants in air and water.
- ***Water Supply and Regulation.*** Storing and providing water within watersheds and aquifers.
- ***Erosion and Sediment Control.*** Retaining soil within an ecosystem, preventing damage from erosion and siltation.
- ***Hazard Mitigation.*** Reducing vulnerability to damage from flooding, storm surge, wildfire, and drought.
- ***Pollination.*** Providing pollinator species for reproduction of crops or other plants.
- ***Habitat Functions.*** Providing refuge and reproduction habitat to plants and animals, thereby contributing to conservation of biological and genetic diversity and evolutionary processes.
- ***Waste Decomposition and Treatment.*** Breaking down waste and cycling nutrients.
- ***Human Health and Well-Being Benefits.*** Enhancing physical, mental, and social well-being as a result of interaction with nature.
- ***Food and Renewable Non-Food Products.*** Producing food, fuel, energy, medicine, or other products for human use.
- ***Cultural Benefits.*** Enhancing cultural, educational, aesthetic, and spiritual experiences as a result of interaction with nature.

Increased understanding of the value of these services has led to acknowledgment of the way current land practices can imperil such essential benefits as air purification, water retention, climate regulation, and erosion control. Careless land practices, such as excessive reduction of vegetative cover, can start a cascade of negative effects that destroy ecosystems and degrade air and water quality. As many communities have found, it is difficult, expensive, and sometimes impossible to duplicate these natural services once they are destroyed.

However, as **Figure 6-D.2** illustrates, sustainable practices of stewardship, such as improving soil conditions, can reverse the effects, preserving and restoring healthy ecosystems and thereby increase the ecosystem services they provide after development – whether that development is a backyard garden, a housing development, or a state park. Water on the site can be managed to imitate natural water cycling, vegetation can be used strategically to cool the area and filter water, and soils can be restored to support healthy vegetation and filter pollutants.

Figure 6-D.2. Degradation versus Stewardship Progressions

The Initiative's development of site-specific performance benchmarks is grounded in an understanding of healthy systems and natural processes. Achieving these benchmarks will help to maintain or support those natural processes and the services that they provide to humans. The SSI's overview document, *The Case for Sustainable Landscapes* (ASLA et al., 2009a), is intended to provide readers with more background on the science underlying the guidelines for sustainable practices – to explain the connection, for example, between excessive use of nitrogen fertilizers and the increase in "dead zones" in coastal waters downstream, or between an increase in impervious cover and reduced base flow to creeks, streams, and rivers.

The Case for Sustainable Landscapes also offers evidence for the economic benefits that can accrue from adopting sustainable practices. For example, as a number of developers have found, bioswales, rain gardens and other low-impact development strategies to reduce runoff not only help recharge groundwater but also can save developers anywhere from 15 to 80 percent in total capital costs. And as New York City has found, a long-term investment in protecting its watershed can save billions in avoided costs for a new water treatment plant—a cost saving passed on to rate payers.

The science demonstrates that humans are an integral part of the environment. As people acknowledge this link, they recognize that human decisions and behavior are in fact components of a global feedback loop: what people do affects the health and well-being of the rest of the natural world, which in turn affects human health and well-being – physical, mental, economic, and social. According to the SSI, the guiding principles of a sustainable site are as follows:

- ***Do no harm.*** Make no changes to the site that will degrade the surrounding environment. Promote projects on sites where previous disturbance or development presents an opportunity to regenerate ecosystem services through sustainable design.

- ***Precautionary principle.*** Be cautious in making decisions that could create risk to human and environmental health. Some actions can cause irreversible damage. Examine a full range of alternatives – including no action – and be open to contributions from all affected parties.
- ***Design with nature and culture.*** Create and implement designs that are responsive to economic, environmental, and cultural conditions with respect to the local, regional, and global context.
- ***Use a decision-making hierarchy of preservation, conservation, and regeneration.*** Maximize and mimic the benefits of ecosystem services by preserving existing environmental features, conserving resources in a sustainable manner, and regenerating lost or damaged ecosystem services.
- ***Provide regenerative systems as intergenerational equity.*** Provide future generations with a sustainable environment supported by regenerative systems and endowed with regenerative resources.
- ***Support a living process.*** Continuously re-evaluate assumptions and values and adapt to demographic and environmental change.
- ***Use a systems thinking approach.*** Understand and value the relationships in an ecosystem and use an approach that reflects and sustains ecosystem services; re-establish the integral and essential relationship between natural processes and human activity.
- ***Use a collaborative and ethical approach.*** Encourage direct and open communication among colleagues, clients, manufacturers, and users to link long-term sustainability with ethical responsibility.
- ***Maintain integrity in leadership and research.*** Implement transparent and participatory leadership, develop research with technical rigor, and communicate new findings in a clear, consistent, and timely manner.
- ***Foster environmental stewardship.*** In all aspects of land development and management, foster an ethic of environmental stewardship – an understanding that responsible management of healthy ecosystems improves the quality of life for present and future generations.

The *Millenium Ecosystem Assessment*, a United Nations study completed in 2005, highlighted the need for all development to address considerations in three key arenas: social, environmental, and economic (MEA, 2003). Unless all three aspects are equally vibrant, true sustainability is not possible. A sustainable site also needs to take into account the challenges on all three fronts. An environmentally sustainable site that does not engage its users on multiple levels – physical, aesthetic, cultural, spiritual – will lose crucial human stewardship. By the same token, creation and maintenance of the site must be economically feasible for the site to exist at all.

In view of the pressing need for an economy less reliant on fossil fuels and more attuned to potential climate change, the SSI hopes to encourage land design, development, and management professional to engage in a re-evaluation of conventional practices – a new valuation of ecosystem services – so that built landscapes will support natural ecological functions throughout the life cycle of each site, adopting the philosophy of low impact development.

Beginning in April 2010, a number of pilot projects will help test and refine the *Guidelines and Performance Benchmarks 2009* and its rating system over the course of two years. For more information on the pilot program, visit http://www.sustainablesites.org/pilot/ .

6-D.2.0. THE ECONOMICS OF SUSTAINABLE DESIGN

The central message of the Sustainable Sites Initiative is that any landscape – whether the site of a large subdivision, a shopping mall, a park, an office building, or even an individual home – holds the potential both to improve and to regenerate the natural benefits and services provided by ecosystems in their undeveloped state. These benefits – such as the supply and regulation of clean air and water, the provision of food and renewable resources, and the decomposition of waste, to name only a few – are essential to the health and well-being of humans and all other life on the planet. President Theodore Roosevelt stated a similar notion: “The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased, not impaired, in value” (ASLA et al., 2009a).

In reality, most people often underestimate or simply ignore these benefits and services when making land use decisions, only to realize later how expensive and sometimes impossible it is to replicate them once they are lost. Yet efforts to build landscapes that preserve and restore healthy ecosystems face a significant challenge – namely, persuading decision-makers that the cost of changing conventional methods of landscape design, development, and maintenance is money well spent.

Persuasion must begin with an accurate accounting of what the benefits of ecosystems are worth to the economies of our cities and towns, to developers and individuals. As noted in **Section 6-D.1.0** above, one estimate of the monetary value of the collective ecosystems services is $33 trillion annually– nearly twice the value of the global gross national product of $18 trillion, both figures in 1997 dollars (Costanza et al., 1997). An accurate accounting must take into consideration how the adoption of sustainable practices can not only be cost-effective for both public and private entities, but also can leverage additional costs and multiple benefits.

In fact, the elements in a functioning ecosystem are so highly interconnected that unsustainable approaches to land development and associated management practices can have a devastating ripple effect throughout the system. Specific to stormwater management, the following examples of sustainable approaches demonstrate how thoughtful design, construction, operations and maintenance can reduce construction and life-cycle costs while enhancing an restoring ecosystem services that would otherwise be lost.

6-D.2.1. Treating Water as a Resource

As discussed in **Chapter 4**, freshwater resources are under duress all over the world, and Virginia is no exception. Demand for water has tripled in the United States in the last 30 years, even though the population has grown only 50 percent. Globally, demand for water is doubling every 20 years. As water rates rise, the imbalance between supply and demand has become so striking that investment bank Goldman Sachs has dubbed water “*the petroleum of the next century*” (Cooper, 2008). Yet two practices, both traditionally accepted among land design, development, and management professionals, not only contribute to the imbalance but also ignore the looming crisis.

- ***Undervaluing rain.*** In most cities and towns around the country, rainfall is treated as waste, to be funneled directly from roof gutters to sewers or streams. In older cities, this stormwater flows into combined sewer/stormwater systems that flow to sewage treatment plants, thus raising the cost of purifying waste water. In heavy storms, these combined sewer systems can overflow, dumping raw sewage into fresh water. Rather than getting rid of stormwater runoff as quickly as possible, a sustainable approach to stormwater management would find ways to harvest it on site (using cisterns or surface ponds) and use it for groundwater recharge, irrigation, ornamental water features, drinking water (treated), and other domestic uses, potentially lowering water and sewer utility costs.

- ***Wasteful Irrigation.*** Irrigation of unsustainable landscapes accounts for more than a third of residential water use – more than 7 billion gallons of potable water *per day* nationwide (EPA, 2008). With the compaction of soils a common condition in developed areas (see **Section 6-D.2.2** below, *Valuing Soils*), the infiltration rates of water are significantly reduced, causing much of the water used to irrigate lawns to end up as runoff or evaporation, instead of filtering down to recharge the water table. A sustainable approach to landscape design would minimize or eliminate the use of potable water or the drawing off of natural surface water or groundwater for landscape irrigation once plants are established. An effective alternative would be to employ rainwater harvesting techniques to supply water for irrigation systems at residences, commercial office parks, golf courses, etc., potentially lowering water utility costs.

6-D.2.2. Valuing Soils

The undervaluation of soils is one of the most significant failings of the conventional development approach. For example, a frequent consequence of standard construction practices is compaction of the soil, which seriously damages soil structure by shrinking the spaces between soil particles available to hold air and water. If not restored, compacted soil can start a spiral of degradation.

- ***Damage to Vegetation.*** Compacted soil particles restrict a plant’s root growth and its access to nutrients. If soil compaction continues, vegetation becomes unhealthy and unsightly and eventually dies or, making the soils vulnerable to erosion.
- ***Reduced Infiltration.*** Compacted soils are less able to absorb water, which reduces the recharge of groundwater and aquifers.
- ***Excess Runoff.*** Reduced infiltration leads to increases in the volume of runoff and the probability of flooding. On developed sites where there is widespread use of impervious material such as concrete and asphalt, even more runoff is likely, as reflected in changing *runoff curve numbers* (see **Figure 6-D.3**).
- ***Water Pollution.*** Without a sustainable approach to managing water on-site, excess runoff damages soils and vegetation in one area, and also creates further hazards downstream – exponentially so during heavy rains or storm events. As noted in **Chapter 4**, water leaving developed sites can contain a host of pollutants, depending on the type of development or other land use. These pollutants may range from excessive nutrients, oil, grease, and heavy metals to contaminants such as E. coli, hepatitis A, and persistent bioaccumulative toxic (PBT) chemicals. Stormwater runoff is one of the leading sources of pollution for all water body types in the United States, with impacts that escalate with increased development and urbanization (EPA, 2007a). Furthermore, as noted elsewhere in this Handbook, stormwater runoff is the only steadily increasing source of pollution in the Chesapeake Bay watershed of Virginia. Around the country, polluted and contaminated stormwater runoff accounts for 70 percent of

water pollution in urban areas and is the leading cause of poor water quality and the degradation of aquatic habitat (Loizeaux-Bennet, 1999).

In a sustainable approach to construction, a soil management plan communicated to contractors prior to construction would limit disturbance of healthy soil, assist soil restoration efforts, and define the location and boundaries of all vegetation and soil protection zones.

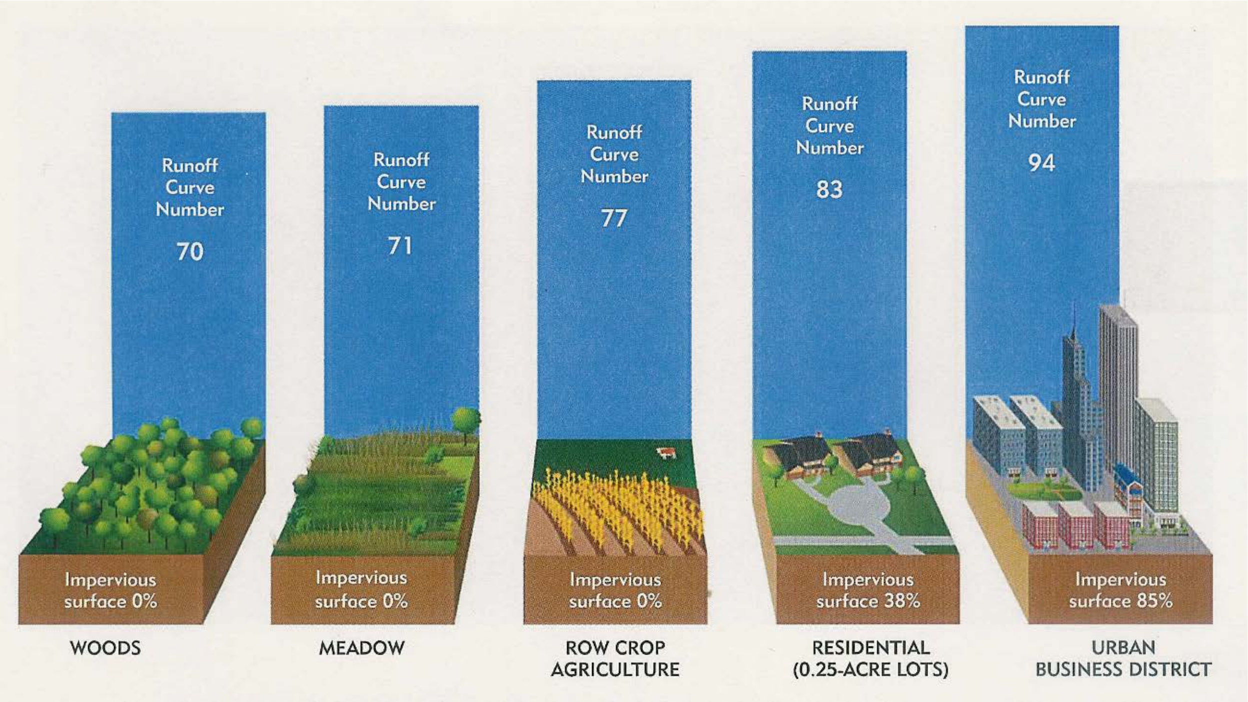

Figure 6-D.3. Runoff Curve Numbers for Different Site Types. *The runoff curve number is a product of empirical data from many sites across the country. It takes into account the amount of rainfall that is intercepted by vegetation, stored in surface depressions, and infiltrated. Any rainfall not retained on site becomes runoff. All sites in this Figure are assumed to have similar slopes and similar soils. However, as development increases – from woods to row crop agriculture to residential and urban landscapes – so does soil compaction. Compaction and increasing amounts of impervious area result in less water retained on-site and more of it running off, thus raising a site's curve number. A higher curve number, in turn, corresponds to a greater predicted runoff volume (see* ***Figure 6-D.4,*** *next page).* Source: Source: ASLA et al. (2009a)

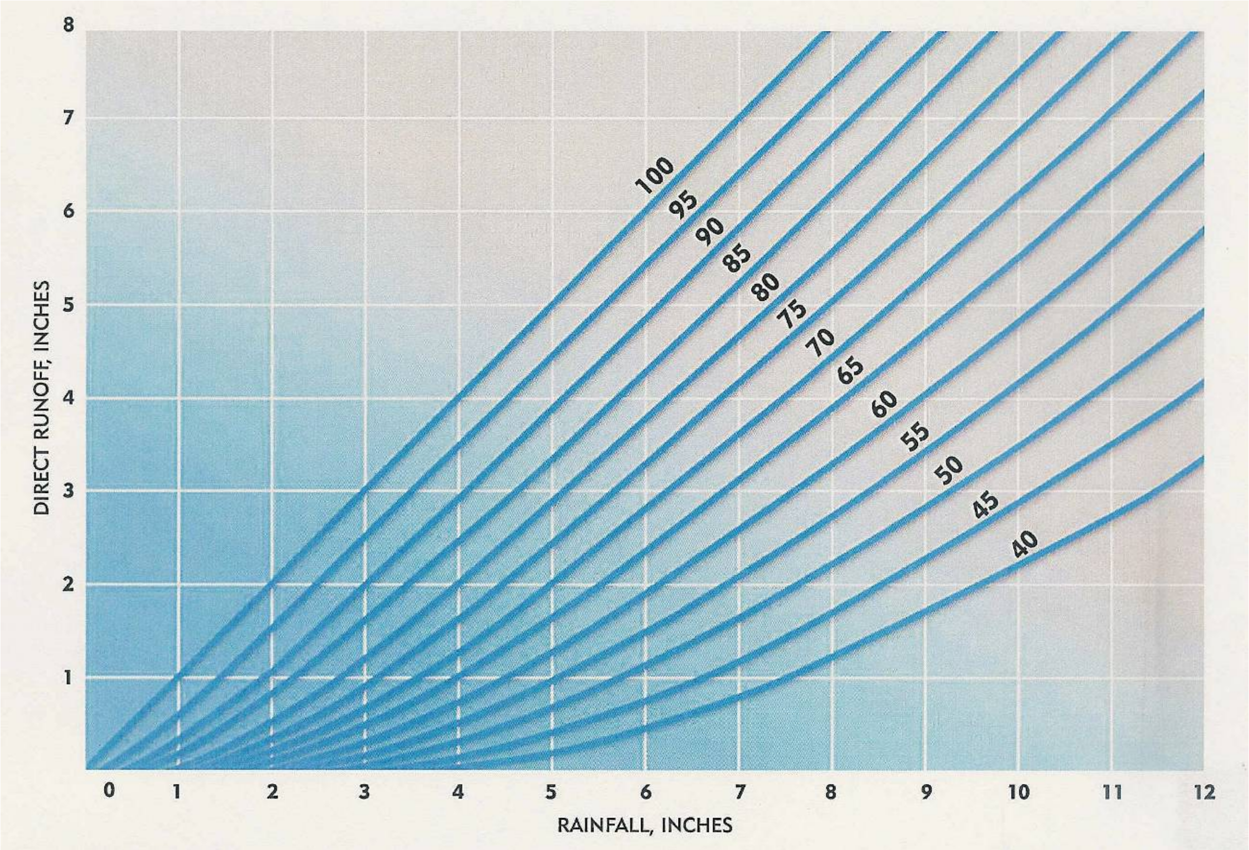

Figure 6-D.4. Predicting Stormwater Runoff. The runoff potential of sites varies with their runoff curve numbers, which characterize a site's response to long-term patterns of precipitation. Sites with higher curve numbers will produce more runoff than sites with lower curve numbers for the same amount of rainfall. For example, with 6 inches of rain, a site with a curve number of 40 yields just over 1/2-inch of runoff, while a site with a curve number of 90 yields produces nearly 5 inches of runoff.

6-D.2.3. Preserving Vegetative Cover

Removing existing vegetation disturbs soils and has other consequences as well. Without vegetation, a site loses its natural capacity for stormwater management, filtration, and groundwater recharge. Reduced vegetative cover also affects soil health, because vegetation maintains soil structure, contributes to soil organic matter, and prevents erosion.

- ***Excess Sedimentation.*** Removing vegetation increases the likelihood of erosion, which contributes to increased sediment runoff. Sedimentation is a major cause of polluted rivers and streams in the United States, second only to pathogens. Sediment runoff rates from construction sites can be up to 20 times greater than agricultural sediment loss rates and 1,000 to 2,000 times greater than those of forested lands (EPA, 2005)
- ***Increased Greenhouse Gases.*** Because so much organic carbon is stored in soils, significant amounts of carbon dioxide can be emitted when soils are disturbed. Disturbed soils also release substantial amounts of methane and nitrous oxide, both gases that trap heat even more effectively than carbon dioxide (Flannery, 2005; Smith, 2003). Although all of these

greenhouse gases are emitted as part of natural nutrient cycling, the natural balance is upset by increased soil erosion and by activities such as tillage and fertilizer application, all of which increase the natural emission rates.

By adopting a plan with defined vegetation protection zones, a sustainable approach to site design and construction would preserve or restore appropriate plant biomass on the site as well as preserve native plant communities and mature trees.

6-D.2.4. Conserving Material Resources

Materials are natural resources that have been extracted, processed, and/or manufactured for human use. One way of evaluating a product's sustainability is to look at the energy and resource consumption involved, from the extraction of raw materials through processing and manufacturing, to the product's use and disposal or recycling. However, conventional attitudes toward materials in society as a whole have not been focused on conserving either resources or energy. The land development and management industries are no exception.

- ***Yard Waste.*** Yard and landscape trimmings are a significant contributor to landfills. In 2007, approximately 33 million tons of yard waste entered the municipal waste stream, representing 13 percent of total municipal waste in the United States (EPA, 2007b).
- ***Construction Waste.*** An estimated 170 million tons of building-related construction and demolition wood waste are generated each year in the United States (EPA, 2003). Recoverable wood from construction and demolition could be reused in new applications, thereby reducing the need for virgin timber.

A sustainable approach to materials use in landscapes begins with an assessment of the existing site – both built and non-built features – and a design that seeks to incorporate and reuse as much of the existing site materials as practicable. For example, composting vegetation trimmings on-site would provide an excellent source of soil nourishment. Careful materials selection can also reduce the energy used in both the production and the transport of the materials, thereby decreasing greenhouse gas emissions and the impact on the global climate. For example, fly ash (a by-product of coal combustion) could be a substitute for energy-intensive portland cement in the production of concrete. Each ton of fly ash used to replace portland cement reduces greenhouse gas emissions by approximately one ton – equivalent to the emissions released by driving about 2,500 miles in an average car (Mehta, 2001). Selecting locally produced materials reduces the amount of energy used for transport, which also reduces greenhouse gas emissions.

The concept of the *waste hierarchy*, depicted in **Figure 6-D.5**, is that the more sustainable the practice, the more efficient the use of resources. Prevention consumes the least energy and produces the least volume of waste, while disposal is the most wasteful practice. Sustainable practices have the added benefits of reducing greenhouse gas emissions, protecting public health through safe management of potentially hazardous substances, and protecting soils and groundwater.

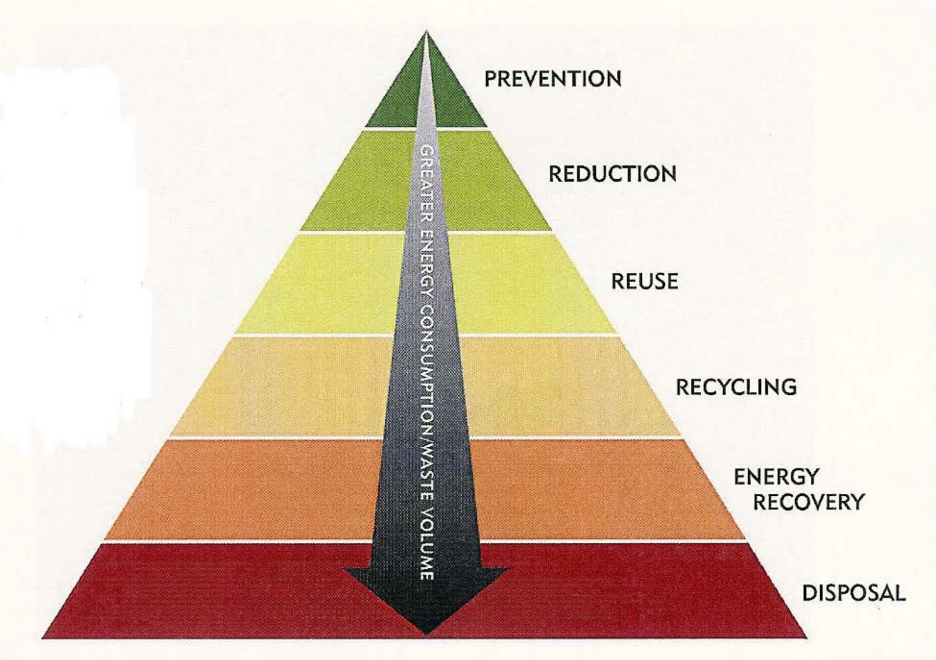

Figure 6-D.5. The Waste Hierarchy

6-D.2.5. Accounting for Direct and Indirect Benefits

Given the environmental cost of unsustainable land and development practices, a more sustainable approach is certainly desirable, but at what price? Those who make spending decisions in any field are accustomed to considering the trade-offs needed among economic, environmental, and social needs and constraints. However, often these trade-offs are evaluated based on incomplete information. That is, the full direct and indirect economic value of the goods and services produced by a healthy environment – and the economic consequences of an impaired ecosystem – are not fully understood and not taken into account.

The economic value of benefits for which markets currently exist is relatively easy to quantify, as is the case with the commercial harvest of fish or timer, for example. However, even these relatively straightforward market prices do not usually include such external effects as the artificial price elevation for timber and agricultural products that results from government subsidies or the cost of cleaning up resulting pollution, no matter who pays for it.

Measuring the economic significance of benefits for which markets do not exist is even more challenging. For example, what is the economic value of an aesthetic or cultural or educational experience of nature, or the value of an endangered species? However, in recent decades, economists have developed and tested techniques that can approximate the economic values of some of these benefits, with methods and results subjected to peer review in academic journals and presentations at scholarly conferences (e.g., see NRC, 2004). The following are some examples:

- ***Energy Savings.*** Many ecosystem services have values that take the form of cost savings, which a number of studies have begun to quantify. For example, the local climate regulation provided by shade trees results in an avoided cost for summertime electricity usage for the residence or commercial building cooled by that shade. Trees also block wind, potentially reducing demand for heating during the winter months. Studies conducted by American Forests found that tree canopy reduces residential home cooling costs, saving an average of between $11 per household per year in Portland, Oregon, and $28 per household per year in Atlanta, Georgia (American Forests, 2001). Multiplied across the region, this household benefit can add up. In the Atlanta region, savings in home cooling costs could amount to $2.8 million per year with adequate tree canopy.

- ***Water Treatment Savings.*** Similarly, when an urban forest prevents thousands of gallons of stormwater runoff from flowing into a municipal sewer system, that municipality saves money in water treatment. For example, a study by the U.S. EPA found that a 2,500-acre wetland in Georgia saves $1 million in water pollution abatement costs each year (EPA 2007c). In New York City, urban trees intercept almost 890 million gallons of rainwater each year, preventing that much runoff from entering storm sewers and saving the city an estimated $35 million annually in stormwater management costs alone (Peper et al., 2007).
- ***Air Cleansing.*** Trees also provide an air-cleansing benefit. In the Chicago area, urban trees filter an estimated 6,000 tons of air pollutants each year, providing air cleansing valued at $9.2 million (McPherson et al., 2994).
- ***Habitat and Species Preservation.*** Along with habitat loss, exotic invasive species are a major cause of loss of biodiversity and species. Increasing the use of native plants in landscape design reduces the risk from invasive species and helps bolster the wild native plant populations. This practice can also save considerable money. In the United States, exotic invasive species have been responsible for $38 billion of annual damage (Pimentel et al., 2000).
- ***Water Supply.*** On a broader scale, New York City took a long-term ecosystem view of protecting its drinking water supply. Starting in 1992, the city began acquiring thousands of acres of watershed lands and working with communities in the watershed on the need for environmentally sensitive development. The city's planned investment – approximately $1.5 billion over the course of ten years – saved it anywhere from $4 billion to $6 billion in construction costs and an estimated $300 million in annual operations costs for a new water filtration plant that it no longer had to build. The new treatment plant would have doubled or tripled rate payers' bills; by contrast the provisions of the watershed protection plan increased the average residential customer's water bill by only $7 per year (Archives of the Mayor's Press Office, 1996).

In addition, according to a study by the U.S. EPA (2007a), in the vast majority of cases, implementing thoughtfully selected LID/ESD practices saves money – for developers, property owners, and communities alike, as demonstrated by the following examples and **Table 6-D.1** below:

- ***Preserving Forested or Natural Areas.*** This can save up to $10 per square foot or $435,000 per acre over conventional landscape solutions.
- ***Balancing Cut and Fill on a Site.*** This can save up to $100 per cubic yard in haul costs.
- ***Using On-Lot Rain Gardens and Bioretention Areas.*** This can save up to $4,800 per residential lot over conventional engineered solutions, such as standard stormwater pond costs, and up to 75% of stormwater utility fees per residential lot. (Gap Creek, 2000; Somerset, MD, 2005; Kensington Estates, WA, 2001)

- ***Creating Narrow Streets (24 feet wide) versus Wide Streets (32 feet wide).*** This can save up to $30 per linear foot in street costs.
- ***Shade trees on the South Side of Buildings.*** This can save up to $47 per tree per year in energy costs. (Peper, 2007)
- ***Vegetated Roofs.*** These can retain more than 75% of rainfall annually, reducing downstream stormwater management costs. (ASLA Green Roof, 2007)
- ***Recycling Construction Waste.*** This can save tens of thousands of dollars in haul costs, dump fees, and material costs. (Stapleton, 2006).

Table 6-D.1. Summary of Cost Comparisons Between Conventional and LID/ESD Approaches

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

Conventional Development Cost refers to costs incurred or estimated for a traditional stormwater management approach, where *LID/ESD Cost* refers to costs incurred or estimated for using LID or ESD practices. *Cost Difference* is the difference between the conventional development cost and the LID/ESD cost. *Percent Difference* is the cost savings relative to the conventional development cost. Negative values denote increased cost for the LID/ESD design over conventional development costs. *NOTE:* The *Mill Creek* costs are reported on a per-lot basis.

Beyond cost reductions and savings, the communities subject to the EPA study also experienced a number of associated amenities and economic benefits, including aesthetic amenities, improved quality of life, improved habitat, and enhanced property values. Although the EPA study did not attempt to monetize these additional benefits or consider them in its calculations of each project's costs, it found the additional economic benefits to be "real and significant" (EPA, 2007a). Studies like this offer on-going evidence of the satisfying return on investment to developers, communities, and individuals from adopting sustainable practices of land development and management.

6-D.2.6. Development Costs versus Life Cycle Costs

Many communities around the nation are recognizing the need to begin developing in a sustainable manner. To set the example for other developers, these communities have adopted requirements to follow LEED® guidelines in the design and construction of public buildings within their jurisdictions. However, one key to the willingness of local governments to make such a commitment is that they will continue to own and operate these properties, once developed.

In contrast, many private development projects, especially those involving construction of residential neighborhoods, are constructed with the intent that they will be sold to others upon completion. Therefore, the only costs these developers are concerned with are those involving design and construction, and they are typically motivated to keep their costs as low as possible to achieve a quality development and, thus, maximize their profit margin. However, this motivation can be a deterrent to achieving sustainable designs, because many of the economies that result from sustainable design are reflected in long-term, “life-cycle” costs, such as lower utility costs, lower maintenance costs, and intangible values pertaining to aesthetics, wildlife habitat, etc. The temptation is to ignore the cost to achieve such long-term economies because the developer himself will not benefit directly from those project enhancements.

Of course, some sustainable design objectives *will* result in initial project construction savings as well as achieve sustainable results (e.g., using stormwater management practices that result in lower overall drainage system costs, minimizing imperviousness, using narrower streets and smaller parking rations or parking bay dimensions). However, there are really only two strategies that are likely to achieve the full range of sustainable design outcomes. The first is to rely on the good will of project developers and designers, depending on their recognition of the need for and wisdom of sustainable design and understand that our culture must start to build in ways that protect our ecosystem services and reduce energy consumption – even if costs more initially and reduces their profits somewhat. History and economic stress argue against this strategy achieving much success on its own.

The second strategy is reflected in communities who decide, as a matter of public policy, that they want to achieve greater sustainability within their own small sphere of influence. Such communities may follow up such a policy decision with green infrastructure planning, appropriate regulations, and/or zoning or comprehensive plan amendments that translate the policy into local requirements for the building industry to employ sustainable design. This is a big step, and it would typically require a strong measure of citizen support, because it could place a community at a disadvantage in competing with its neighbors for economic growth and development.

In the long run, to achieve truly sustainable development on a consistent and widespread basis, the public will have to be made more aware of how important sustainable design and development is for future generations and even, in the long term, national security (energy security, water availability, etc.). Only then is there likely to be sufficient public support and pressure on the development industry to adopt sustainable practices.

6-D.3.0. SUSTAINABLE SITES INITIATIVE SCORING CATEGORIES

In the course of identifying the specific and measurable criteria for site sustainability, members of the SSI's committees recognized the need to acknowledge that different regions of the country have distinct requirements and conditions. The committees therefore worked to develop performance benchmarks that would shift the market toward sustainability while remaining practical and achievable on a regional basis. The *Guidelines and Performance Benchmarks 2009* (ASLA et al., 2009b) encompass a series of prerequisites and credits for measuring site sustainability. The document explains the credit point system and rating scale. Benchmarks outlined under *prerequisites* are *required* and must be met in order for a site to participate in this voluntary program. Benchmarks outlined under *credits* are *optional*, but a certain number of them must be attained for a project to achieve eventual recognition as a Sustainable Site. The following is the list of prerequisites and credits:

1. Site Selection (21possible points)
Select locations to preserve existing resources and repair damaged systems
Prerequisite 1.1: Limit development of soils designated as prime farmland, unique farmland, and farmland of statewide importance
Prerequisite 1.2: Protect floodplain functions
Prerequisite 1.3: Preserve wetlands
Prerequisite 1.4: Preserve threatened or endangered species and their habitats
Credit 1.5: Select brownfields or greyfields for redevelopment (5–10 points)
Credit 1.6: Select sites within existing communities (6 points)
Credit 1.7: Select sites that encourage non-motorized transportation and use of public transit (5 points)

2. Pre-Design Assessment and Planning (4 possible points)
Plan for sustainability from the onset of the project
Prerequisite 2.1: Conduct a pre-design site assessment and explore opportunities for site sustainability
Prerequisite 2.2: Use an integrated site development process
Credit 2.3: Engage users and other stakeholders in site design (4 points)

3. ***Site Design – Water*** (44 possible points)
Protect and restore processes and systems associated with a site's hydrology
Prerequisite 3.1: Reduce potable water use for landscape irrigation by 50 percent from established baseline
Credit 3.2: Reduce potable water use for landscape irrigation by 75 percent or more from established baseline (2–5 points)
Credit 3.3: Protect and restore riparian, wetland, and shoreline buffers (3–8 points)
Credit 3.4: Rehabilitate lost streams, wetlands, and shorelines (2–5 points)
Credit 3.5: Manage stormwater on site (5–10 points)
Credit 3.6: Protect and enhance on-site water resources and receiving water quality (3–9 points)
Credit 3.7: Design rainwater/stormwater features to provide a landscape amenity (1–3 points)
Credit 3.8: Maintain water features to conserve water and other resources (1–4 points)

4. Site Design – Soil and Vegetation (51 possible points)
Protect and restore processes and systems associated with a site's soil and vegetation

Prerequisite 4.1: Control and manage known invasive plants found on site
Prerequisite 4.2: Use appropriate, non-invasive plants
Prerequisite 4.3: Create a soil management plan
Credit 4.4: Minimize soil disturbance in design and construction (6 points)
Credit 4.5: Preserve all vegetation designated as special status (5 points)
Credit 4.6: Preserve or restore appropriate plant biomass on site (3–8 points)
Credit 4.7: Use native plants (1–4 points)
Credit 4.8: Preserve plant communities native to the ecoregion (2–6 points)
Credit 4.9: Restore plant communities native to the ecoregion (1–5 points)
Credit 4.10: Use vegetation to minimize building heating requirements (2–4 points)
Credit 4.11: Use vegetation to minimize building cooling requirements (2–5 points)
Credit 4.12: Reduce urban heat island effects (3–5 points)
Credit 4.13: Reduce the risk of catastrophic wildfire (3 points)

5. ***Site Design—Materials Selection*** (36 possible points)
Reuse/recycle existing materials and support sustainable production practices
Prerequisite 5.1: Eliminate the use of wood from threatened tree species
Credit 5.2: Maintain on-site structures, hardscape, and landscape amenities (1–4 points)
Credit 5.3: Design for deconstruction and disassembly (1–3 points)
Credit 5.4: Reuse salvaged materials and plants (2–4 points)
Credit 5.5: Use recycled content materials (2–4 points)
Credit 5.6: Use certified wood (1–4 points)
Credit 5.7: Use regional materials (2–6 points)
Credit 5.8: Use adhesives, sealants, paints, and coatings with reduced VOC emissions (2 points)
Credit 5.9: Support sustainable practices in plant production (3 points)
Credit 5.10: Support sustainable practices in materials manufacturing (3–6 points)

6. ***Site Design—Human Health and Well-Being*** (32 possible points)
Build strong communities and a sense of stewardship
Credit 6.1: Promote equitable site development (1–3 points)
Credit 6.2: Promote equitable site use (1–4 points)
Credit 6.3: Promote sustainability awareness and education (2–4 points)
Credit 6.4: Protect and maintain unique cultural and historical places (2–4 points)
Credit 6.5: Provide for optimum site accessibility, safety, and wayfinding (3 points)
Credit 6.6: Provide opportunities for outdoor physical activity (4–5 points)
Credit 6.7: Provide views of vegetation and quiet outdoor spaces for mental restoration (3–4 points)
Credit 6.8: Provide outdoor spaces for social interaction (3 points)
Credit 6.9: Reduce light pollution (2 points)

7. **Construction** (21 possible points)
   Minimize effects of construction-related activities
   Prerequisite 7.1: Control and retain construction pollutants
   Prerequisite 7.2: Restore soils disturbed during construction
   Credit 7.3: Restore soils disturbed by previous development (2–8 points)
   Credit 7.4: Divert construction and demolition materials from disposal (3–5 points)
   Credit 7.5: Reuse or recycle vegetation, rocks, and soil generated during construction (3–5 points)
   Credit 7.6: Minimize generation of greenhouse gas emissions and exposure to localized air pollutants during construction (1–3 points)

8. ***Operations and Maintenance*** (23 possible points)
   Maintain the site for long-term sustainability
   Prerequisite 8.1: Plan for sustainable site maintenance
   Prerequisite 8.2: Provide for storage and collection of recyclables
   Credit 8.3: Recycle organic matter generated during site operations and maintenance (2–6 points)
   Credit 8.4: Reduce outdoor energy consumption for all landscape and exterior operations (1–4 points)
   Credit 8.5: Use renewable sources for landscape electricity needs (2–3 points)
   Credit 8.6: Minimize exposure to environmental tobacco smoke (1–2 points)
   Credit 8.7: Minimize generation of greenhouse gases and exposure to localized air pollutants during landscape maintenance activities (1–4 points)
   Credit 8.8: Reduce emissions and promote the use of fuel-efficient vehicles (4 points)

9. ***Monitoring and Innovation*** (18 possible points)
   Reward exceptional performance and improve the body of knowledge on long-term sustainability
   Credit 9.1: Monitor performance of sustainable design practices (10 points)
   Credit 9.2: Innovation in site design (8 points)

The SSI has developed a 250-point rating system providing designers the opportunity to achieve certification of a site as a *Sustainable Site*. Remember that the prerequisites of each category are *required* and therefore are not assigned a point value. Credited activities are assigned a point value and, in many cases, offer a range of points, providing projects additional flexibility in selecting the level (or benchmark) that is appropriate and achievable for them. The certification rating system is shown in **Table 6-D.2**.

Table 6-D.2. Sustainable Sites Initiative Rating Scale

Award Level	**Total Points (250 max.)**
One Star	100 points (40% of total available points)
Two Stars	125 points (50% of total available points)
Three Stars	150 points (60% of total available points)
Four Stars	200 points (80% of total available points)

Many of the SSI's guidelines and performance benchmarks integrate or overlap with the Environmental Site Design practices described in this chapter, aimed at more effective management of stormwater runoff. Other benchmarks – such as those relating to site selection and pre-design, choices of construction materials, design for human health and well-being, construction, operation and maintenance, and monitoring – are aimed more at general site sustainability and have little or nothing to do with stormwater management. Those guidelines and benchmarks will not be referenced herein.

The benchmarks that relate most to Environmental Site Design are benchmark categories 3 (Site Design – Water) and 4 (Site Design – Soil and Vegetation). Specific benchmarks will be referenced, where applicable, so designers will understand what SSI certification credits may apply to the use of particular ESD practices. However, it is important to understand that in order to achieve the number of points constituting eligibility for a certification level, an applicant will need points from the other categories as well.