CHAPTER 1

INTRODUCTION TO STORMWATER MANAGEMENT

1.1 INTRODUCTION

Whenever rainfall hits the surface of the Earth, one of several things will happen. The rainfall may wet a dry surface, cling to that surface, and evaporate after the rainfall event ends. It may collect and be held in a surface depression where it will infiltrate slowly into the Earth's subsurface. It may infiltrate directly into the soil, wetting and saturating the soil and subsurface, eventually adding to the local groundwater supply. It also may be repelled by a saturated soil or impervious surface and gathered to form surface runoff. This last possibility of rainfall transforming into surface runoff is a critical issue in land development. When land is developed, the site will respond differently to rainfall. The change is usually dramatic, with increases in runoff rates and runoff volumes. Stormwater management is that specialized field of science and engineering that is applied to minimize, control, and remediate the effects of land-use change on a watershed or land development site.

1.2 EFFECT OF LAND DEVELOPMENT

The development of land to construct industrial facilities, businesses, and homes involves land-use change that transforms pervious surfaces of woods, pasture, and meadow into impervious surfaces of stone, pavement, and roofing. The addition of impervious area to a site changes the hydrology of that site and the surrounding watershed. The topography of a site is almost always disturbed to accommodate the construction of an impervious structure. Changing topography usually removes natural surface depressions in the landscape that capture, hold, and slowly infiltrate water into the subsurface. Grading of a site usually transforms an undulating vegetated surface into a plane impervious surface or grass lawn. In either case, surface depressions are removed and water that was once captured and infiltrated now accumulates and travels across the landscape to a downstream point.

Natural flow paths that twist and wind across the landscape are usually altered into linear, constant-slope paths that are changed in length and roughness. The change in these flow-path characteristics affect the time required for surface runoff to move across and through the landscape. This change in timing directly affects runoff rates, usually increasing their magnitude and causing an increase in the frequency of flooding.

The addition of impervious area requires a reduction in pervious area that reduces the capacity of a site to infiltrate rainfall. When infiltration capacity is reduced, runoff potential increases and groundwater recharge potential decreases.

1.3 STORMWATER DESIGN CRITERIA

Since the late nineteenth century until the mid-twentieth century, stormwater management was usually considered the successful collection and disposal of increased surface runoff. The solution was usually a comprehensive design of roof gutters, downspouts, swales, curbed gutters, sewer inlets, and sewer pipes to collect, convey, and discharge surface runoff to streams, rivers, lakes, and other water bodies in the most efficient manner possible. The central theme of stormwater management design was to collect and transport the runoff to a nearby body of water as quickly as possible, ridding the developed site of the excess runoff. Little thought was given to the effects of excess runoff and decreased infiltration on the surrounding watershed.

In the 1970s, many states recognized the need to consider the effects of land development on downstream flooding, including local nuisance flooding and larger-scale flood plain overflow. Regulations were put in place to control peak runoff rates. The common regulation required the developer to release no more runoff flow after development than was coming from the site prior to development. The design was focused on peak flow control, which was typically achieved through collection, detention, and slow release of surface runoff through a regulating outlet structure.

In the 1980s, partially as a result of the National Urban Runoff Program (U.S. EPA, 1983), more attention was placed on pollution from developed land, with particular emphasis on nonpoint source pollution. As a result, sev-

Figure 1.1 Channel and roadway flooding caused by upstream land development (courtesy of F. Thornton, Darby Creek Valley Association, Delaware County, PA).

eral states and municipalities required developers to address the polluted runoff issue. Suspended solids in runoff were identified as a primary transport mechanism for nonpoint source pollutants such as copper, zinc, lead, nitrogen, phosphorous, and others. Therefore, many stormwater management designs included measures to remove sediment in runoff. The capture, detention, and very slow release of the first flush of runoff was considered one of the most effective measures to allow sediment in the runoff to settle out, thus reducing the pollutant load to downstream waters.

Temperature increase in nearby streams was also brought to the attention of land development designers. As cool fresh rainfall travels across a black, hot, summer sunned parking lot, the water temperature can increase dramatically. Even small changes in stream temperature can cause a bad environment for fresh-water aquatic life, particularly fish. The concept of cooling runoff through stormwater management design was thrown into the mix.

In the early 1990s to the turn of the twenty-first century, additional issues were recognized. They included increased streambank erosion and reduced groundwater recharge. Streambank erosion was attributed to the extended release of target design flows from flow-control facilities. Although these facilities provided some measure of flood control, they inadvertently delivered to the downstream channel a design release rate over a longer period of time. The design release rate was almost always at a velocity that was bank-erosive for a longer duration than had naturally occurred before development. In almost all regions where peak flow mitigation was required, excessive streambank erosion became more prevalent. Shrinking groundwater storage levels

Figure 1.2 A sediment forebay used to capture the first flush of runoff (courtesy of R. Traver, Villanova Urban Stormwater Partnership, Villanova University).

in urbanized areas prompted many state and local officials to examine the effect of land development on groundwater recharge. Obviously, if rainfall is being converted into large amounts of surface runoff, then the amount of infiltration must be reducing. Several states and local municipalities are now requiring a developed site to include a design for providing groundwater recharge areas.

In summary, the issues that must be addressed in a stormwater management plan have changed over the past half century, as illustrated in Table 1.1. Mere collection and disposal of runoff has transformed into runoff collection with peak flow control, volume control, groundwater recharge, water quality treatment, downstream channel protection, or a combination of these. A good stormwater management plan will address all of these issues through a comprehensive design.

1.4 COMPREHENSIVE AND INNOVATIVE DESIGN

To develop a better stormwater management plan, the prospective site must be evaluated prior to the design of roadways, lots, building locations, and

Figure 1.3 Stream bank erosion caused by upstream stormwater detention facilities (courtesy of Cahill Associates, West Chester, PA).

other development features. Preservation of natural vegetation, reduction of impervious areas, and protection of high-infiltration soils are just some of the elements of stormwater design that should be considered prior to the selection and design of management structures.

Very early in the planning and design process, the site should be examined to identify the constraints and opportunities for smart design. Constraints may

Figure 1.4 Groundwater recharge through an infiltration trench (courtesy of P. DeBarry, Borton-Lawson Engineering, Wilkes-Barre, PA).

TABLE 1.1 Progressive Change in Stormwater Design Issues during the Past Half Century

	Approximate Timeline				
Stormwater Design Issue	Pre-1970	1975	1985	1995	2000
Flooding within project site	X	X	X	X	X
Flooding outside project site		X	X	X	X
Surface water quality			X	X	X
Temperature			X	X	X
Groundwater recharge				X	X
Stream bank erosion					X

include poorly drained soils, steep slopes, unstable soils, shallow soils, high water table, wetlands, riparian buffer zones, utility easements, and certain property covenants. Opportunities may be well-drained soils, wooded areas, panoramic views, surface water ponds, and old hedge rows. Old structures of historical significance, such as a one-room schoolhouse, stone barn, fieldstone walls, covered bridge, stone arch bridge, and well-maintained farm buildings, can also be used as land development opportunities.

During the evaluation process some constraints might be turned into opportunities. Riparian buffers can be used to the advantage of the development if the buffer zone is maintained and utilized for walking paths, observation points, park benches, and other parklike facilities. Wetlands can be protected and still used to enhance property value if development is worked around the wetland area and the wetland is highlighted as a natural area within the development. The perimeter of a small cluster of woods might be used as the back lot lines of a circle of several homes, and preserved as a community asset and natural area.

Beyond opportunities and constraints, conservation design should be used. These methods are anything that reduces disturbed areas, protects streams and natural drainage paths, and minimizes impervious cover. Example methods are open space design and cluster housing. Figure 1.5 shows a developed site maintaining open (green) space and protecting the natural drainage paths. This type of design reduces the impact of development on the site hydrology. There are other methods that can be used, many of which are mentioned in several state stormwater management manuals, including those of New York, Maryland, Virginia, and Georgia.

For the developer, this design approach may be more costly in terms of engineering fees, yet in the end, a cleverly designed plan that takes advantage of site opportunities and utilizes open space design can reduce surface area needed for an expansive detention facility. This will, in turn, open up space for other use, such as additional building lots or conservation space that will enhance the market value of the developed property.

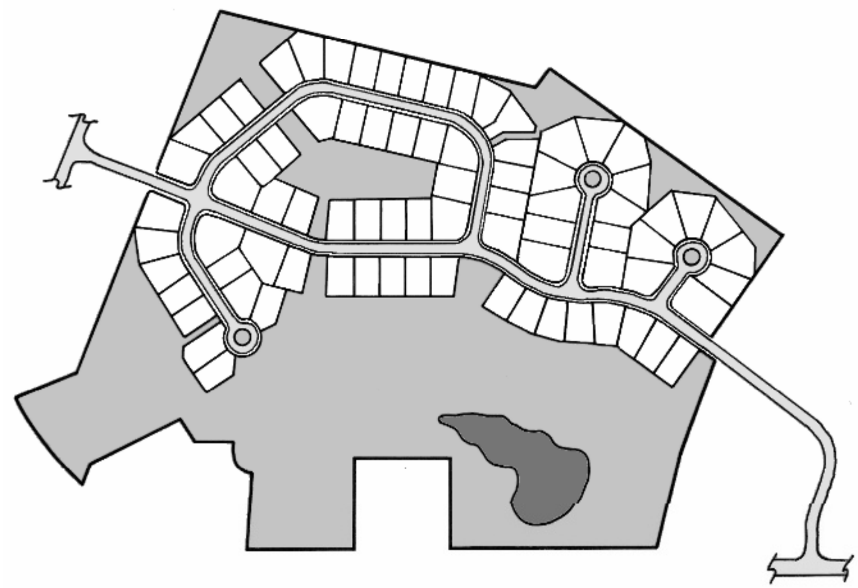

Figure 1.5 Open space design is used to reduce the effect of development (courtesy of Atlanta Regional Commission).

The worst approach to stormwater design is to think solely in terms of maximum number of postage-stamp lots that can fit into a property, with the stormwater management design treated as a last-minute addition to the design. In this approach, integration of the opportunities available to assist in minimizing the negative impact of the development is usually lost. The stormwater plan is typically reduced to an uninspired design of concrete curb gutters, inlets, pipes, and a pond stuck in the lowest corner of the site. Admittedly, detention facilities are difficult to avoid in stormwater design, and almost always necessary. Curb gutters are often required, with no option for the designer. Yet, if stormwater management is a first priority in the design process, the size of a detention pond can be reduced, and the negative effect of necessary conventional development structures like curb gutters and detention ponds can be minimized.

Sometimes innovative stormwater design is not readily accepted by counties or municipalities because the review agency is simply not familiar with the design benefits and new design methods. In the creation of any stormwater management plan, it is almost always beneficial to the designer and the review agency to have a preliminary meeting, very early in the design process, with the reviewer to discuss a general stormwater management scheme for the site. At this time, innovative methods can be presented, with expected benefits and design methods explained. Many times, a conversation like this will make the entire design and approval process much simpler.

Figure 1.6 A retention basin in a professional office park (courtesy of S. Brown, Penn State University).

1.5 BOOK ORGANIZATION

The impacts of development are mitigated in some way through structural devices or nonstructural land use practices. In all cases, the selection and design of these structures or practices are based on the estimation of surface runoff rates and volumes for the pre-development and post-development site conditions. Methods for analyzing flow rates and depths across the landscape are necessary. Sizing of conveyance structures and storage facilities is almost always necessary. Therefore, a fundamental understanding of surface hydrology, fluid flow, and methods to model both are necessary.

To support quantity calculations used in stormwater design, this book is organized into three groups of chapters, providing coverage of: (1) basic fluid mechanics, (2) fundamental surface hydrology, and (3) stormwater design methods, with all three sections geared toward stormwater management design for land development.

The first group includes chapters 2 through 4, which deal with fundamental methods in fluid mechanics. Chapter 2 deals with basic fluid properties and the analysis of fluids at rest, including static pressure and forces on submerged surfaces. Chapter 3 includes methods used to analyze fluid that is moving in a closed flow system. Chapter 4 covers fundamental methods of hydraulic analysis used in open channel flow. The material provides general fluid mechanics knowledge and a foundation for the design of conveyance structures in a typical stormwater management plan.

The second group includes chapters 5 through 10, which present hydrologic topics that are directly related to stormwater quantity control. Chapter 5 covers the hydrologic cycle and the hydrologic characteristics of watersheds that are important to standard stormwater calculations. Chapter 6 gives an overview of rainfall, providing data sources for design rainfall and methods to create design storms. Chapter 7 covers watershed time of concentration, presenting several methods and illustrating the most popular methods used. Chapter 8 presents the common runoff depth and peak flow estimation methods used in stormwater design, namely the NRCS and Rational methods. Chapter 9 explains fundamental concepts in hydrographs, including the unit hydrograph. This is followed with an explanation of the NRCS unit hydrograph and Rational hydrograph methods. Finally, Chapter 10 covers fundamental routing methods used for channel and detention basin routing.

The third group includes chapters 11 and 12, which covers procedures used to design stormwater management structures for collection, conveyance, storage, and release of surface runoff. Chapter 11 deals mainly with the analysis and design of swales, channels, pipes, and culverts. Chapter 12 deals specifically with the sizing of detention facilities and the design of multiple-stage outlet structures.

There are many other topics that must be addressed in stormwater management. This book, however, is intended to cover the most common computational methods for stormwater runoff estimation and analysis that supports stormwater management. Other chapters may be added in future editions of this text to address other elements of stormwater design.

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