CHAPTER

1

INTRODUCTION

1.1 URBANIZATION AND STORMWATER RUNOFF

The rainfall-runoff process is extremely complex, making it difficult to model accurately. In undeveloped areas, the quantity and rate of stormwater runoff are affected by natural surface detention, soil infiltration characteristics, and the drainage pattern formed by natural flow paths. The soil type, vegetative cover, and topography play key roles.

Urbanization impacts the rainfall-runoff process in a variety of ways. Infiltration is reduced due to the addition of impervious surfaces, resulting in increasing quantities of runoff. Tree removal, surface leveling, soil flipping, and surface compaction are also likely to boost the quantity of runoff. In addition, the rate of stormwater runoff is intensified due to the extensive network of pipes and channels that are designed into the urban environment. The long surface travel times from undeveloped land are shortened, and gutters and pipes quickly convey stormwater to receiving streams. Unfortunately, the increase in runoff quantities and rates can produce downstream flooding and accelerate channel erosion.

Stormwater quantity isn't the only problem associated with urbanization. Stormwater quality is impaired as well. Urban land surfaces are subject to the buildup of pollutants during dry weather, many of which are associated with human activity. When it rains, these pollutants are washed off the land surface and contribute to diminished receiving water quality. In fact, this nonpoint source pollution is the primary source of water quality impairment in the United States and many other countries of the world. Nonpoint source pollution includes eroded soil from construction sites, oil and grease from cars, nitrogen and phosphorus from fertilizers, pesticides from lawn and shrub care products, fecal droppings from pets and other animals, dust and dirt from dry fall, and various pollutants from illegal dumping and spills.

1.2 URBAN HYDROLOGY, HYDRAULICS, AND STORMWATER QUALITY

An understanding of urban hydrology, hydraulics, and stormwater quality is necessary to address the previously documented problems. In fact, many innovative practices have been developed over the last two decades to mitigate the detrimental effects of urbanization on stormwater runoff. These practices are often referred to as *stormwater management*. This book goes beyond the scope of stormwater management. It investigates the occurrence of stormwater in urban watersheds, its movement through the different elements of the drainage system, its collection and transport of various nonpoint source pollutants, its response to various stormwater management practices, and the incorporation of all of these elements into modern computer software. Simply stated, this book provides the reader with pertinent information on the quantity and quality of stormwater runoff that is essential to proper planning, design, and operation of stormwater management practices.

The field of urban hydrology, hydraulics, and stormwater quality is not an exact science. Certainly the principles of hydraulics are well developed and understood. The principles of hydrology are less advanced and still rely occasionally on empirical or semiempirical coefficients. On the other hand, the science of stormwater quality is in its infancy and relies heavily on empirical techniques and good field data to calibrate the appropriate models. Nonetheless, the science of the latter two has advanced over the last few decades, and physically based mathematical models are rapidly replacing empirical techniques. In addition, the use of desktop hydrologic techniques is being replaced with hydrologic computer models. These models incorporate many of the physically based techniques in a user-friendly environment. Unfortunately, more and more software users understand less and less about the underlying algorithms. This book provides the reader with a working knowledge of modern hydrologic models and the algorithms on which they rely. This knowledge will help the reader pick the most appropriate algorithms (since most computer models allow the user to choose from a variety of hydrologic algorithms) and verify the model results. The book also provides a number of desktop methods for small projects that do not justify computer modeling. These methods may also be used to check the results from computer models.

1.3 ORGANIZATION OF THE BOOK

Modern hydrologic computer models follow the path of a drop of water through the hydrologic cycle. Thus, these computer models start with a design or historic rainfall event, remove the losses (rainfall abstractions), route the excess over the land surface and through the conveyance system (pipes, channels, and ponds), and finally account for any stormwater management devices that are placed in the system. Therefore, the chapters have been arranged in a similar sequence.

The first and probably the most important task in designing a stormwater project is the selection of a storm on which the design will be based. Both the hydrologic and probabilistic characteristics of the historical, local rainfall data are considered in selecting a design storm. *Chapter 2* of this book describes various methods to determine the elements of a design-storm hyetograph.

Part of the design rainfall, collectively referred to as losses from rainfall, is diverted from becoming runoff due to several processes, such as interception by trees and infiltration into the soil. Reasonably accurate determination of the rainfall losses is important, because the quantity of design runoff (or rainfall excess) results from the removal of these losses from the design rainfall. *Chapter 3* describes the types of rainfall losses and presents several methods to calculate the quantity of rainfall excess.

The rainfall excess is transported to the design point through various flow processes. The flow in most elements of an urban watershed has a free surface at atmospheric pressure and is generally classified as open-channel flow. *Chapter 4* presents the basic concepts of open-channel flow relevant to urban watersheds. It also discusses the two basic types of open-channel flow occurring in an urban watershed, overland flow and channel flow. The methods described in this chapter are critical to understanding the key components of a complex urban drainage system.

Chapter 5 describes a variety of lumped urban rainfall-runoff models to calculate the design flows resulting from specified rainfall excess. These methods simulate the response of an urban watershed as a whole during design-storm conditions. The time-of-concentration concept is introduced along with unit hydrograph techniques, the U.S. Soil Conservation Service methods, U.S. Geological Survey (USGS) regression equations, and the rational method.

Chapter 6 is devoted to the design of drainage structures. Typical drainage structures found in urban stormwater systems include gutters (street flow), storm sewers, culverts, and surface drainage (open) channels. Special attention is given to the design of storm sewer systems, including drainage inlet placement, drainage inlet hydraulics, storm sewer sizing, and hydraulic grade line calculations.

The increased stormwater runoff due to urbanization needs to be controlled to protect the downstream areas from flooding. Detention basins are often used to control the post-development peak flow rates. *Chapter 7* describes the analysis and design of flood protection detention basins. In addition, infiltration practices are covered, including infiltration basins, infiltration trenches, dry wells, and porous pavements.

The quality of stormwater is also impaired due to urbanization as addressed in *Chapter 8*. Single-event pollutograph calculations are presented considering both the impervious and pervious areas of an urban watershed. Also, several methods, including the Environmental Protection Agency (EPA) and USGS procedures and the simple method, are presented to predict the annual pollutant loadings in urban stormwater runoff.

Chapter 9 describes how the quality of urban stormwater runoff can be enhanced using various best management practices (BMPs). BMPs covered include extended detention basins, retention basins, water quality trenches, sand filters, stormwater wetlands, and grass swales. The National Stormwater BMP Database is introduced and referenced.

Chapter 10 introduces two of the most frequently used hydrologic computer models, the Corps of Engineers' HEC-HMS model and the EPA's SWMM model. The chapter begins with a brief modeling overview. Then the model structure and features are covered along with the technical capabilities. A detailed example problem is provided for both computer models along with a discussion of the model results and error checking.

A variety of both physically based and empirical methods developed by a number of different organizations and individuals is presented throughout the book. Physically based equations are dimensionally homogeneous, and they are valid for any consistent system of units. In a consistent unit system, we can use any units of length, time, and force we wish as long as we use them consistently. In other words, if we select *meter* as the length unit, *second* as the time unit, and *newton* as the force unit, all the depths involved will be in *meters*, areas in *square meters*, volumes in *cubic meters*, velocities in *meters per second*, discharges in *cubic meters per second* (cms), and pressures in *newtons per square meter*. The empirical equations, generally, are not dimensionally homogeneous. Many of these equations employ mixed units, such as *acres* for area and *cubic feet per second* (cfs) for discharge. The coefficients and the parameters involved in empirical equations are specific to the unit system used. Therefore, the applicable units are clearly indicated in the text for all the empirical equations. Where feasible, different values of the empirical coefficients and parameters are also provided in multiple unit systems.

PROBLEMS

1. Obtain some references (other than this textbook) on the topic of urban stormwater hydrology or urban stormwater management. Based on these references, identify the factors that lead to hydrologic (i.e., rainfall-runoff) changes when a watershed is urbanized. Describe the changes and comment on their importance.

2. Many governmental agencies collect and distribute hydrologic and environmental data that are useful to those of us working in the field of urban stormwater hydrology. Perform an Internet search to obtain web addresses for the following: United States Geologic Survey (USGS), National Weather Service (NWS), Environmental Protection Agency (EPA), United States Army Corps of Engineers (USACE), United States Bureau of Reclamation (USBR), and Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service, SCS). Browse the home pages of these agencies to become acquainted with the information they collect and make available to the public.