Green Stormwater Infrastructure
Fundamentals and Design

Allen P. Davis
William F. Hunt
Robert G. Traver

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To our families and to creating a better earth for our children and grandchildren.

Contents

Preface

The intention of the authors is to present the fundamentals of green urban stormwater infrastructure from an engineering design and performance analysis perspective. This book is intended to be used as a textbook in senior-undergraduate and first-year graduate courses in water resources/environmental engineering. It is also envisioned to be a reference for practicing engineers and other water/environment professionals. The book focuses on novel stormwater control measures (SCMs) and related technologies for the reductions of detrimental impacts from urban stormwater. Stormwater challenges have risen in importance as clean water focus has shifted from point to non-point source pollution as a source of water impairments. Stormwater also becomes part of the "one water" focus on long-term sustainable urban water. Many novel SCMs are nature-based and are considered as part of a "green infrastructure" approach that includes bioretention, vegetated swales, vegetated filter strips, green roofs, pervious pavements, water harvesting, and wetlands.

It is expected that users of this book would have had a course in engineering hydraulics/hydrology and some exposure to environmental engineering treatment processes and water quality. It is also complementary to graduate surface water hydrology and traditional water and wastewater treatment engineering. While written with an engineering focus, nonengineers such as landscape architects, planners, and environmental scientists should find the text useful. Specific attempts have been made to integrate both English (US customary) and metric units throughout the book.

The initial chapters provide background information on urban hydrology, water quality, and stormwater generation and characteristics. The preponderance of the book focuses on stormwater control and improvement via a suite of different green infrastructure technologies and techniques. Within this context, background information on engineering unit processes for affecting the water balance and improving water quality are presented. The evolving challenge of setting and meeting stormwater control metrics is discussed. The latter chapters provide specific details on categories of SCMs; topics such as selection, design, performance, and maintenance are presented in detail. SCM selection, treatment trains, and climate change are included as a final chapter. This text provides a baseline as this topic is a rapidly changing field.

About the Authors

Allen P. Davis, Ph.D., P.E., D. WRE, F.EWRI, F.ASCE, is the Charles A. Irish Sr. Chair in Civil Engineering and Professor in the Department of Civil and Environmental Engineering and Affiliate Professor in Plant Science and Landscape Architecture at the University of Maryland, College Park, MD. He is the Editor of the *ASCE Journal of Sustainable Water in the Built Environment*.

William F. Hunt III, Ph.D., P.E., D. WRE, is a William Neal Reynolds Distinguished University Professor and Extension Specialist in the Department of Biological and Agricultural Engineering at the North Carolina State University, Raleigh, NC. He is the leader of the Stormwater Engineering Group at NC State.

Robert G. Traver, Ph.D., P.E., D. WRE, F.EWRI, F.ASCE, is a Professor in the Department of Civil and Environmental Engineering at Villanova University, Villanova, PA, and former Edward A. Daylor Chair in Civil Engineering. He is the Director of the Villanova Center for Resilient Water Systems and the Villanova Stormwater Partnership.

Collectively, the authors have 90 years of research, education, and outreach experience encompassing the topics covered in this book. They have built, maintained, and monitored hundreds of SCM research practices and have authored over 300 refereed journal articles, including several together. They have presented research results all over the world, hosted international conferences, while also helping address state and local water challenges. The authors love each other, the field in which they work, and the people with whom they partner.

Acknowledgments

The authors are grateful for the contributions of many, many colleagues in the various research projects that have led to many subjects of this text. These include students, post-doctoral researchers, and faculty colleagues. We also thank the various agencies that supported, and continue to support and promote, green stormwater infrastructure research.

About the Companion Website

This book is accompanied by a companion website which includes a number of resources created by author for instructors that you will find helpful.

www.wiley.com/go/davis/greenstormwater

The Instructor website includes answers to the end-of-chapter problems

Please note that the resources in instructor website are password protected and can only be accessed by instructors who register with the site.

1

Introduction to Urban Stormwater and Green Stormwater Infrastructure

1.1 Population and Urban Infrastructure

Human population continues to increase in most areas of the world, including developed countries such as the United States. Two of the basic needs of humans are shelter and community. As we have progressed over the millennia, the ideas of shelter and community have evolved, first from simple villages to larger cities. More recently, these populations are shifting, generally from rural and inland areas to the coasts, while residents of inner cities are migrating to less dense suburban development. Frequently, the result is the consumption of pristine and agricultural land at rates disproportionately greater than population growth. As part of the development process, natural vegetation is replaced by lawn or pavement, soils are disrupted and compacted, pipes replace natural water courses, and the native topography is smoothed. Even in areas of urban redevelopment, frequently the impervious footprint increases as the living infrastructure becomes larger (Boorstein 2005; Hekl and Dymond 2016; MacGillis 2006).

Our past and current land development practices rely heavily on the use of impervious area infrastructure (materials that cover the ground and do not let water infiltrate down into the ground as it would in an undeveloped area) and piped systems. Large-area rooftops for homes and garages, highways, sidewalks, wide driveways, and generous patios are all desired attributes of increasingly affluent (sub)urban areas. Commercial and institutional properties provide for similar large impervious infrastructure and ample (if not excessive) parking. This urban network has replaced lands that were once undeveloped, such as forest, meadow, or open plains.

Rain that falls on developed areas is transported via impervious conveyance systems rapidly away from the original surface contact point, typically being discharged into the nearest waterway. This impervious area, coupled with a drainage system that accelerates the movement of runoff, vastly alters the water balance in the urban system. A variety of problems, including flooding, stream damage, loss of aquatic habitat, and significant downstream water body degradation, are the result. The amount of urbanization and related impervious area created has, and continues to, expand in many areas as demonstrated in Figure 1.1 for the greater Las Vegas area.

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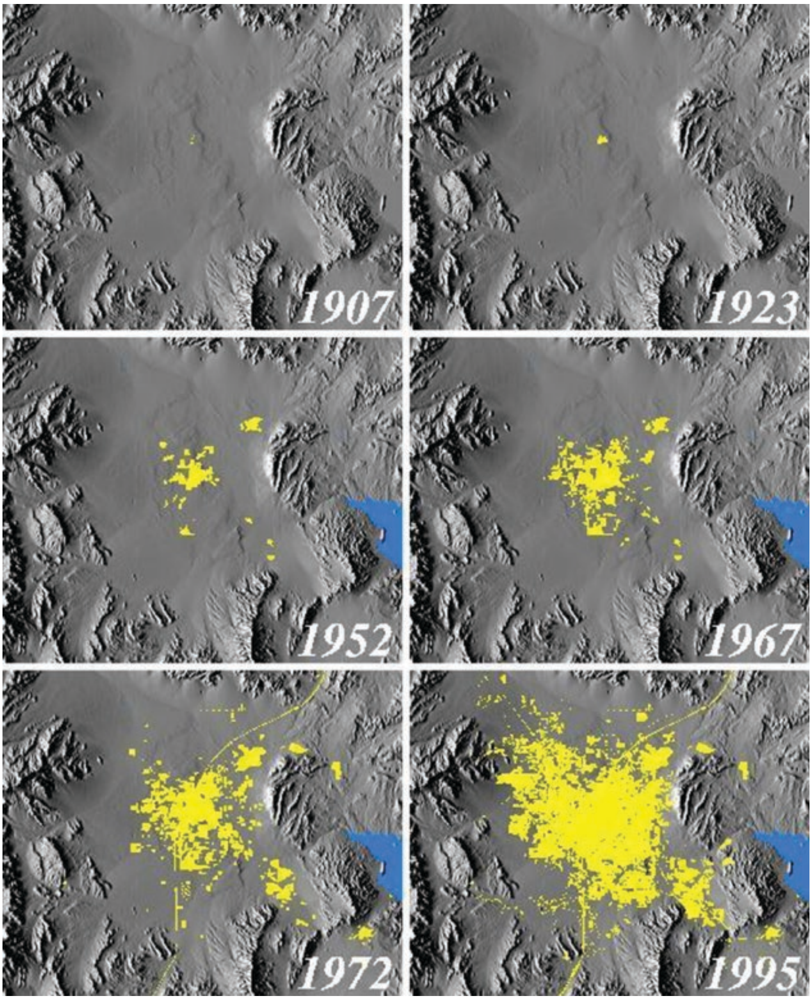

Figure 1.1 Spatial Patterns and Rates of Change Resulting from Urbanization of the Las Vegas Areas. (Credit: US Geological Survey).

1.2 Impacts of Urbanization

Our cities, towns, and villages, and the transportation networks that connect them, all rely on impervious infrastructure. Rooftops, roadways, sidewalks, driveways, parking lots, basketball and tennis courts, and patios all direct rainfall rapidly to their periphery, eliminating the natural runoff reduction and filtration of the vegetated systems that have been replaced.

Figure 1.2 shows the water balance around areas with different levels of urban development. In the undeveloped lands (humid regions), about half of the annual incoming water via rainfall infiltrates, supplying both shallow and deep groundwater. Another large fraction of this volume is evaporated from the soil and vegetation and transpired through the leaves of the vegetation, the combined processes known as

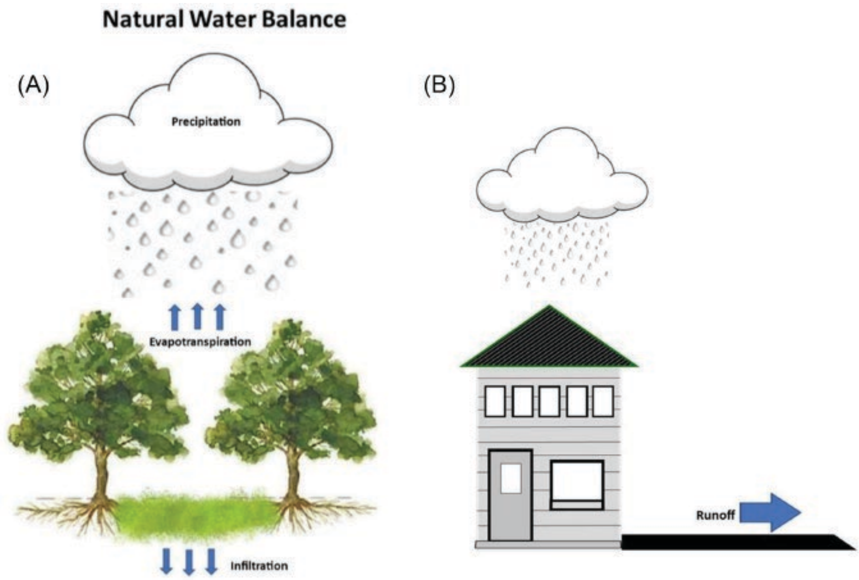

Figure 1.2 Water Balances for Different Land Use Conditions: (A) Natural Water Balance Showing Primary Water Pathways of Evapotranspiration and Infiltration and (B) Urban Water Balance Includes Runoff from Impervious Surfaces.

evapotranspiration (ET). This leaves only a small fraction of the incoming rainfall to become surface runoff.

As the amount of development increases within an area, so does the amount of impervious area. The vegetated land area available for the infiltration and ET of runoff becomes increasingly small. In highly urbanized areas, the water balance changes drastically, as shown in Figure 1.2B. Infiltration and ET are now greatly reduced. The bulk of the incoming rainfall now is converted to surface runoff, which must be responsibly managed so as to not to create public safety and health concerns, and to protect our waterways and water bodies from environmental problems.

Environmental impacts of land development are well known and additional details on these impacts continue to be forthcoming (Booth 2005). The increased volume and flows of stormwater runoff from urbanized areas, coupled with impaired water quality and increased temperature, amplify the magnitude and increase the probability of flooding, decrease stream baseflow, degrade downstream river channels, adversely affect the quality of receiving waters, and impact stream ecology (e.g., Walsh et al. 2005; Wang et al. 2003). High sustained flow rates (not just peaks) are associated with accelerated stream bank erosion and gully formation (Figure 1.3). Elimination of stream baseflow in headwater areas by eliminating rainfall infiltration can greatly impact downstream ecology and ecological processes (Sweeney et al. 2004). Loss of biological nutrient cycling processes in small streams will adversely impact water quality in downstream areas (Peterson et al. 2001).

While certainly flooding occurs with or without urbanization, the changes to the land increase the frequency and magnitude of such events, magnifying the impact to the local waterways. Figure 1.4 shows the great increase in amplitude in flow rate from