RESEARCH IN LANDSCAPE AND ENVIRONMENTAL DESIGN

LANDSCAPE PERFORMANCE

IAN MCHARG'S ECOLOGICAL PLANNING IN THE WOODLANDS, TEXAS

BO YANG

Landscape Performance

Ian McHarg's ecological planning approach has been influential since the 20th century. However, few empirical studies have been conducted to evaluate the performance of his projects. Using the framework of landscape performance assessment, this book demonstrates the long-term benefits of a renowned McHargarian project (The Woodlands town development) through quantitative and qualitative methods.

Including 44 black and white illustrations, *Landscape Performance* systematically documents the performance benefits of the environmental, social, and economic aspects of The Woodlands project. It delves into McHarg's planning success in The Woodlands in comparison with adjacent Houston developments, which demonstrated urban resilience after Hurricane Harvey in 2017. Lastly, it identifies the ingredients of McHarg's ability to do real and permanent good.

Yang also includes a number of appendices which provide valuable information on the methods of assessing performance in landscape development. This book would beneficial to academics and students of landscape and planning with a particular interest in Ian McHarg.

Bo Yang is an associate professor of landscape architecture at the University of Arizona, USA.

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Ian McHarg's Ecological Planning in The Woodlands, Texas

Bo Yang

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I dedicate this book to my family
Shujuan, Jon, and Haoran

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Preface

Landscape performance assessment posits a frontier in research and practice, with the goal of quantitatively demonstrating the benefits of built landscape projects. It encourages a healthy partnership of diverse stakeholders. The premises are to improve research validity and to boost confidence in assessing performance of future, similar projects.

Ian L. McHarg is one of the pioneers who established performance goals for his projects and integrated respective goals throughout the planning and design processes. McHarg's 1969 seminal book *Design with Nature* and his ecological planning approach have been influential since the 20th century. However, few empirical studies exist that quantitatively evaluate the performance of his projects. As an evolving field, ecological planning presents uncharted territory that requires rigorous scholarly work. In particular, the long-term benefits of McHarg's approach warrant assessment.

This book applies the innovative analytical framework of landscape performance assessment to examine one of McHarg's most successful built projects – The Woodlands town development in Texas, USA. The author's objectives are to: (1) demonstrate the long-term landscape performance benefits of this exemplary project (Is McHarg right?), (2) review the history of McHarg's ecological planning theory and methodology (How can McHarg do it?), and (3) identify the challenges and pitfalls in adopting McHarg's approach uncritically in today's practice (How can we adapt this approach?). Specifically, this book systematically documents and analyzes the performance of The Woodlands ecological plan from environmental, social, and economic aspects, as well as considering the challenges to maintain the original high-performing designs.

PART I provides an overview of where landscape performance scholarship stands today and subsequently introduces the forerunner, Ian McHarg. PART II introduces one of the current leaders in this enterprise, Landscape Architecture Foundation, and its initiatives on landscape performance, followed by further assessments of the social and economic benefits. PART III elaborates on The Woodlands project performance, pulling together empirical studies that assessed its multifaceted benefits and metrics. PART IV further describes the project's performance post-McHarg after an ownership change. This section compares the performance of the early- and later-constructed phases. PART V explores the genesis of McHarg's ecological wisdom as epitomized in The Woodlands planning success. The book closes with The Woodlands project's contemporary relevance and implications for urban resilience.

In August 2017, catastrophic Hurricane Harvey dumped in excess of 50 inches (1,270 mm) of rainfall in southern regions of Texas. With 9 trillion gallons of water released in two days, a large area of Greater Houston was paralyzed. The Texas Department of Public Safety estimated that more than 185,000 homes were damaged and 9,000 homes were destroyed. In fact, the Houston area had experienced several significant storms in 1979, 1994, and 2017, all of which exceeded 100-year levels. Houston and the suburbs of Oak Ridge North and Timber Ridge, which are adjacent to The Woodlands, were awash during these events, while The Woodlands, 43 km north of Houston, sustained minimal flooding during most of these events, with relatively minor impact during Harvey. In particular, the early-constructed subdivision villages that most closely followed McHarg's approach were unscathed. To a large extent, the sharp contrast could be attributed to the comprehensive ecological plan implemented in The Woodlands, which is lacking in Houston. When Houston communities look for examples for recovery, The Woodlands could help reshape the way future communities are built or rebuilt.

Additionally, the book synthesizes new paradigms that carry forward McHarg's ecological wisdom and his spirit for urban resilience. Today, The Woodlands presents a global model of stormwater management and design for resilience. It remains a living laboratory, and undoubtedly a showcase of the U.S. Environmental Protection Agency's low-impact development and green infrastructure proposals.

This book is one of the first to provide an overview of the current status of landscape performance research and practice. It reviews major scholarship endeavors, policy requirements or institutional mandates, and creative collaborations of academic and industry partners in this enterprise. Equally important is that the book offers a robust, longitudinal, and quantitative assessment of McHarg's ecological planning approach through the lens of landscape performance. Most significantly, it attests to McHarg's approach as being efficacious and cost-effective. The tactics that McHarg proposed are actionable and meaningful. Considerable literature exists on The Woodlands' landscape performance in various articles, books, reports, and gray literature. This book compiles these numerous pieces of information and presents them in one volume. Likewise, the mixed methods and multiple data sources presented here would be inspirational for future project assessments.

The book is written for academic researchers and practitioners who are interested in landscape performance and land stewardship in general. This book is also recommended for landscape architecture, planning, urban design, and architecture faculty and students who seek an in-depth understanding of McHarg's ecological planning and contemporary relevance of his work. Students, professionals, and policy makers in related fields, such as city and regional planning, landscape ecology, human ecology, and urbanism, who seek talking knowledge as well as working familiarity with McHarg's theory and methodology would benefit from this book.

Finally, the book responds to the long-standing sentiment that landscape architects' contribution to society's sustainability agendas is inconsequential – The Woodlands project illuminates the significant contributions from the landscape architecture profession, such as in the field of ecological planning.

Bo Yang, PhD
The University of Arizona
Tucson, Arizona, USA

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Part I

Introduction to landscape performance

1 Overview of landscape performance scholarship

Introduction

It is commonly accepted that the landscape architecture discipline needs original research to support its growth and to improve its scientific rigor. Landscape architecture cannot rely on other disciplines to generate new knowledge, and recent work has critiqued the long-standing tendency to consider ideas generated in other disciplines to be of a higher status (Deming & Swaffield, 2011; Francis, 2001; Murphy, 2005).

Scholars contend that it is imperative to disseminate the theory and expertise of landscape architecture in high-quality venues in order to achieve a sustained growth of the profession, and further, to make meaningful contributions to society (Forman, 2002; Milburn & Brown, 2003). In this sense, scholarly publications, especially by designers and planners, are valuable and impactful. High-quality scholarly works can elevate the stature of the profession. "Long-term monitoring and evaluation of completed projects," for instance, was suggested by Forman as one promising area that can benefit from high-quality research (Forman, 2002). Similarly, other scholars suggested the importance of post-occupancy evaluation of built works (Brown & Corry, 2011; Preiser, Rabinowitz, & White, 1988). This strategy can help landscape architecture research approach the rigorous research methods utilized in other fields such as medicine, whose high societal impact and reputation are a result of the discipline's constant reflecting on its success and failure in practice, and more importantly, documenting empirical evidence to support change or suggesting direction (Brown & Corry, 2011).

An important question remains unanswered: "How can the client, designer, and user feel confident that designed landscapes will perform the way they are intended, or at even higher levels in the future?" To put it another way, "How can designers, planners, allied professionals, decision makers, and the general public know, ascertain or validate that a high-performing landscape has been created that will provide the same benefits or even more for future generations?" (Ndubisi, 2013).

This question could be answered through *landscape performance* – a research frontier proposed by the Landscape Architecture Foundation (LAF) in 2010.[1] Existing sustainability assessment and rating systems, such as the Leadership in Energy and Environmental Design (LEED, U.S. Green Building Council, 2009) and the Sustainable Sites Initiative (SITES™) focus on evaluating design strategies employed *before* the project is constructed. Landscape performance research complements these systems and further improves the understanding of post-construction performance and subsequent benefits.

The past several years witnessed a strong wave of activities in promoting landscape performance research and evidence-based practice. The following sections review scholarship development, and expectations or requirements of landscape performance by the LAF, Council of Educators in Landscape Architecture (CELA), Council of Landscape Architecture Registration Board (CLARB), Landscape Architectural Accreditation Board (LAAB), U.S. Environmental Protection Agency (U.S. EPA), and American Society of Landscape Architects (ASLA). Ongoing research activities in China and other select undertakings on this topic in North America are also introduced.

Landscape Architecture Foundation (LAF)

The Landscape Architecture Foundation is a non-profit organization established in Washington, DC in 1966 by influential leaders in the discipline. Although the concept of performance assessment on landscapes is not new, it was LAF that first put forth the assessment framework, as well as establishing an innovative partnership with academia and industry.

The LAF defines *landscape performance* as "the measure of efficiency with which designed landscape solutions fulfil their intended purpose and contribute to sustainability" (LAF, n.d.; Ndubisi, Whitlow, & Deutsch, 2015). In 2010, the LAF launched the *Landscape Performance Series* (LPS) to demonstrate project post-construction performance. Its purpose is to "fill a critical gap in the marketplace and make the concept of *landscape performance* and its contribution to sustainability as well known as *building performance* is today."[2] LPS is an online platform that provides methods, tools, and resources to quantify landscape benefits and to highlight sustainable design solutions.

The LAF has a premier grant program that supports the LPS, called the Case Study Investigation (CSI). CSI sponsors collaborations between academic researchers and professional firms. Each year, five to ten research teams composed of landscape architecture faculty members, research assistants, and design firms are selected from across the U.S. and abroad. The CSI grant program was officially launched in 2011 and it is expected to continue into the future. More than 50 Research Fellows have participated in the CSI programs from 2011 to 2018 (see Appendix 1). As of this writing, there are approximately 110 case studies published on the LPS website after the peer-review process. In addition to the CSI research grant, the LAF offers Education Grants to university faculty to support curriculum development that integrates landscape performance assessment.[3] Appendix 2 presents education grant recipients and their course titles.

The LAF also collaborates with leading landscape architecture firms to provide free distance learning opportunities to practitioners on how to conduct performance assessment in professional practice.[4] More information about landscape performance can be accessed at (https://landscapeperformance.org/). For additional information regarding LAF's research and scholarship initiatives, visit https://lafoundation.org/.

Council of Educators in Landscape Architecture (CELA)

The Council of Educators in Landscape Architecture (CELA) is the international organization that "encourage, support and further education in the field of landscape architecture specifically related to teaching, research, scholarship, and public service" (CELA, n.d.). It currently has more than 130-member schools in the continents of North America, Europe, Australia, and Asia (www.thecela.org).

In 2012, CELA responded to the rapidly growing area of landscape performance through opening a new CELA conference track, Landscape Performance, to document and disseminate scholarship in this area.

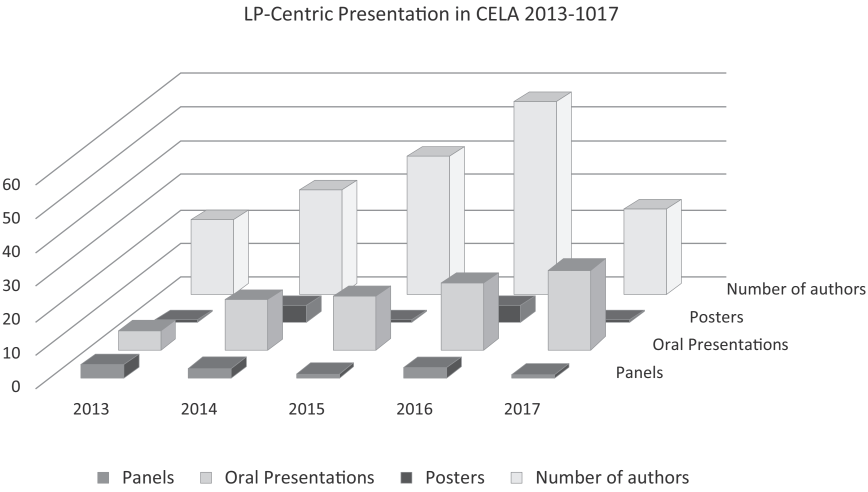

Figure 1.1 Scholarly contributions to the Landscape Performance (LP) track of the Council of Educators in Landscape Architecture (CELA) annual conference 2013–2017.

Figure 1.1 presents landscape performance-centric contributions to the annual CELA conference from 2013 to 2017. A robust growth trend is evident. Since 2013, a number of studies have been published through CELA peer-reviewed venues or other journals, such as Luo and Li's article on the relationships of the three benefit categories (Luo & Li, 2013), Myers' case study on multifunctional landscapes (Myers, 2013), Yang and colleagues' paper on economic benefits of streetscape projects (Yang, Zhang, & Blackmore, 2014), and several other studies, reflective essays, reviews, and books (e.g., Burke, 2017; Canfield & Yang, 2014; Canfield et al., in press; Dai & Li, 2015; Ellis, Kweon, Alward, & Burke, 2015; Li, Dvorak, Luo, & Baumgarten, 2013; Ndubisi et al., 2015; Thoren, 2014; Yang, Li, & Binder, 2016). An additional six articles (Li, Dvorak, Luo, & Manskey, 2014; Luo & Li, 2014; Ozdil, Modi, & Stewart, 2014; Xu, Wu, & Ma, 2014; Yang, Lin, & Zhao, 2016; Yu & Walliss, 2017) have been published in CELA's peer-reviewed *Landscape Research Record*. Previous issues of *Landscape Research Record* are available from (http://thecela.org/landscape-research-record/).

Landscape Architectural Accreditation Board (LAAB)

The Landscape Architectural Accreditation Board (LAAB) is the official accrediting body for the first professional programs in landscape architecture in the U.S. There are seven standards that landscape architecture programs shall address in the Self-Evaluation Report submitted to LAAB prior to an accreditation visit. In 2016, in LAAB's latest *Accreditation Standards for First-Professional Programs in Landscape Architecture* (LAAB, 2016), landscape performance was specified as a new requirement.

Standard 3 Professional Curriculum requires that program curriculum be guided by the coverage of (but not limited to) nine topic areas (e.g., History, theory, philosophy, principles, and values; Design processes and methodology, etc.). In particular, the topic area of Assessment and Evaluation contains (1) site assessment, (2) pre-design analysis, (3) *landscape performance*, (4) post-occupancy evaluation, and (5) visual and scenic assessment.

As a result, landscape architecture programs, including all bachelor's and master's level programs that are scheduled for accreditation reviews since fall 2017 are subject to this new requirement on "landscape performance." The expectation is that "Future landscape architects must be able to assess and communicate the environmental, social, and economic impacts of design solutions" (LAF, 2016).

Appendix 3 presents Standard 3 Professional Curriculum. The full version of the 2016 LAAB Accreditation Standards can be accessed at (www.asla.org/uploadedFiles/CMS/Education/Accreditation/LAAB_ACCREDITATION_PROCEDURES_March2016.pdf).

Council of Landscape Architecture Registration Board (CLARB)

The Council of Landscape Architecture Registration Board (CLARB) administers the Landscape Architect Registration Examination (L.A.R.E.) and has its licensure boards across the U.S., Canada, and Puerto Rico. The L.A.R.E. exam accesses candidates' ability to protect the public's health, safety, and welfare. The exam currently includes four sections: Section 1 Project and Construction Management, Section 2 Inventory and Analysis, Section 3 Design, and Section 4 Grading, Drainage, and Construction Documentation.

Performance assessment is a required component communicated throughout. For instance, Section 1 covers the subject areas of (pre-) project management, bidding, contract, maintenance, and other legal aspects of the profession. According to the 2017 L.A.R.E. Reference Manual, "collect and analyze performance metrics" is a subject area listed in Section 1 (CLARB, 2017, p. 7). Likewise, in other sections – Section 4 in particular – prospective licensees are expected to assess multiple aspects of project performance, such as using the Rational Method for stormwater runoff calculation and evaluating grading plan scenarios with respect to cut and fill balance.

The 2017 L.A.R.E. Reference Manual is available at (www.clarb.org/docs/default-source/take-the-exam/lareorientationguide.pdf?sfvrsn=4).

U.S. Environmental Protection Agency (U.S. EPA)

Since 2012, the U.S. Environmental Protection Agency's (U.S. EPA) Office of Water has been managing the annual Campus RainWorks Challenge design competition. Colleges and universities in the U.S. and its territories are eligible to participate. The EPA encourages participation from both undergraduate and graduate students, and favors interdisciplinary team projects. The goal of the competition is to showcase green infrastructure (GI) practices in stormwater management on campus. Projected GI performance benefits are required to be assessed at the environmental, economic, and social categories in the competition submission. This assessment framework resembles that of LAF's CSI grant program.

There are two submission categories defined by the EPA: Demonstration Project and Master Plan. For both categories, performance assessment is a high-stake evaluation criterion; in fact, it consists of the highest percentage of evaluation points. For instance, in the Demonstration Project category, submissions can obtain a maximum of 100 points, broken down into the 11 criteria: documentation (10 points), *performance (20 points)*, resiliency (5 points), innovation and value to campus (15 points), interdisciplinary collaboration (10 points), likelihood of implementation (5 points), financial viability (5 points), community engagement (5 points), maintenance (5 points), quality of graphics (10 points), and video presentation (10 points) (U.S. EPA, 2017, p. 10).

In the Master Plan category (maximum score of 100), the criterion of performance assessment also contains the highest points (20 points). Description of the "Performance" criterion is the same for both categories, and is listed as follows:

> Performance (20 points) (same for Demonstration Project category and Master Plan category)
>
> - Will the design retain and treat stormwater runoff on site (e.g., through infiltration, evapotranspiration, or harvest and use) to improve water quality?
> - Will the design address multiple water resource goals (e.g., water conservation, flood mitigation, groundwater recharge, water harvesting and use, water reuse)?
> - Is the predicted performance quantified and supported by appropriate modeling and calculations? Calculations should include the design storm managed and/or the annual reduction in runoff volume.

See 2017 competition Request for Proposal (www.epa.gov/sites/production/files/2018-01/documents/competition_brief.pdf) for the judging criteria (p. 10 for Demonstration Project criteria, and p. 12 for Master Plan criteria) (U.S. EPA, 2017). Previous winning submissions can be retrieved from www.epa.gov/green-infrastructure/2017-campus-rainworks-challenge and www.epa.gov/green-infrastructure/campus-rainworks-challenge-0.

American Society of Landscape Architects (ASLA)

The American Society of Landscape Architects (ASLA) bestows awards to the highest accomplishments in the profession on an annual basis. ASLA collaborates with LAF and CELA on the Research Category of the Professional Awards. Although the awards criteria of the Research Category currently do not specifically require landscape performance, projects that emphasize performance outcomes are received more favorably, as shown in recent years' winning entries.

In 2016, the Research Category conferred one Honors Award to Andropogon Associates, for a park project on the University of Pennsylvania campus. The project, entitled "Weather-smithing: assessing the role of vegetation, soil, and adaptive management in urban green infrastructure performance," exemplifies the success of green stormwater infrastructure (GSI) through a long-term monitoring and assessment. Empirical results showed that, compared with predictions done by engineering models, the integrated GSI system tripled the capacity in managing stormwater.

The implication is perhaps more resounding that, as the Awards Jury commented: "They built research into the design process. This project is unique in that respect." In addition, "the process clearly laid out so it can be replicated and applied by other landscape architects” (www.asla.org/2016awards/170435.html). Details of this project can be found at the project link above.

Additionally, in 2017, the ASLA presented five awards in the Research Category (www.asla.org/2017awards/), with three of them emphasizing performance evaluations, including a green roof project in Lincoln, Nebraska, resilience assessment of cultural landscapes under climate change in the Pacific West Region, and water quality improvements through greenways for the Los Angeles River. Quantitative and qualitative procedures toggled seamlessly.

For instance, Richard Sutton’s project, entitled “Seeding Green Roofs for Greater Biodiversity and Lower Costs,” presents a controlled experimental design that examined a suite of materials and techniques to improve the use of native grasses on green roofs. Innovative seeding procedures and techniques were tested to enhance installation, reduce costs, expand biodiversity options, and, at the same time, meet the industry coverage standard. Details of this project are available at www.asla.org/2017awards/298372.html.

Landscape Performance Scholarship in China

As described in the aforementioned initiatives and activities, the past few years have witnessed an exponential growth in landscape performance research in the U.S. and other parts of the world, such as Europe, Australia, and Asia.

Participation in the LAF grant program

Chinese scholars are particularly active in landscape performance research. For the two major grant programs offered by the LAF (CSI and Education Grant), researchers with Chinese nationality were awarded seven times, followed by Turkey (3), Canada (2), and Australia (1) (see Appendices 1 and 2 for details).

National Natural Science Foundation of China (NSFC) support

Researchers in mainland China have received significant funding support in the 2017 and 2018 fiscal years from the National Natural Science Foundation of China (NSFC). Research funds at several million RMBs were invested to support projects that collect empirical data on landscape performance.

As one of the first awardees of performance research, Yin and colleagues (Yin, 2017) at Huazhong University of Science & Technology (HUST) utilized project sites that examine vegetation performance in treating stormwater, in least-used public spaces beneath urban viaducts. The research team assessed the effectiveness of different planting designs for stormwater quality, and how the underutilized spaces can provide social benefits to adjacent communities (Yin, Wang, & Wang, 2018).

Lin and colleagues (Lin, 2017) at South China University of Technology also targeted the less tangible category of social benefits. Their project goals included developing metrics and assessment methods to evaluate landscape performance of urban comprehensive parks in the Pearl River Delta, one of the most populous regions in China. The study would offer innovative ways for social benefits assessment and help people better understand the value that urban comprehensive parks can provide.

A handful of projects examine the multifunctional benefits provided by park and lake systems. These include:

- Tao and colleagues (Tao, 2018) at Shanghai Jiao Tong University assess the health benefits of community parks. The research team expects to establish park quality evaluation protocols based on human-health objectives, and to explore optimal design strategies.
- Qiu and colleagues (Qiu, 2018) at Huazhong Agricultural University investigate design strategies and effective regulations that enhance performance of lake parks in a metropolitan area through the coordination of lake and green systems.
- Shen and colleagues (Shen, 2018) at Tongji University assess the multiple values of high-performing stormwater management projects and explore metrics and methods following evidence-based design principles (Shen, Long, & Chen, 2017).

Other funded projects took a truly interdisciplinary approach to enhance metropolitan sustainability. For instance, in light of the growing air quality concerns in major cities in China, Dai's research team (Dai, 2017) at HUST evaluated the correlation of the spatial distribution of urban green infrastructure and the reduction of air pollutants (e.g., reduction of $PM_{2.5}$ and PM_{10}). Field data collection was conducted at urban- and block-scales, coupled with air-quality modeling and simulations. Throughout the process, atmospheric science and transportation researchers collaborated closely with landscape architecture faculty and students. Appendix 4 lists research projects on landscape performance that were supported by the NSFC from 2017 to 2018.

Journal special issue

In 2013, the journal of *Landscape Architecture* (China) published the first special issue of landscape performance (Li, 2015). Seven articles are featured in this special issue, which cover topical areas and development trends in landscape performance (Dai & Li, 2015; Deming, 2015; Ellis et al., 2015; Luo & Li, 2015; Ndubisi et al., 2015; Ozdil & Stewart, 2015; Yang, Blackmore, & Binder, 2015).

In 2018, the journal *Modern Urban Research* collaborated with CELA on a special issue of Urban Stormwater Management Frontiers (Fang, LeBleu, Zhao, Liu, & Yang, 2018; Yang & Fang, 2018). Landscape performance of green stormwater infrastructure is a key aspect in this issue. Also, several authors of this special issue are regular contributors to the CELA Landscape Performance conference track. Appendix 5 is a select list of publications on landscape performance.

Academic conferences

A number of conferences in China have featured landscape performance as their main conference theme or a sub theme. Southeast University (Nanjing, China) for instance, hosts the annual Digital Landscape Architecture (DLA) International Conference.[5] DLA's 3rd conference theme was Landscape Performance (October 14–15, 2017) (www.jchla.com/?Index_News – 1291.html). As of this writing, Guizhou Normal University (Guiyang, China) is collaborating with National Taipei University, University of Washington, Michigan State University, and University of Arizona in hosting the 2nd International Mountain Landscape Architecture Forum (IMLA) in summer 2018. Landscape performance is scheduled as one of the key sessions followed by a round table discussion.

Finally, over the past decade, Cheng and his colleagues in the Department of Landscape Architecture at Southeast University have been conducting landscape performance research at various project sites in Nanjing. The research team focused on using sensor technologies and visualization tools to demonstrated the performance of green stormwater infrastructure.

Other scholarly activities on landscape performance

There are numerous other ongoing activities and initiatives related to landscape performance. The list which follows epitomizes the widespread, encouraging trend observed in industry, academia, and creative partnerships.

- Project commissioned by public and private sectors
    - The U.S. General Services Administration commissioned Professor Christopher Ellis and his research team at University of Maryland to develop a Landscape Performance Report for the Coast Guard Headquarters campus (Ellis & Reilly, 2015).
    - Industry leaders sponsored the LAF on various aspects of the Landscape Performance Series. For instance, the Interlocking Concrete Pavement Institute is in discussion with the LAF on providing technical support for project performance evaluation and on developing education resources through its Foundation for Education and Research (https://landscapeperformance.org/).

- Integrated education/research center
    - Based on a generous donation, Professors Michael Murphy, Scott Shafer, Ming-Han Li, and others at Texas A&M University established the 7.44-acre (3 ha) Schob Nature Preserve. The Preserve functions as an integrated education-research-outreach center that features a whole gamut of low-impact development (LID) strategies and performance assessment initiatives (http://laup.arch.tamu.edu/research/schob-nature-preserve/).
- Other creative collaborations
    - Research teams from Utah State University, Temple University, and Kansas State University worked together to develop a guidebook on landscape performance assessment (funded by LAF). The teams have conducted a content analysis as well as a quality assessment of the published CSI projects. The guidebook provides metrics and methods that are defensible and easy to use by non-experts (https://landscapeperformance.org/guide-to-evaluate-performance).
    - Research teams led by Professor William Sullivan at University of Illinois, Professor Bin Jiang at Hong Kong University, and Professor Chun-Yen Chang at National Taiwan University have been conducting research over the past years on urban landscape designs and associated impacts/benefits for human health and well-being (Jiang, Chang, & Sullivan, 2014; Jiang, Li, Larsen, & Sullivan, 2016).
    - The landscape architecture and planning firm, Design Workshop, Inc., is collaborating with Professor Yi Luo at Texas Tech University to explore the proper procedure and protocols of collecting project baseline data. In addition, the principals Kurt Culbertson and Allyson Mendenhall with Design Workshop have been using Legacy Design®, the firm's philosophy and methodological framework, for performance evaluation for decades (Jost, 2012).
- Other scholarly products and dissemination venues
    - Professor Roxi Thoren at University of Oregon published *Landscapes of Change: Innovative Designs Reinventing Sites* (Thoren, 2014) which features case studies that demonstrate performance benefits.
    - Professors Mary McGuire and Jessica Henson at University of Illinois Urbana-Champaign hosted the Fresh Water Symposium. Central questions in discussion included: how to curb the degradation of performance of major watersheds, and how landscape architects can contribute to regional sustainability (http://conferences.illinois.edu/freshwater/index.html).

Last by not least, integrating performance assessment into design studio instruction has becoming a new norm. In addition to LAAB's accreditation requirement on landscape performance, increasing numbers of oral presentations, posters, and full-paper submissions are received by the Landscape Performance track of the CELA annual conference. Many of these studies are based on project findings from design studios (also see Appendix 2, Landscape Architecture Foundation Education Grant Recipients). At the University of Arizona, for instance, Professor Kirk Dimond frequently demonstrates tactics in design and construction studio courses.

In my own experience at three academic institutions, I have taught courses related to planning, design, and construction, and have covered various aspects of performance assessment. Last but not least, other scholars, particularly those who once participated in LAF's grant programs, have been actively engaging in the scholarship of this area. These scholars have firmly established themselves among the vanguard in this burgeoning area of research.

Notes

1 Established in 1966, the mission of the Landscape Architecture Foundation (LAF) is to support the preservation, improvement, and enhancement of the environment. LAF invests in research and scholarship to increase our collective capacity to achieve sustainability (http://landscapeperformance.org/about-landscape-performance).

2 For more information about the Landscape Performance Series, see www.lafoundation.org/research/landscape-performance-series.

3 Five education grants were awarded in 2014 to support curriculum development that integrate landscape performance assessment (www.lafoundation.org/news-events/blog/2013/12/03/lp-education-grant-recipients/?utm_source=2013-12+LAF+Dec+eNewsletter&utm_campaign=2013-Dec+eNewsletter&utm_medium=email).

4 Webinars on landscape performance assessment are available at www.lafoundation.org/news-events/lp-webinars/practice-based-research/. Attendees can earn Professional Development Hours (PDHs) through the Landscape Architecture Continuing Education System (LA CES).

5 Two international conferences (in 2013 and 2015) were co-hosted by Southeast University in China. China's Digital Landscape Architecture conference has its established counterpart in Europe (www.digital-la.de).

2 Ian McHarg

A pioneer in performance evaluation

Introduction

American ecological planner and landscape architect Ian Lennox McHarg (1920–2001) developed the theory and methodological framework of ecological planning in his influential book *Design with Nature* (McHarg, 1969). The book has been influencing landscape architecture practices worldwide since the 20th century. Ecological science serves as the theoretical core, and interdisciplinary collaboration is a unique aspect of the design process. This process greatly facilitates the establishment of performance benchmarks and allows the opportunity to measure performance outcomes post-construction (McHarg, 1996).

Being a prolific writer on ecological planning, McHarg emphasized the importance of assessing projects' performance benefits with proper documentation. Despite the fact that McHarg was one of the pioneers who proposed performance assessment, few of his projects have been evaluated (McHarg & Steiner, 1998; Thompson & Steiner, 1997). This chapter reviews the relevance of assessing performance benefits in the landscape architecture profession. It suggests that landscape performance would be one way to improve the validity of the ecological planning method and contribute to this evolving field.

Landscape performance and relevance to practice

Landscape architects and planners face imposing challenges today, such as providing resilient landscapes for a changing climate, addressing rapid urbanization, planning adaptations for natural disasters, designing for health and well-being, and performing ecological restoration of degraded urban areas (Heatherington, Jorgensen, & Walker, 2017; Jorgensen, 2014; Jorgensen & Gobster, 2010; Nassauer, Wu, & Xiang, 2014; Steiner, 2014; Xiang, 2017). Landscape architects and urban planners benefit from the accumulation of knowledge and experience from precedents, and post-occupancy evaluation on cases presents a powerful way to inform best practices (Deming & Swaffield, 2011; Francis, 2001; Xiang, 2014. In the era of the Anthropocene, designers seek creative solutions to social-ecological challenges, and which solutions are defensible and informative to a layman audience.

Scholarly documentations and studies on the performance and value of landscape design certainly exist (e.g., Bookout, Beyard, & Fader, 1994; Cheng, 2010; Culbertson & Martinich, 2012; Deming & Swaffield, 2011; Nassauer, 1995, 2012; Ndubisi, 2002, 2008). An expected contribution of the emerging research/practice area of landscape performance is to *quantitatively* demonstrate a project's environmental, social, and economic benefits through a voluminous number of high-quality case studies. Additionally, looking back into the history of the profession, there is no lack of examples that are prominent with respect to doing real and permanent good for the human and nonhuman inhabitants, with performance benefits recognized in various ways and emphasis areas, yet the ingenious solutions they presented are still relevant to today's practitioners. This list may include renowned examples such as the Dujiangyan irrigation system in Sichuan, China (256 BC, by Li Bing), Central Park in New York City (1857, by Frederick Law Olmsted and Calvert Vaux), and the Emscher Landscape Park in Ruhr, Germany (1988, primarily through the International Building Exhibition). Designers of these projects tackled unique planning and design challenges in their time, with a common thread being the adaptive strategies they developed that fit the site's ecological processes and cultural practices.

Another important dimension is that performance assessment opens up an appealing direction for scholarship endeavor in the landscape architecture profession. Compared with other comparable disciplines, scholarly productivity within the field of landscape architecture remains low (Christensen & Michael, 2014; Gobster, Nassauer, & Nadenicek, 2010; Milburn, Brown, Mulley, & Hilts, 2003; Milburn, Brown, & Paine, 2001). To address this issue, recent discussions on landscape architecture research have moved beyond the level of increasing the awareness of research to focusing on offering strategies and actionable agendas (Deming & Swaffield, 2011; Francis, 2001; Johnson & Hill, 2002; LaGro, 1999; Lovell & Johnston, 2009; Milburn & Brown, 2003; Milburn & Brown, 2016; Tai, 2003). For instance, van den Brink and Bruns (2014) offered three types of landscape architecture research and emphasized the importance of research in design.

In *Design with Nature*, McHarg put forth one of the most impactful bodies of knowledge in landscape architecture and planning, in which he synthesized and generalized his experience. As the book title suggests, following nature's lead in planning and design is the wisdom of achieving sustainability. Anthropogenic uses or interventions shall become an integral part of the natural processes. McHarg's expectation on performance assessment was based on the idea that the profession shall bear minimum standards in practice. The demand on standards of care for the client, and for the good of society at large, becomes increasingly higher. As a reliable and reputable profession, landscape architects take the responsibility for public health, safety, and welfare. As the profession evolves, it works for the best interest of landscape architects and planners to articulate the positive, and pervasive benefits of their practice. Performance evaluation thus supports the profession's compelling portfolio of the value and essential contributions to the society.

Additionally, McHarg's design process is a case in point for the ongoing dialogue of making science actionable. Ecological science, in this case, serves as the theoretical core for the ecological planning field. McHarg's process demonstrates how scientific inquiries can be integrated into the design process, and how "design" and "science" complement each other in this process (Nassauer & Opdam, 2008; Opdam et al., 2013; Wang & Li, 2016; Xiang, 2017).

Ecological planning

Five decades is a long period of lifetime for average human beings. For a new discipline, however, after half a century it may still be in its infancy. Ecological planning is such an example. It is an ecology-based approach in land planning. Furthermore, it offers a promising direction in balancing human needs, and land carrying capacities and sustainability (McHarg, 1969; Spirn, 1984; McHarg & Steiner, 1998). Ecological planning embraces the principle of using ecological science as the basis for planning and design (Bergen, Bolton, & Fridley, 2001; Steiner, Young, & Zube, 1988). In practice, ecological planners fuse the science of ecology and the art of planning and design, and mandate that planning and design facilitate ecosystems' functions. Anthropogenic uses superimposed as a result of land use planning shall produce the least amount of interference with ecosystems' natural processes (Zipperer, Wu, Pouyat, & Pickett, 2000; Ndubisi, 2002).

In over 90 projects, McHarg used ecological science to create safe and healthy human settlements (McHarg, 2006a, 2006b). McHarg focuses on the natural, social, and cultural processes and sees design as an iterative process that is largely shaped by the interactions between humans and ecosystems (McHarg, 1969; McHarg & Steiner, 1998).

Similar to other disciplines, tracing the family tree allows the identification of forerunners and prescient masters. Before McHarg, other theorists and practitioners have put forth similar ideas, with the common thread that humans need to respect ecological concerns when satisfying their needs. According to Ndubisi (1997, 2002), the history of ecological planning can be divided into five transitional periods. Key figures and their ideas are presented chronologically in Table 2.1.

Theoretical foundation aside, Steinitz and colleagues synthesized the development of map overlays and put McHarg's contribution in context (Steinitz, Parker, & Jordan, 1976; Woodfin, 1993). But it was McHarg who systematically laid out a roadmap of integrating ecological science into the design process. His process emphasizes the dynamics of fusing ecological knowledge and processes, with the creativity and spontaneity characteristics

Table 2.1 History of ecological planning and design.

Phase	*Period*	*Representative*
Awakening	1830–1910	Ralph Waldo Emerson, Henry David Thoreau, Frederick Law Olmsted Sr., George Perkins Marsh
Formative	1910–1930	Patrick Geddes, Frederick Clements
Consolidation	1930–1940	Lewis Mumford, Aldo Leopold, Henry Cowles
Acceptance	1940–1970	Rachel Carson, Ian McHarg, Eugene Odum
Diversity	1970-present	Carl Steinitz, Frederick Steiner, Forster Ndubisi

(Adapted from Ndubisi, 1997, 2002).

of design. This process further provides a feedback loop that has been widely practiced today. McHarg's work formulates a new framework and a process model which are critical for informing sustainable or even regenerative solutions for planning and design (Ndubisi, 2014; Wang & Li, 2016). For over four decades, this process with its underlying principles has been applied in projects of various scales and focuses (Steiner & Osterman, 1998; McHarg, 2006b; Ndubisi, 2008). Many of the projects were completed by McHarg's team at the University of Pennsylvania, when he served the chair position beginning in 1959 in the Department of Landscape Architecture and Regional Planning.

Although McHarg did a great inspirational pitch for ecological planning in *Design with Nature*, the field remains unfinished. It is an evolving field with fertile grounds for exploration (Ndubisi, 1997, 2002, 2014; Steiner, 2002, 2008). More importantly, it is "an uncharted territory for rigorous scholarly work" (Ndubisi, 2014, p. xviii). Ecological planning holds promises but performance evaluation remains esoteric to practitioners in their ordinary work. For instance, what is the roadmap of conducting performance evaluation? What are the expertise and efforts required in this process? Where are the data sources and, how, and when, to collect data? What are the possible limiting factors or tradeoffs? What about cost? How to isolate the value of landscape projects (environmental, social, and economic aspects) on regional, city, neighborhood, and site scales? In this sense, landscape performance assessment could serve as one way to enhance the rigor and validity of the ecological planning method, and to further contribute to its theoretical framework.

McHarg's method to enhance environmental performance

McHarg's method has been influenced by numerous forerunners, including the Scottish pioneer in urban planning, Patrick Geddes (see Table 2.1). According to Geddes, people need to understand their landscapes ("civic survey"), with the understanding at the regional-scale being paramount (Meller, 2005; Talen, 2005). Focusing on this scale, Geddes proposed a method called "Valley Section," to understand human activities and their relations to nature (Welter, 2002; Steiner, 2008). Influenced by Geddes, McHarg incorporated the understanding of nature into the design process through an "ecological inventory," also known as the "layer-cake" model. As the first step of the process, the inventory includes major environmental variables such as climate, geology, hydrology, limnology, soils, vegetation, and wildlife. It is the same list regardless of the location, size, or purpose of the site (Spirn, 1984, 2000, 2014; Ndubisi, 2002, 2014). These environmental variables are overlayed to assess the site's suitability for a certain type of land use.

Methods and models for ecological planning which were developed prior to 1969, especially between 1961 and 1969, represent the first generation of the Landscape-suitability Approach (LSA) 1 (Ndubisi, 2002). For McHarg, design is a process of co-evolution of human and the site, which can only "be understood through [the site's] physical evolution" (McHarg, 1969, p. 105; Spirn, 2014). Suitability analysis and the use of overlays are inherent features of most of McHarg's projects.

More than 50 years ago when the ecological inventory was done, the state-of-the-art working tools were transparent acetate sheets, aerial photographs, and color markers (Almiñana & Eisenman, 2003; Ndubisi, 2002). These tools were greatly revamped or entirely replaced during the digital revolution. Today, geographic information systems (GIS) and visualization technologies have rapidly increased the efficiency of landscape analysis, and at the same time, allowed more accurate interpretation of environmental data – both are important for a robust design process. With advancements in GIS technologies, for instance, upon generation of the design proposal, projected environmental impacts such as runoff volume, water quality, microclimate, and human comfort zones, and/or policy ramifications can be simultaneously generated. These powerful functions warrant a myriad of design scenarios be tested, compared, and contrasted to seek an optimum fit to the site. Thus, the suitability analysis can be done with greater precision and efficiency, in order to allow intelligent land use decisions to be made.

In 1974, Ian McHarg and team members (notably Narendra Juneja) began to explore performance requirements for Medford Township, New Jersey (Juneja, 1974; Palmer, 1981; Steiner, 2008). McHarg and Juneja's team was based at the Center for Ecological Research in Planning and Design at the University of Pennsylvania. This project became one of the first that investigated the feasibility of establishing performance requirements and benchmarks in planning. Following the analysis of constraints and opportunities, McHarg and Juneja established a framework for performance requirements, which were further proposed to be integrated into the Medford Township plan and zoning ordinances (Juneja, 1974; Steiner, 2008). The plan specified that "[Medford] development could not adversely affect water quality or quantity, vegetation, or wildlife habitat" (McHarg, 1996, pp. 273–285). Social values, in addition to the natural environment, were overlaid to develop performance requirements (Steiner, 2008). This marked the *human*-ecological planning approach characterized in the later cadre of McHarg's projects. The human-ecological planning approach, as demonstrated in Medford, used the natural environment as a model for maintaining social values, marking the Landscape-suitability Approach (LSA) 2.

In other larger, regional-scale studies such as complex river basins of the Potomac and Delaware, McHarg drew analogy between the systematic and interconnectivity of the natural systems with that of the opportunities and constraints presented in the planning process. Particularly, after the assessment of the Potomac basin, McHarg concluded that the "planning process can become overt, explicit, replicable, having the characteristics of a scientific experiment" (McHarg, 1996, p. 328). According to McHarg, an evolution occurred in ecological planning method after these basin-scale studies (McHarg, 1996).

Subsequently, in another renowned project, The Woodlands town development in Texas, McHarg's design process continued with the concept of "scientific experiment" (McHarg & Sutton, 1975). The process presents one of the first of its kind using an Environmental Impact Statement (EIS) as part of the assessment framework for environmental impacts. Quantitative projections were completed using modeling analyses. Also, the overlay method used in The Woodlands showcased the methodological improvements in LSA 2, which integrates social values and processes, also known as the applied-human-ecology method (Ndubisi, 2002, 2014).

Additionally, McHarg was influential outside of landscape architecture and planning fields (Spirn, 1985, 2000; Schnadelbach, 2001; Steiner, 2004). He had the right magic and capability to communicate in layman's language, which persuaded numerous individuals to accept his ideas (Spirn, 2000). His theory and methodology pervaded the National Environmental Protection Agency (NEPA) and then other federal and state environmental management programs (Bass, Herson, & Bogdan, 2001). EIS, as required by NEPA, embraces the principles and method proposed by McHarg, started in the peak era of environmental sensitivity. The early cohort of EIS studies, along with projects described in *Design with Nature* (e.g., Staten Island, Washington DC, Philadelphia) serve as methodological mileposts (Woodfin, 1993).

Being the consummate innovator, McHarg had early involvement with the Landscape Architecture Foundation when it was founded 1966, which organization has been forcefully advocating for sustainability agendas and initiatives, such as landscape performance scholarship in the current discussion. For the past 50 years, LAF has been fulfilling its mission to "support the preservation, improvement and enhancement of the environment" (https://lafoundation.org/about/). The LAF made its debut in *Declaration of Concern* (https://lafoundation.org/about/declaration-of-concern/), put forth by six giants in the field (Campbell Miller, Grady Clay, Ian L. McHarg, Charles R. Hammond, George E. Patton, and John O. Simonds). In another monumental event, the LAF's 50th anniversary, *The New Landscape Declaration: A Call to Action for the Twenty-first Century* came to birth (LAF, 2017). On June 10–11, 2016, more than 750 professionals convened in the LAF Summit in Philadelphia. The call for actions was resounding, both within and beyond the landscape architecture profession, to address grand challenges facing the society today. It was not surprising that McHarg's legacy was illuminated in the Summit. Many presenters were McHarg's followers, or have been heavily influenced by him.

Similar to McHarg's concept of experimenting with performance evaluation, his peers Julius Fabos, Ervin Zube, and other colleagues with the METLAND (Metropolitan Landscape) at University of Massachusetts Amherst comprised another landscape architects group that was actively conducting similar work from 1970 to 2000 (Fabos, 1979, 1995, 2004; Fábos & Gross, 1997; Ndubisi, 2002). Like McHarg's team at Penn, METLAND's work explored suitabilities for all types of development, with the foci expanding to metropolitan landscapes (Fabos, 2004). McHarg's approach can be described as the "landscape approach"; whereas the METLAND's can be characterized as the "parametric approach" (Fabos, 2004). Both approaches are quantitative in nature, with their capacities greatly enhanced in parallel with computer technology advancements (Fábos, 1979, p. 165). PART II reviews recent scholarship development at the LAF which focuses on quantitative assessment of built projects.

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Part II

Recent development of performance assessment

3 Premier research programs

Introduction

The Landscape Architecture Foundation (LAF), founded by visionaries in the discipline in 1966, is on the forefront today promoting research in landscape performance. This chapter introduces LAF's premier research platform and supporting program – the Landscape Performance Series (LPS) and Case Study Investigation (CSI). Under these initiatives, leading landscape architecture firms and academic institutions have been collaborating on studies that quantitatively assess environmental, economic, and social benefits of high-performing landscape projects.

Landscape Performance Series (LPS)

The purpose of LPS is to demonstrate project post-construction performance, with several characteristics elaborated as follows.

- *As an online platform*, LPS provides methods, tools, and resources to quantify landscape benefits and to highlight sustainable design solutions.
- *LPS is not a rating system*, but a venue for the procurement and dissemination of research and best practices pertaining to landscape performance based on built projects.
- *LPS's audience* is not limited to landscape architects. It also targets other audiences such as allied disciplines, non-profit organizations with similar missions, federal and municipal agencies, and corporations with sustainability agendas.

The LPS has four components: Case Study Briefs, Fast Fact Library, Benefits Toolkit, and Collections (https://landscapeperformance.org/). LPS compiles information and innovations from research, professional practice, and student work about landscape performance. Figure 3.1(a) describes the contents of landscape performance assessment, which are the three pillars of sustainability; Figure 3.1(b) illustrates the collaborators of landscape performance research through its supporting grant program CSI; and Figure 3.1(c) shows the research-teaching-practice feedback loop

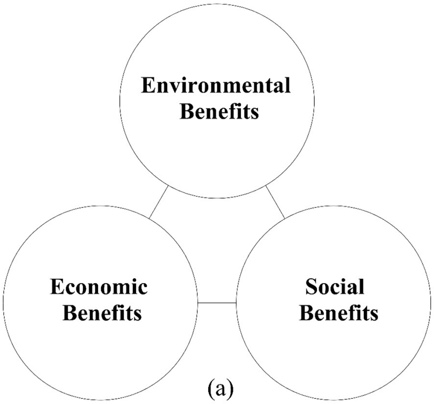


Figure 3.1a Triangulation of relationships in the Landscape Architecture Foundation landscape performance research: (a) contents of assessment.

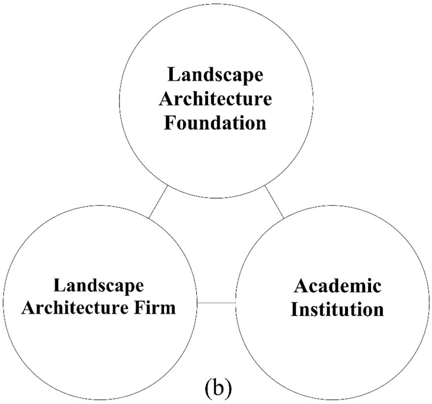


Figure 3.1b Triangulation of relationships in the Landscape Architecture Foundation landscape performance research: (b) participants and collaborators.

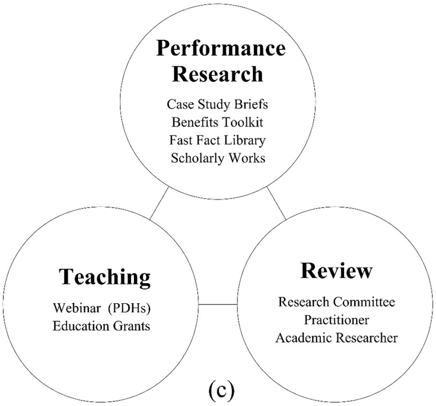


Figure 3.1c Triangulation of relationships in the Landscape Architecture Foundation landscape performance research: (c) supporting system and feedback loop.

and the peer-review process for case study publication. Details on the CSI program are described later.

Case Study Investigation (CSI)

CSI is a grant program that supports the LPS, with case studies published under LPS's Case Study Briefs. CSI sponsors collaborations between academic researchers and professional firms. To participate in the CSI program, faculty-student teams submit proposals with research qualifications, and design firms submit proposals of high-performing built works.

Process

Proposals are reviewed based on quality of built projects, technical merit, expertise, availability of information to document performance, and scientific rigor. Each year five to ten research teams composed of landscape architecture faculty members, research assistants, and design firms are selected from across the U.S. and abroad. In 2010 several pilot case studies were published on the CSI website. In 2011 the CSI program was officially launched, and the grant program is expected to continue into the future. Case study selection balances project type, scale, and geographic location.

The CSI program has been attracting high-profile landscape projects, many of which achieved noteworthy recognitions (e.g., awards from the American Society of Landscape Architects, Urban Land Institute, and International Federation of Landscape Architects). Although a majority of the projects thus far are located in the U.S., the number of international case studies is increasing. Projects from Italy, South Korea, Australia, and China have been studied, many of which tackle significant scales and pressing issues concerning metropolitan sustainability.[1]

Components

There are 24 required components in the CSI case study submission. Major components related to performance outcomes include: (1) Overview, (2) Sustainable Features, (3) Performance Benefits, (4) Cost Comparison, (5) Images, and (6) Methodology documentation. The Overview section is a succinct description of project goals and design intents, and it is expected that performance outcomes would be highly correlated with the original project goals. Two other closely related components are *Sustainable Features* and *Performance Benefits*. Landscape architects are generally more familiar with sustainable design features (e.g., green roof, wetland) and less acquainted with performance benefits.

Examples of design features and possible/expected performance benefits are shown in Table 3.1. Therefore, research efforts are needed to demonstrate the numerical values of performance benefits according to design

Table 3.1 Examples of quantitative performance assessment based on design features (adapted from Landscape Architecture Foundation, 2012).

Design feature	*Expected benefit*	*Quantitative performance measures*
Stormwater planters	Captures and cleans stormwater runoff	Captures and infiltrates 30% of all rain falling on the site
10 new trees	Sequesters carbon	Traps 1,500 lbs of carbon annually in tree biomass
New public park	Increases property value	Increased adjacent property values by 10%
5 new seating areas	Increases social value of space	Increased café patronage by 30% on weekdays and 50% on weekends

features. Table 3.2 provides further examples of evaluated sustainable features and performance benefits detailed in 38 LAF defined performance benefit subcategories. LAF-defined performance benefit subcategories increased from 31 (2011) to 38 (2017). The current list includes 19 subcategories in environmental benefits, 11 subcategories in social benefits, and eight subcategories in economic benefits. Appendix 6 provides a detailed list of these benefits subcategories and the 38 metrics.

Cost Comparison is a showcase of cost savings from sustainable practices (built conditions) compared with traditional practices ("what if" scenario for the same project). Project images are presented as a pair on the case study front page, illustrating the project pre- and post-conditions (Figure 3.2). Alternatively, this pair of images can present sustainable solutions versus traditional appearance. Up to five supporting images are allowed that may include site plans, additional photos, and design diagrams.

The final and perhaps most important section is a detailed *Methodology Document* that includes data sources and calculations for each performance benefit claimed. A wide range of methods have been used in previous CSI projects, such as methods that examine coupled environmental and economic benefits in property value enhancement and water savings (Newman, Sohn, & Li, 2014; Ozdil & Stewart, 2015), urban heat island effect and stormwater quality assessment (Ellis & Reilly, 2015; Ellis, Kweon, Alward, & Burke, 2015), and visual and bioclimatic analyses of residential landscapes (Yang et al., 2015). These methods, along with the corresponding metrics and sample projects, are summarized in a book published by the LAF, *Landscape Performance: A Guidebook for Metric Selection* (Canfield et al., in press).

The Benefits Toolkit on the LPS website provides a "one-stop shop" for online calculation tools and resources (http://landscapeperformance.org/benefits-toolkit). In addition, a number of CSI case studies have employed online calculation toolkits, such as the National Tree Benefit Calculator (www.arborday.org/calculator/index.cfm) which assesses multifaceted

Table 3.2 Project examples of sustainable features and performance benefits in the Landscape Architecture Foundation Case Study Investigation program (adapted from Yang, Zhang, & Blackmore, 2014).

Project Example	*Environmental*																*Economic*					*Social*				
	Land		*Water*				*Habitat*			*Carbon, Energy & Air Quality*			*Materials & Waste*													
	Transportation	Land efficiency/ preservation	Soil creation/restoration	Stormwater management	Water conservation	Water quality	Flood protection	Habitat preservation	Habitat creation/ restoration	Temperature & urban heat island	Air quality	Energy use & emissions	Carbon storage & sequestration	Reused/recycled materials	Local materials	Waste reduction	Property values'	Operation & management savings	Economic development	Job creation	Recreational & social value	Public health & safety	Educational value	Noise mitigation	Food production	Scenic quality/views
Charles City				•		•	•							•				×	×		×					
Park Avenue	•	×		•	×	×		×			•	×		×				•	×		×	×				•
South Grand	•		×	•	×				×			•	•	×		×		•	•		×	•		•		•
Cherry Creek North	×			×	•					•		•		•		×		•	•		×	×				

× Sustainable feature; • Performance benefit

Figure 3.2 Example of *before* and *after* images of Cascade Garden Residence, Colorado.

Adapted from Yang, Blackmore, & Binder (2013). Image credit: "Before" image (Design Workshop, Inc.); "After" image (D.A. Horchner/Design Workshop, Inc.)

benefits of certain tree species, and the Plant Stewardship Index (www.bhwp.org/psi/) which evaluates the overall ecological quality of the site. Appendix 7 summaries these online tools and resources for performance assessment. Further details regarding the supporting databases can be accessed at https://landscapeperformance.org/benefits-toolkit.

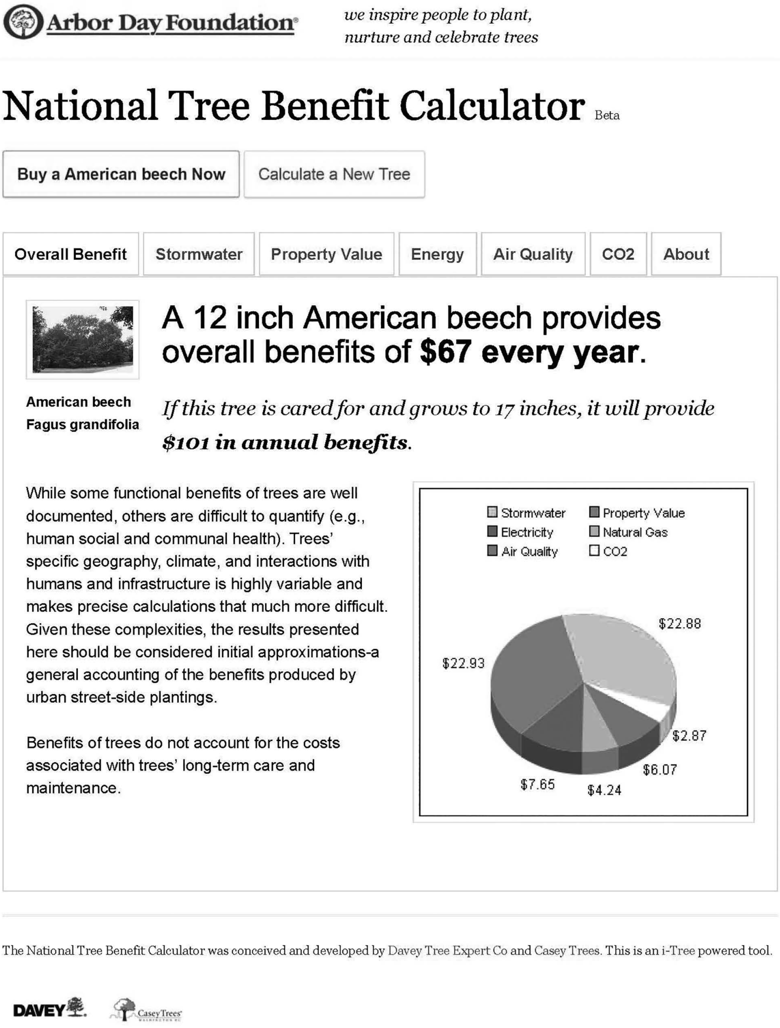
It is worth mentioning that the National Tree Benefit Calculator has been widely used in assessing tree benefits (Figure 3.3). The input data include the project's zip code, the tree species and diameter, and the project land-use type. The outcomes are a set of environmental and economic estimates, such as annual stormwater interception, energy savings, air quality improvement, and property value increase. This tree benefit calculator can provide a gross estimate of environmental benefits, but it is considered to present less validity in projecting economic benefits (Canfield et al., in press; Luo & Li, 2013, 2015).

Peer-review process and outcomes

Case studies undergo a double-blind peer-review process before publication. The LAF Research Committee does the first round of screening/review before seeking external reviews from academia and industry. The revised and accepted case studies are published on the CSI website. Participation in the CSI program does not guarantee that the case study will be published. Approximately 110 case studies have been published on the LPS website after the rigorous peer-review process.

The appendices listed as follows provide additional information and resources for performance assessment.

- Appendix 8 provides a complete list of published project reports funded through the CSI program by country, and breakdowns by states for projects in the U.S.
- Appendix 9 introduces common methods and data sources for social benefits assessment.
- Appendix 10 illustrates common methods and data source for economic benefits assessment.



National Tree Benefit Calculator Beta

A 12 inch American beech provides overall benefits of **$67 every year.**

American beech
Fagus grandifolia

*If this tree is cared for and grows to 17 inches, it will provide **$101 in annual benefits**.*

While some functional benefits of trees are well documented, others are difficult to quantify (e.g., human social and communal health). Trees' specific geography, climate, and interactions with humans and infrastructure is highly variable and makes precise calculations that much more difficult. Given these complexities, the results presented here should be considered initial approximations-a general accounting of the benefits produced by urban street-side plantings.

Benefits of trees do not account for the costs associated with trees' long-term care and maintenance.

The National Tree Benefit Calculator was conceived and developed by Davey Tree Expert Co and Casey Trees. This is an i-Tree powered tool.

Figure 3.3 Example calculation from the National Tree Benefit Calculator.

(Image source: www.arborday.org/calculator/index.cfm)

Given the stronger emphasis on environmental benefits in landscape architecture education, academic studies that specifically addressed social benefits and economic benefits have been sparse. Chapters 4 and 5 fill in these gaps in the literature through investigating the research status of social and economic benefits.

Note

1 Published case studies can be reviewed at (http://landscapeperformance.org/browse). The LAF welcomes project entries in its Landscape Performance Series project portal (https://lafoundation.org/submit-case-study-overview/).

4 Social benefits

Introduction

Social benefits assessment is critical although an under-investigated aspect of landscape design sustainability. Academic studies that specifically addressed social benefits have been sparse. Since 2012, the CSI program has mandated that every project must quantify all three benefit categories (environmental, social, and economic), and since then, the program specifically emphasizes the importance of social benefit. Chapter 4 assesses the effectiveness and status of published CSI case studies based on data published in an early cohort of studies (produced 2010–2012). This chapter also categorizes and summarizes method types and data sources commonly used.

LAF's CSI program produces perhaps the largest portfolio of landscape performance projects. These case studies were produced following a standard format, with a rigorous peer-review process involved before publication. This allows the possibility to identify trends and issues, as well as affording insights for future work. In addition, these studies are produced following a standard format, and the main content of assessment (the three benefit categories) are also known as the three pillar areas supported by sustainability science (Burton, 1987; Singh, Murty, Gupta, & Dikshit, 2012).

In this chapter, 58 case studies published before 2012 were evaluated. The total number of performance benefits as well as the number of social benefits documented in these cases were calculated. Because the number of case studies produced each year is different, in order to standardize the comparison, the average numbers of performance benefits and social benefits documented per case study were compared. In addition, the percent of social benefits out of the total benefits each year was calculated. Specifically, this chapter examined to what extent social benefits were quantified compared with stated design goals, the benefits across the LAF case portfolio (e.g., per benefit category and project type), and methods and data options available to perform the analyses.

Analysis

Method types and data sources

According to the structure and contents of the CSI program, the methodology document presents a thorough step-by-step procedure on how the claimed benefits were arrived at. In this chapter, the methodology document for each case study was reviewed in order to examine the various methods in which researchers arrived at their quantifiable benefits. Table 4.1 shows four method types for social benefits assessment.

In many case studies, data were produced by a third-party but reported by the CSI researchers. This includes observations by design firms, statistics reported in publications, and performance data recorded by clients and others. Despite the varying data sources, the calculation was done via a straightforward comparison of empirical data that reflects project pre- and post-conditions. This method type was defined as Quantitative Assessment.

Survey is another important method in social benefit assessment. This method is useful to assess user experience, perception, satisfaction, and value judgments of the design/space. Traditional face-to-face surveying has been extensively used. Some CSI researchers took advantage of online survey tools for rapid, and sometimes higher, response rates. In either situation, survey instruments need to be reviewed and approved by the university's Institutional Review Board for research that involves human subjects.

CSI researchers also conducted interviews or communicated with key informants (e.g., project manager, client, and users) on project performance via emails, meetings, or phone conversations. Although occasionally only qualitative information such as expression of perception/feeling, anecdotes, or a generic number (e.g., around 100 park visitors last week) can be received, this method proves to be crucial in helping researchers understand how the project is functioning, and it leads to the identification of additional data sources and contact persons.

Table 4.1 Method types used in social benefits assessment in the Landscape Architecture Foundation Case Study Investigation program.

Method type	*Description*
Quantitative assessment	Use basic arithmetic and data that represent pre- and post-conditions
Survey	In-person or online survey (e.g., social media)
Interview, personal communication	Speaking with project managers, client, or users on design efficacy
Observation	Observe how space is used, behavior mapping, and predictions

Finally, several CSI researchers conducted direct observations on users in the space (e.g., plaza or park). On other occasions observations were done by design firms and the CSI researchers reported the results. These were grouped into the method type of Observation.

Obtaining quality data is equally important as a careful method selection. Table 4.2 presents a list of data sources that have been used in CSI research. From the methodology document of each of the 58 case studies, the data sources of all the 90 social benefits were recorded. Another content analysis was conducted to identify typology and occurrence of different data sources. Some benefits utilized only a single data source while others relied on several. In total eight data source categories were summarized. In 34 social benefits (25.7%) CSI researchers gathered and synthesized multiple data sources. Each of these data sources was counted in the calculation. There were nine instances (6.8%) where data sources were not provided and they were excluded from the analysis.

Table 4.2 Data sources used in social benefits assessment in the Landscape Architecture Foundation Case Study Investigation program.

Data source	*Description*	*Example*
Survey, observation, or measurement	Researcher or a third-party conducted surveys, observations, or measurements	Visitor surveys, direct observation of users (e.g., population, behavior)
Government record or publication	Information produced by an agency of a local, state, or federal government	Crime statistics, Environmental Impact Statements, or state park visitor counts
Interview, personal communication	Information provided by key informants	Designer, manager, or owner
Private entity publication	Gray literature and information pertinent to a project or site	Magazines, newspapers, brochures, or flyers
Calculation and analysis	Researcher calculations based on measurements or other researched data	Statistical analyses, valuations of materials or produce, and quantified estimations
Scholarly publication	Published journal articles, books, or other peer-reviewed venues	Journal of Environmental Psychology, Landscape and Urban Planning
Design, consulting firm	Practitioner, contracting/consulting firm that undertook the project	Survey by the design firm, photographs, figures, plans, construction documents
Website data source	Information or calculations from independent websites	Plangarden for produce amounts and values (www.plangarden.com/)

The eight data source categories identified in the previous step were assigned to the benefit statements. Then, each benefit statement was cross-listed with the method type that assessed it for a further examination of the data source breakdowns per method types. For each data source its original reference(s) were reviewed to determine if the data were obtained first-hand or second-hand. First-hand data is defined as information obtained in-person by the CSI researchers, such as a trip to the project site, administering a survey, or creating a behavior map through onsite observations. If the data were collected by the client, the designer, or another third party, they are considered as second-hand, despite the fact that the CSI researchers obtained the data (in-person) via contacting the project informants.

Social benefits as design goals

The Overview section of the CSI report describes the most critical considerations of the design, which would influence project performance outcomes. It is hypothesized that social benefits would stand out with compelling evidence if they are part of the project goals stated in the Overview. A content analysis was conducted to examine the extent to which social benefits belong to project goals. This was done through identifying keywords listed in the LAF social benefit subcategories from the Overview. There are eight social benefit subcategories, including cultural heritage, educational value, food production, noise mitigation, public health and safety, recreational and social value, and scenic quality and views. The occurrence of these keywords was recorded, while allowing some flexibility in counting. For example, if "education," "health," and "recreation" were identified in the Overview, a note was made that this case study has three keywords related to social benefits. Also, "recreational value" (a LAF defined subcategory) and "recreation opportunity" are both eligible (i.e., counted as one keyword).

Then the total number of performance benefits and the number (with respective percentage) of social benefits reported in each case study were counted. These cases were placed into five groups based on the number of keywords (i.e., 1–5 keywords), and the average percentage of social benefits in each keyword-number group was calculated. Last, these percentages were compared to determine if a correlation exists between keyword-number group and performance outcomes.

Social benefits distribution across benefit category and project type

Each performance benefit statement was reviewed in order to determine which ones would be categorized as social benefits. Then each social benefit was coded in one of the eight social benefit subcategories. These subcategories are not mutually exclusive. There are eight incidences where a certain social benefit could be coded in two subcategories. For instance, a performance benefit statement that equally emphasizes education value and recreation value. Under this circumstance this social benefit was counted twice, one for each subcategory.

In addition, the LAF defines 28 project types (e.g., civic/government facility, community, etc.).[1] Each case study can be listed under three project types when it is submitted for publication consideration. The project types were coded based on which project type is listed first, assuming that this primary project type best represents the nature and focus of the project.

Results

Overall research outcomes and social benefits assessment

A total of 343 performance benefits, including 90 social benefits, were assessed in 58 published case studies. Forty-six case studies (79%) documented social benefits, covering all eight social benefits subcategories. Figure 4.1 shows the average CSI research outcomes and the status of social benefits assessment. From 2010 to 2012, the average number of performance benefits produced by each case study increased by 15%. In addition, there is a substantive increase of 133% in the average number of *social benefits* reported per case study. The same trajectory is true in the "bigger picture." In 2012, social benefits accounted for 33.9% of the total benefits assessed, compared with that of 2010 (15.7%) and 2011 (25.7%). This means that social benefits are considered to be equally, or even more important, than environmental or economic benefits in the 2012 CSI research.

Social benefits as design goals

Table 4.3 shows the five keyword-number categories and the percentages of social benefits assessed. All 58 case studies contained social benefits as design goals in the Overview; however, 12 of them did not quantitatively

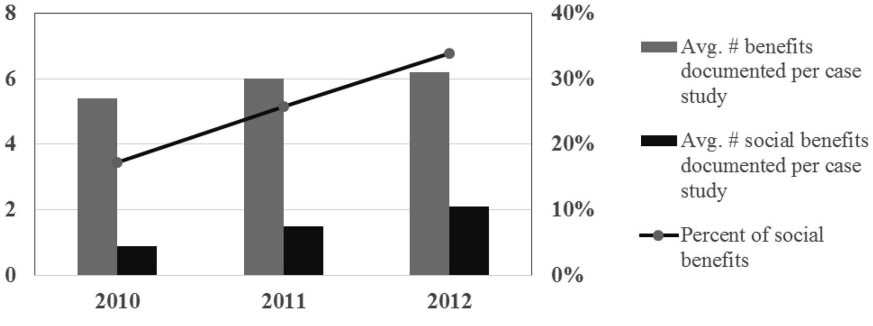


Figure 4.1 Status of social benefits assessment in the Landscape Architecture Foundation Case Study Investigation program.

Table 4.3 Number of keywords related to social benefits and corresponding outcomes of social benefits examined in the Landscape Architecture Foundation Case Study Investigation program.

Keyword-number category concerning social benefits	*Percent of cases from keyword-number category*	*Avg. % of social benefits*	*Avg. # of performance benefits per case study*
5	2	33	6
4	5	42	4.3
3	10	20	5.5
2	28	20	6.4
1	55	31	5.9

assess social benefits. In total only 7% of the case study Overviews have 4–5 keywords. In sharp contrast, case studies that have 1–3 keywords consist of 93% of the case population. Generally speaking, there is a weak correlation between the number of social benefit keywords and the extent that social benefits are assessed, which is a different result from the original hypothesis.

Social benefits distribution across benefit category and project type

Table 4.4 shows the distribution of social benefits across the eight benefit subcategories. It is evident that social benefits concentrate in 2–3 major categories, where the top two categories (recreational and social value, and educational value) add up to 74% of the total benefits. If the next most represented category (i.e., public health and safety) is also considered, this percentage rises to 86%. The five remaining categories only consist of 14% of the total, suggesting great disparities across categories.

Project type likewise shows disparities (Table 4.5). A sum of the top three project types (park, courtyard/plaza, and school/university) equals 51% of the total benefits. Furthermore, these top three project types are reported in 23 case studies, a full 50% of the total cases. By contrast, the other 23 cases are of the less-examined 13 project types.

In fact, results from Tables 4.4 and 4.5 have some correlations. Recreational, social, and educational values (Table 4.4) are well demonstrated in project types such as park, courtyard/plaza, and school/university (Table 4.5). These public facility and open space type of projects are also the traditional strength areas of landscape architects. Data accessibility, especially second-hand data, is also better for these project types than others.

Stormwater management facility ranks as the number four most assessed project type. Stormwater benefits are reported in the environmental benefit section of almost every CSI project. This may be because using green infrastructure or other “green” solutions to manage stormwater promises educational benefits such as raising environmental consciousness and promoting socially cohesion through community interaction.

Table 4.4 Number of social benefits reported in eight social benefit subcategories in the Landscape Architecture Foundation Case Study Investigation program.

Benefit category	*Benefit number*
Recreational & social value	38
Educational value	31
Public health & safety	11
Food production	5
Noise mitigation	3
Cultural heritage	2
Scenic quality & views	2
Other	1

Table 4.5 Number of social benefits and number of cases documented per project types in the Landscape Architecture Foundation Case Study Investigation program.

Project type	*Number of documented social benefits*	*Number of case studies reported social benefits*
Park	26	15
Courtyard/Plaza	10	4
School/University	10	4
Stormwater management facility	7	3
Garden/Arboretum	5	2
Stream restoration	5	3
Streetscape	5	3
Nature preserve	4	2
Office	4	2
Single family residence	4	1
Resort/Hotel	3	1
Wetland creation/ restoration	2	2
Youth/Community center	2	1
Recreational trail	1	1
Waterfront redevelopment	1	1
Zoo	1	1
TOTAL	90	46

Method types and data sources

Table 4.6 presents method and data types, and Table 4.7 provides detailed data source categories. Standard research methods in social science have been used (e.g., survey, interview). However, data availability appears to be a limiting factor in the current CSI studies as second-hand data are predominantly used. This could be largely attributed to the short research time frame of the CSI program (3.5–4 months, mostly during summer), making

Table 4.6 Method and data types used in social benefits assessment in the Landscape Architecture Foundation Case Study Investigation program.

	First-hand data	*Second-hand data*
Quantitative assessment	0	39
Survey	14	9
Interview	0	16
Observation	3	9

Table 4.7 Data source categories and number of sources per category in the Landscape Architecture Foundation Case Study Investigation program.

Data source	*Number*
Survey, observation, or measurement	24
Government record or publication	23
Interview or personal communication	21
Private entity publication	20
Calculation and analysis	13
Scholarly publication	11
Design, consulting firm	10
Website data source	10

first-hand data gathering difficult. Although less polarizing than the compositions shown in benefit category and project type (see Tables 4.4 and 4.5), the top three data sources still account for 52% of the total. Survey and observation methods employed first-hand data more than the other two. Out of the 23 survey studies, CSI researchers directly conducted 14 (61%) of these studies. Research validity accrues under these circumstances because CSI researchers develop the survey instruments that target the research questions specifically. On the contrary, research validity would be undermined if the results were derived and interpreted based on other related surveys or studies.

Thirty-four (37.8%) out of the 90 social benefits gathered data from multiple sources. A small portion of the data were sourced from design firms, such as the original design drawings. Although most CSI research teams conducted site visits and some were involved with extensive field work (e.g., interview users for social benefits, vegetation survey for environmental benefits), it is challenging to visit every project site to ascertain that built conditions are as designed. This is due to logistical, budget, and time constraints on research teams. Planning/design documents or aerial photos are often used as proxy of the built conditions.

Several CSI studies took advantage of other empirical research conducted for the same project site where social benefits were the research focus. For instance, one of the 2011 CSI case studies (Daybreak master-planned community in Utah, Yang, & Goodwin, 2011) demonstrated outstanding social benefits – 88% of the children in Daybreak walk to school as a result of the extensive trail system integrated with amenities provided by green infrastructure designs, whereas this figure trims down to 17% in two adjacent communities (Gallimore, Brown, & Werner, 2011; Napier, Brown, Werner, & Gallimore, 2011). These studies were conducted by interdisciplinary research teams and reported in high-quality scholarly journals.

Summary

It is not entirely a surprise that social benefits account for more than one-third of the total benefits documented by CSI in 2012, and this encouraging figure could be partly attributed to LAF's stringent requirement to include social benefits in all case study submissions. This chapter suggests that social benefits are becoming increasingly important in landscape performance assessment and that CSI researchers continue to elevate their research productivity and scientific rigor. As the awareness and interest continue to grow in performance research, future efforts promise a steady improvement in the quality of assessment – with respect to embracing interdisciplinary theoretical frameworks and expertise (social science in particular), diversifying research methods, increasing validity of data sources, and covering a wider range of project types and social benefit categories.

Note

1 Project types defined by the Landscape Architecture Foundation (https://lafoundation.org/submit-case-study-overview/).

5 Economic benefits

Introduction

Economic benefits are defined through their intimate connections with nature, justice, and time (Faber, 2008). This definition demonstrates how economic benefits exist in concert with environmental and social benefits (nature and justice) but that they also must be lasting and sustainable. As one of the three pillars of sustainable development (environmental, social, and economic), economic benefits have been examined by a number of studies within the landscape architecture discipline (e.g., Luo & Li, 2013; Yang, Zhang, & Blackmore, 2014; Ozdil & Stewart, 2015). For instance, an urban forest provides multi-faceted environmental benefits (e.g., improved air quality, reduced urban heat island effect, better urban habitat) and these ecosystem services generate economic benefits. Other observable economic outcomes would also benefit local businesses, who may see more customers as a result of their business's proximity to the urban oasis; may attract qualified workers who appreciate clean air and recreation opportunities; and may find that their property value has increased.

Although economic considerations are included as a crucial component of the LPS research, little progress has been made toward evaluating the rich LPS database in order to identify trends (or pitfalls) and best practices in economic benefits assessment. This chapter performs a comprehensive analysis of the current status of economic performance assessment, and summarizes metrics and methods used for the assessment based on published LPS cases. Academic institutions and design firms may incorporate lessons learned from empirical analyses of built projects in order to optimize landscape designs for better performance outcomes.

Economic benefits categories and assessment status

This section outlines the results of a comprehensive analysis of the LPS research approaches, as organized following the seven economic performance categories established by the LAF: (1) property value, (2) operations-and-maintenance-savings, (3) construction-cost-savings, (4) job creation, (5) visitor spending, (6) increased-tax-base/revenue, and (7) economic development (Table 5.1). Table 5.2 is an overview of the percentages of economic

Table 5.1 Categories and metrics for economic benefits assessment in Landscape Architecture Foundation's Landscape Performance Series.

	Economic Benefits Categories						
	Property Value	*Operations and Maintenance*	*Construction*	*Job Creation*	*Visitor Spending*	*Tax Revenue*	*Economic Development*
Benefit Metrics	Increase in Property Value Increase in Sales Price Increase in Rents	Heating and Cooling Irrigation and Water General Maintenance Volunteer Hours	Hauling/Dumping Materials Installation	Earthworks Permanent	Temporary Entry Fees Sales Rentals	General Spending Projected Tax Revue	Projected Tac Revenue Investment/Projects Catalyzed Retail Sales Space or Units Occupancy Rate General
Total	14	40	23	20	13	7	22

Table 5.2 Percentage of economic benefits by category in the Landscape Architecture Foundation's Landscape Performance Series.

Benefit category	*Percentage*
Operations and Maintenance	34
Construction Cost Saving	19
Economic Development	18
Job Creation	17
Property Value	12
Visitor Spending	11
Tax and Revenue	6

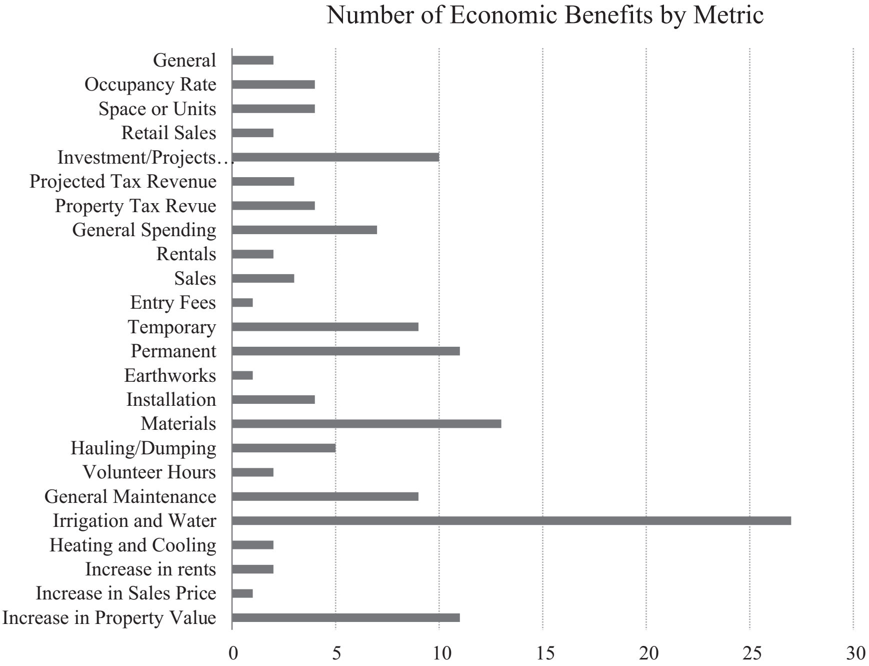


Figure 5.1 Economic benefits assessed by metric categories in Landscape Architecture Foundation's Landscape Performance Series.

benefit categories in LPS. There are 24 detailed metrics under these seven categories. Figure 5.1 shows the benefit breakdowns per metric.

As shown in Table 5.2, the top three assessed economic benefit categories are: operations-and-maintenance-savings (34%), construction-cost-savings (19%), and economic development (18%). The sum of these three totals is 71% of the total cases evaluated. In addition, 68% of the cases that fall under the operations-and-maintenance-savings category belong to the metric of irrigation-and-water. The disparity is apparent with respect to benefit categories and associated metrics being assessed, while suggesting room for improvement in other less evaluated areas.

It is apparent that the top-assessed categories and metrics (see Table 5.2 and Figure 5.1) are directly related to the design process (e.g., site inventory, planning/design, construction), and as a result, designers and researchers find first-hand data readily accessible. On the other hand, in benefit categories that designers tackle less in their daily practice, or when designers/researchers need to rely on additional information or expertise to perform the assessment (e.g., tax revenue, visitor spending), the numbers of reported LPS cases decrease substantially. The following section provides a detailed account on possible metrics and methods for economic benefits assessment as synthesized from the LPS database.

Existing metrics and methods in LPS

Table 5.3 presents a comprehensive list of metrics and methods used in LPS economic benefit research. For most of the metrics, project performance may be obtained remotely using secondary data. Regarding the metric of construction-cost-savings, data may be available from contractors, clients, municipalities, or other sources. In other cases, such as for the metrics of visitor spending and increased-tax-base/revenue, it would be necessary to review receipts or financial records in order to assess visitor spending and tax revenue data. No specialized or expensive equipment is necessary to perform the methods recommended in Table 5.3. The following is a description of the seven LAF defined economic benefit categories.

Property values

Property values are a benefit concerned with measuring the increase in real estate value derived from a landscape design. Property value increases are perhaps the most tangible indicators of landscape economic performance, and are highly relevant to real estate developers and others who often fund the development of green spaces (Tyrväinen & Miettinen, 2000). At times, the landscape project may be the only change which occurred in an area, showing a direct impact on property values. At other times, the project may have occurred in conjunction with a rezoning, additional development, or other relevant factors. In the latter cases, the landscape intervention can be framed as a contributor to increased property values rather than the sole driver.

Operations and maintenance savings

By creating a resilient and self-sustaining landscape that requires fewer inputs of time, money, and resources than are traditionally required,

Table 5.3 Metrics and methods used in landscape performance assessment in Landscape Architecture Foundation's Landscape Performance Series.

Category	*Metric*	*Method*
(1) **Property Value**	Increase in property value for adjacent or nearby properties	• Compare all real estate values within an established vicinity of the site before and after project completion • Compare the property value of a single building before and after the landscape intervention • Compare real estate values to other comparable properties elsewhere in the vicinity that do not enjoy benefits from the landscape intervention
	Increases in sales price for adjacent or nearby properties	• Consult municipal or online real estate databases of sales prices
	Increases in rents for adjacent residential or commercial properties	• Compare rent charges in adjacent or nearby residential or commercial properties before and after the landscape intervention
(2) **Operations and Maintenance Savings**	Reduction in heating and cooling costs	• Compare heating and cooling bills from before and after the implementation of a landscape design • Compare heating and cooling bills from the property with similar properties that have not had a landscape intervention • Use local energy costs to convert energy savings into cost savings[a]
	Reduction in irrigation or potable water costs	• Calculate the value of water reused on site • Compare use of water on the site to use on a similar site without a sustainable design • Compare water bills from before and after design implementation
	Reduction in maintenance costs, mowing, fertilizer, and others	• Compare the relevant needs for the landscape before and after the design implementation
	Value of volunteer hours	• Multiply typical value of an hour of labor by the total number of volunteer hours to obtain a value of volunteer contributions

(3) **Construction Cost Savings**	Reduced hauling and/or dumping costs	• Record the amount of material reused on site that did not then need to be hauled away • Calculate the savings associated with avoiding dumping fees by reusing materials
	Reduced material purchasing costs	• Record the amount of materials reused and calculating the cost of purchasing those materials new and transporting them to the site
	Reduced installation costs	• Calculate the savings associated with installing green infrastructure instead of traditional infrastructure
	Reduced earthworks costs	• Consult construction documents to assess the cut/fill operations and determine the savings associated with eliminating purchasing and hauling of fill to the site or disposal of cut from the site
(4) **Job Creation**	Number of permanent jobs created directly for the operation of the site	• Consult public data, client records, or other sources to determine the number of park staff, event staff, or other employees that rely directly on the landscape project for their jobs, or can be attributed to the nearby or adjacent landscape project
	Number of permanent jobs created for surrounding, related development	
	Number of temporary jobs created for the construction of the site, seasonal operations, or other temporary needs	• Contact construction contractors or consult their records to discover the number of man-hours dedicated to a project • Estimate the jobs created based on the overall cost of the landscape project
(5) **Visitor Spending**	Revenue generated by entry fees	• Review visitor counts or other collected data sources • Interview with staff and other personnel who keep records of visitation
	Revenue generated through direct sales	• Review sales records from cafes, gift shops, and other retail establishments affiliated with the project in question
	General visitor spending in nearby or adjacent areas	• Review and analyze data reflecting total visitor spending in the city or region

(*Continued*)

Table 5.3 (Continued)

Category	*Metric*	*Method*
(6) **Increased Tax Base/Revenue**	Increase in office, commercial, or residential space or units	• Map or consult commercial or municipal records to quantify the extent that development has increased the potential tax base
	Actual increase in tax revenue	• Consult government records to ascertain the before and after development amounts of tax revenue collected
	Projected increase in tax revenue	• Project tax revenue by calculating the square footage of different types of space and extrapolating taxes based on those types
(7) **Economic Development**	Increase in retail sales	• Researching retail sales information from public records or through contacting private businesses to determine increases after landscape project completion
	Increase in commercial establishments	• Perform a count of new commercial business directly adjacent to the site or in the larger neighborhood to assess the number of retail establishments whose existence can be linked to the landscape improvements
	Decrease in retail vacancies and/or increase in occupancy	• Consult records to determine if vacancy rates decreased or occupancy rates increased for both commercial and residential spaces following the completion of the landscape project
	Revenue generated through project-related events	• Contact employees of the site or nearby businesses (such as hotels) that cater to those who attend events

[a] Utilizing a calculating tool such as the Green Roof Energy Calculator from Portland State University or the Center for Neighborhood Technology's Value of Green Infrastructure Guide (http://greenbuilding.pdx.edu/GR_CALC_v2/grcalc_v2.php#retain)

landscape design can result in significant long-term savings over the entire life of a project. The savings that accrue fall into the category of operations and maintenance savings.

Construction cost savings

LPS categorizes one-time savings that result from reducing the expenses associated with implementing a landscape design as construction cost savings. The construction phase of landscape design can be a planned in such a manner that it results in significant cost savings for the client (Thompson & Sorvig, 2000). In turn, many of these cost-saving measures also provide environmental benefits. For example, reusing concrete from a demolished building on a site not only obviates the need to purchase new concrete, it also reduces the project's environmental impact by diminishing the materials and energy needed to produce new concrete, aggregate, etc. Demonstrating construction cost savings can be a valuable tool in persuading clients of the value of sustainable landscape practices. Calculating the value of materials and the costs of hauling and dumping are based on local prices for landfill access, gasoline, and other items.

Job creation

Landscape development projects can often result in the creation of full-time permanent employment for land managers, support staff, maintenance crews, and others. In addition, projects may contribute to the local economy by indirectly creating jobs in nearby areas that serve visitors, residents, or others who are drawn to the area by the landscape development (Hubbard, 1995). Finally, all projects not undertaken entirely by volunteers will also create temporary jobs during the construction and implementation of the design. These facets of economic growth fall under the category of job creation, including direct and indirect permanent jobs. Job creation is a key indicator of economic health and can be a powerful tool for researchers quantifying landscape performance.

Visitor spending

Visitor spending refers to the amount of money spent by visitors to a designed landscape. This spending is derived from landscape design projects that have the ability to draw local, regional, national, and international visitors. Depending on the type of landscape, there may be entrance fees, membership fees, or other types of visitor spending that can be quantified and analyzed. Particularly large and well-known sites that may draw hundreds of thousands or even millions of visitors per year can have a significant impact on the visitor spending within a city or a region. These projects can be treated as having enough impact on larger trends to derive information about their contribution from city- or region-wide data on visitor spending and other activity.

Increased tax base/revenue

Measuring the tax revenue generated for towns, municipalities, or other governments through landscape improvements falls into the category of increased-tax-base/revenue. An increase in tax base can be seen as the public-sector equivalent benefit that derives from increased property values. This information can be enormously valuable to municipal partners investing in parks, open spaces, business improvement districts, and other landscape projects. Investment in landscape projects can lead to a broader tax base, which may lead to increased revenue district-wide as an area becomes a more popular and active destination.

Economic development

Finally, landscape design can have a profound influence on overall economic development of a site, neighborhood, or region (Shafik, 1994). Economic development is a catch-all category that concerns benefits that assess the impacts on spending and occupancy derived from landscape projects. Economic development can be indicated by measurements of spending, growth, and increased revenue in areas directly affected by landscape development projects. Typologies such as streetscapes, transit-oriented developments, and waterfront redevelopments are particularly suited to this category of benefit quantification.

Case studies

Three case studies are chosen, and each represents a good example for one of the top three economic benefit categories assessed. These three categories are: operations-and-maintenance-savings, construction-cost-savings, and economic development (see Table 5.2). The specific benefit shown for each case study is chosen because its method is highly replicable in similar projects. Table 5.4 summarizes basic information of the three cases and the corresponding economic benefits.

Gary Comer Youth Center – an example of operations-and-maintenance-savings

The Gary Comer Youth Center (GCYC) is located on Chicago's south side. It offers extracurricular activities and hands-on learning opportunities in a safe environment. Its economic benefit assessment offers an example of operations-and-maintenance-savings because of an intensive green roof design (Yocom & Lacson, 2011).

Table 5.4 Select cases for the top three reported economic benefits categories in Landscape Architecture Foundation's Landscape Performance Series.

Project	*Location*	*Size (ha)*	*Category*	*Benefit*
Gary Comer Youth Center	Chicago, Illinois	0.08	Operations and maintenance savings	Saves $250 in annual heating and cooling costs as compared to a conventional roof by moderating heat gain and loss.
Blue Hole Regional Park	Wimberley, Texas	50.99	Construction savings	Saved approximately $230,000 in mulch costs by double-shredding the trunks of invasive cedars removed from the site and using this to cover all designed mulch areas.
Uptown Normal Circle and Streetscape	Normal, Illinois	1.97	Economic development	Generated more than $680,000 of revenue through conferences held in Normal that featured the Uptown Redevelopment.

Energy savings from this green roof are calculated based on the Green Roof Calculator developed by the Portland State University Green Building Research Laboratory (www.greenbuilding.pdx.edu/CalculatorInfo.php). The Green Roof Energy Module estimates the combined energy savings (cost/therms and cost/kWh) compared to a conventional roof. This Module is based on the type and location of the building, roof surface area, growing media depth, leaf area index, and percentage of plant coverage (Yocom & Lacson, 2011).

Electricity rates for the state of Illinois are based on the U.S. Department of Energy's Average Retail Price for Consumers by Sector, Census Division, and State, 2009 (www.eia.doe.gov/cneaf/electricity/esr/table4.xls). The average cost of natural gas is 121.8 cents/therm and 9 cents/kWh (www.npga.org/14a/pages/index.cfm?pageid=914). The total amount of energy saved is based on GCYC roof specifications and averaged energy costs. The energy savings are then used to calculate the corresponding monetary savings. The estimated savings of 642.58 kWh and 156.53 therms, would generate an annual savings of $248.80 (Yocom & Lacson, 2011).

Blue Hole Regional Park – an example of construction-cost-savings

The Blue Hole Regional Park is located in the heart of the rugged Texas Hill Country. In 2005, the city of Wimberley purchased the "Blue Hole" swimming area and surrounding 126 acres in order to protect the pristine waters (Canfield & Fagan, 2013). According to the construction documents, nearly 5 acres of the park receives mulch. This area is multiplied by a 5-inch average depth (number confirmed by the landscape contractor). The total volume is multiplied by the average cost of local mulch (ca. \$70/cubic yard) (Canfield & Fagan, 2013).

Construction savings are calculated as follows:

4.957 acre (23,992 square yards) of mulch used on site (Design Workshop, 2010)
23,992 square yards @ average 5-inch depth = 3332 cubic yards
3332 cubic yards @ \$69/cubic yard (Spears, 2012) = \$229,908 saved

Enough cedar mulch is created to cover all designed mulch areas plus an additional 1–2 inch, and to create a stockpile on site for future freshening of the mulch areas (Canfield & Fagan, 2013). Limitations of this method include fluctuating mulch prices and an assumption that the mulch is spread at a uniform thickness throughout all mulched areas of the park.

Uptown Normal Circle and Streetscape – an example of economic development

This streetscape retrofit project incorporates stormwater management and public recreation into a vibrant gathering space that also encourages economic development (Ellis, Kweon, Alward, & Burke, 2011). Researchers' communication with the Bloomington-Normal Marriott hotel indicated that there have been four professional conferences held in Normal because of the completion of the traffic circle (AIA Illinois Chapter, Illinois Association for Floodplain and Stormwater Management, Illinois Association of Wastewater Agencies, Illinois City/County Management Association, and Illinois Chapter American Planning Association) (Ellis et al., 2011).

Researchers then contacted the organizations holding the conferences to obtain data on attendance, hotel room rates, registration fees, and other economic impacts. As a result, the approximate amount of revenue generated is determined: number of participants x registration fees + cost of hotel rooms (assuming \$119 per night per person, the conference rate) + a \$46 per diem per day (based on the federal per diem rate for Illinois). For these four conferences, the estimated revenue generated totals \$681,398 (Ellis et al., 2011). Limitations of this method include an inability to determine further impacts that conference attendees may have had while dining in restaurants, using local transportation, and other spending.

Summary and suggestions

Landscape performance assessment would be an actionable agenda item that contributes to landscape research and practice. Supported by empirical examinations such as cases from the LPS database, landscape architecture as a discipline would gain a better status in society. The need of demonstrating economic benefits of landscape performance is clear, while some considerations are key to the success of performance assessment. Temporal scale is one of them. Landscapes are dynamic systems, hence the reported benefits are arguably temporary, given that no tree or other landscape modification will last forever without maintenance. A tree itself needs time to reach maturity in order to provide the expected benefits. Therefore, truly sustainable economic benefits must be more than simply the construction of a beneficial landscape – they must also include a long-term plan for the upkeep and continued viability of that landscape that is self-sustaining and able to carry the current benefits into the future.

Another important consideration is to contextualize economic analysis and report the direct impacts from the project under investigation, rather than encompassing the spillover effects. For the metric of job creation, for instance, it is cautionary to attribute job creation in nearby developments as being caused by the landscape project. There must be a direct and identifiable link between the landscape project and the jobs created in order to create a defensible benefit. Similarly, for the metric of economic development, the size of the project and its impact on the area must be accounted for and noted in reporting benefits. It may be advantageous to state that the landscape project *contributed* to certain increases rather than to say it *caused* them as there are likely many variables at play.

Last, the robustness of methodology and validity of data sources in LPS in general need improvement. Using the metric of property values as an example, one should be careful not to substitute one metric with another, as oftentimes data are reported in different forms, such as a total value, a percentage change in value for the entire assessed area, or a percentage change per property in relation to city median. It is also recommended that researchers collect first-hand data whenever possible and develop hypotheses that directly examine the research questions, and reduce the instances where proxy data or information are relied upon.

Implications to landscape architecture education and design process

Although economic benefits are often considered as project priorities in professional practice, (Simon, 1983a, 1983b; Hack, Birch, Sedway, & Silver, 2009), the assessment of these benefits in education needs to be better emphasized, as it is not a strength area in the current curricula. Most curricula emphasize environmental benefits. When economic benefits are addressed, few courses illustrate a procedure that can effectively measure or assess them.

Compared with environmental benefits which may be predicted in the design phase, many economic benefits aforementioned (e.g., visitor spending, increased-tax-base/revenue) are not easy to predict at this phase. Landscape architects are either not acquainted with ways to access these benefits, or they do not normally perform a follow-up analysis after the project is built. On other occasions where economic benefits could be assessed during project design and construction, designers are recommended to document evidence. For example, the reuse of materials will generate construction cost savings, a metric that can be assessed rather accurately through construction documentation (e.g., delineate areas where reused materials are applied).

In short, integrating economic benefits assessment in the design process, and in studio teaching in particular, would help instill a culture of performance assessment for the next generation of practitioners, in the enterprise of achieving (better) sustainable design solutions anchored in empirical evidence. It takes time for a project's economic benefits and fiscal impacts to become observable and measurable. Long-term and short-term economic benefits need to be gauged for benefit optimization. So doing will enhance designers', decision makers', and the general public's confidence in the level of services that landscape designs can provide.

PART II reviews landscape performance scholarship predominantly using case studies published by the LAF. However, long-term, comprehensive performance assessments of built projects are still lacking. The following chapters are devoted to one of McHarg's most successful projects, The Woodlands town development in Texas.

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Part III

Performance evaluation

The Woodlands versus Houston

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6 The Woodlands

An exemplary case for performance assessment

Introduction

Since the late 1960s, suburban development in the U.S. has been criticized for causing ecological damage and environmental degradation (Ewing, 1997; Forsyth, 2002; Spirn, 1984; Susskind, 2009). Various community development alternatives were put forth, including a noteworthy one that is an ecology-based land-use planning approach, proposed in McHarg's *Design with Nature* (McHarg, 1969). For more than four decades, ecological planners have been using ecology as the basis for planning and design in projects of various scales and foci (McHarg, 1996; Ndubisi, 2002, 2008; Steiner & Osterman, 1998).

Among these projects, The Woodlands, Texas, a 28,000-acre (113-sq km) master-planned community, is an excellent example of ecological planning that followed McHarg's nature-led design approach (McHarg & Sutton, 1975; Forsyth, 2002; Kim & Ellis, 2009). McHarg, himself, considered The Woodlands as "the best example of ecologically based new town planning in the United States during the 1970s" (McHarg, 1996, p. 325). The town was created at the peak of the 1970s environmental era as an alternative development model in lieu of suburban sprawl (Forsyth, 2003, 2005; Morgan & King, 1987).

The Woodlands is located 43 km (27 miles) north of downtown Houston, and in the Houston – The Woodlands – Sugar Land metropolitan area. U.S. Interstate Highway 45 runs parallel to The Woodlands to the east and is a major transportation corridor connecting Houston to the south and to Dallas/Fort Worth (338 km away) to the north. The Woodlands currently has eight subdivision residential villages (Table 6.1). Most of them are located in Montgomery County, with portions of them extending into Harris County. As of 2016, The Woodlands Development Company estimated the population to be 114,625 (The Woodlands Development Company, 2017). Figures 6.1a and 6.1b show the built conditions in The Woodlands.

Why The Woodlands for performance assessment?

The Woodlands devolvement over the past four decades provides a typical as well as an atypical case for examination. It is typical because it exemplifies McHarg's tenet that design is a process of human evolution. The Woodlands

Table 6.1 Population and land area of residential subdivision villages in The Woodlands.

Subdivision village	*Open year*	*Area (acre)*	*Population (2012)*	*Pop. density (cap./acre)*
Grogan's Mill	1974	4,320	14,640	3.4
Panther Creek	1979	2,070	14,132	6.8
Cochran's Crossing	1983	3,358	15,933	4.7
Indian Springs	1984	1,879	6,344	3.4
Alden Bridge	1994	3,602	21,546	6.0
College Park	2000	1,073	6,898	6.4
Sterling Ridge	2001	4,061	14,662	3.6
Creekside Park	2007	3,492	5,592	1.6

Source: The Woodlands Demographics (The Woodlands Development Company, 2012)

Figure 6.1a A neighborhood street view in Grogan's Mill, the first subdivision village of The Woodlands. Unlike conventional development, McHarg used narrow and curbless streets, with open surface drainage, mandated to preserve the original vegetation after development.

Figure 6.1b A street view of The Woodlands Parkway. Commercial and residential buildings are hidden by the tree mask.

demonstrates a model of following the site's natural processes to manage stormwater and facilitate ecosystem services. It is also an excellent example of the interdisciplinary work of McHarg's firm, Wallace, McHarg, Roberts, and Todd (WMRT, now WRT), that enjoys a national/international reputation. Part of McHarg's (WMRT) work was to essentially model ecological processes by using metrics. Performance forecasts were the foci of the ecological plan (Ndubisi, 2014).

In particular, McHarg systematically tested the impacts of different development scenarios using quantitative metrics. The Woodlands study belongs to the first cohort of Environmental Impact Statement (EIS) (Ndubisi, 2014; Yang & Li, 2016). Community development such as The Woodlands occupies the single largest share of construction in the U.S. since the 20th century. Mitigating the development impacts is a ubiquitous challenge that municipalities face. Thus, lessons learned from The Woodlands would be beneficial for similar projects elsewhere in the country.

The Woodlands is atypical because of several idiosyncratic traits of the project, which deserve consideration in the assessment all together. The first was the birth of the town was developer George Mitchell's fair intention to solve America's urban illnesses, not purely profit-driven, which may have otherwise driven the project to an opposite marching order. Therefore, some "green" practices in The Woodlands may elicit the perception of being "ahead of" their time. Furthermore, the interesting dynamics over the course of development went beyond Mitchell's control or expectations. The Woodlands was never annexed to Houston, contrary to what Mitchell had envisioned. For Mitchell, a gloomier event happened when he had to sell The Woodlands, for which decision he expressed deep grief on several occasions afterward (Kutchin, 1998; Galatas & Barlow, 2004; Steiner, 2011). After the ownership change, new developers deviated from the original ecological plan, while The Woodlands remained a pioneer in advancing sustainability agendas for the Houston region in many ways.

Although it was unfortunate from Mitchell's perspective, it is perhaps "fortunate" from a scientific evaluation standpoint that an investigation of The Woodlands' performance "post-McHarg" would shed light on what's working, as well as lessons learned. The Woodlands development went parallel with the increasing level of ecological awareness in society. The required working knowledge in order to minimize human interventions on landscapes has greatly increased over the latter half of the 20th century (Thompson & Steiner, 1997; Ndubisi, 2014). The suitability analysis as practiced in The Woodlands created an important methodological innovation in ecological planning (Ndubisi, 2014; Steiner, 2016; Yang & Li, 2016).

In 1975, McHarg and Sutton called for a post-occupancy evaluation of The Woodlands' performance in order to increase the collective knowledge of the profession (McHarg & Sutton, 1975). Further, in a 1979 article, Johnson and colleagues (Johnson, Berger, & McHarg, 1979) indicated that the "viability of deriving performance measures from suitability analysis, which is extremely useful in ascertaining how well a design of plan has performed in reaching its targeted goals" (Ndubisi, 2014, p. 433). Similarly, in his 2001 extensively cited article on Case Study Method, Mark Francis listed The Woodlands as one of the "Seminar Case Studies in Landscape Architecture" (Francis, 2001, p. 19).

In short, there is perhaps no better example coming from the environmental era than The Woodlands that deserves the attention for a rigorous, long-term performance assessment. The assessment would attest to the extent to which McHarg's method was effective for ecological planning. Foundational work like this helps enhance the understanding of the biophysical and social-ecological systems and how they shape the built environment.

Developer George P. Mitchell

Developer George P. Mitchell (1919–2013) initiated The Woodlands project in the early 1960s. Mitchell is a son of Greek immigrants and a self-made oil and real estate businessman, who established his own firm, Mitchell Energy & Development Corporation (Morgan & King, 1987). As Mitchell traveled around the nation, he was concerned about the environmental, economic, and social problems associated with urban development (Malone, 1985). Mitchell observed that a number of metropolitan areas, including New York, Philadelphia, Boston, Cleveland, Chicago, Cincinnati, and his home area, the Houston/Galveston, were experiencing deterioration. The middle class slowly moving to suburbs had led to urban blight, where the minorities, the poor, and disadvantaged groups were left behind.

Mitchell started scoping of The Woodlands town project under this historical background. Early generations of new town development (Reston, Virginia, and Columbia, Maryland) created considerable interest and were considered to solve America's urban problems (Ewing, 1997; Forsyth, 2002; Spirn, 1984). In addition, the 1960s and 1970s also marked a peak of environmental sensitivity, particularly following the passage of the National Environmental Policy Act (NEPA) in 1970. Environmental impact analysis was not emphasized in the earlier new towns, but it was a heavy focus in The Woodlands (McHarg & Steiner, 1998).

The Woodlands town project was Mitchell's experiment to help cure the American urban illnesses post-World War II (Forsyth, 2005; Galatas & Barlow, 2004; Malone, 1985). The philosophical concept and the potential real estate profits of the new town were appealing to George Mitchell. Before McHarg's team, Mitchell had invited a number of teams for the project (Malone, 1985). The first plan was proposed by Houston architect Karl Kamrath in 1966. Kamrath proposed a 20,000-acre site with a population of 50,000 and the plan was a traditional subdivision. After that, Mitchell commissioned Cerf Ross, another Houston architect, to prepare the second plan in 1969. Ross proposed a 15,000-acre community that had four residential subdivision villages surrounding a business complex.

HUD experience

Based on these early plans, Mitchell realized the tremendous financial requirements. At that time (1970), the Urban and New Community Development Act was passed, and under its Title VII, the U.S. Department of Housing and Urban Development (HUD) was authorized to provide loan guarantees of a maximum of $50 million to new town developers (Morgan & King, 1987).

On June 17, 1970, Mitchell's pre-application to HUD was approved, but he was invited to assemble a more competent team for a better application (Malone, 1985). Robert Hartsfield, Mitchell's in-house director of planning and design, once studied under environmentalist and ecological planner/landscape architect Ian McHarg at the University of Pennsylvania. Hartsfield recommended McHarg to Mitchell by suggesting that Mitchell read McHarg's *Design with Nature*. Mitchell was thoroughly impressed by this book and decided to hire McHarg's firm, WMRT, for The Woodlands project (Morgan & King, 1987). Mitchell turned to McHarg because of WMRT's reputation in environmental planning, which proved to be a critical decision for The Woodlands project success (Morgan & King, 1987).

Subsequently, Mitchell assembled a strong team, including some of the top names in the nation. McHarg's team, WMRT, was in charge of environmental planning. William L. Pereira Associates of Los Angeles was to prepare land use planning. Gladstone Associates of Washington, DC, was to provide an economic analysis. Richard P. Browne Associates of Columbia, Maryland, was the engineering consultant. Another team from the University of Texas School of Public Health was in charge of institutional and social planning (Malone, 1985). Mitchell submitted a formal proposal and master plans on August 10, 1971 and received HUD approval on November 23, 1971 (Morgan & King, 1987).

Including The Woodlands, a total of 13 Title VII new towns were approved, and an EIS was required for all of them (McHarg & Sutton, 1975; Steiner, 1981). It is noteworthy that The Woodlands received the maximum loan of $50 million from HUD (Malone, 1985; Kutchin, 1998). In addition, the timing of the WMRT studies on The Woodlands coincided with the passage of NEPA. As a result, these WMRT studies became one of the early EIS reports.

Unique design challenges

The lush pine forest and proximity to the Interstate 45 and proposed Houston international airport made The Woodlands an attractive place for development. Actually, developer Mitchell took advantage of these factors when he selected the project location (Kutchin, 1998; Steiner, 2011). However, McHarg and his WMRT team faced challenges in land development and drainage design. About one-third of the site lies within the 100-year floodplains of the three creeks on site, making developable land limited. The poorly draining soils and extremely flat topography caused drainage problems (WMRT, 1973a). Local people's experiences were that one cannot tell where the water is draining unless the wind direction is known. The annual precipitation of the Houston area is around 840 mm, whereas coastal hurricanes usually cause widespread flooding by generating intense rainfalls in single events.

During the site visits, McHarg and his WMRT colleagues found that in adjacent developments, concrete ditches were constructed to facilitate runoff. However, this solution will lower the groundwater table and cause the trees to die. Further, it would have increased the severity and frequency of

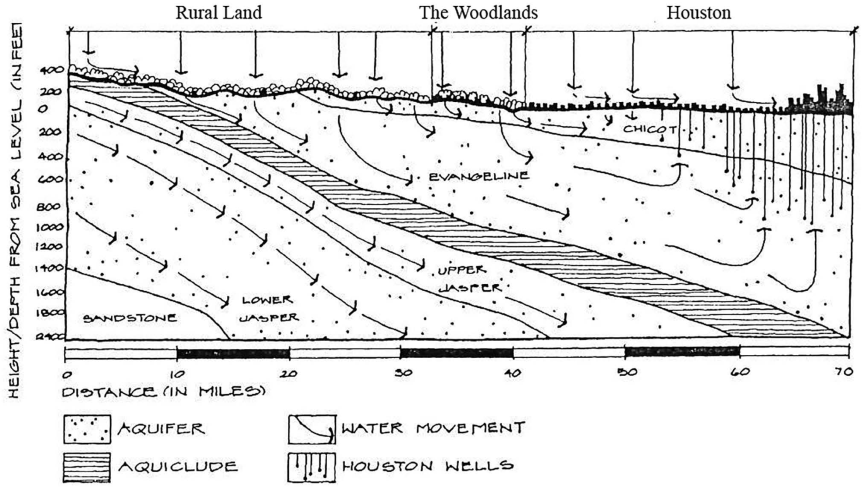


Figure 6.2 Regional study of the Chicot and Evangeline aquifers underlying Houston and The Woodlands, Texas.

(Adapted from Spirn, 1984, p. 164, Figure 7.10. Used by permission)

floods in Houston downstream (McHarg, 1996). The Woodlands lies on top of the recharge areas for aquifers that underlie Houston (Figure 6.2). Some areas in Houston had already subsided by approximately 3.1 m (10 feet) because of oil and water extraction (Spirn, 1985). If conventional drainage solutions were used, The Woodlands development may have further threatened the support of high-rise buildings in downtown Houston. As McHarg recalled, each of these challenges required a novel approach in land planning.

7 Planning and design process

McHarg (WMRT)'s ecological plan

As described in Chapter 6, these planning challenges are wicked in nature (Rittel & Webber, 1973; Xiang, 2013), because urbanization inevitably increases runoff and flooding potential and degrades water quality. Adaptive strategies should be developed to accommodate and minimize these impacts. McHarg's design process has several interwoven, reiterative steps, with key steps as illustrated in Figure 7.1. This process demonstrates an interdisciplinary team approach for planning and design, in lieu of a plan produced by a single designer. The process starts with a comprehensive ecological inventory of the site, followed by data interpretation and (re)prioritization of goals and objectives. Based on a series of map overlays, various factors such as ecological, economic, and political issues are superimposed to determine the land's carrying capacity to support certain human activities and land uses (primarily residential in The Woodlands). Four polished reports were produced (WMRT, 1973a, 1973b, 1973c, 1974), and these innovative studies became one of the early EIS studies of the NEPA process.

WMRT delivered to HUD a preliminary report on ecological planning on March 14, 1971. Other members (in particular, Narendra Juneja) of WMRT then created four additional, more-polished reports in 1973 and 1974 that included ecological inventory, land planning, site planning, and a final ecological plan (WMRT, 1973a, 1973b, 1973c, 1974). The first report, the ecological inventory, described the existing natural phenomena, including geology, groundwater hydrology, surface hydrology, limnology, pedology, plant ecology, wildlife, climatology, and landscape interacting processes. The remaining three reports were comprised of ecological data interpretations, assessment of landscape tolerance, design synthesis, and guidelines and plans for Phase I development (subdivision village of Grogan's Mill).

Goals and strategies

McHarg (WMRT)'s main goal was to preserve the pine forest, and several integrated planning strategies were used in order to maintain the site's

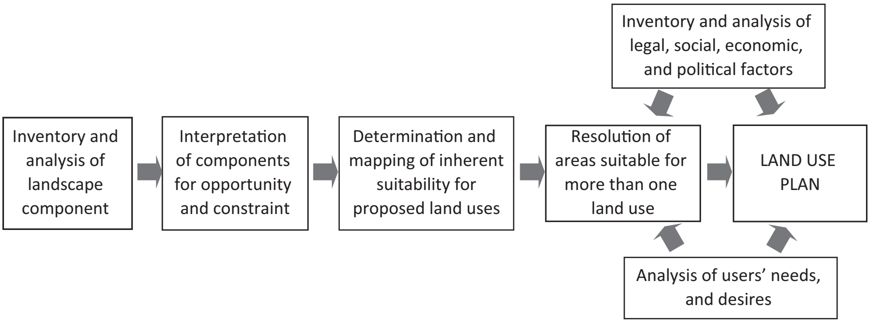


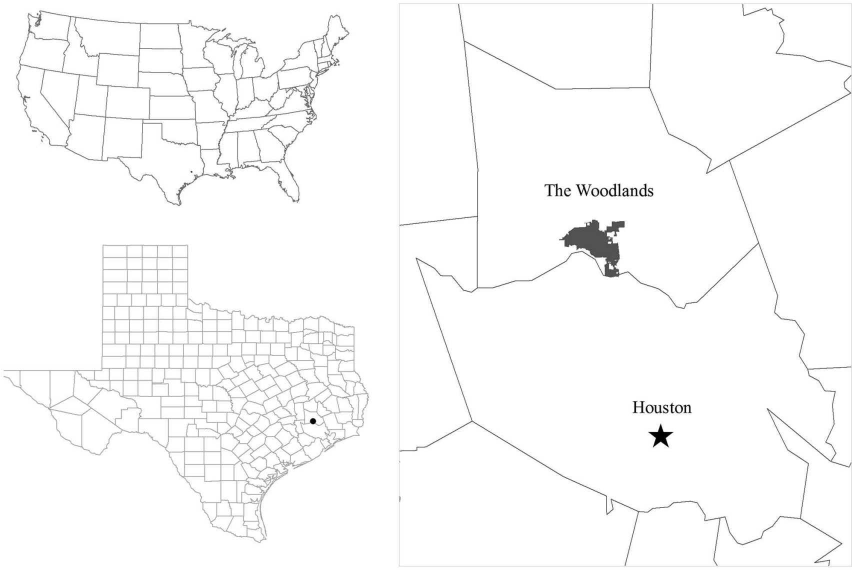
Figure 7.1 Flow chart of the ecological planning process in The Woodlands. (Adapted from Johnson et al., 1979; McHarg & Steiner, 1998, p. 244, Figure 1).

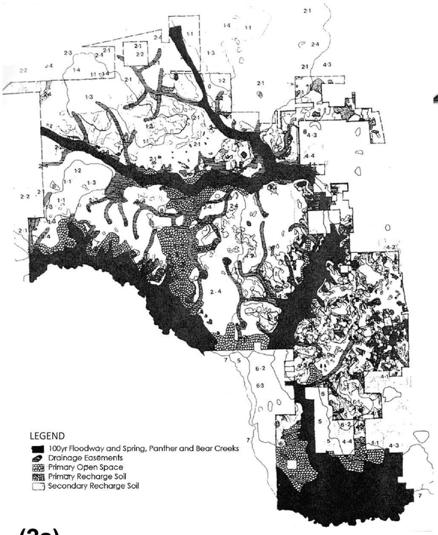
natural hydrologic balance (WMRT, 1973b, 1974). The main strategies were to: (1) preserve land with highly permeable soils, (2) maintain forest preserve land, and (3) use open surface drainage. Early environmental planning was based on these strategies. In addition, these integrated strategies were implemented through a holistic "natural" drainage scheme to tackle wicked design problems (e.g., drainage design, flood control, and groundwater recharge) residing in a wide range of scales.

Strategy 1: preserve permeable soils

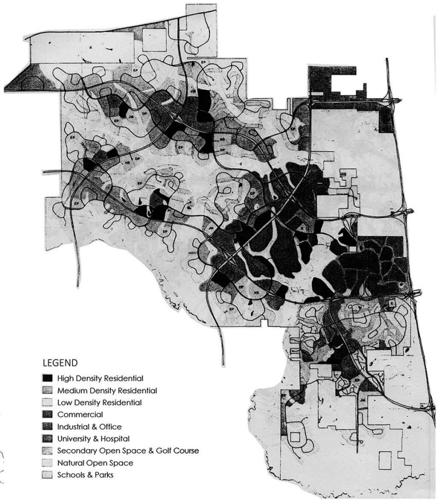
The most important land-planning strategy was to determine building densities and land use based on soil permeability (WMRT, 1973a, 1973b, 1973c, 1974). This is achieved by preserving land with high soil permeability as open space and land with low soil permeability for development. Hence, runoff is infiltrated in proximity to where it is generated (Figure 7.2; WMRT, 1973c). The proposed development locations are largely determined by soil patterns to allow maximum runoff infiltration. This figure shows regional-scale analysis of the biophysical features and the proposed development, in which densities and locations are largely determined by soil patterns to allow maximum runoff infiltration (WMRT, 1973a, 1973b, 1973c, 1974). Specifically, Figure 7.2 (2a) shows primary open space and recharge soils, and in Figure 7.2 (2b), these areas were excluded from development. Conversely, land areas that have low infiltration capacities were proposed for community development, the darker the area, the greater was the building density. High-density land uses were proposed relatively near the roads and to avoid prime recharge soils.

At finer site scales, design guidelines were specified for onsite stormwater detention and infiltration. Adaptive design strategies are specified for soils and housing development (Table 7.1, Figure 7.3). For Phase I development,





(2a)



(2b)

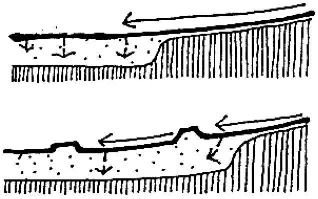
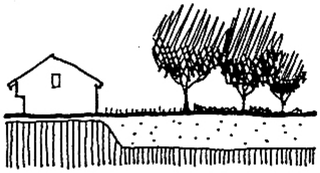
Figure 7.2 Location map of The Woodlands, Texas, USA.
Figure 7.2 (2a) Community-scale analysis of The Woodlands (a) Design synthesis

(WMRT, 1974, p. 35).

Figure 7.2. (2b) Proposed land use plan (WMRT, 1974, p. 41). The proposed development locations are largely determined by soil patterns to allow maximum runoff infiltration.

(Image courtesy: WRT).

Table 7.1 The Woodlands site planning guidelines and adaptation strategies for soils.

Objective 1 Adaptations	Use recharge capacities of suitable soils to enhance a natural drainage system and even out base flow of streams.
Direct runoff over permeable soils with excess storage capacity. Use roads, berms, and check dams in swales to impound runoff by blocking flow over permeable soils.	
Objective 2 Adaptations Locate structures on impermeable soils. Locate backyards and intensively used recreation areas on permeable soils.	Minimize coverage on top of permeable soils. 
Objective 3 Adaptations Buildings and patios should be constructed on raised foundations or fill.	Houses and outdoor activity areas should be located to be as dry as possible. 
Pedestrian paths should be raised or on fill if located on impermeable soils.	

(WMRT, 1973b, p. 11)

the guidelines required no excessive runoff to be generated (WMRT, 1973b). Modeling analyses further compared the after-built runoff scenarios and ascertained that runoff is detained as close as possible to where it is generated, using grading and landscape designs (Figure 7.4).

Strategy 2: protect forest environment

The second strategy was to preserve a significant portion of the pine forest (WMRT, 1973a). To ensure the minimum clearance of vegetation, a Landscape Clearance Index was developed, which guided vegetation preservation under different soil conditions (WMRT, 1973a, p. 39). For example, a pine forest with the highest recharge soils (e.g., sandy soils) could be cleared

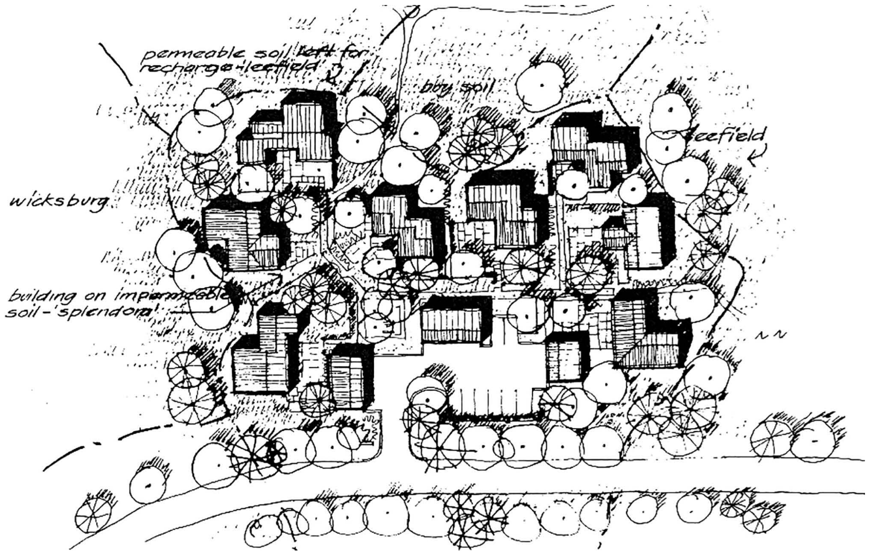


Figure 7.3 Site-level design guidelines. Housing cluster and grouped parking conformed to the boundaries of soils with low infiltration capacities (WMRT, 1974, p. 72).

(Image courtesy: WRT)

up to 90%, regardless of the vegetation types. If a forest has medium-high recharge soils (e.g., sandy loam and loam soils) and medium-sized trees, the allowed clearance ratio is then reduced to 75%. In addition, the runoff recharge area must remain forest after development. In terms of the choice of preservation, species with high ecological values are given the priority. Some advanced technologies at that time were used, including analyzing infrared images to identify tree species (WMRT, 1973a).

There were two main components under this index. The first was to preserve trees and understory along major streets. Buildings were thus hidden by the tree mask, which gave visitors and homeowners a distinct impression that the forest environment was protected. The second component was to maintain the natural forest within each parcel. As a result, there were trees preserved in parking lots, near buildings, and in community parks (Galatas & Barlow, 2004; Kutchin, 1998).

Strategy 3: use open surface drainage

The third strategy was to use open surface drainage (e.g., grassy swales). These drainage channels were located along streets, and check dams were strategically placed where permeable soils were available for runoff

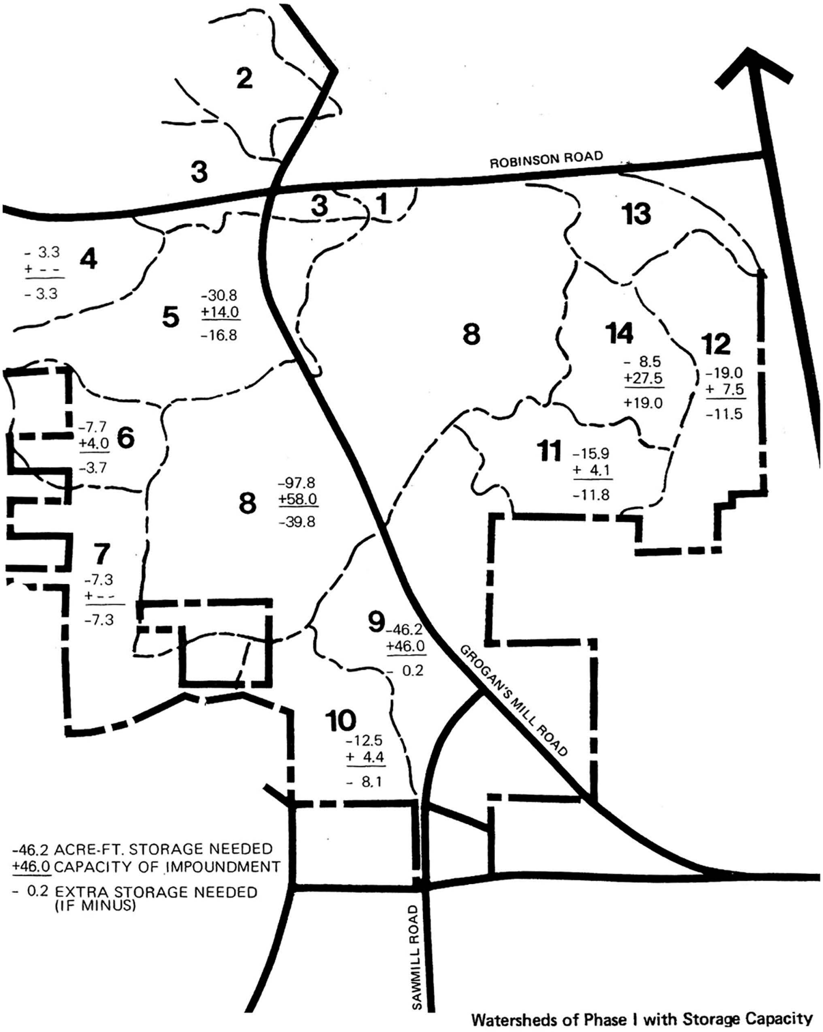
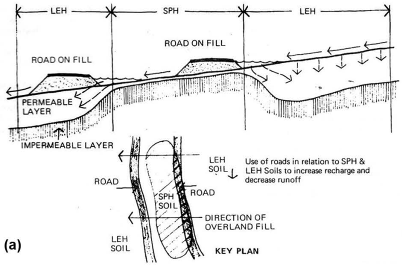


Figure 7.4 Modeling analysis on runoff storage in Phase I development (8 km^2), with no excessive runoff allowed (WMRT, 1973c, p. 9).

(Image courtesy: WRT)

infiltration (Figure 7.5, WMRT, 1973b, p. 31). Collector streets, neighborhood roads, and commercial buildings were placed on ridgelines and higher elevations. The 100-year floodplains of three creeks on site were preserved, as were sandy soils in parks and public right-of-way. Golf courses, parks, and open space detain runoff over sandy soils to enhance infiltration (McHarg, 1996; Spirn, 1985; WMRT, 1973b). In short, the “natural” drainage scheme determined the overall layout and structure of The Woodlands.



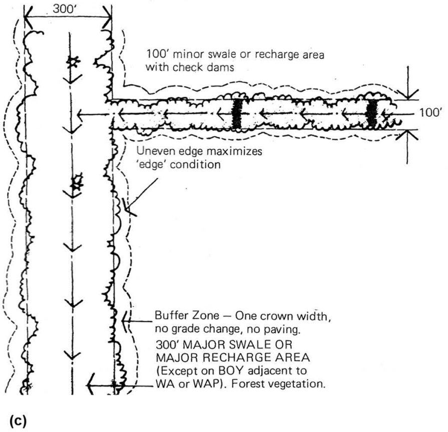


Figure 7.5a Open drainage design guideline which promotes impoundment on permeable soils. Check dams retard runoff and increase infiltration. LEH: medium to well-drained soil; SPH (Splendora): poorly drained soil (WMRT, 1973c, p. 31) (Image courtesy: WRT).

Figure 7.5b Open surface drainage along collector streets in The Woodlands.

Figure 7.5c Construction principles for grassed drainage swales. A minimum buffer zone width is specified for major and minor swales. BOY: medium to well-drained soil; WA (Waller): poorly drained soil; WAP (Waller ponded): very poorly drained soil (WMRT, 1973c, p. 19) (Image courtesy: WRT).

In fact, streets with open drainage are superior to streets with curb-and-gutter for maintaining safe traffic flow during heavy rainfalls. In the former condition, the built-up street allows proper drainage, whereas in the latter condition, the street is set at a lower elevation to collect runoff (Galatas & Barlow, 2004). Another benefit of open drainage was that substantial site excavation was not required. Existing vegetation in drainage easements, along swales and creeks, and within development areas was preserved (WMRT, 1974).

Mitchell and his staff were at first skeptical about the open drainage solution because they did not believe that ecological planners knew hydrology better than engineers. Mitchell asked Espey Associates, his engineering consultants, to process McHarg's proposal on their computers. Espey employees reported later that McHarg's open drainage solution did work. They also confirmed the enormous savings this solution could provide: for Phase I alone, conventional drainage would cost $18.7 million, whereas open drainage would cost $4.2 million, a savings of $14 million (McHarg, 1996).

Interdisciplinary design process

The aforementioned strategies were resultant from an interdisciplinary design process. In fact, the emphasis on process rather than a prescribed plan product is important. The regional effects of land development on groundwater, in particular, would not have been identified with a less-comprehensive approach to study The Woodlands site. An interdisciplinary team in this case was essential to this study approach. The WMRT team conducted an ecological inventory that described the existing natural phenomena (Table 7.2).

The study of natural features and processes revealed important issues of which George Mitchell's staff were unaware initially. The WMRT study showed the regional aquifer system beneath The Woodlands and Houston (see Figure 6.2), which suggested that runoff from upstream areas needed to infiltrate and percolate into the ground to sustain two aquifers that provide water for Houston. Through this process of examining the regional effects, it also became apparent that surficial hydrology, soils, and vegetation constituted a closely linked system. The development of adaptive strategies that augment the function of this linked system is crucial (McHarg & Steiner, 1998; WMRT, 1973a). As a result, central problems identified from this design process included stormwater drainage, flooding, and groundwater recharge.

Thus, The Woodlands design process reveals a dynamic framework from data analysis, synthesis, and interpretation, to planning, design, and implementation. This design process illuminates central problems, reveals interactions

Table 7.2 Select inventory maps in The Woodlands project.

	Category	*Detailed item*
1	Physiography	Elevation, slope
2	Geology	Bedrock or sub-surface geology, surficial deposits, geological cross-sections
3	Soils	Series or phases, drainage classes, hydrologic groups, capability group, depth to seasonal high water table, as applicable
4	Hydrology	Depth to water table, aquifer yields, direction of groundwater movement, recharge areas, water quality, surface waters (lakes, streams, wetlands), flood zones, drainage basins
5	Vegetation	Distribution of associations, communities, and habitats as identifiable, are as important as noise buffers, food supplies, for wildlife, nesting areas
6	Wildlife	Identification of species and their habitats and ranges, movement corridors
7	Climate	Macro-and microclimate parameters (temperature, moisture, wind). Ventilation and insulation may be determined in conjunction with physiography
8	Resources	Mineral or other valuable natural resources

(Adapted from McHarg & Steiner, 1998, p. 245, Table 6) of issues, informs possible design interventions with corresponding outcomes (development scenarios), and facilitates the integration of design solutions at both regional- and site-level scales. The aforementioned strategies and examples show that McHarg's design process forged actionable steps in practice, in that landscape architects and planners essentially need to give physical forms to a land or space in a spatially meaningful way.

Additionally, McHarg had strived seriously in the planning stage to encompass human ecology into the ecological model. This was the *human-ecological planning* approach that he later elaborated in his autobiography (McHarg, 1996). McHarg invited a group of distinguished social scientists to brainstorm ideas regarding future residents' profiles and their preferences of the environment. Knowledge generated from this conference was used for The Woodlands planning and design (McHarg, 1996, p. 345). Despite the great success of this conference, McHarg's proposal for the human ecology piece was unfortunately not used. The proposal was suppressed by an economist in the team, among other reasons (McHarg, 1996, p. 345).

Nevertheless, unlike the first-generation Landscape-suitability Approach (LSA) 1 that only focuses on biophysical factors, the methods that McHarg (WMRT) employed in The Woodlands encompassed ecological, economic, as well as social variables. (Ndubisi, 2002, 2014). This was made possible because of the interdisciplinary team that McHarg assembled. In addition, various consultants were involved including Land Design Research (LDR) of Columbia. LDR redid WMRT's original land availability analysis, adding consideration of views. LDR's work was incorporated in the WMRT published reports (Forsyth, 2003).

Apparently, an interdisciplinary, holistic solution serves many purposes and this solution benefits not only The Woodlands but also the Houston region's sustainability in the long run. The sum of the benefits brought about by a holistic solution is more than those of its pieces. However, a holistic solution is arguably one-of-a-kind for a particular site – to tackle specific (wicked) design problem(s). In The Woodlands, it was the design process that led to the identification of central problems. McHarg considered his approach as "diagnosis and prescription" for land planning (Spirn, 2000). And he believed that it was an objective procedure used in The Woodlands that could be replicated to produce similar outcomes: "A method was developed which insured that anyone would reach the same conclusions . . . any engineer, architect, landscape architect, developer, and the client himself were bound by the data and the method" (McHarg & Sutton, 1975, p. 78).

As McHarg and Sutton stated in their 1975 article,

> It is the quantitative capabilities of the method which deserve the greatest attention and refinement. While the data and the hypothesis employed in formulating the conclusions await testing, they represent a dimension of causality and quantification not heretofore accomplished in any projects by WMRT.
>
> (McHarg & Sutton, 1975, p. 90)

Summary of literature

The Woodlands received numerous awards that exalted its efforts of environmental stewardship, with quite a few noteworthy ones such as the 1974 Design Award from HUD (Department of Housing and Urban Development) (Morgan & King, 1987) and the 1994 Award of Excellence from the Urban Land Institute. Appendix 11 lists major awards that recognize The Woodlands' accomplishments in planning and design from 1974 to 2016 (over 60 awards).

Echoing these recognitions, McHarg's (WMRT) design process allows establishing landscape performance benchmarks quantitatively. In fact, The Woodlands survived storms that exceeded a 100-year level in 1979 and a 500-year level in 1994 with little property damage, while Houston (43 km away) was severely flooded during both events (Girling & Kellett, 2005). In a tropical storm in 1987, two adjacent communities (Oak Ridge North and Timber Ridge) were awash, while The Woodlands survived unscathed. In recent regional storms (e.g., in 2015, 2016, and 2017), The Woodlands was less impacted compared with adjacent communities developed according to the conventional approach.

Before the writing of this book, a number of studies have documented The Woodlands development history and evaluated McHarg's planning approach. Selected works are presented as follows. Appendix 12 provides a detailed list of literature from 1973 to 2017.

- McHarg and Sutton (1975) first featured The Woodlands ecological planning concept, with a focus on stormwater management.
- Two monographs, by Morgan and King (1987) and Galatas and Barlow (2004), reviewed the development history of 1964–1983 and further to 2004.
- Forsyth (2002, 2005) compared three new town developments (The Woodlands, Texas; Irvine, California; and Columbia, Maryland) and indicated that current planning practice could still benefit from these experiences.
- In McHarg's autobiography *A Quest for Life* (McHarg, 1996), he shared anecdotes of The Woodlands project and revealed his insights on the human-ecological planning approach that he seriously attempted in this project.
- In his 2011 book, Steiner reflected on the success and lessons learned after 40 years, especially on the social dimension. Steiner devoted generous ink to the comparisons between The Woodlands and contemporary New Urbanism projects (Steiner, 2011).

Other quantitative and modeling assessments have been done regarding The Woodlands' landscape performance.

- Bedient and colleagues (Bedient, Flores, Johnson, & Pappas, 1985) compared more than a dozen development scenarios and concluded that The Woodlands development plan mitigates flooding.

- Doubleday and colleagues (Doubleday, Sebastian, Luttenschlager, & Bedient, 2013) further showed that The Woodlands can attenuate peak discharges during 100-year storm events.
- Compared with adjacent Houston communities, The Woodlands showed substantially lower levels of forest fragmentation (Kim & Ellis, 2009). In addition to the above examinations, additional positive implications for environmental, economic, and human well-being are expected to be enormous.

Comparing performance with project goals

In addition to the previous literature, Table 7.3 summarizes empirical studies conducted on The Woodlands, presented in 11 metrics that cover environmental, social, and economic aspects of sustainability. To its credit, The Woodlands' landscape performance has been assessed in a number of scientific studies conducted in the past four decades, highlighting the credibility of McHarg's (WMRT) ecological plan. These findings present considerable similarities with what McHarg and his colleagues have envisioned or forecasted, suggesting that WMRT's plan successfully achieved the planning goal (Yang & Li, 2016).

For instance, compared with adjacent Houston communities, The Woodlands shows significantly less stormwater runoff during 100-year storms, substantially lower pollutant loadings (e.g., NO_3^-N, NH_3^-N, and TP), lower levels of forest fragmentation, an average of 2°C lower land surface temperature, and higher walkability and pedestrian access to open space. Also, some of the performance forecasts were close to the observed situations numerically. McHarg's (WMRT) plan predicted that peak flows in The Woodlands would increase by 55%, versus 180% in Houston conventional development (WMRT, 1973a, 1973b, 1973c, 1974; Juneja & Veltman, 1980; Spirn, 1984, 2000). Using observed data and coupled with computer simulations, several studies show that The Woodlands peak flows are 2–3 times lower than conventional Houston development (Doubleday et al., 2013; Yang & Li, 2010, 2011; Yang, Li, & Li, 2013).

More importantly, several of McHarg's unique planning concepts have proved to be successful. It is efficacious to use soil permeability as a key variable to guide land use planning to achieve the zero-runoff objective (Yang & Li, 2011). The holistic, "natural" drainage system demonstrated flood mitigation effectiveness in that the runoff regimen retains its forest conditions after development.

The following chapters in PART III provide a detailed review of The Woodlands' landscape performance in flood control, stormwater quality, and urban heat island reduction.

Table 7.3 Integrated planning and design in The Woodlands: metrics, strategies, and performance forecasts in Ian McHarg's (WMRT's) original plan and empirical examinations decades later. Landscape performance is in accord with WMRT's projections.

Metric	*WMRT strategies, performance forecast*	*Reference*	*Empirical analysis decades later*	*Reference*
1 Stormwater runoff	Link soil permeability with housing density; would generate lower runoff than conventional development	WMRT, 1973c; McHarg & Sutton, 1975; Juneja & Veltman, 1980	The Woodlands land use plan minimizes the hydrologic impacts; lower runoff than conventional Houston communities	Juneja & Veltman, 1980; Bedient et al., 1985; Yang & Li, 2010, 2011; Doubleday et al., 2013; Yang et al., 2013
2 Flood control	Predicted peak flows increase by 55%, versus 180% in Houston's conventional development	WMRT, 1973a, 1973b, 1973c, 1974; Juneja & Veltman, 1980; Spirn, 1984, 2000	Peak flows 2–3 times lower than conventional development; peak flows similar to forest conditions during 100-year storms, and would be 50% lower if strictly followed McHarg's approach	Doubleday et al., 2013; Yang & Li, 2010, 2011; Yang et al., 2013
3 Water quality	Open drainage, wetland, permeable pavement, building construction BMPs[a]; lower pollutant levels than Houston's conventional communities	WMRT, 1974; Juneja & Veltman, 1980	Pollutant loadings (NO_3-N, NH_3-N, and TP) are substantially lower than Houston communities[b]	Yang & Li, 2013
4 Water conservation	Minimize irrigation water use through limiting lawn areas and irrigated public space	Spirn, 1984, 1985; Kutchin, 1998	n/a	n/a
5 Forest protection	Large, permanent forest preserve; tree protection at street right-of-way and individual parcels	WMRT, 1973a, 1973b, 1973c, 1974; Spirn, 1984	Lower levels of forest fragmentation than North Houston communities; 25% land preserved as open space in perpetuity	Morgan & King, 1987; Galatas & Barlow, 2004; Kim & Ellis, 2009
6 Wildlife	Preserve continuous wildlife corridors at wetlands and floodplains	WMRT, 1973b, 1974	Wildlife corridor and forest connectivity well preserved	Spirn, 1984; Forman, 2002; Kim & Ellis, 2009

7 Urban heat island	Not a focus area in WMRT plan	n/a	On average 2°C lower land surface temperature than Houston communities	Sung, 2013; Yang & Li, 2013
8 Energy conservation	Solar panel application; planting design and housing orientation strategies	Kutchin, 1998; Galatas & Barlow, 2004	n/a	n/a
9 Social value	Integrate ecological and social goals; use of floodplains and drainage channels as open space	WMRT, 1973b; Spirn, 1984	Good ethnical diversity and integration; rich social events and community employment opportunities; good stand of resident's satisfaction and well-being	Morgan & King, 1987; Galatas & Barlow, 2004; Forsyth, 2002, 2003, 2005; The Woodlands Township, 2011
10 Transportation	Not a focus area in WMRT plan	n/a	Better interconnectedness, higher walkability than conventional Houston communities	Zhang & Yi, 2006
11 Cost benefit	Would save $14 million for Phase I alone; low-maintenance parkland and residential yards	McHarg & Sutton, 1975	Potential avoided costs include flooding damage and salvation, personnel injuries, erosion, and sediments control, and water quality pollutants treatment; increased housing value due to park and open space	Yang & Li, 2010, 2011; Yang et al., 2013; The Woodlands Township, 2011

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[a] BMP (Best Management Practice). Construction fencing is usually only a few feet away from the building footprint to ensure minimum site disturbance.

[b] NO_3-N (nitrate-nitrogen); NH_3-N (ammonia nitrogen); TP (total phosphorous).

8 Resilience to flood

Introduction

This chapter presents a comparative study of flood resilience in The Woodlands and two comparative community developments in suburban Houston, Texas. Empirical data were used to examine daily streamflow and runoff correlation, given the assumption that a lower precipitation-runoff correlation means a higher level of resilience to flood. The Woodlands and two comparative sites were examined in regard to their different planning approaches (ecological vs. Houston conventional).

Background

The major urban development project of the past century in the U.S. has been the development of suburban communities. Conventional community development practice imposes a homogeneous hardscape pattern on the natural landscape, giving little consideration to advantageous drainage opportunities. Conventional drainage solution (curb-and-gutter, drop inlet, and underground piping) aims to remove stormwater as quickly as possible, thus creating a flooding problem downstream (Ferguson, 1995, 1998; Paul & Meyer, 2001).

Common mitigation measures such as detention basins focus on peak discharge reduction and present limited success in runoff volume reduction or water quality improvement (Booth & Jackson, 1997; Scholes, Revitt, & Ellis, 2008). Moreover, if the basin is located inappropriately, it may aggravate flooding (Ellis & Marsalek, 1996; Maxted & Shaver, 1996; Perez-Pedini, Limbrunner, & Vogel, 2005).

Prince George's County, Maryland, piloted a more comprehensive hydrological mitigation approach, called "low-impact development" (LID) (Prince George's County, 1999). LID suggests development policies and urban guidelines and also combines a number of techniques, including storing, infiltrating, evaporating, and releasing runoff slowly, at a rate not exceeding that of the predevelopment condition (U.S. EPA, 2008). The U.S. EPA advocates retrofitting the conventional stormwater system toward using LID and green infrastructure (GI) design (Prince George's County, 1999; Benedict & McMahon, 2006; U.S. EPA, 2008). GI design typically encompasses open space, parks, green roofs, bioretention, and constructed wetlands, decentralized water management (e.g., rainwater harvesting), protection of riparian areas, and various hybrids of pervious surfacing options (Benedict & McMahon, 2006; Tzoulas et al., 2007).

As described in previous chapters, integrated GI strategies have been adopted throughout The Woodlands in order to minimize development impacts on stormwater. It is hypothesized that The Woodlands would present a lower precipitation-runoff correlation than Houston communities, and therefore, a higher level of performance in flood control.

Study sites

Development started around the same time in the three sites in the 1970s, yet development approaches differed. Using watershed as the study unit, three watersheds that overlay the communities are delineated for comparison (Table 8.1, Figure 8.1). Figure 8.2 shows typical views of the study sites, in respect to drainage and landscape designs. Panther Creek watershed (Site 1) consists of the majority of The Woodlands (Montgomery County, Texas). Sites 2 and 3 contain conventionally developed communities in west Houston (Harris County, Texas), falling within Langham Creek and Bear Creek watersheds, respectively.

Site 1 is The Woodlands in which McHarg's ecological planning approach was used. Sites 2 and 3 are part of residential development areas, designated by the West Houston Association (WHA, 2003) and City of Houston General Plan (City of Houston, 2012). West Houston is a rapidly growing area. Its population has surpassed 1 million since 1999, and 34% of new single-family home construction in the Greater Houston area occurs in west Houston (WHA, 2003). A conventional "cookie-cutter" community design approach

Table 8.1 Study sites and respective watersheds.

Watershed	*Drainage area (km^2)*	*Development start date*	*Population*	*Household number*
1 Panther (Woodlands)	100.7	1974	66,143	24,655
2 Langham (comparative)	74.8	1978	56,976	16,973
3 Bear (comparative)	46.1	1976	33,763	9,559

Notes: Watersheds are defined by the U.S. Geological Survey gauging stations: No. 08068450 (Site 1), No. 08072760 (Site 2), and No. 08072730 (Site 3). Slopes in all the three watersheds are less than 1%. Population and household information is based on 2010 U.S. Census Block data.

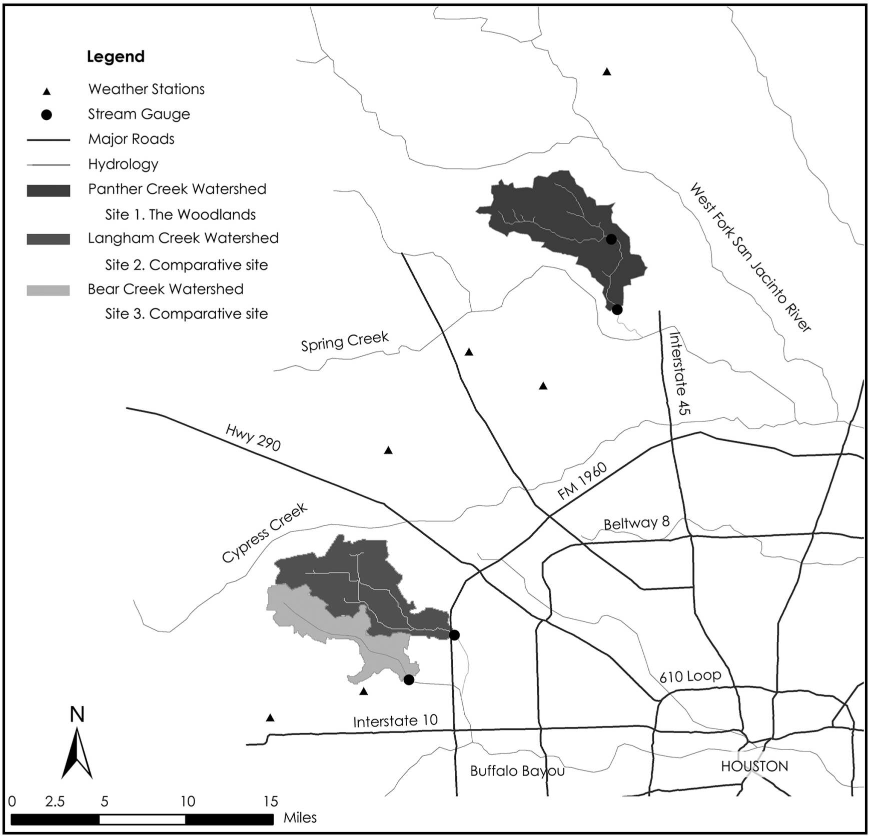

Figure 8.1 The Woodlands (Panther Creek watershed) and two comparative communities (Langham Creek and Bear Creek watersheds) in west Houston, Texas, USA.

Figure 8.2 Typical neighborhood views in (a) The Woodlands (McHarg's ecological design: curbless streets, open surface drainage, and well-preserved vegetation) and (b) comparative Houston communities (curb-and-gutter conventional drainage and less consideration of preserving vegetation).

is used. Stormwater is managed through an artificial curb-and-gutter system and natural vegetation is subjected to destruction during construction.

Data

Table 8.2 provides data sources and explanations. Development, soil, precipitation, and streamflow data are used for stormwater runoff comparison. Development extent and soil conditions were first assessed to demonstrate the background conditions of the comparative analysis.

Development extent

Development data were used to quantify the impervious cover area. Imperviousness continues to be the single most important variable that defines the amount of urban development and predicts runoff volume (Schueler, 1994; Arnold & Gibbons, 1996). The latest development data were obtained from the U.S. Geological Survey (USGS) 2006 National Land Cover Dataset (NLCD, www.mrlc.gov/nlcd06_data.php) at 30-m resolution. Data accuracy of the NLCD national datasets (e.g. 1992, 2001 and 2006) ranges from 73% to 85% (Homer, Huang, Yang, Wylie, & Coan, 2004; Wickham et al., 2013) and is regarded as acceptable in assessing land development and stormwater quantity and quality outputs (Earls & Dixon, 2005; Wolter, Johnston, & Niemi, 2006).

For each land development pixel (30 × 30 sq m), the two NLCD datasets (NLCD, 2001, 2006) contain information on percent developed imperviousness (Fry et al., 2011). All the pixels that contain impervious cover were used to estimate the extent of development and the total impervious cover areas. Previous NLCD datasets (e.g., NLCD, 1992 do not contain the same impervious cover information and were not included in this study.

Table 8.2 Data source and explanation.

Data	*Source*	*Explanation*
Land use land cover	NLCD website www.tnris.state.tx.us/	Provide development conditions of 2001 and 2006
Landsat	USGS Earth Resource Observation Systems Data Center website http://glovis.usgs.gov	Used for land surface temperature estimation
Streamflow	USGS website www.usgs.gov/	Provide daily mean streamflow
Precipitation	NCDC website www.ncdc.noaa.gov	Provide daily precipitation
Soil	NRCS website http://soildatamart.nrcs.usda.gov/	Soil Survey Geographic (SSURGO) 1:24,000 scale

Geographic Information Systems (GIS) has been widely used in assessing the impact of land development and anthropogenic uses on the natural landscape (Rogers & DeFee, 2005; Merem et al., 2011). In this study, GIS was used to quantify the total development area and further calculate the total impervious cover area. As previously mentioned, the two NLCD datasets (i.e., 2001, 2006) process a GIS data layer that shows the percent developed imperviousness for each land development pixel (30 × 30 sq m) (Fry et al., 2011). For each watershed, totaling the developed pixels allows an estimation of the total development area, calculated with Equation 8.1 as follows.

$$\text{Total development area} = \sum_{i}^{n} Pixel_{developed} \times 900m^2 \tag{8.1}$$

where *Total development area* represents the sum of areas where development has occurred (sq m); $Pixel_{developed}$ represents each pixel that has impervious cover (e.g., developed); and 900 (sq m) is the unit area of each pixel.

As aforementioned, the NLCD 2001 and NLCD 2006 datasets have included the percent developed imperviousness for each pixel (Fry et al., 2011). The total impervious cover area was then calculated by multiplying each individual pixel's percent developed imperviousness with the unit area of each pixel (900 sq m), calculated with Equation 8.2 below.

$$\text{Total impervious cover area} = \sum_{i}^{n} Pixel_{developed} \times \%\text{Imperviousness} \times 900m^2 \tag{8.2}$$

where *Total impervious cover area* represents the sum of areas that are classified as impervious (sq m) (e.g., rooftop and road); $Pixel_{developed}$ represents each pixel that has impervious cover; % *Imperviousness* represents the percent of impervious cover in each pixel; and 900 (sq m) is the unit area of each pixel.

Table 8.3 shows the percent of developed land and percent of impervious cover area. It is evident that for both 2001 and 2006, Panther Creek

Table 8.3 Percent of developed land and percent of impervious cover areas in 2001 and 2006.

Site No.	*Watershed*	*% developed land*		*% impervious cover*	
		2001	*2006*	*2001*	*2006*
1	Panther creek (Woodlands)	62.2	70.9	27.1	31.8
2	Langham creek (comparative)	16.3	38.2	8.8	15.6
3	Bear creek (comparative)	15.8	36.9	4.6	12.0

watershed (Site 1) presents higher levels of impervious cover and development areas than Sites 2 and 3. In 2001, Site 1 imperviousness is around three times that of Site 2 and six times that of Site 3. In 2006, Site 1 imperviousness is approximately twice and three times that of Site 2 and Site 3, respectively. More importantly, Site 1 imperviousness (31.8%) surpasses the critical impervious cover threshold (ca. 20%–25%), after which much higher watershed runoff and erosion are expected (Schueler, 1994), whereas impervious cover percentages in Sites 2 and 3 are still lower than this value.

Hydrologic soil group distribution

The soil dataset used was the 1:24,000 scale Soil Survey Geographic (SSURGO) database developed by the Natural Resources Conservation Service (NRCS). The U.S. Department of Agriculture (USDA) (USDA, 2002) defines four hydrological oil groups (A, B, C, and D) based on soil infiltration rates. A soils are sandy and loamy sand soils; B soils are sandy loam and loam soils; C soils are silt loam and sandy clay loam soils; and D soils are clay loam, silty clay loam, and clay soils. A soils have the highest infiltration rate, B and C soils have moderate infiltration rates, and D soils have the lowest infiltration rate. GIS was used to analyze the percentages of different hydrologic soil groups, which will provide insights into the overall stormwater infiltration capacity across the study sites.

Table 8.4 shows the area distribution of four hydrologic soil groups in the three watersheds. These four soil groups were further divided into two groups: A and B (sandy and loam), and C and D (silt and clay), in order to show the overall stormwater infiltration capacity (e.g., good versus poor).

It is evident that stormwater infiltration capacity of Site 1 (The Woodlands) is lower than that of Sites 2 and 3, because Site 1 has a lower percentage of A and B soils (39% in Site 1 versus 40% and 80% in Sites 2 and 3, respectively).

Precipitation and runoff

It is hypothesized that runoff discharge volume (or detention volume vice versa) from different drainage systems will be different, and The Woodlands' integrated stormwater management system would yield lower discharges than the other two sites. In lieu of directly assessing runoff volume, a widely used method is to examine the correlation of daily precipitation and runoff

Table 8.4 Area distribution of four hydrologic soil groups and water surface in Sites 1–3.

	A	*B*	*C*	*D*	*Water*
Site 1 (Woodlands)	8.3%	30.4%	40.1%	19.9%	1.2%
Site 2 (Langham)	0%	39%	36.3%	19.0%	5.7%
Site 3 (Bear)	0%	80.2%	9.8%	9.0%	0.9%

(Jennings & Jarnagin, 2002). As the three sites are geographically close to one another (e.g., similar precipitation), low precipitation-runoff correlation would indicate that the watershed is less sensitive to rainfalls and presents a robust situation that is resilient to flood.

Observed streamflow data are collected from the USGS website, based on the USGS stream gauging stations at the outlets of the three watersheds (see Table 8.1 and Figure 8.1). Historical precipitation data that are coincident with flow data were obtained from the National Climatic Data Center (NCDC) website (www.ncdc.noaa.gov/oa/ncdc.html). The Thiessen polygon method (Haan, Barfield, & Hayes, 1994) was used to estimate precipitation for all three watersheds. Three weather stations (COOPID No. 411956, No. 419076, and No. 414300) were identified for Site 1, and three other stations (COOPID No. 412206, No. 414704, and No. 414313) were used for Sites 2 and 3. The area weighted percentage of each station was used to calculate the composite precipitation value. Sample days for which rainfall data are missing were excluded from analysis; no attempt was made to estimate the missing data.

Daily mean precipitation and daily mean flow data of 2006–2010 were used, if the corresponding precipitation is greater than 0 mm. Precipitation data were further grouped into three categories: 0–6 mm, 6–35 mm, and >35 mm to represent light, moderate, and heavy rainfall events (Jennings & Jarnagin, 2002).

Results and summary

Similar annual precipitation amounts were observed in Sites 1–3, due to site proximity to one another. Table 8.5 shows the precipitation–runoff correlation expressed as Pearson's *r* correlation coefficients. The higher the *r* value, the higher the correlation between precipitation and runoff is, and the more likely the site is subject to flooding. Despite the fact that Site 1 presents a much higher impervious cover percentage than Sites 2 and 3, its *r* value is lower than that of the latter two consistently across the three rainfall categories.

Table 8.5 Regression analysis of precipitation and daily mean streamflow for 2006–2010.

Site No.	*Watershed*	*Drainage method*	*Pearson's correlation (r)*			*Avg. annual precip. (mm)*
			0–6 mm	*6–35 mm*	*>35 mm*	
1	Panther creek (Woodlands)	Ecological	0.031	0.147	0.716	1.18×10^3
2	Langham creek (comparative)	Conventional	0.046	0.341	0.814	1.19×10^3
3	Bear creek (comparative)	Conventional	0.055	0.332	0.766	1.15×10^3

To reiterate, Site 1 impervious cover has exceeded a threshold (ca. 20%–25%) after which runoff is expected to increase substantially, if the conventional curb-and-gutter drainage method is used (Schueler, 1994; Dietz & Clausen, 2008). Given the fact that Site 1 has a lower percentage of recharging soils (e.g., A and B soils, see Figure 8.4) with a much higher percentage of impervious cover (31.8%), McHarg's approach presents benefits of maintaining the original site hydrologic regime and mitigating flood.

Pearson's *r* values (see Table 8.5) show the correlation relationships – the higher the *r* value the more sensitive the drainage system responses to rainfalls, suggesting a vulnerability, or less resilient situation to flooding (Sites 2 and 3). The contrary is true for Site 1, that the correlation is particularly weak in heavy rainfall conditions, which shows that the drainage system successfully maintains a steady streamflow and is less prone to flooding. The findings suggest that Site 1 (The Woodlands) is less sensitive to rainfalls and presents a greater level of resilience to flood risk.

In fact, The Woodlands' natural drainage system has been proven to be effective after construction of the first phases. James Veltman, director of environmental planning, reported

> that despite 13 inches of rain in three days, and four inches of rain in one hour, there was no surface water within six hours and that during this period there was effective operation of detention ponds which filled when it rained and reverted to their normal level within six hours.
>
> (McHarg & Sutton, 1975, p. 339; Galatas & Barlow, 2004).

The Woodlands residents are expected to "understand the drainage function of wet-weather ponds and temporarily wet lawns. They should realize that presence of tear in their yards is critical to the survival of The Woodlands themselves" (McHarg & Sutton, 1975, p. 339).

Finally, it is acknowledged that using watershed as the unit of analysis cannot encompass all the study areas that are part of the land use plan. Around one-third of The Woodlands' early phases (e.g., strictly followed McHarg's design) do not lie in the Panther Creek watershed. Therefore, the efficacy of McHarg's design may not be fully revealed because of the research design. Also, this current study cannot completely tease out the performance of the early-built and later-built villages in respect to their performance because they were treated together as one study site. Chapters 9 and 10 further evaluate the performance of runoff volume and stormwater quality.

9 Runoff volume

Introduction

In order to properly manage stormwater runoff, studies have suggested that *integrated* GI designs can be more effective than single-design strategies (Villarreal, Semadeni-Davies, & Bengtsson, 2004; Yang & Li, 2010; Yang, Li, & Li, 2013). While the main focus of conventional drainage solution is peak discharge reduction, GI design aims at restoring the predevelopment flow regimes, such as reduction of runoff volume, enhancement of stormwater quality, and maintenance of base flows (Ahern, 2007; Dietz, 2007; Dietz & Clausen, 2008).

To achieve these performance benefits, GI design treats runoff close to where it is generated. For instance, runoff is detained or infiltrated onto permeable surfaces onsite. As a result, the amount of effective impervious area (EIA) that directly contributes to runoff is reduced. EIA is a subset of the commonly used term "total impervious area" (TIA), which is often used to define the extent of community development. TIA is the sum of all non-infiltrating surfaces. EIA, or directly connected impervious area, includes only those impervious areas that drain into a piped storm sewer and further discharge into a surface-water body (e.g., parking lot runoff goes directly to a stormwater drain) (Alley & Veenhuis, 1983; Han & Burian, 2009).

Although EIA increases when the connectivity of TIA increases, development patterns can be better indicators than TIA alone in estimating stormwater runoff and pollutant exports (Mejía & Moglen, 2009; Roy & Shuster, 2009). Despite the fact that community development inevitably increases the TIA, GI design can be effective in reducing the EIA and runoff volume (Holman-Dodds, Bradley, & Potter, 2003; Brander, Owen, & Potter, 2004; Dietz & Clausen, 2008; Pataki et al., 2011). However, most current knowledge of GI design is based on isolated design strategies used at small-scale sites. Few studies have fully measured the effectiveness of integrated GI design that encompasses entire watersheds (Jaffe et al., 2010; ASLA, 2011).

McHarg's (WMRT) plan adopted extensive infiltration-based drainage strategies in The Woodlands. These GI strategies were integrated from regional to site levels to help minimize the TIA and the EIA (WMRT, 1973a). Typical streets in The Woodlands are 1.5–2.4 m [5–8 ft] (on average 10%)

narrower than Houston subdivision standards for road width (WMRT, 1973b). Open surface drainage channels were used to detain runoff, and curb-and-gutter drainage was avoided (see Figure 7.5).

Study sites

Chapter 9 used two of the study sites in Chapter 8: Panther Creek watershed (The Woodlands) and Bear Creek watershed (west Houston communities) to further assess runoff volume conditions as a result of different planning approaches (ecological vs. Houston conventional). These two watersheds have different stormwater infrastructures, development densities and patterns, and levels of impervious surface cover (Figure 9.1, Table 9.1). Both watersheds belong to the northern humid gulf coastal prairies of Texas and present similar land use/land cover conditions before development.

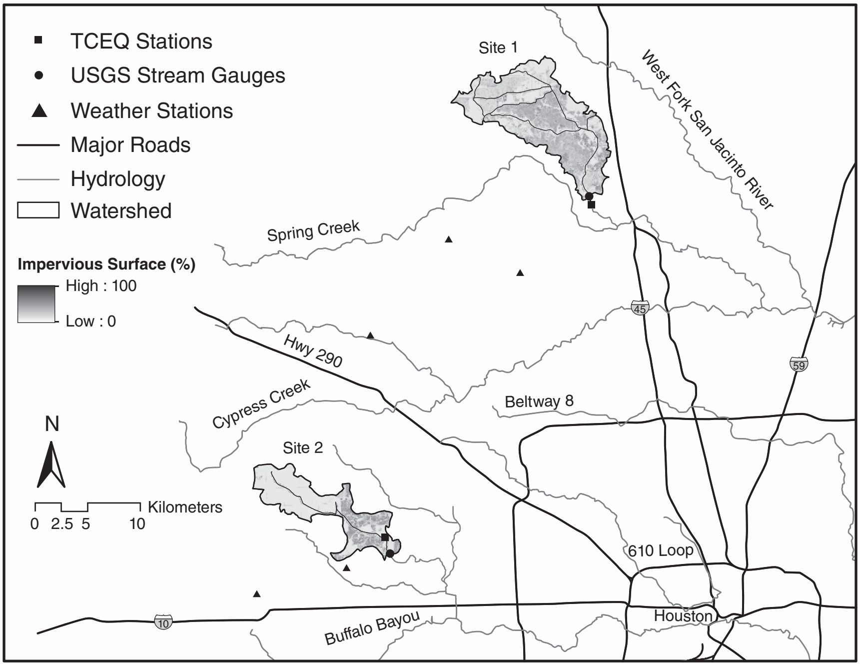

Figure 9.1 Study sites Panther Creek watershed (Site 1 The Woodlands green infrastructure development) and Bear Creek watershed (Site 2 conventional development) in Texas. USGS, U.S. Geological Survey. TCEQ, Texas Commission on Environmental Quality.

Notes: (1) At both sites the USGS and TCEQ gauge stations are on the main stream channel. (2) At Site 1, the TCEQ gauge station (No. 16628) is 55 m downstream of the USGS gauge station (No. 08068450). For graphic presentation purposes, the distance between these two stations is shown as larger than 55 m. There is a 1.01-km2 (250-acre) recreation lake (built in 1985) 2,332 m upstream of the TCEQ gauge station. (3) At Site 2, the TCEQ gauge station (No. 17484) is 1,656 m upstream of the USGS gauge station (No. 08072730).

Table 9.1 Study sites and respective watersheds.

Watershed	*Drainage area (km^2)*	*Development start date*	*Population*	*Household number*	*% Impervious cover (2009)*
1 Panther Creek (Woodlands, GI)	89.4	1974	66,143	24,655	32.3
2 Bear Creek (comparative)	55.7	1976	33,763	9,559	13.7

Notes: Watersheds are defined by the U.S. Geological Survey gauging stations: No. 08068450 (Panther) and No. 08072730 (Bear). Slopes in these two watersheds are less than 1%. Population and household information is based on 2010 U.S. Census Block data.

Bear Creek watershed is located in the fast-growing west Houston region. Houston is one of the most rapidly expanding regions in the nation, and west Houston shares more than one-third of Houston's residential community development (WHA, 2003; U.S. Census Bureau, 2011; City of Houston, 2012). Bear Creek watershed presents typical subdivision developments: cookie-cutter lot layout, turfgrass-dominated landscaping, and curb-and-gutter and underground pipe drainage (see Chapter 8). There are significant flooding and water quality concerns in this region (U.S. EPA, 2010).

Data

Development data

In land use planning, three data sources and methods are generally used to capture the impervious cover area: (1) use parcel data to quantify the impervious area (Alley & Veenhuis, 1983; Rogers & DeFee, 2005), (2) classify Landsat remote sensing imagery to extract the impervious area (Light, 1993; Alberti et al., 2007; Shandas & Alberti, 2009), and (3) digitize high-resolution aerial photographs to delineate the impervious area (Light, 1993; Jennings & Jarnagin, 2002). This study used multiple data sources to quantify impervious cover area. Parcel data provide the parcel boundary and location, parcel area, building type, year built, and building square footage. Road information was obtained from the Texas Transportation Institute (Texas Transportation Institute, n.d.).

Soil data

Soil infiltration capacity can be assessed through examining the area of hydrologic soil groups in the two watersheds. The soil dataset used was the 1:24,000 scale Soil Survey Geographic (SSURGO) database developed by the NRCS (NRCS, n.d.).

Precipitation data

Historical precipitation data were obtained from the National Climatic Data Center (NCDC) and the Thiessen polygon method (Hann et al., 1994) was used to estimate precipitation for each watershed. Three weather stations (COOPID No. 411956, No. 419076, and No. 414300) were identified for Panther Creek watershed, and three other stations (COOPID No. 412206, No. 414704, and No. 414313) were used for Bear Creek watershed (see Figure 9.1). The area weighted percentage of each station was used to calculate the composite precipitation value.

Streamflow data

Streamflow and water quality data of 2002–2009 were used for comparison. Streamflow data were collected from the U.S. Geological Survey (USGS) gauge stations No. 08068450 and No. 08072730 (USGS, n.d.), at the watershed outlets (see Figure 9.1). Slopes in these two watersheds are less than 1%.

Analysis

Two sets of analyses were conducted to compare the impacts of different drainage methods on flow regime. The first set of analyses assessed development extent and soil conditions to provide background conditions of stormwater quantity and quality comparisons. Geographic Information System (GIS) was used to analyze the parcel data. Building footprint and other impervious cover areas were calculated and sorted by year built, which provides the state of development in the watershed each year. Road surface area was estimated by multiplying the road length by the average width of the roads in the watershed (Rogers & DeFee, 2005).

A majority of the developments in this study have sidewalks on both sides of the road. Hence, the road length was doubled for the sidewalk length. Estimation was also made of the driveway impervious area. Previous studies have used the number of garage stalls multiplied by the average width (3 m) of the driveway (Stone, 2004; Stone & Bullen, 2006). However, parcel data do not provide driveway information. The Woodlands Residential Development Standards specified the front yard setback distance: "a garage or garage addition must be set back at least 16 feet (4.88 m) from the side property line" (Community Associations of The Woodlands, 1996, Section 2.1, p. 14). This setback distance was multiplied by the width of a two-stall garage (6 m) to approximate the driveway impervious area in The Woodlands, calculated by Equation (9.1):

$$\begin{aligned}\text{Driveway area}\left(\text{m}^2\right) &= \text{Front-yard setback}\left(\text{m}\right)\times 3\text{ m}\\ &\quad\times \text{Number of garage stalls}\end{aligned}\tag{9.1}$$

Then, this driveway area was multiplied by the total number of parcels in the watershed to estimate the total driveway areas. Likewise, estimation of driveway area was made for Site 2 (Bear Creek watershed), based on the 20-feet (6.1-m) garage setback distance for local streets (Houston Code of Ordinances, n.d.). GIS was also used to analyze the percentages of different hydrologic soil groups, which will provide insights into the overall stormwater infiltration capacities of the study sites. Soil condition is of particular importance to The Woodlands because McHarg's unique development concept is to preserve high-infiltration soils for stormwater management.

The second set of analyses examined the relationships of watershed streamflow volume and streamflow-precipitation ratio with impervious cover percentage. Streamflow depths and streamflow-precipitation ratios were examined for water years 2002–2009 for each watershed. A water year, according to the USGS definition, is from October of the preceding year to September of the current year (i.e., water year 2002 = 10/01/2001 to 9/30/2002).

Streamflow-precipitation ratio (as %) for each year was calculated by dividing annual streamflow (m) by annual precipitation (m), and multiplying by 100. Annual streamflow depth (m) is calculated by dividing the total streamflow volume (cubic m) by the watershed area (sq m), using Equation (9.2):

$$H = \frac{Q_i \times t}{A} \tag{9.2}$$

where H is the watershed annual streamflow depth (m); Q_i is the annual mean flow at year i ($m^3 \bullet s^{-1}$); t is a constant, 31,536,000 seconds, the total number of seconds in a year; and A (sq m) is the watershed area. This method assumes a uniform depth of precipitation falling onto the watershed; therefore, flow volume is standardized and becomes comparable.

Results

Impervious cover

Figure 9.2 shows the accumulative impervious cover percentage of the two sites with development from 2002 to 2009. It is evident that Site 1 (GI) shows a higher impervious cover percentage than Site 2 (conventional) across the study period. As of 2009, the percentage of impervious cover in Site 1 (GI, 32.3%) is more than twice that of the Site 2 (conventional, 13.7%).

Hydrologic soil group distribution

In Chapter 8, Table 8.4 shows the area distribution of four hydrologic soil groups in Sites 1 and 2. These four soil groups were further divided into two groups: A and B (sandy and loam), and C and D (silt and clay), in order to

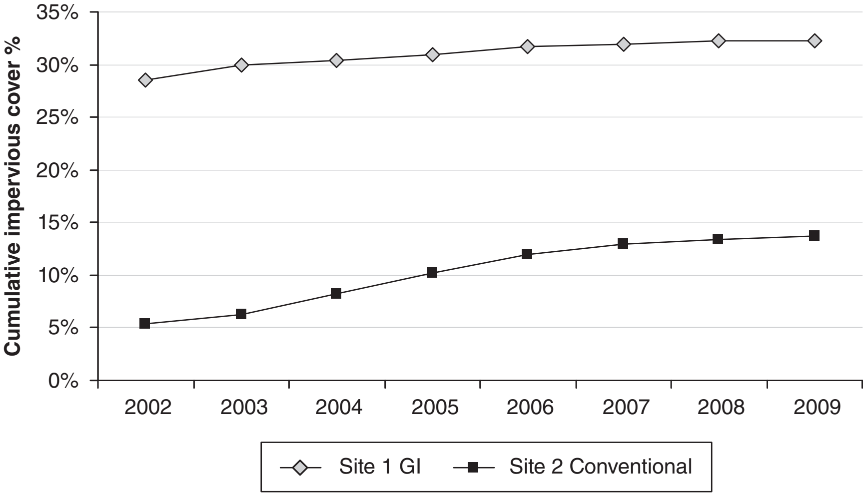

Figure 9.2 Accumulative percentages of impervious cover area of Site 1 (Panther Creek watershed, The Woodlands green infrastructure development) and Site 2 (Bear Creek watershed, conventional development), 2002–2009.

show the overall stormwater infiltration capacity (e.g., good versus poor). It is evident that stormwater infiltration capacity of Site 1 (GI) is lower than that of Site 2 (conventional), because Site 1 has a much lower percentage of A and B soils (38.7% versus 80.2% in Site 2).

Precipitation and streamflow

Figure 9.3 shows the annual precipitation in Sites 1 and 2 (approximately 45 km from each other). Figures 9.4a and 9.4b illustrate the annual precipitation depths (m) and the annual streamflow-precipitation ratios (%) at Sites 1 and 2. The average precipitation of 2002–2009 at Site 1 (GI, 1.48 m) is 15.3% higher than that at Site 2 (conventional, 1.28 m).

Despite this, Site 1's streamflow volume is 6% lower than that of Site 2. More importantly, Site 1's (GI) precipitation-streamflow ratio is kept within a steady, lower range (32%–49%) than that of Site 2 (conventional, 30%–66%). Site 2's more fluctuating ratio suggests a "flashy" stream condition.

Summary

The eight years of empirical data yield consistent results showing that GI design produces less development impact on the flow regime than the conventional drainage design. As of 2009, the percentage of impervious cover in Site 1 (GI, 32.3%) is more than twice that of the Site 2 (conventional,

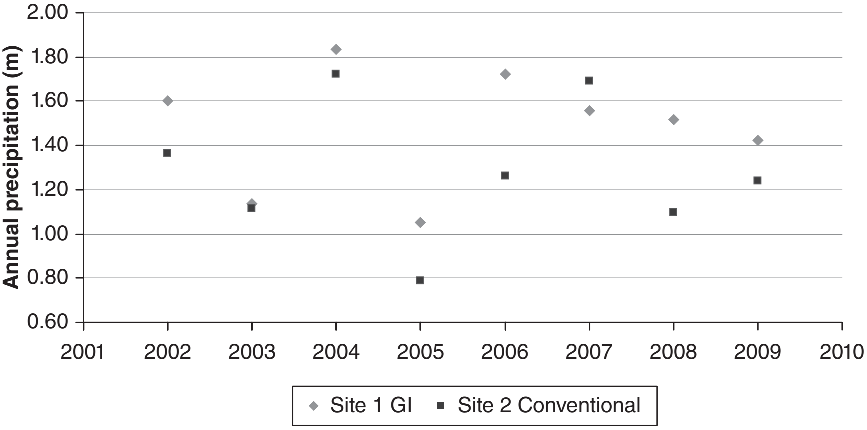

Figure 9.3 Annual precipitation in Site 1 (Panther Creek watershed, The Woodlands green infrastructure development) and Site 2 (Bear Creek watershed, conventional development), 2002–2009.

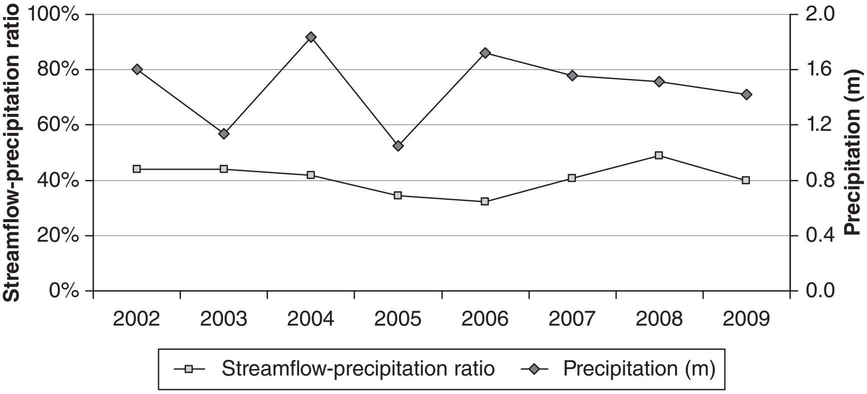

Figure 9.4a Annual streamflow-precipitation ratio and precipitation depth of (**a**) Site 1 (Panther Creek watershed, The Woodlands green infrastructure development).

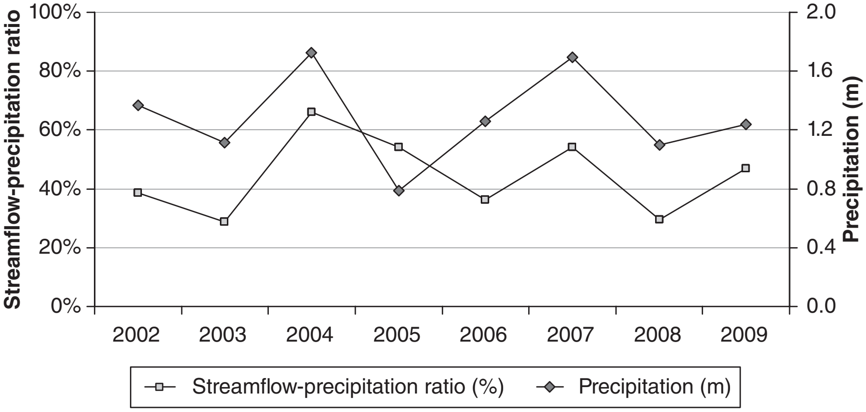

Figure 9.4b Annual streamflow-precipitation ratio and precipitation depth of (**b**) Site 2 (Bear Creek watershed, conventional development), 2002–2009.

13.7%). In addition, Site 1's (GI) total precipitation is 15.3% higher than that of Site 2 (conventional). Further, Site 1 (GI) has a much lower runoff infiltration capacity than Site 2 (conventional) (e.g., 38.7% versus 80.2% of A and B soils). The opposite is true, however, when comparing watershed outputs – the Site 1 (GI) streamflow volume and streamflow-precipitation ratio are lower than those of Site 2 (conventional). Therefore, the differences in streamflow response can be attributed largely to the different drainage designs.

To summarize, this study demonstrates that GI design can be applied across different scales. As The Woodlands landscape performance suggests in this study, large-scale GI performance (e.g., a few thousand acres) can be as effective as in site-level scales (e.g., 10–50 acres). GI design was implemented across various scales in The Woodlands. Moreover, this study confirms previous studies that *integrated* GI design strategies are better than a single strategy (Villarreal et al., 2004; Yang & Li, 2010; ASLA, 2011). This is because Site 1's GI design mimics the natural hydrological cycle by keeping the portion of runoff that originally infiltrates underground. Soil and vegetation medium further improve water quality. In other words, the decentralized, onsite runoff treatment reduced the EIA after The Woodlands development. However, as mentioned in Chapter 8, the efficacy of McHarg's GI design may not be fully revealed because of the research design of this study. McHarg's GI design innovations were primarily used in early phases of community development, during which McHarg presided over the design (McHarg, 1996). Full performance of GI design may be underestimated due to these study limitations. Chapter 10 expands on findings in Chapters 8 and 9 and further assesses performance in stormwater quality.

10 Stormwater quality

Introduction

Chapter 10 assesses stormwater quality performance in the comparative sites used in Chapter 9. The Woodlands has been well-managed as a planned community from its inception (McHarg, 1996; Bedient, Flores, Johnson, & Pappas, 1985). In addition to flood-control and properly managed runoff, McHarg's decentralized, infiltration-based drainage designs also aimed at improving water quality (WMRT, 1973a, 1973b, 1973c, 1974). McHarg's GI design was ahead of his time in that most Houston subdivision communities have been adopting conventional drainage practices.

Study sites

The test-bed watersheds are The Woodlands (Panther Creek watershed) and conventional communities in west Houston (Bear Creek watershed). These two watersheds employed different approaches in managing stormwater. They also differed in terms of the intensity and amount of development (e.g., impervious surface cover) (see Figure 9.1, Table 9.1).

In The Woodlands, in collector streets, runoff is detained and treated in the vegetated street medium for better water quality. Check dams were used to retard runoff and further soak it (see Figure 7.5). Porous pavements were used in the commercial district of the first subdivision village and other locales (Kutchin, 1998). Wetlands are protected for water quality treatment and to facilitate ecosystem services (Forsyth, 2003, 2005; Kim & Ellis, 2009).

Data

Streamflow and water quality data of 2002–2009 were used for comparison. Streamflow data were collected from the USGS gauge stations No. 08068450 and No. 08072730 (USGS, n.d.), at the watershed outlets. Water quality data were obtained from the Texas Commission on Environmental Quality (TCEQ) (TCEQ, 2012) stations No. 16628 and No. 17484 (see Figure 9.1). The TCEQ also collects streamflow data when water quality data are collected but with some data gaps. Because the TCEQ monitoring stations are placed close to the USGS gauge stations, the USGS streamflow data were used for consistency.

Since 2000, the TCEQ has been collecting 5–12 water quality samples each year for each station. Water-quality samples were consistently obtained on the same day at these two stations. The date of sampling during a particular month was irregular, and the samples may not necessarily have been taken after a rainfall event. Nutrient-related parameters that show consistent records from these two stations were analyzed, including nitrate-nitrogen (NO_3^-N), ammonia nitrogen (NH_3^-N), and total phosphorous (TP). If in either site there were fewer than six samples for a year, that year was excluded from the analysis. Other data including development data, soil data, precipitation data, and streamflow data are obtained from the same sources as described in Chapter 9.

Analysis

This set of analyses examined annual nutrient export in order to compare the impacts of different drainage methods on stormwater quality. The study used the annual flow-weighted method developed by Littlewood (Littlewood, 1992, 1995) to calculate nutrient loadings for NO_3^-N, NH_3^-N, and TP, according to Equation (10.1):

$$Flux = KV \frac{\sum_{i=1}^{n} C_i Q_i}{\sum_{i=1}^{n} Q_i} \qquad (10.1)$$

where *K* is the conversion factor to adjust for units and intervals of sampling; *V* is the annual accumulative flow (calculated from continuous data) ($m^3 \bullet s^{-1}$); C_i is the concentration measured at the day and time of the *i*th sample ($mg \bullet L^{-1}$); and Q_i is the flow rate measured at the day and time of the *i*th sample ($mg \bullet L^{-1}$).

Regression analysis was conducted for each watershed, with the independent variable being watershed impervious coverage (%), and pollutant loading being the dependent variables. Each point on the graphs therefore represents a year. Regression significance testing, R^2 calculations, and parameter estimates were performed with the SPSS statistical package.

Results

Impervious cover

In Chapter 9, Figure 9.2 shows the accumulative impervious cover percentage of the two sites with development from 2002 to 2009. As of 2009, Site 1 (GI, The Woodlands) presents a higher impervious cover percentage than Site 2 (conventional) (32.3% and 13.7%, respectively).

Nutrient export loading

Figure 10.1, Tables 10.1 and 10.2 show the regression analyses between nutrient loading and impervious cover percentage. The results reveal that nutrient loadings are tightly correlated with impervious cover in Site 2 (conventional). In contrast, in Site 1 (GI, The Woodlands), there is little correlation between nutrient loadings and the extent of impervious ground cover. These analyses further suggest that GI design can create a robust system that is tolerant to development impacts. Thus, nutrient loadings show a similar response to streamflow volume analyses. NO_3^-N export increased in Site 2 (conventional) after development; however, little change was found in Site 2 (GI). NH_3^-N export shows a similar trend as NO_3^-N export from Site 2 (conventional). Likewise, TP export presented a significant ($p < 0.01$) trend in Site 2 (conventional), whereas no trend was found for Site 1 (GI).

Discussion and summary

The eight years of empirical data yield consistent results showing that GI design produced less development impacts on the flow regimen and better stormwater quality than the conventional drainage design. As of 2009, the percentage of impervious cover in Site 1 (GI, 32.3%) is more than twice that of the Site 2 (conventional, 13.7%). In addition, Site 1 (GI)'s total precipitation is 15.3% higher than that of Site 2 (conventional). Water quality analyses showed consistency with findings in streamflow, as presented in Chapter 9. Nutrient exports from Site 1 (GI) are lower than that of Site 2 (conventional). And to reiterate, Site 1 (GI, The Woodlands) presents a much higher TIA than Site 2 (conventional) (ca. 2.4–5.4 times). However, its streamflow volume is 6% less than that of Site 2 (conventional) (see Chapter 9). This means that the EIA of Site 1 (GI) – the direct contributor to runoff volume and water quality impairment – is considerably lower than Site 1's TIA (32.3%). Site 1's EIA can be even lower than Site 2's (conventional) TIA (13.7%), because the impervious surface areas in Site 2 (conventional) are considered to be well connected for efficient drainage design.

The effectiveness of single GI designs is often reported in the literature, such as pollutant removals of rain gardens, green roofs, and porous pavements (Dietz & Clausen, 2005; Ferguson, 2005; Davis, Hunt, Traver, & Clar, 2009; Berndtsson, 2010; Gregoire & Clausen, 2011), and the U.S. EPA's current guidelines are also focusing on performance measures of individual GI designs (U.S. EPA, 2008). Thus, findings from Chapters 8–10 contribute to the U.S. EPA's guidelines by demonstrating that *integrated* GI design strategies are effective in reducing the EIA and stormwater runoff, as well as improving stormwater quality.

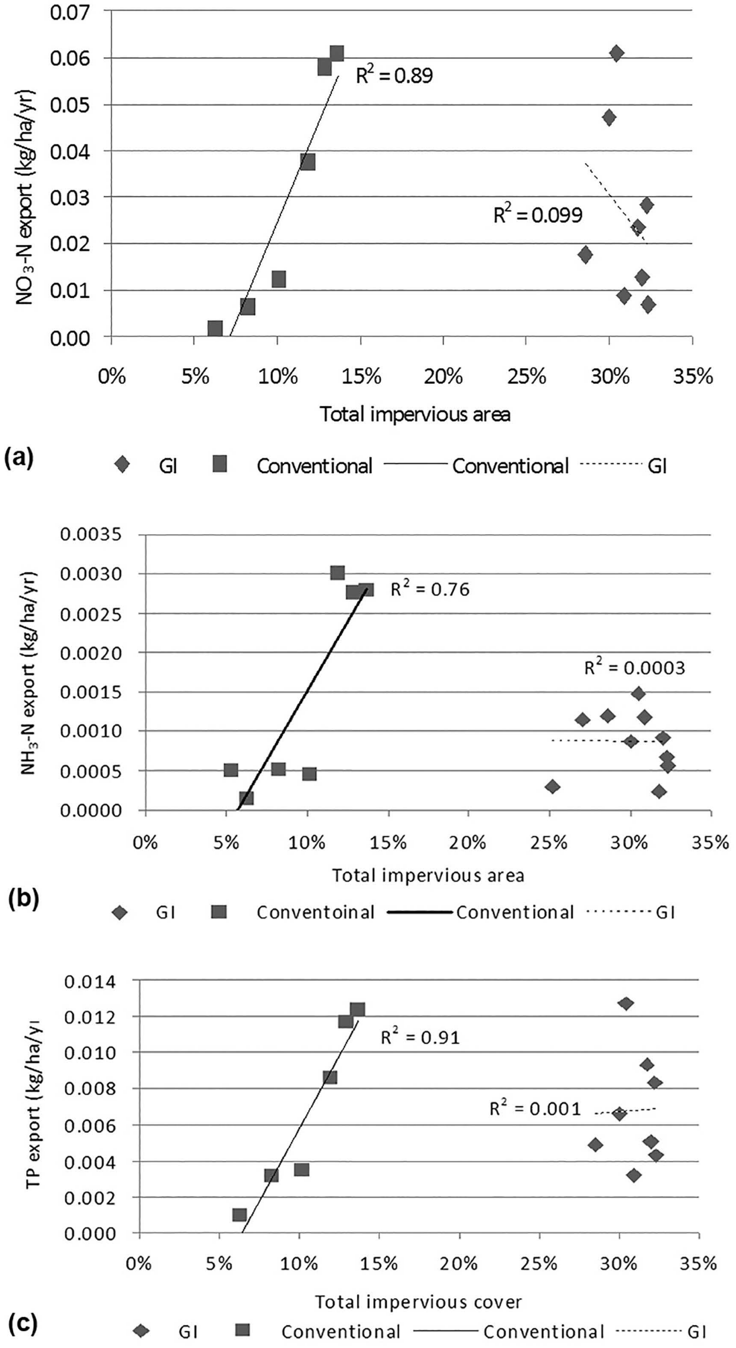

Figure 10.1 Annual loadings of nutrient exports from Site 1 (Panther Creek watershed, The Woodlands green infrastructure development) and Site 2 (Bear Creek watershed, conventional development), 2002–2009: (a) NH_3^-N, (b) NO_3^-N, and (c) TP.

Table 10.1 Relationship between watershed impervious cover percentage and nutrient loading in Site 1 (Panther Creek watershed, The Woodlands green infrastructure development).

	R^2	*Equation*	*P-value*	*Sample size (2002–2009)*
NH_3-N	0.108	NA	0.427	58
NO_3-N	0.001	NA	0.930	33
TP	0.028	NA	0.693	33

Table 10.2 Relationship between watershed impervious cover percentage and nutrient loading in Site 2 (Bear Creek watershed, conventional development).

	R^2	*Equation*	*P-value*	*Sample size (2002–2009)*
NH_3-N	0.829	$y = 0.028x - 0.002$	0.004	78
NO_3-N	0.894	$y = 0.666x - 0.046$	0.004	57
TP	0.923	$y = 0.12x - 0.007$	0.002	56

Note: x is watershed impervious cover percentage, and y is nutrient loading

Study limitations

The small water-quality sample size may decrease the precision of nutrient loading estimations. The TCEQ uses a sampling frequency of one month to meet the monitoring objectives in western Houston areas. Littlewood's method used in this current study is based on these discrete water-quality data to estimate annual mass loads (Littlewood, 1992, 1995). The precision range and confidence level of estimation decrease when the sampling frequency (e.g., monthly) and the length of the estimation period (e.g., five years) decrease. A sampling frequency that is too low (e.g., less than six samples per year) is not recommended – a principle followed in this study. In addition, estimates for dry years exhibit higher precision than those for wet years. This study used the best available data and the study period contains normal variations of dry versus wet years.

Additionally, the 1.01-sq km (250-acre) lake in Site 1 (GI, The Woodlands) upstream of the TCEQ gauge station is likely to dilute the concentration of pollutants contributed by the upstream areas of the lake. This study cannot tease out this lake dilution effect and the effect presents some limitations. However, according to the original design (Morgan & King, 1987), the lake is intended to serve as a recreation amenity and as a flood control device in The Woodlands comprehensive stormwater management plan. Therefore, this integrated design strategy showed success in flood control and water quality improvement.

11 Urban heat island

Introduction

The urban heat island effect (UHI) is a commonly known phenomenon in which urban atmosphere and surfaces present higher temperatures than the non-urbanized surrounding areas (Stone & Rodgers, 2001). The magnitude of atmospheric temperature elevation has significant implications for human health, energy use, and air quality (Akbari, Pomerantz, & Taha, 2001; Akompab et al., 2013).

Study sites

Chapter 11 examines the UHI of three comparative sites used in Chapter 8. These are: The Woodlands (Panther Creek watershed, Site 1) and two comparative communities (Langham Creek and Bear Creek watersheds, Sites 2 and 3, respectively) in west Houston. Land surface temperature (T_s) is often used to estimate the surface UHI intensity (Tomlinson, Chapman, Thornes, & Baker, 2011). Estimation for T_s requires land use/land cover (LULC) and the corresponding infrared information.

Data

LULC data (30-m resolution) for 1999 and 2006 were obtained from the national NLCD datasets (www.mrlc.gov/). Eighteen LULC classes from the NLCD datasets were associated with this study. They were further grouped to match the five LULC classes specified by Stathopoulou and colleagues (Stathopoulou, Cartalis, & Petrakis, 2007), including urban/densely built, suburban/medium built, mixed urban area, rural area, and water surface.

Landsat data were also used for the UHI effect assessment. The infrared information was assessed using high spatial resolution (60-m) satellite images provided by the Landsat Enhanced Thematic Mapper (ETM+) sensor with Landsat 7 satellite. Landsat 7 thermal images were obtained from the USGS Earth Resource Observation Systems Data Center (http://earthexplorer.usgs.gov). Due to technical errors of the scanner, data collected from 2003 onward (including 2006 data) are impaired. Despite these errors, data quality is still considered to be acceptable and these data have been used in past studies (Tomlinson et al., 2011).

It takes 16 days for Landsat 7 to rescan a location. However, all three sites are located along the Gulf Coast of Mexico, where cloudy days are common. To evaluate the maximum intensity of UHI effect, summer days with clear atmospheric conditions are preferred. The best quality data for this study were available in September 1999 and May 2006, which were used.

Analysis

The surface UHI temperature (T_s) was estimated based on the methodology developed by Stathopoulou and Cartalis(2007). First, calibration was conducted for Landsat 7 ETM+ image data through two steps (Landsat Project Science Office, n.d.): (1) calculating the spectral radiance L ($Wm^{-2}sr^{-1}\mu m^{-1}$) based on the digital number (DN) values of thermal band 6 with Equation 11.1:

$$L = 0.0370558 \times DN + 3.2 \tag{11.1}$$

and (2) computing the at-sensor brightness temperature (BT) using the spectral radiance L with Equation 11.2:

$$BT = \frac{K_2}{\{\ell_n[\frac{K_1}{L} + 1]\}} \tag{11.2}$$

where BT is the at-sensor brightness temperature (Kelvin); K_2 is the calibration constant (1282.71 K); K_1 is the calibration constant (666.09 $Wm^{-2}sr^{-1}\mu m^{-1}$); and L is the spectral radiance at-sensor ($Wm^{-2}sr^{-1}\mu m^{-1}$). Second, the land surface temperature (T_s) was assessed after correction of emissivity for each LULC type (Stathopoulou et al., 2007). The surface emissivity (ε) of the five composite LULC types are presented in Table 11.1.

T_s was then calculated by Equation 11.3:

$$T_s = \frac{BT}{\{1 + [\frac{\lambda BT}{\rho} \times \ell_n \varepsilon]\}} \tag{11.3}$$

Table 11.1 Surface emissivity values by land cover type.

Land cover type	*Emissivity*
Urban/densely built	0.946
Suburban/medium built	0.964
Mixed urban area	0.950
Rural area	0.980
Water surface	0.990

where T_s is the land surface temperature (K); BT is the at-sensor brightness temperature (K); λ is the wavelength of emitted radiance (11.5 μm); ρ equals 1.438×10^4 μm K; and ε is the spectral surface emissivity (see Table 11.1). Finally, GIS was used to map the T_s of the three watersheds and adjacent areas for a summer month in 1999 and 2006.

Results

Figures 11.1 and 11.2 show the land surface temperature (T_s) distribution, and Table 11.2 shows comparisons of the mean surface temperatures of the three watersheds. It is evident that The Woodlands' (Site 1) T_s is lower

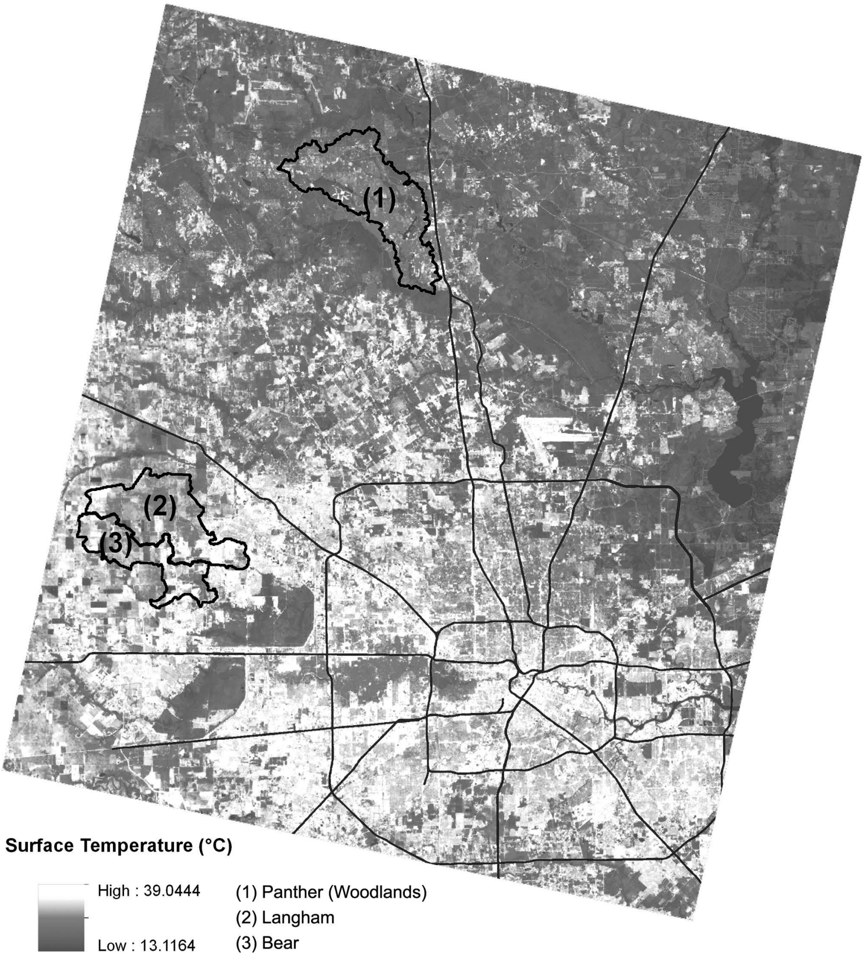

Figure 11.1 Surface temperature of Sites 1–3 and surrounding areas on September 20, 1999.

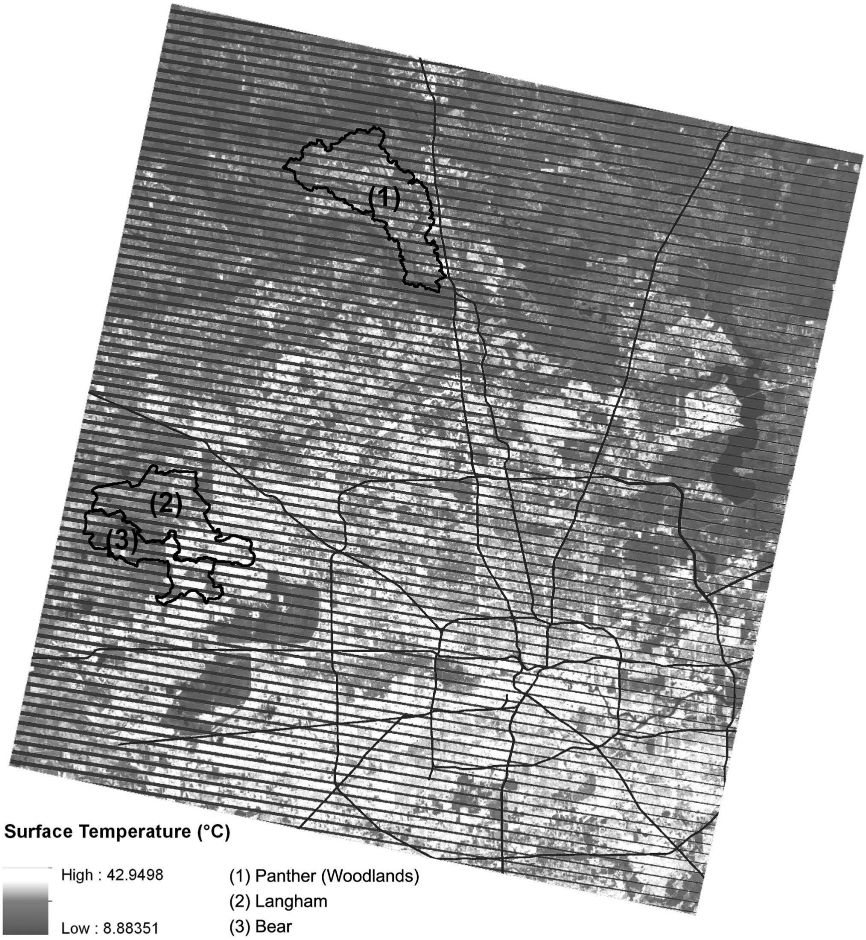

Figure 11.2 Surface temperature of Sites 1–3 and surrounding areas on May 18, 2006.

Table 11.2 Mean surface temperature (°C) on September 20, 1999, and May 18, 2006.

Site No.	*Watershed*	*9/20/1999*	*5/18/2006*
1	Panther creek (The Woodlands)	24.5	23.8
2	Langham creek (comparative)	26.3	25.5
3	Bear creek (comparative)	26.4	25.0

than that of the conventionally developed sites (Sites 2 and 3) in both years examined. *Ts* in Sites 2 and 3 are 1.1–1.9 degrees (°C) higher than Site 1. Although Site 1's development area and impervious coverage are much higher than Sites 2 and 3 (see Table 8.3), the extensively preserved forest land effectively mitigates the UHI effect by reducing the surface radiative properties (albedo) and ameliorates the ambient temperature.

Preserving the original forest (tree canopy and understory) is mandated in The Woodlands Residential Development Standards (WMRT, 1973a, 1973c, 1974; The Woodlands Association, 2007). However, this emphasis is typically lacking in Houston subdivision development Code of Ordinances (Kim & Ellis, 2009). In short, vegetation preservation as an important design strategy has shown benefits not only in hydrology, but also has contributed to a better thermal environment.

Summary

This chapter shows that McHarg's (WMRT) plan can achieve performance benefits in UHI effect remediation. The results show that during summer months, The Woodlands' land surface temperature can be almost 2°C cooler than Houston communities. According to Adams' 1999 study (Adams, 1999), a 1.7°C reduction in temperature can result in air quality benefits that are almost equal to replacing all the gas-powered vehicles with electric ones in a city. In addition to the expected air quality benefits, it is postulated that the 2°C temperature drop in The Woodlands may yield other positive implications on human well-being, such as reduction in heat-related diseases (Hansen et al., 2011), reduction in energy consumption (Akbari et al., 2001), and culinary water consumption for landscape irrigation (Endter-Wada, Kurtzman, Keenan, Kjelgren, & Neale, 2008).

It is also speculated that the performance benefits go beyond stormwater reduction and UHI effect remediation, as presented in other chapters of PART III. These benefits and services are partly maintained through the preservation of the natural stands of the pine forest (see Chapters 7 and 8). The naturally vegetated open space and the extensive trail systems can provide various ecological (e.g., wildlife habitat), cultural and recreation (e.g., contemplation, environmental education, and wildlife watching), and healthy benefits (e.g., physical exercise opportunities and social interaction), and it is a low-maintenance solution (Girling & Helphand, 1994; Forsyth, 2002, 2005; Galatas & Barlow, 2004).

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Part IV

The Woodlands performance post-McHarg

12 An evolving ecological plan

Introduction

A main strategy of McHarg's (WMRT) ecological plan was to determine building densities and land use based on the hydrological properties of the soil – that is, permeability. This concept was achieved by preserving land with high soil permeability as open space and using land with low soil permeability for commercial or residential developments (McHarg, 1996). Hence, runoff is infiltrated in close proximity to where it is generated. However, the plan was subjected to several changes over the course of development. This main strategy was followed in the first suburban village (Village of Grogan's Mill) and part of the second village (Village of Panther Creek) of The Woodlands but was adjusted to meet the homeowners' preferences of conventional suburbs in the later villages (Galatas & Barlow, 2004).

Setbacks from the original plan occurred in 1985, although the spirit of the "ecological plan" remained in the community mission statement (Girling & Helphand, 1994). The year of 1997 witnessed a further adjustment to the plan when George Mitchell sold The Woodlands to Crescent Real Estate Equities and Morgan Stanley Real Estate Fund II (ownership 1997–2003), after which development sped up and did not follow McHarg's concept (Galatas & Barlow, 2004). After 1997, the pace of construction accelerated and much of the forest preserve land was converted into residential and commercial developments (Haut, 2006). More pronounced environmental impacts emerged – The Woodlands was flooded in 2000 (NOAA, 2000) and again in 2008 as a result of Hurricane Ike (Madere, 2008). During Hurricane Ike, western Woodlands, containing villages developed after 1997, was particularly hard-hit. However, the early villages developed following McHarg's approach remained safe places (Madere, 2008). The objective of this chapter is to assess The Woodlands development conditions during 1974–2005 on whether land use locations are based on soil infiltration capacities.

Study site

The study area is the Panther Creek watershed, in which the majority of The Woodlands is located. Figure 12.1 presents development conditions in the

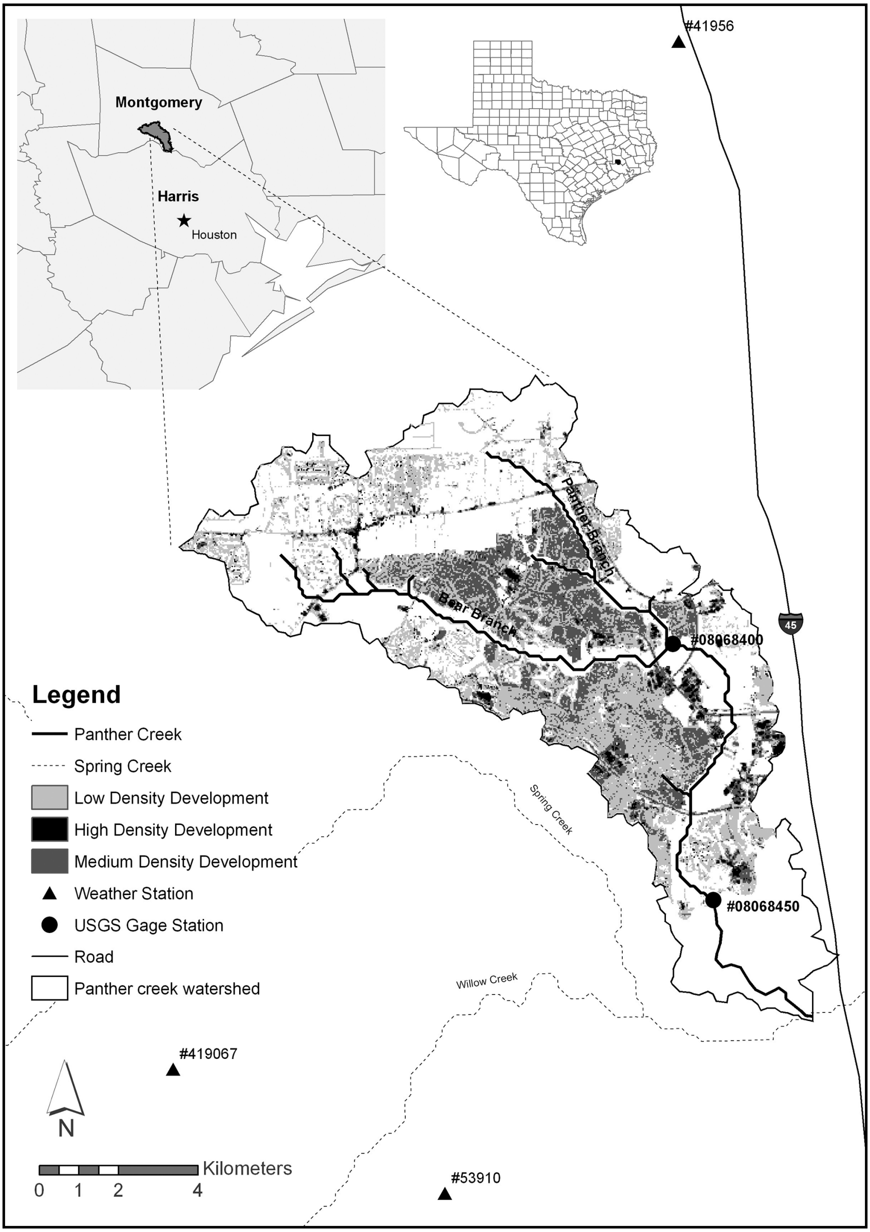

Figure 12.1 Panther Creek watershed development and stream network. According to the USGS, the percentages of impervious surface for low-density, medium-density, and high-density development are 20–49%, 50–79%, and 80–100%, respectively.

Panther Creek watershed. The watershed lies completely within Montgomery County, Texas, and is a sub-watershed of the Spring Creek watershed, whose U.S. Geological Survey (USGS) hydrological unit code is 12040102.

The Panther Creek watershed boundary was delineated using the outlet located at the confluence of Panther Creek and Spring Creek (Bedient, Flores, Johnson, & Pappas, 1985). The drainage area of the watershed is 94.2 sq km. The linear length of the watershed is approximately 37 km from the headwater to the outlet. The average slope of the watershed is less than 1%. There are two USGS gauge stations on the main channel of Panther Creek: station No. 08068450 and station No. 08068400 (see Figure 12.1).

Data

River reach files of the Panther Creek watershed were downloaded from the USGS National Hydrography Dataset (NHD) website, and topographical data at 30-m resolution of this watershed were obtained from the USGS National Map Seamless Data Distribution System. The soil dataset used in this study was the 1:24,000 scale Soil Survey Geographic (SSURGO) database developed by the Natural Resources Conservation Service (NRCS).

Land use information for four years (1984, 1996, 2001, and 2005) was obtained from various national land use/land cover (LULC) datasets. The 1984 dataset was obtained from the U.S. EPA Geographic Information Retrieval and Analysis System (GIRAS) at 80-m resolution (EPA Spatial Data Library). This dataset was then resampled to 30-m resolution. The 1996 and 2005 datasets were obtained from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center at 30-m resolution. The 2001 dataset was obtained from the USGS National Land Cover Dataset (NLCD; Homer, Huang, Yang, Wylie, & Coan, 2004) at 30-m resolution. Data accuracy of the 1996, 2001, and 2005 datasets ranges from 73% to 85% (Stehman, Wickham, Smith, & Yang, 2003; Homer et al., 2004; NOAA), and the 1984 dataset accuracy is at a lower level (U.S. EPA Spatial Data Library). Data accuracy of the above national datasets has been proved to be acceptable in various studies on land use patterns with respect to water quantity and quality assessment (Earls & Dixon, 2005; Wolter, Johnston, & Niemi, 2006).

These national datasets are produced through classifying Landsat images into different LULC classes (Jensen, 2000). The urban land use class in the datasets comprises several densities based on the level of impervious cover. Low-density and medium-density urban developments have 20% to 49% and 50% to 79% impervious surfaces, respectively, and common land uses are single-family housing units. High-density urban development (80% to 100% impervious surface) includes apartment complexes, row houses, and commercial/industrial/transportation facilities (Homer et al., 2004).

Yang and colleagues developed a method to quantify different levels of imperviousness in the urban land use class (Yang, Huang, Homer, Wylie, & Coan, 2003). For example, in developing the NLCD 2001 dataset, four imperviousness levels are determined via the following procedure. First, the impervious areas of several 1-m resolution orthophoto quadrangles are estimated. Second, these impervious areas are cross-referenced with the Landsat scene to calibrate the relationship between percent impervious cover and the Landsat spectral data. Third, this relationship is modeled using regression analysis. Last, the models are applied to all pixels in the Landsat scene to define the impervious cover level of each pixel. In this current study, the high and low impervious cover levels were referenced to create high- and low-density scenarios, respectively.

Eighteen LULC classes that were associated with The Woodlands development were used in this study. For simplicity, these classes were further grouped into seven categories: (1) water (open water, woody wetlands, and emergent herbaceous wetlands), (2) urban land uses (low-density residential, medium-density residential, high-density residential, and commercial/industrial/transportation), (3) forest (deciduous forest, evergreen forest, and mixed forest), (4) agriculture (pasture/hay, row crops, and small grains), (5) urban/recreational grasses, (6) grasslands/herbaceous and shrubland, and (7) others (bare rock/sand/clay and transitional).

Analysis

The seven land use class categories were used to examine the LULC distribution in the Panther Creek watershed (The Woodlands) over the period of 1974–2005.

LULC distribution and development location

This set of analyses evaluated the extent to which The Woodlands development followed McHarg's ecological plan to preserve more lands with permeable soils than those with less permeable soils. The LULC distribution was examined in the watershed of four years (1984, 1996, 2001, and 2005). Furthermore, the grids were overlaid with soil grids to quantify the percentage of impermeable cover on each soil group. Soils in the watershed were grouped according to their hydrological properties defined by the U.S. Department of Agriculture (USDA, 2002). There are four hydrological soil groups: A, B, C, and D – A soils are sandy and loamy sand soils; B soils are sandy loam and loam soils; C soils are silt loam and sandy clay loam soils; and D soils are clay loam, silty clay loam, and clay soils. A soils have the highest infiltration rate, B and C soils have moderate infiltration rates, and D soils have the lowest infiltration rate.

Results

LULC distribution and development location

The Woodlands (Panther Creek watershed) has experienced fast-paced residential and commercial developments in the past three decades. Especially after the 1997 ownership change, the final date of completion is expected to be ten years earlier than the date anticipated by the original developer, George Mitchell (Galatas & Barlow, 2004). By 2005, around half of the watershed was composed of urban land uses (Figure 12.2).

As previously mentioned, McHarg's planning approach had experienced several changes, and notable adjustments were made in 1985 and 1997 (Girling & Helphand, 1994; Galatas & Barlow, 2004). Coincidentally, national LULC datasets of 1984 and 1996 could reflect the development conditions before these changes, and development was accordingly divided into three periods: 1972–1984, 1985–1996, and 1997–2005. In addition, each period is associated with a development zone where the majority of the development occurred during that period.

Figure 12.3 presents the three zones and periods and the distribution of hydrological soil groups in the Panther Creek watershed. Figure 12.4 shows the developed area of each zone for different soil groups and periods. Developed areas consist of various urban land uses, including low-density residential, medium-density residential, high-density residential, and commercial/industrial/transportation. As Figure 12.4 shows, development occurred mainly during 1972–1984 in Zone I, during 1985–1996 in Zone II, and during 1997–2005 in Zone III. Also notice that infill developments occurred in Zone II and Zone III in the two later periods.

Tables 12.1 and 12.2 further combine the data from Figure 12.4 to create a dichotomy of soil groups: the A and B soil group indicates soils with sound infiltration capacities, and the C and D soil group represents soils with poor infiltration capacities. Table 12.1 shows the land areas of each soil group, and Table 12.2 lists development areas placed on each soil group in each time period.

In Zone I, the land area of A and B soils (1327 hectares) is 63% more than that of C and D soils (813 hectares). Generally speaking, it is challenging to

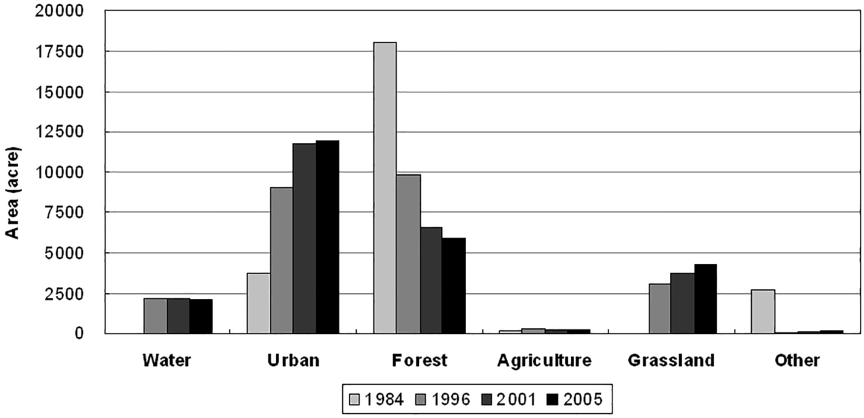

Figure 12.2 Land use land cover distribution in the Panther Creek watershed (The Woodlands).

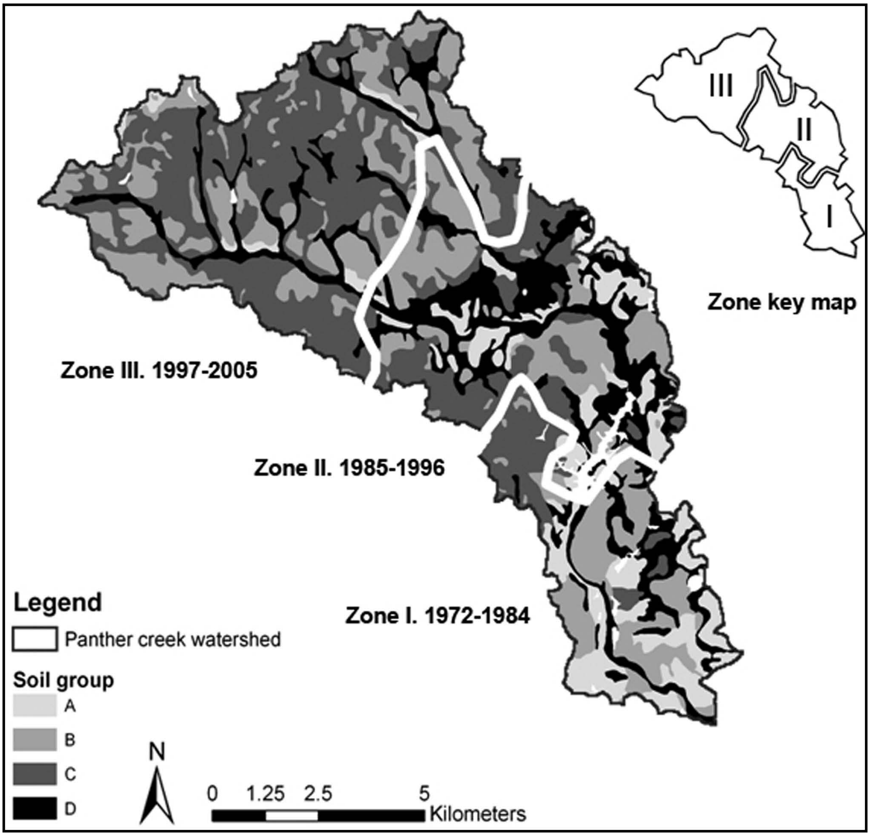

Figure 12.3 Soil distribution in the Panther Creek watershed (The Woodlands) and three development zones. In Zone I development, McHarg's approach was well followed. In Zone II and Zone III development, McHarg's approach was largely abandoned.

follow the natural soil pattern to overlay urban infrastructure and various developments. For example, layout of a road network needs to consider engineering principles, safety, and sometimes aesthetic views. Complete match between a proposed road network and the random soil pattern is nearly impossible. Although it is true that more development occurred on A and B soils than on C and D soils, the percentage of developed area on A and B soils (49%) was less than that on C and D soils (75%). This result suggests that A and B soils were given priority of preservation in Zone I development and McHarg's approach was followed during 1972–1984.

In Zone II during 1985–1996, A and B soils ceased to be the priority of preservation. The land area of A and B soils (1351 hectares) is smaller than that of C and D soils (1881 hectares) in Zone II. Yet, a higher percentage of

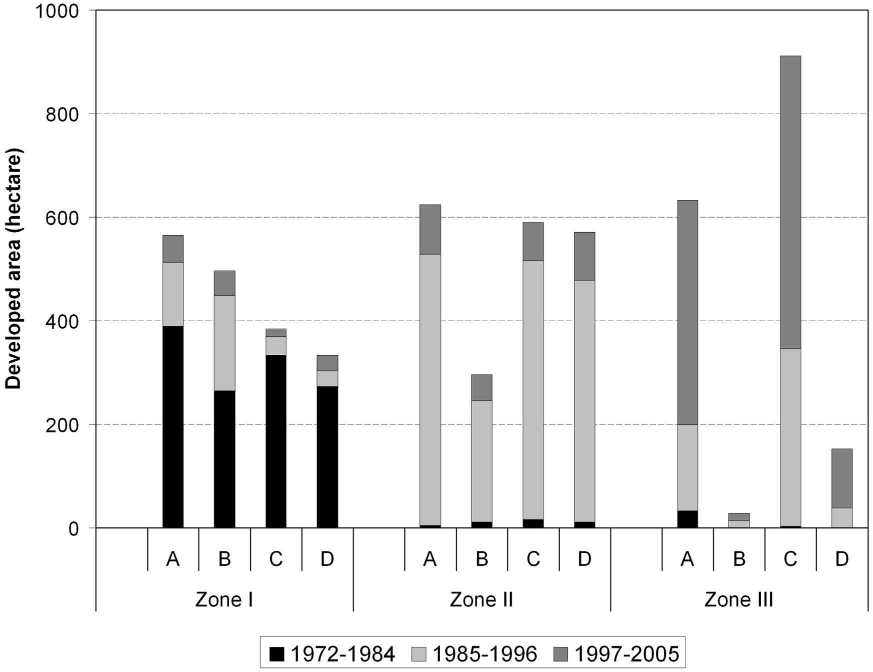

Figure 12.4 Development area on different hydrological soil groups in three development zones during three time periods in the Panther Creek watershed (The Woodlands). Numbers indicate additional development instead of accumulative development areas. In Zone I, majority of the development occurred during 1972–1984, in Zone II during 1985–1996, and in Zone III during 1997–2005.

Table 12.1 Land area and area percentage of two soil groups (A and B; C and D) in three development zones in the Panther Creek watershed (The Woodlands). The A and B soil group represents soils with good infiltration capacities, and the C and D soil group represents soils with poor infiltration capacities.

	Zone area	*A and B*		*C and D*	
	ha	*ha*	%	*ha*	%
Zone I	2140	1327	62	813	38
Zone II	3232	1351	42	1881	58
Zone III	4567	1611	35	2956	65

Table 12.2 Development area and area percentage for two soil groups (A and B; C and D) in three development zones during three time periods in the Panther Creek watershed (The Woodlands). Numbers indicate additional rather than accumulative development areas in each period.

	A and B	*Development on A and B*		*C and D*	*Development on C and D*	
	ha	*ha*	%	*ha*	*ha*	%
1972–1984						
Zone I	1327	654	49	813	606	75
Zone II	1351	17	1	1881	27	1
Zone III	1611	33	2	2956	3	0
1985–1996						
Zone I	1327	306	23	813	67	8
Zone II	1351	757	56	1881	964	51
Zone III	1611	180	11	2956	382	13
1997–2005						
Zone I	1327	100	8	813	44	5
Zone II	1351	146	11	1881	168	9
Zone III	1611	447	28	2956	678	23

A and B soils was developed (56%) than that of C and D soils (51%). In the meantime, 306 hectares of infill development were placed on A and B soils in Zone I, which accounted for 23% of Zone I area. In contrast, the other part of the infill development in this zone was 67 hectares of development on C and D soils, only 8% of the zone's area. This result is consistent with the literature that suggests McHarg's approach was less well followed after 1985 (Girling & Helphand, 1994).

In Zone III during 1997–2005, the departure from McHarg's approach was further demonstrated. Even though the land area of A and B soils (1611 hectares) is only 55% of that of C and D soils (2956 hectares) in this zone, a higher percentage of A and B soils (28%) than C and D soils (23%) was developed. Similar developments that ignored soil permeability also occurred in Zones I and II during the 1997–2005 period. Evidently, developments post-1997 had largely abandoned McHarg's planning approach.

Discussion

It is evident that in Zone II and Zone III developments, soils with good infiltration capacities were not given the first priority in the community plan. After The Woodlands ownership change in 1997, McHarg's approach was not followed. Today, the development pattern in The Woodlands presents a gradient from adherence to abandonment of McHarg's approach. In the early period, the pattern was largely determined by an important environmental factor – soil permeability. In the later period, especially after 1997, the pattern gradually shifted to the conventional "cookie-cutter" Houston type of development. Soil permeability, as defined by NRCS hydrological soil group, has been a good consideration in the selection of building locations. The common practice is to place building foundations on sandy soils and to avoid clay soils, because sandy soils provide better drainage and have a higher bearing capacity than clay soils. To build foundations on clay soils may require special treatment, which adds to the construction cost.

McHarg's concept is in contrast to the common practice and expands from site-level scale to community and regional scales. In The Woodlands development, McHarg suggested building on clay soils while preserving sand soils, to respond to a major site constraint – flooding hazard in the Houston coastal area (McHarg, 1996). As indicated by historical extreme storms, this concept used in the first two suburban villages evidently minimized the potential flooding damage to the community property (Girling & Kellett, 2005). The additional cost due to the special treatment of building foundations thus became minor.

Summary

When integrating urban development into the natural system, planners and landscape architects must seek harmony rather than produce conflict. There are several important factors affecting stormwater runoff, including precipitation volume and intensity, time parameters, and soil permeability. Perhaps the only factor that designers can manipulate is ground cover (density, configuration, and surface texture). McHarg's (WMRT) plan for The Woodlands was based on a profoundly simple concept: coordinating development density and land use based on the hydrological properties of the soils. His plan aimed to maintain the natural hydrological conditions and to minimize urbanization impacts. Development patterns per soil location reflects the evolvement of the ecological plan. This chapter shows that ownership change became a turning point in The Woodlands development. Based on these findings, Chapter 13 evaluates different development scenarios and their respective impacts on stormwater runoff and flood-control effectiveness.

13 Modeling development and runoff scenarios

Introduction

Previous chapters show that McHarg's approach generated much less stormwater runoff and lower peak discharges compared with the conventional development approach. Additionally, Chapter 12 assessed the community development pattern and suggested that The Woodlands deviated from McHarg's approach after ownership change in 1997. McHarg's (WMRT) design is distinguished from the conventional community design particularly in that soil permeability is used to coordinate land-use type and development density. This aspect is a particularly unique land planning strategy.

The objective of this chapter is to compare stormwater runoff generated in different planning approaches (conventional low-density, clustered high-density, and The Woodlands approaches) using watershed streamflow modeling. Five "what-if" land use scenarios of The Woodlands that reflect different planning approaches were created for watershed simulation. Furthermore, development was designated onto different soil types (e.g., sandy or clay soils) to assess McHarg's concept. A homogeneous forest land use scenario served as the baseline condition to represent The Woodlands prior to any development (Soil Conservation Service, 1972). Scenarios were compared by using the Automated Geospatial Watershed Assessment (AGWA) tool that simulates streamflow (Miller et al., 2007).

Study site

The study site is the Panther Creek watershed, in which the majority of The Woodlands is located (see Figure 12.1).

Data

Streamflow data from both USGS gauge stations on Panther Creek during the water years of 1999–2006 were used for the AGWA hydrological model calibration and validation analysis. A water year is from October 1 of the previous year to September 30 of the following year (e.g., water year 1999 = 10/01/1998–9/30/1999). Historical weather data (e.g., precipitation and temperature) were obtained from the National Climatic Data Center website (NCDC). Thiessen polygon method (Hann, Barfield, & Hayes, 1994) was used to calculate precipitation for the Panther Creek watershed.

Three weather stations (COOPID No. 411956, COOPIN No. 419067, and WBANID No. 53910) and their representative rainfall areas were identified using the Thiessen method. Data from 1999 to 2006 were collected from these three stations. River reach files of the Panther Creek watershed were downloaded from the USGS National Hydrography Dataset (NHD) website, and topographical data at 30-m resolution of this watershed were obtained from the USGS National Map Seamless Data Distribution System (USGS). The soil dataset used in this study was the 1:24,000 scale Soil Survey Geographic (SSURGO) database developed by the NRCS. Land use information for four years (1984, 1996, 2001, and 2005) was obtained from various national land use/land cover (LULC) datasets (see Chapter 12 Data section).

Analysis

The original 18 LULC classes were reclassified to match the LULC classes specified by the AGWA hydrological models. Land use scenarios are simulated in this set of analyses to assess the potential impact of different planning approaches on streamflow. Two important *planning variables* were examined in the scenarios. The first one was development density; the second was development location, that is, which type of soil on which to place development.

Rationale for scenario

Scenario-based investigations of alternative futures contribute to informed planning and facilitate the decision-making process, and they have been used in landscape and urban planning for over three decades. Scenarios serve two main functions: real-world planning for the future and scientific inquiry (modeling) (Xiang & Clarke, 2003).

Related to these two functions are the two main types of scenario-based studies: the "surprise-free" alternatives that explore reasonable and feasible futures and "novel" scenarios that investigate extreme conditions of benefits or risks (Shearer, 2005). Belonging to the second type, this study compared five extreme "what-if" land use scenarios that used different planning approaches and assessed the potential impact of these approaches on streamflow.

Considerations in creating scenarios

Three *considerations* were taken into account when creating scenarios. The first consideration was to maintain the *total impervious cover area* in the watershed. Impervious cover presents an important variable affecting watershed runoff. Generally, the higher the development density, the higher the impervious surface percentage and the more runoff that is generated (Schueler, 1994).

The Woodlands 2005 land use dataset was used to determine the percent of *total impervious cover area* in the watershed. An Impervious Cover Ratio Index (Table 13.1) was developed to capture the 2005 total impervious cover area and to create scenarios that maintained the same impervious cover area. To create the Table 13.1 Index, the lowest median value (that of the low-density residential land) was assigned the baseline value of 1. Then, the index values of the medium-density residential land and high-density residential land were calculated based on their median values of imperviousness. For instance, the impervious surface area of 2.6 hectares of low-density residential land will approximate that of 1 hectare of high-density residential land. The value of 2.6, as shown in the Table 13.1 Index, was calculated by dividing 90 by 35, where 90 is the median value of the impervious percent range of the high-density residential and 35 is that of the low-density residential.

The 2005 Panther Creek watershed (The Woodlands) percent of impervious cover area was calculated using Equation 13.1. Variables in Equation (13.1) are listed in Table 13.2. Since all the LULC datasets are at 30-m resolution, the number of pixels was used as the surrogate for the land area. The calculated watershed percent of imperviousness (21.5%) was kept constant when developing scenarios.

$$\text{Imperviousness }\%_{\text{year 2005}} = \frac{\begin{array}{c}\text{No.}_{\text{low}} \times 35\% + \text{No.}_{\text{medium}} \times 65\% + \text{No.}_{\text{high}} \\ \times 90\% + \text{No.}_{\text{commercial/industrial/transportation}} \times 90\%\end{array}}{\text{No.}_{\text{watershed}}} \tag{13.1}$$

Another closely related variable was the *total developed area*, primarily residential and commercial land uses. The 2005 watershed percent of *total developed area* was calculated using Equation 13.2. Variables in Equation (13.2) are also listed in Table 13.2. Note that the calculated 2005 watershed percent of total developed area (48.5%) differed from that of the scenarios, as explained in the following section.

Table 13.1 Impervious cover ratio index.

Land use	*Impervious percent range*	*Median*	*Ratio*
Residential low density	20–49	35	1.0 (baseline)
Residential medium density	50–79	65	1.9
Residential high density	80–100	90	2.6
Commercial/industrial/transportation	80–100	90	2.6

$$\text{Total developed area \%}_{\text{year 2005}} = \frac{\text{No.}_{\text{low}} + \text{No.}_{\text{medium}} + \text{No.}_{\text{high}} + \text{No.}_{\text{commercial/industrial/transportation}}}{\text{No.}_{\text{watershed}}} \quad (13.2)$$

The second consideration was to maintain the general trend of The Woodlands development in history. Historically, the first suburban village started downstream of Panther Creek, and development evolved along the creek to the north. Hence, in creating scenarios, the general trend of development from downstream to upstream was kept.

The third consideration was the location of development with respect to the location of soil type. This issue was addressed according to the purpose of each scenario. Figure 13.1 shows five hypothetical scenarios that were in accordance with or were contrary to McHarg's planning approach of placing developments based on hydrological properties of soils.

Scenarios

Five scenarios were created, including a forest baseline condition (Scenario 1), high-density scenarios (Scenarios 2 and 3), and low-density scenarios (Scenarios 4 and 5). High-density scenarios represent high-density residential land use plans and a large amount of open space is preserved from development in other parts of the watershed. Low-density scenarios employ the conventional Houston low-density development approach where low-density residence is promulgated in the watershed.

Table 13.2 Variables in Equation (13.1) used to calculate the percent of impervious cover area in the Panther Creek watershed (The Woodlands). The median values of impervious percent ranges are presented in Table 13.1.

Variable	*Explanation*
Imperviousness %	Percent of impervious cover of the Panther Creek watershed
No._{low}	Pixel number of low-density residential class
35%	Median of impervious percent range (low-density residential)
$\text{No.}_{\text{medium}}$	Pixel number of medium-density residential class
65%	Median of impervious percent range (medium-density residential)
No._{high}	Pixel number of high-density residential class
90%	Median of impervious percent range (high-density residential)
$\text{No.}_{\text{commercial/industrial/transportation}}$	Pixel number of commercial/industrial/transportation class
90%	Median of impervious percent range (commercial/industrial/transportation)
$\text{No.}_{\text{watershed}}$	Total pixel number of the Panther Creek watershed

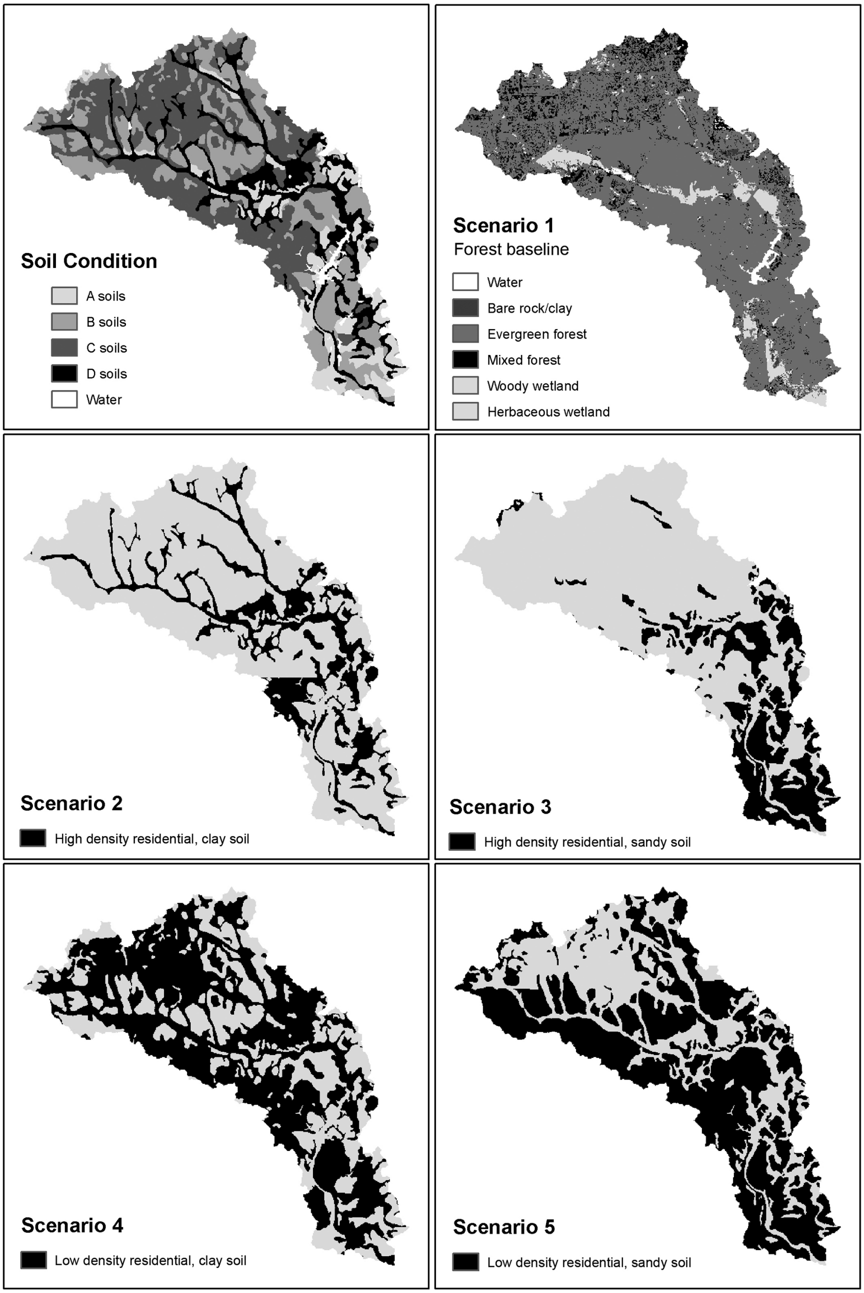

Figure 13.1 Five hypothetical land use scenarios and watershed soil conditions.

1 Baseline scenario

- *Scenario 1: forest baseline condition*
  - The Woodlands 2005 land use dataset was used to create this scenario. Urban developed areas (low-density residential, medium-density residential, high-density residential, and commercial/industrial/transportation) were reclassified into evergreen forest, and other nonurban land covers were maintained. Loblolly pine (*P. taeda*) evergreen forest was the site condition prior to development (Soil Conservation Service, 1972; McHarg, 1996). This scenario served as the baseline condition.

2 High-density scenarios

To create high-density scenarios, medium-density and low-density residential and commercial/industrial/transportation land uses of 2005 were reclassified into high-density residential using ArcGIS. The watershed percent of *total developed area* in Scenarios 2 and 3 was calculated using Equation (13.3). Variables in Equation (13.3) are listed in Table 13.2. Scenarios 2 and 3 have the same *total developed area* and *total impervious cover area*. However, the development pattern varies as a result of the different purposes of the scenarios.

$$\text{Total developed area \%}_{\text{high-density scenarios}} = \frac{\begin{array}{c}\text{No.}_{\text{low}} \times \frac{35\%}{90\%} + \text{No.}_{\text{medium}} \times \frac{65\%}{90\%} \\ + \text{No.}_{\text{high}} + \text{No.}_{\text{commercial/industrial/transportation}}\end{array}}{\text{No.}_{\text{watershed}}} \tag{13.3}$$

- *Scenario 2: high-density development on clay soil*
  - High-density residential development occurred on C and D soils. This scenario was the optimal condition in reducing surface runoff. It best adhered to McHarg's approach, which suggests placing development on soils with low infiltration capacities (C and D soils) and preserving soils with high infiltration capacities (A and B soils).
- *Scenario 3: high-density development on sandy soil*
  - High-density residential development occurred on A and B soils. Presumably, Scenario 3 would yield more runoff than Scenario 2, because Scenario 3 placed development on top of A and B soils, instead of on C and D soils. Comparing Scenarios 2 and 3 would reveal the significance of development location per soil permeability in forecasting watershed runoff.

3 Low-density scenarios

To create low-density scenarios, medium-density and high-density residential and commercial/industrial/transportation land uses of 2005 were reclassified into low-density residential. The watershed percent of *total developed area* in Scenarios 4 and 5 was calculated using Equation (13.4). Variables in Equation (13.4) are also listed in Table 13.2. Likewise, Scenarios 4 and 5 have the same *total developed area* and *total impervious cover area*, whereas the development pattern varies as a result of the different purposes of the scenarios.

$$\text{Total developed area } \%_{\text{low-density scenarios}} = \frac{\text{No.}_{\text{low}} + \text{No.}_{\text{medium}} \times \frac{65\%}{35\%} + (\text{No.}_{\text{high}} + \text{No.}_{\text{commercial/industrial/transportation}}) \times \frac{90\%}{35\%}}{\text{No.}_{\text{watershed}}} \quad (13.4)$$

Scenarios 4 and 5 represent conventional low-density residential development approaches ubiquitous in the U.S. Compared with high-density scenarios, low-density scenarios have a larger *total developed area* and a smaller open space area, but the *total impervious cover area* stays the same.

- *Scenario 4: low-density development on clay soil*
  - Low-density residential development first occurred on C and D soils. Lands with A and B soils were preserved as open space for stormwater detention and infiltration. It was expected that less runoff would be generated in Scenario 4 than in Scenario 5. Comparing Scenarios 4 and 5 should likewise reflect the importance of development location per soil permeability.
- *Scenario 5: low-density development on sandy soil*
  - Low-density residential development first occurred on A and B soils. Scenario 5 was the worst case scenario among the five in terms of runoff. This was because placing development on A and B soils would generate more runoff than development on C and D soils. Therefore, Scenario 5 would yield more runoff than Scenario 4. Further, low-density scenarios (Scenarios 4 and 5) would generate more runoff than high-density scenarios (Scenarios 2 and 3) as aforementioned.

The percentages of the *total impervious cover area* and the *total developed area* in the watershed of these scenarios are presented in Table 13.3. In this study, high-density scenarios are regarded as cluster compact development. This was

Table 13.3 Observed land use conditions and land use scenarios in the Panther Creek watershed (The Woodlands).

Conditions and scenarios	*Percent urban developed area*	*Percent impervious cover*[a]	*Watershed CN*	*Data*[b]
1984 observed	15	9.3	71.6	EPA
1996 observed	37	15.9	72.1	NOAA
2001 observed	47.9	20.9	77.6	NLCD
2005 observed	48.5	21.5	80.4	NOAA
1 Forest baseline	0	0	66.9	NOAA
2 High-density clay soil	23.9	21.5	73.3	NOAA
3 High-density sandy soil	23.9	21.5	74.4	NOAA
4 Low-density clay soil	61.4	21.5	79.0	NOAA
5 Low-density sandy soil	61.4	21.5	80.8	NOAA

[a] The median value of the impervious cover percentage range was used to calculate the *percent impervious cover*. The median values are presented in Table 13.1. Scenarios 2–5 used the same amount of total impervious cover area as given for 2005.

[b] The land-use and land-cover datasets are 1984 U.S. EPA GIRAS data (80 m), 1996 and 2005 National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center data (30 m), and 2001 USGS National Land Cover Dataset (NLCD) (30 m).

because high-density development plans concentrate impermeable cover. Compared with low-density scenarios, high-density scenarios have lower percentages of *total developed area* in the watershed as a whole (see Equations 13.3 and 13.4, and Table 13.3). As a result, large amounts of open space were preserved in high-density scenarios for stormwater detention and infiltration.

Automated geospatial watershed assessment simulation

In the second set of analyses, AGWA (Miller et al., 2007) was used to evaluate the hydrological consequences of urban development in the watershed. AGWA is a multipurpose hydrological tool for watershed modeling. Embedded in ArcGIS interfaces, AGWA combines two extensively used watershed hydrological models: the Soil and Water Assessment Tool (SWAT) (Arnold, Williams, Srinivasan, King, & Griggs, 1994) and the Kinematic Runoff and Erosion model (KINEROS) (Smith, Goodrich, Woolhiser, & Unkrich, 1995). SWAT is a hydrological and water quality model for long-term watershed simulations. Although it is widely used in agriculture-dominated land uses (Srinivasan & Arnold, 1994), SWAT could also be used for urban watershed modeling (Arnold & Fohrer, 2005). KINEROS is an event-driven model designed to simulate runoff and erosion for single-storm events in small watersheds. In KINEROS, a network of channels and planes is used to represent a watershed and the flood routing is based on the kinematic wave method (Smith et al., 1995).

The main reason for using SWAT was because the concept of SWAT is in accordance with McHarg's planning approach. In SWAT, each unique combination of land use and soil type generates a Hydrological Response Unit (HRU). Superimposing various land use types onto different soil patches allows runoff estimates for comparison. Each HRU is directly related to a Curve Number (CN) (Srinivasan & Arnold, 1994), and CN is determined by land use and soil type (Hann et al., 1994). Therefore, McHarg's approach of allocating land use based on soil type could be assessed with SWAT.

For the purpose of this study, CN was the main parameter calibrated in the SWAT model to reflect the 2005 LULC condition. In the KINEROS model, Manning's roughness coefficient (Manning's *n*) and CN were the parameters calibrated. In SWAT, the average runoff depths of the watershed from 2001 to 2005 were simulated. In KINEROS, the Soil Conservation Service's rainfall frequency maps (Soil Conservation Service, 1986) were used to generate 24-hour storm events of four return-periods (10, 25, 50, and 100 years). In each scenario, the composite CN of the watershed was calculated using Equation 13.5:

$$CN_{composite} = \frac{\sum_i A_i CN_i}{\sum_i A_i} \tag{13.5}$$

where A_i is the area of sub-watershed *i* and CN_i is the CN of sub-watershed *i*. The SWAT model simulation was run for a five-year period (2001–2005) following a two-year warm-up period (1999–2000). The warm-up period was used to establish appropriate initial conditions for soil water storage. Then the five-year period was divided into two parts to perform model calibration (2001–2003) and validation (2004–2005). USGS measured data were used for calibration. In the calibration process, a base flow program was used to screen the base flow component in the USGS measured flows in order to increase SWAT model efficiency (Arnold & Allen, 1999). The SWAT model efficiency was assessed by two criteria. The first criterion is the Nash and Sutcliffe coefficient (Nash & Sutcliffe, 1970), calculated with Equation 13.6:

$$E = 1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - Q_{mean})^2} \tag{13.6}$$

where E is the coefficient of efficiency; Q_{obs} is the observed streamflow (mm); Q_{sim} is the simulated streamflow (mm); and Q_{mean} is the mean observed streamflow during the evaluation period. E varies from minus infinity to 1, with 1 representing a perfect fit of the model. The second criterion is regression analysis. For calibration, regression analysis shows how well the simulated data match the measured data. For validation, regression analysis shows how accurately the calibrated model predicts the subsequent measurements.

Results

SWAT simulation

CN modeling

Developed by NRCS (Hann et al., 1994), CN indicates the site infiltration and runoff relationship, with a range between 0 and 100. The higher the CN, the larger the runoff volume generated. CN of 100 indicates no infiltration capacity. SWAT model calculated the watershed CNs for the five scenarios and the actual conditions of four different years (see CN results in Table 13.3. Anthropogenic land uses (e.g., residential and commercial) were grouped together as urban developed area. The simulation yielded expected results, in which the high-density scenarios (Scenarios 2 and 3) had lower CNs than the low-density scenarios (Scenarios 4 and 5). This was mainly because the high-density scenarios have smaller *total developed areas* than the low-density scenarios.

It was also found that The Woodlands actual development condition in 2005 was similar to the worst case scenario (Scenario 5, *low-density development on sandy soils*) simulated in the watershed modeling. CNs of the 2005 actual condition and the worst case scenario (Scenario 5) were 80.4 and 80.8, respectively. This indicates that watershed runoff volume of 2005 was similar to that of the Houston conventional low-density development. This result was not expected and details are discussed in the Discussion section.

Calibration and validation

Calibration and validation were performed on SWAT and KINEROS models. In SWAT, CN was adjusted, while in KINEROS CN and Manning's *n* were adjusted. Simulated flows were compared with USGS measured flows. The calibrated models were then used for simulation of five scenarios. SWAT calibration shows promising results in The Woodlands watershed modeling. As shown in Figure 13.2, USGS measured flows can be reasonably predicted by the SWAT model after calibration. The Nash and Sutcliffe (N-S) model efficiencies also confirm the calibration and validation results (Table 13.4). According to Van Liew and Garbrecht (2003), simulation with yearly data is considered "good" when the N-S efficiencies are greater than 0.75. When using monthly data, values of N-S efficiencies greater than 0.52 are considered as good results.

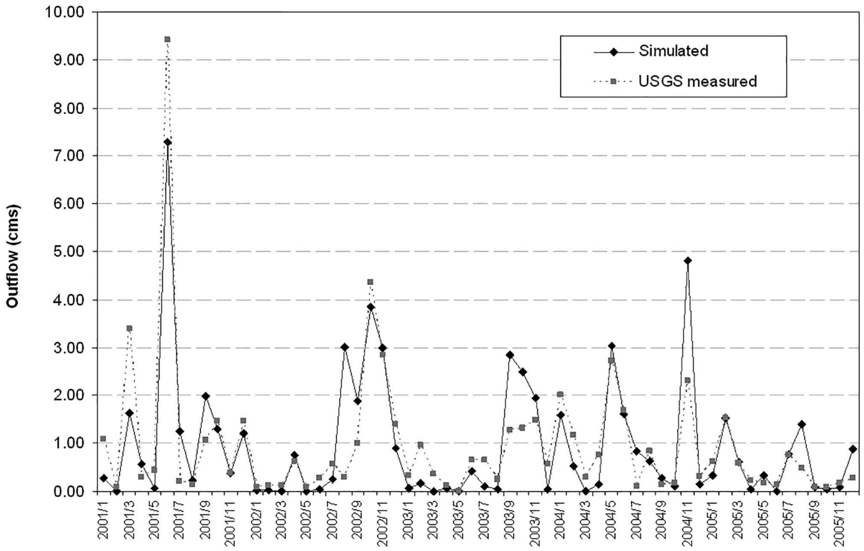

Figure 13.2 Simulated and observed surface runoff by SWAT for the calibration and validation periods at USGS gauge station #08068450.

Table 13.4 Model efficiency and statistics from ordinary least squares regression analyses for the calibration and validation periods.

USGS Gauge	*Nash Sutcliffe Coefficient*				R^2	
	Calibration		*Validation*		*Calibration*	*Validation*
	(monthly)	*(yearly)*	*(monthly)*	*(yearly)*	*(monthly)*	*(monthly)*
#8068450	0.76	0.97	0.63	0.92	0.76	0.70
#8068400	0.71	0.79	0.59	0.98	0.72	0.58

Note: Linear regression analysis, $y = a + bx$; independent variable x is precipitation (mm), dependent variable y is streamflow (m^3s^{-1}).

Stormwater runoff

Using the observed weather data (2001–2005), the SWAT model simulated the annual surface runoff for the five land use scenarios, and the results are presented in Figure 13.3. As expected, the high-density scenarios generated lower amounts of runoff than the low-density scenarios. For the *low-density sandy soil scenario* (Scenario 5), where A and B soils were used for development and became impervious covers, the value was the highest. All land use scenarios produced higher runoff compared with the forest condition

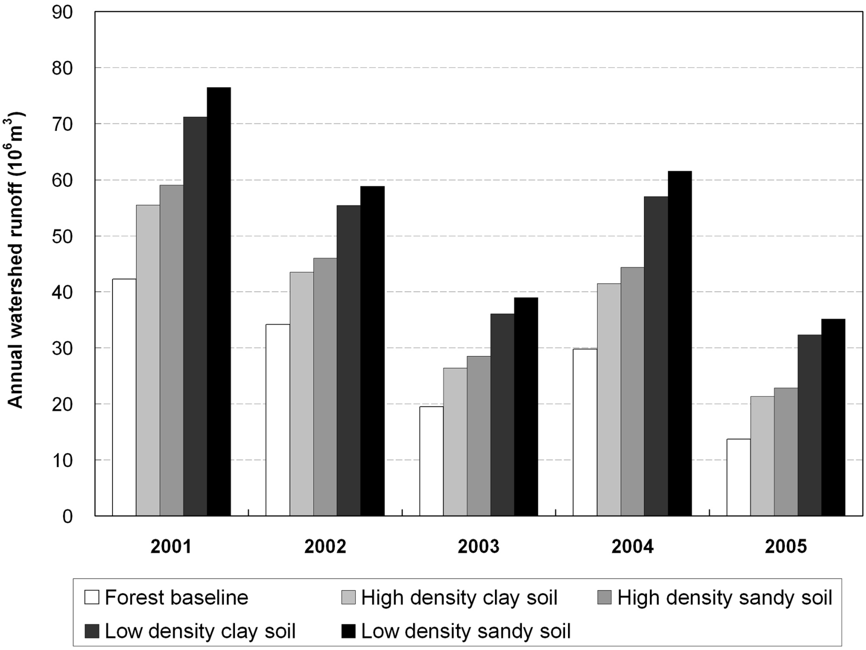

Figure 13.3 Simulated annual surface runoff of five land-use scenarios.

(Scenario 1). On average, high-density scenarios generated around 40% to 50% more runoff than the forest condition, and low-density scenarios increased these values to around 90% to 100%. Also note that the differences between the two soil groups were not as pronounced as the differences between the two density groups.

Table 13.5 shows the average values (2001–2005) of the watershed outputs. The trend was evident that surface runoff increased as development density decreased, where situations became worse when A and B soils were paved over. Likewise, a similar trend was predicted that less aquifer recharge and more sediment loading were expected when low-density development spread in the watershed. From the forest baseline scenario (Scenario 1) to the low-density development scenarios (Scenarios 4 and 5), sediment loading and surface runoff almost doubled, whereas aquifer recharge reduced to less than 50% of the forest condition.

Similar to the results in Figure 13.3, Table 13.5 shows that the differences of watershed outputs between the two density groups were larger than the differences between the two soil groups. For example, the *low-density sandy soil scenario* (Scenario 5) would generate 3.4 million cubic m more runoff than the *low-density clay soil scenario* (Scenario 4) on a yearly basis (8% increase). However, in comparing the *low-density sandy*

Table 13.5 Simulated watershed outputs, average of years 2001–2005.

Scenario	*Surface runoff*	*Total aquifer recharge*	*Total sediment loading*
	(10^6m^3)	*(10^6m^3)*	*(tons/year)*
1 Forest baseline	25.1	36.0	565.0
2 High-density clay soil	33.8	27.9	753.3
3 High-density sandy soil	36.1	25.9	753.3
4 Low-density clay soil	45.0	18.2	1035.8
5 Low-density sandy soil	48.4	14.9	1035.8

soil scenario (Scenario 5) with the *high-density sandy soil scenario* (Scenario 3), a more significant increase of 12.3 million cubic m runoff (34% increase) would occur.

KINEROS simulation

Peak flow

Rainfall return frequencies of 10, 25, 50, and 100 years were simulated and are presented in Figure 13.4. As expected, the high-density scenarios – *high-density clay soil scenario* (Scenario 2) and *high-density sandy soil scenario* (Scenario 3) – generated lower peak discharge than the low-density scenarios – *low-density clay soil scenario* (Scenario 4) and *low-density sandy soil scenario* (Scenario 5) – for all four frequencies. In addition, the differences between the two density scenarios were not substantial during small rainfall frequencies (i.e., 10 years [not shown] and 25 years). But the differences became more prominent as the rainfall frequency decreased (i.e., 50 and 100 years). The *low-density clay soil scenario* (Scenario 4) and the *low-density sandy soil scenario* (Scenario 5) could create a peak discharge around *nine* times of what the *high-density clay soil scenario* (Scenario 2) and the *high-density sandy soil scenario* (Scenario 3) could have during a 100-year storm.

Similar to the SWAT results, the differences between the two soil groups were less compared with the differences between the two density groups. The variations within each density group decreased as the storm frequencies decreased. However, the differences in peak discharges between the high-density scenarios were large. During a 100-year storm, the *high-density sandy soil scenario* (Scenario 3) generated around 50% more peak discharge than the *high-density clay soil scenario* (Scenario 2). During smaller storms (25 and 50 years), the *high-density sandy soil scenario* (Scenario 2) generated around six times more peak discharge than the *high-density clay soil scenario* (Scenario 3). Finally, it was unexpected that the *low-density sandy*

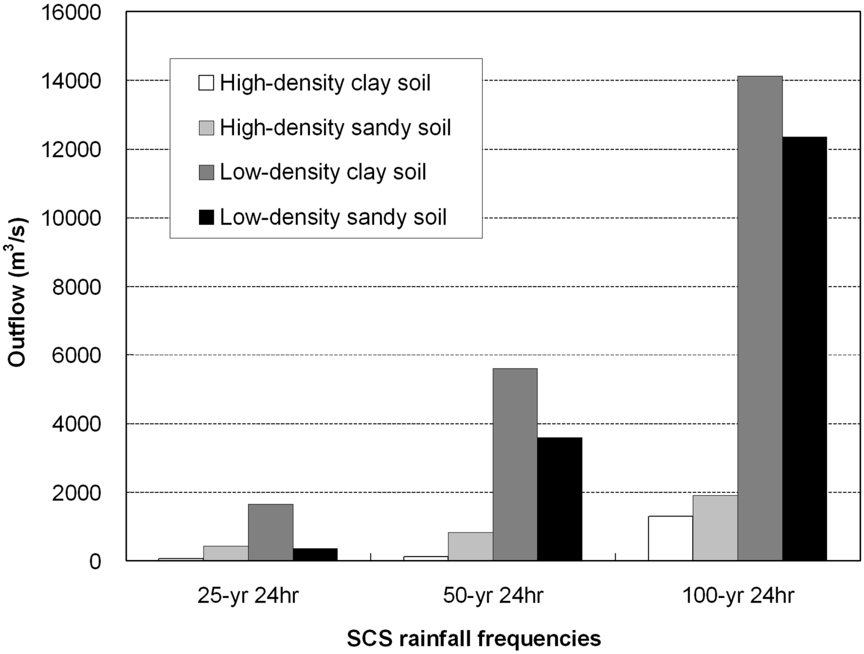

Figure 13.4 Simulated watershed peak discharges of four land use scenarios during three rainfall frequencies.

soil scenario (Scenario 5), where A and B soils were paved over, generated less peak discharge than the *low-density clay soil scenario* (Scenario 4), which preserved A and B soils for stormwater infiltration.

Peak discharge spatial distribution

The spatial patterns of peak discharge at a 100-year frequency are presented in Figure 13.5. Peak discharges were higher in urbanized sub-watersheds than in sub-watersheds that remained natural conditions. In addition, peak discharges increased as the percentages of development increased. Peak discharge patterns in Figure 13.5 resembled the land use distributions in Figure 13.1. Similar peak discharge patterns were found in other storm frequencies (10, 25, and 50 years), but the variations between sub-watersheds became less exaggerated as storm frequencies increased.

Discussion

These results indicate that The Woodlands land use conditions were worse than what the original McHarg (WMRT) plan proposed. The 2005 CN

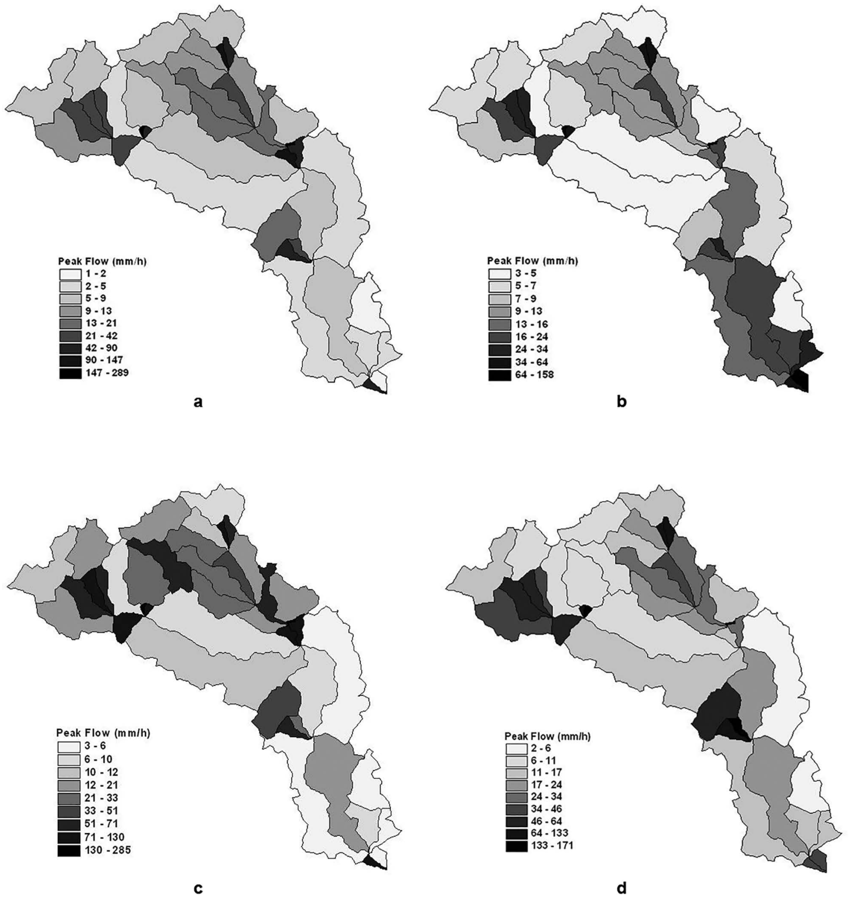

Figure 13.5 Spatial distribution of peak discharge during 100-yr storms. (a) high-density clay soil scenario (Scenario 2), (b) high-density sandy soil scenario (Scenario 3), (c) low-density clay soil scenario (Scenario 4), and (d) low-density sandy soil scenario (Scenario 5).

(80.4) is close to that of the *low-density residential sandy soil* scenario (80.8), the worst case scenario in this study. This value is also as high as that of the conventional quarter-acre single family residential land use (USDA, 2002), and this condition does not approximate the LID recommendations.

Development density plays an important role in affecting CN and watershed runoff. Watershed runoff increases around 35% for high-density scenarios and around 85% for low-density scenarios compared with the forest baseline condition. Likewise, sediment yields increase around 30% and 80% for high- and low-density scenarios, respectively. These results are also consistent with previous studies on the relationship between development densities and watershed outputs (Hammer, 1972; Schueler, 1994). Schueler (1994) reported that compact development could reduce site imperviousness by 10% to 50% and yield less sediment than a dispersed impervious surface. This chapter further demonstrates that even when the *total imperviousness* is held constant, high-density compact development generates 40% less runoff than low-density development. Compared with "typical development" in Houston, which often increases peak flows by 180%, flow in The Woodlands would increase by only 55% according to a simulation study conducted in the 1970s (Spirn, 1984). This finding is consistent with the findings of this study that predicts the increase in runoff of around 50% for high-density development and 100% for low-density development, if McHarg's approach is followed.

Besides density, the other focus of this study was development location, that is, the ideal place to allocate development by soil type. SWAT model shows that the long-term watershed outflows differ slightly (7% to 8%) between the two options in each density group. In other words, development on *clay* or *sandy* soils does not yield much difference in the long-term watershed outflow. However, the differences become extraordinary in extreme storms as shown by the KINEROS model. In a 100-year storm, the *high-density sandy soil scenario* (Scenario 3) could generate around 50% higher peak discharge than the *high-density clay soil scenario* (Scenario 2).

In short, for long-term watershed runoff and during small rainfall events, *development density* is a more prominent factor than *development location*. The *development location per soil permeability* becomes important when extreme rainfalls (e.g., 50 and 100 years) are of concern. Developments that preserve highly permeable soils are less prone to flooding. The *high-density clay soil scenario* (Scenario 2) represents the best solution among the four development scenarios. The *low-density scenarios* (Scenarios 4 and 5) – conventional development typically found in the Houston area – are the least effective plans in stormwater management. Therefore, a more comprehensive development approach is to consider both density and location.

Another finding that corresponds to previous studies is that the pattern of development in the watershed has an influence on peak discharge (Bedient et al., 1985). In the Panther Creek watershed, there are more A and B soils than C and D soils in the lower reaches. The research design thus led more development to be placed on the lower portion of the watershed in the *high-density sandy soil scenario* (Scenario 3) and the *low-density sandy soil scenario* (Scenario 5) than in the *high-density clay soil scenario* (Scenario 2) and the *low-density clay soil scenario* (Scenario 4). Hence, different development locations caused differences in peak discharges among subwatersheds. The *low-density sandy soil scenario* (Scenario 5), although it was projected to be the worst case scenario, generated less peak discharges than the *low-density clay soil scenario* (Scenario 4). This result could be attributed to the large open space preserved in the upper reaches of the watershed in the *low-density sandy soil scenario* (Scenario 5) that detained a large amount of runoff and retarded the momentum of peak discharge when it flowed to the watershed outlet. There are vast differences between each sub-watershed in terms of development densities and soil conditions across the four scenarios. For this reason, comparing peak discharge of each sub-watershed in different scenarios was not possible in the study of this chapter.

Summary

The Woodland's 2005 land use condition has deviated from McHarg's (WMRT) original plan. In particular, developments post-1997, the year of The Woodlands' ownership change, did not use soil permeability as a critical guide for planning. Watershed streamflow modeling on different hypothetical scenarios strongly suggests that compact high-density development combined with McHarg's approach is the best solution among development approaches compared in this study. Using soil permeability to coordinate development densities and land use presents a viable solution to the flooding problems in community development.

The study presented in this chapter only examined snapshots of development conditions of four years. Future study needs to include more samples that present more variations of the watershed conditions. The Woodlands' current conditions, despite having a quality that is less than originally proposed, are further ahead than conventional solutions. Its planning, design, and management remain an excellent example of eco-conscious urban planning for design professionals to consider. Chapter 14 compares different drainage designs in early- and later-constructed residential villages in The Woodlands.

14 Stormwater performance

Introduction

Chapter 14 presents a comparative study of two different drainage designs in The Woodlands, specifically, the designs *before* and *after* the ownership change. One of the main strategies that McHarg used in The Woodlands was to employ surface drainage for stormwater management. Open surface drainage by shallow grassed swales was employed in the first two subdivisions that were developed with the ecological approach. Open surface drainage mimics the natural flow regimen and is regarded to mitigate development impacts on watershed. In other later subdivisions, the drainage design shifted back to a conventional stormwater drainage system, that is, curb and gutter, drop inlet, and underground piping, known to concentrate stormwater and lead to downstream flooding. The objective of this chapter is to compare The Woodlands' two drainage systems on their correlation with downstream floods.

Background

A paradigm shift in stormwater management is to use the natural infiltration mechanism to treat runoff. Current literature suggests the advantage of open surface drainage best management practice (BMP) over conventional pipe drainage, because the former is designed to mimic the natural flow regimen and is considered to facilitate stormwater infiltration, reduce peak discharge, and provide water quality treatment (Coffman, 2000; U.S. EPA, 2000; Villarreal, Semadeni-Davies, & Bengtsson, 2004). The U.S. EPA (1999) suggests that open surface drainage BMP using grassed swales could replace conventional stormwater collection and conveyance systems in urban development. Open surface drainage is often designed as grassed swales pitched with a certain gradient. Grassed swales are placed at low elevations and serve as drainage channels to transport stormwater away from roadways. Roads in this situation are placed at high grounds, minimizing the safety problems.

Dry swale and wet swale are two types of grassed swales that are currently in use. The trapezoidal shape and meandering path increase the storage volume and provide a less efficient system than the channelized pipe system. Similar to the dry swale, wet swale uses natural vegetation growth to control stormwater quantity and quality (Coffman, 2000). If specifically designed, wet swale functions similar to a bioretention basin. A bioretention swale installed in a conventional residential road in Seattle, Washington, reported a 97% runoff volume reduction compared with the pre-construction runoff volume (Horner, Lim, & Burges, 2002). In addition, vegetated filter strips (VFSs) installed at the top of the grassed swale channel banks help reduce and treat sheet flows (U.S. EPA, 1999). Runoff reduction due to the use of VFSs varies between 6% (Chaubey, Edwards, Daniel, Moore, & Nichols, 1994) and 89% (Schmitt, Dosskey, & Hoagland, 1999). Finally, Villarreal and colleagues suggest the benefits of using a combination of BMPs in developing the open drainage system (Villarreal et al., 2004). The synergic effect of BMPs is better than one BMP, and the location of BMP is an important design consideration.

Although open surface drainage may provide an alternative to conventional underground drainage in light of the rising flooding problems, very few subdivisions have implemented open surface drainage at a large scale. The Woodlands is one of the pioneers in the use of open drainage systems (WMRT, 1973a; McHarg & Sutton, 1975; Kim & Ellis, 2009). Further, the surface drainage channels were located where highly permeable soils were present (WMRT, 1973b, 1973c, 1974). McHarg coined the term "ecological plumbing" to represent this open drainage solution (McHarg & Sutton, 1975).

Open surface drainage was implemented in the first two suburban villages (Galatas & Barlow, 2004). However, most homeowners did not like the rustic appearance of the open drainage channels. To improve marketability, The Woodlands gradually shifted to conventional drainage practices (Gause, Garvin, & Kellenberg, 2002; Galatas & Barlow, 2004). Figure 14.1 shows different drainage systems in The Woodlands in the early and later subdivisions. After the conventional system was installed, The Woodlands was flooded in 2000 (NOAA, 2000) and again in 2008 as a result of Hurricane Ike (Madere, 2008).

In this chapter, The Woodlands' two drainage systems on their correlation with downstream floods are compared. Previous studies of open drainage systems usually focused on site-level scale (e.g., Horner et al., 2002; Villarreal et al., 2004). Few studies have been conducted at a larger scale (Brander, Owen, & Potter, 2004), and some studies used a modeling approach when controlled experiment samples were not available (e.g., Girling & Kellett, 2002). This study used empirical data to assess open drainage systems at a watershed scale. Moreover, this study evaluated the system effectiveness, which was considered by the U.S. EPA (1999) as less desirable in intense rainfalls (e.g., Texas coastal rainfall pattern).

Figure 14.1a Different drainage systems in The Woodlands. (a) Open surface drainage system in the first two villages.

Figure 14.1b Different drainage systems in The Woodlands. (b) Conventional underground drainage system in later villages.

Study sites

Figure 14.2 shows the two sub-watersheds in comparison. Watershed #1 (22.3 sq km) and Watershed #2 (67.1 sq km) comprise the Panther Creek watershed – defined by the U.S. Geological Survey (USGS) gauge station #08068450. In 1972, The Woodlands development started downstream of the Panther Creek and evolved along the creek upstream.

It is important to note that Watershed #1 does not constitute a *watershed* in the common definition of watershed. Watershed #1 is the Panther Creek watershed excluding Watershed #2. This is a working definition of Watershed #1 for the purpose of this study. Watershed #1 includes approximately one-third of the first subdivision – Village of Grogan's Mill and the majority of the second village – Village of Panther Creek. An open drainage system was implemented in the first village and part of the second village (Kutchin, 1998; Galatas & Barlow, 2004).

Design guidelines and built conditions of the open surface drainage have been illustrated in previous chapters (see Figures 7.3 and 7.5). Open drainage swales were placed where soils with high infiltration capacities are available, and check dams were used to retard runoff and promote infiltration (WMRT, 1973c). Grassed waterways were used and natural vegetated buffer zones were protected (WMRT, 1973c). After development of the first two villages, open surface drainage was still used in arterial roads and collectors but was changed to a conventional drainage system in subdivisions (Gause et al., 2002).

Watershed #2 is defined by the USGS gauge station #08068400. Watershed #2 remained a pine forest when development started in Watershed #1. Four villages – Alden Bridge, Sterling Ridge, Cochran's Crossings, and Indian Springs – are located in Watershed #2. Conventional drainage systems were installed in those villages.

Data

Three types of data were needed for this study: parcel, streamflow, and precipitation. Parcel data reflect development conditions in the watershed. Urban development introduces impervious cover that presents an important variable affecting watershed runoff. Generally, the larger the development area, the larger the impervious area and the more runoff generated (Schueler, 1994; Arnold & Gibbons, 1996; Booth & Jackson, 1997). Table 14.1 summarizes data source, modification, and analysis. The detailed procedure of data analysis is described in the following section.

Impervious area

The Woodlands development included various types of impervious areas, including roads, building footprints, sidewalks, driveways, etc. The two

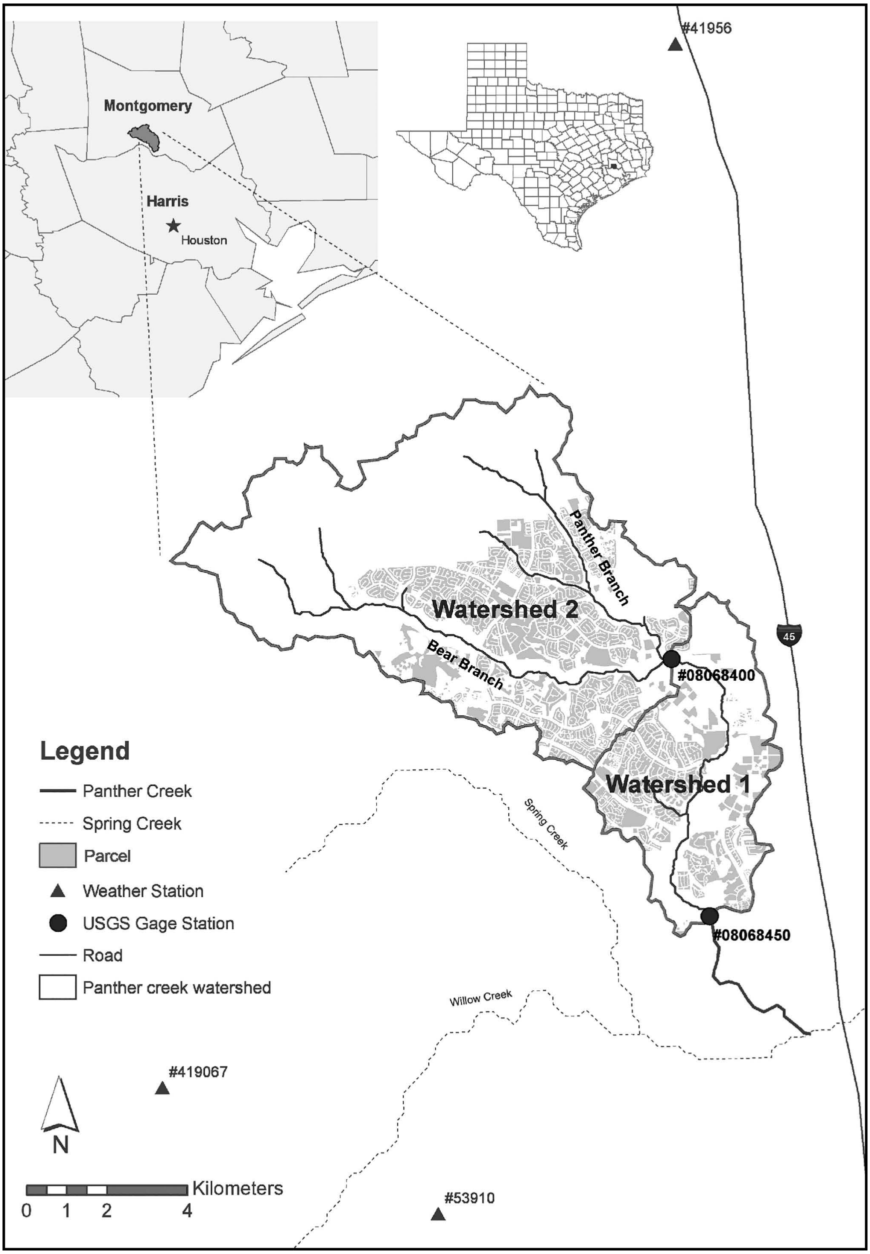

Figure 14.2 Panther Creek watershed development and two sub-watersheds: Watershed #1 and Watershed #2.

Table 14.1 Data source, modification, and analysis.

Data	*Source*	*Explanation/Modification/Analysis*
Parcel	Montgomery County Appraisal District	Provide annual development conditions
Road	TNRIS website www.tnris.state.tx.us/	Provide road length, but no information of year built
Streamflow	USGS website www.usgs.gov/	$\text{Flow}_{\text{watershed \#1}} = \text{Flow}_{\#08068450} - \text{Flow}_{\#08068400}$ $\text{Flow}_{\text{watershed \#2}} = \text{Flow}_{\#08068400}$ Analysis 1: Include lake detention effect Analysis 2: Exclude lake detention effect
Precipitation	NCDC website www.ncdc.noaa.gov	COOPID #411956 substitutes for WBANID #53910 in 1975–1976

primary types were residential buildings and roads. Residential development conditions could be reflected by parcel data, which were obtained from Montgomery County Appraisal District. However, parcel data do not provide the conditions of sidewalks and driveways. Estimation was done for these impervious areas and the procedure is introduced in the Analysis section.

Road information was obtained from the Texas Natural Resources Information System (TNRIS). There were several sources for road information, such as TNRIS and the Texas Transportation Institute (TTI). However, none of them provided the year of road construction. For a particular road, parcels adjacent to it were identified and sorted by year of construction. Then the earliest year was assigned to that road, based on the assumption that the road has to be built for the parcel to be developed (Rogers & DeFee, 2005).

Streamflow

Streamflow data at USGS gauge stations #08068400 and #08068450 were downloaded from the USGS website. Due to data availability, data for water years 1975–1976 represented the early phases of development and data for water years 2000–2002 represented the later phases. According to the USGS definition, a water year is from October of the preceding year to September of the current year (i.e., water year 1975 = 10/01/1974 to 9/30/1975). For both watersheds, water years 1975–1976 and 2000–2002 were examined.

Precipitation

Historical precipitation data that are coincident with flow data were obtained from the National Climatic Data Center website (NCDC). The

Thiessen polygon method was used to estimate precipitation for both watersheds. Three weather stations (COOPID #411956, COOPIN #419067, and WBANID #53910) were identified according to the Thiessen method. The area weighted percentage of each station was used to calculate the composite precipitation value for each rainfall event.

Because station WBANID #53910 did not have data records for water years 1975–1976, data from the nearest station, COOPID #419067 (less than 7 km away), were used as a substitute. For both watersheds, if one station had data missing for a sample day, that day was excluded from analysis. No attempt was made to estimate the missing data.

Data treatment

Streamflow

As mentioned previously, Watershed #1 is not a typical watershed in the hydrologic definition. Watershed #1 is a sub-watershed located at the lower portion of the watershed defined by gauge #08068450 (see Figure 14.2). With the assumption that the flow measured at the upstream gauge #08068400 incurred no loss in moving downstream, streamflow contributed solely from Watershed #1 can be calculated by subtracting flow at the downstream gauge #08068450 from flow at the upstream gauge #08068400 (see Equation 14.1):

$$Q_1 = Q_{pc} - Q_2 \tag{14.1}$$

where Q_1 is the Watershed #1 daily mean streamflow (m^3s^{-1}); Q_{pc} is the daily mean streamflow at gauge #08068450 (Panther Creek watershed outlet) (m^3s^{-1}); and Q_2 is the daily mean streamflow at gauge #08068400 (Watershed #2 outlet) (m^3s^{-1}).

For the same day, flow at the downstream gauge #08068450 is typically greater than flow at the upstream gauge #08068400, a reasonable result as more surface runoff would contribute to downstream areas. Only 19 negative flow values (2.6%; of 731 samples) in water years 1975–1976 were found and removed from analysis. However, negative flow values were much more frequent in water years 2000–2002: 87 negative values (7.9%; of 1096) were observed. The reason for more negative values in water years 2000–2002 than 1975–1976 may be attributed to the 92-hectare Woodlands Lake (built in 1985) that intercepts the stream in Watershed #1. When the lake's water level is low after a long dry period, subsequent rainfall must refill the lake before the downstream section flows again. In this sense, the lake intercepts the flow and detains it.

Two flow datasets were prepared for Watershed #1. The first dataset included The Woodlands Lake detention effect, whereas the second dataset excluded this effect. The first dataset included all the data derived from

Equation (14.1) but excluded negative values. This dataset was used for water years 1975–1976 and 2000–2002. The second dataset excluded the negative values and further excluded data samples when The Woodlands Lake intercepted a significant amount of flow during its low water level periods. This set of data was only used for water years 2000–2002.

Watershed #2 has the same stormwater detention issue as a result of the 21-hectare Bear Branch Reservoir built in 1984. This reservoir should have affected the measured flow in water years 2000–2002. Similar to Watershed #1, two flow datasets were prepared for Watershed #2. The first dataset was used for both water-year periods, and the second dataset was used only for water years 2000–2002.

Excluding lake/reservoir detention effect

Since The Woodlands Lake and the Bear Branch Reservoir will intercept subsequent stream flows after dry periods, it is imperative to exclude the detention effect in order to evaluate the different drainage systems. Two methods were used to exclude such an effect, described in the following subsections.

Method 1

A user-defined point at the outlet of The Woodlands Lake was used to delineate the lake contributing area – Sub-watershed #1. Rain falling onto Sub-watershed #1 should contribute to The Woodlands Lake. Similarly, a user-defined point at the outlet of the Bear Branch Reservoir was used to delineate the reservoir contributing area – Sub-watershed #2.

Assuming uniform precipitation throughout the watershed (or sub-watershed), the depths to fill the lake and reservoir from the normal water level elevations to the maximum water level elevations were calculated using Equation (14.2). Variables in Equation (14.2) are listed in Table 14.2.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{14.2a}$$

$$S = \frac{1000}{CN} - 10 \tag{14.2b}$$

$$Q = \frac{A_{lake/reservoir} \times \Delta H_{lake/reservoir}}{A} \tag{14.2c}$$

According to the original design, $_{\Delta}H_{lake/reservoir}$ was given the value of 0.3 m (1 ft) in calculation. The calculated precipitation depths were 45.4 mm for Watershed #1 and 41.8 mm for Watershed #2. These values were used to identify sample days when the lake/reservoir was filled by rainfall. Seventeen samples were identified for Watershed #1, and 56 for Watershed #2. However, it was found that 15 of the total 17 samples in Watershed #1 and 46

Table 14.2 Variables in Equation 2 to calculate precipitation depths needed to fill the lake and the reservoir from the normal water level elevations to the maximum water level elevations in water years 2000–2002.

Variable	*Value*	*Unit*	*Explanation*
P	45.4 (calculated)	mm	Precipitation depth needed to fill the lake
	41.8 (calculated)	mm	Precipitation depth needed to fill the reservoir
Q	0.31 (calculated)	mm	Runoff volume of Sub-watershed #1[a]
	0.23 (calculated)	mm	Runoff volume of Sub-watershed #2[a]
S	2.7 (calculated)	mm	Potential maximum watershed storage
Curve Number	79	NA	CN used for both sub-watersheds[b]
$A_{lake/reservoir}$	918,030	m^2	Area of The Woodlands Lake
	205,904	m^2	Area of the Bear Branch Reservoir
$\Delta H_{lake/reservoir}$	0.3	m	Elevation difference between the normal water level elevation and the maximum water level elevation (lake bank elevation)[c]
	0.3	m	
A	90,444,600	m^2	Sub-watershed #1 area
	26,986,500	m^2	Sub-watershed #2 area

[a] Assuming a uniform depth of runoff across the watershed.

[b] Using the average value of 2001 and 2005 CNs of Panther Creek watershed for approximation. 2001 CN = 77.6; 2005 CN = 80.4.

[c] According to the original design documents (U.S. Army Corps of Engineers, 1982), the normal water level elevation of The Woodlands Lake is 38.1 m (125 feet), and the lake bank elevation is 38.4 m (126 feet). The normal water level elevation of the Bear Branch Reservoir is 49.1 m (161 feet), and the reservoir bank elevation is 49.4 m (162 feet). There is a 0.3 m (1 ft) elevation difference in both water bodies.

of the total 56 samples in Watershed #2 have streamflow values twice the base flow values. This result indicated that the lake and the reservoir have reached their maximum water level elevations after rainfall at the calculated depths. Method 1 thus yielded values much greater than what was needed to fill the lake and the reservoir.

Method 2

Method 2 used measured precipitation data to calculate the depths, and the results were compared with the results obtained by Method 1. In Method 2, the depths were estimated by averaging precipitation values when corresponding flow values just increased from the base flow value to greater

Table 14.3 Estimated precipitation depths to fill the lake and reservoir using two different methods.

	Rainfall depth (mm)		
	Method 1	*Method 2*	*Avg. of Methods 1 and 2*
The Woodlands Lake	45.4	37.9	41.7
Bear Branch Reservoir	41.8	21.2	31.5

values. Under this condition, the lake/reservoir was just filled up and no substantial additional runoff was generated by these precipitation events. Certain criteria were specified to target those precipitation samples. (1) On the first day when precipitation occurs, flow remains close to the base flow (around 0.3 m^3s^{-1}). (2) There is no precipitation or only modest precipitation on the second day. (3) On the second day, flow becomes slightly greater than the base flow.

In total, 11 precipitation samples met these criteria for Watershed #1, and 16 samples for Watershed #2. The average depths from these samples were calculated for each watershed. Finally, the average depths from Method 1 and Method 2 were used to determine the precipitation depths, and the results are presented in Table 14.3.

Precipitation-streamflow data pair selection

Precipitation-streamflow data pairs were selected to assess how the watersheds responded to rainfall within different drainage systems. Following a long dry period, streamflow is usually lower than the base flow because the arid soil absorbs much rainwater before excessive runoff occurs. The precipitation-streamflow relationship was further complicated after 1985, when The Woodlands Lake and the Bear Branch Reservoir stormwater detention facilities were built.

For both water-year periods, precipitation-streamflow data pairs were assessed under two different conditions. For water years 1975–1976, the first condition was the watershed status quo condition. The second condition excluded the watershed's dry periods. Similarly, for water years 2000–2002, the first condition was the status quo condition, and the second condition excluded the lake/reservoir detention effect.

Water years 1975–1976 (early phases of development)

In the first condition (status quo), precipitation-streamflow data pairs were selected when precipitation was recorded. In the second condition, two criteria were established to exclude the dry periods. (1) Following a long dry period (e.g., a week), rainfall needs to last at least two days, so that rainfall on the first day is able to increase the soil moisture. If the flow is greater than the base flow on the second day, the second day's precipitation-streamflow data pair becomes eligible. (2) The first day precipitation-streamflow data pair is also acceptable, if flow on the first day is already greater than the base flow when a rainfall event occurs on the first day.

Water years 2000–2002 (later phases of development)

Likewise, the first condition (status quo) included precipitation-streamflow data pairs if precipitation was recorded. The second condition excluded data pairs influenced by the lake/reservoir detention effect. If one of the following three criteria is met, the lake or the reservoir is regarded to have reached its maximum storage capacity, and excessive runoff resulted from subsequent rainfall. (1) Precipitation from the first day must be at least 41.7 mm to fill the lake or 31.5 mm to fill the reservoir. (2) It is acceptable if the sum of rainfall depths from several consecutive days reaches the specified depths, but flow values during these days must be consistently greater than the base flow value. (3) It is also acceptable if the first-day precipitation is less than the required precipitation, but the flow is greater than the base flow. This indicates the watershed is experiencing a wet period before this rainfall event.

Analysis

Impervious area

In land use planning, three methods are generally used to capture the impervious surface area of development: (1) use parcel data to quantify the impervious area (Alley & Veenhuis, 1983; Rogers & DeFee, 2005), (2) classify Landsat remote sensing imagery to extract the impervious area (Alberti et al., 2007; Shandas & Alberti, 2009), and (3) digitize high-resolution aerial photographs to delineate the impervious area (Light, 1993; Jennings & Jarnagin, 2002).

This study used the first method to calculate the impervious area from 1972 to 2002 using the Geographic Information System (GIS). GIS parcel data provide the parcel boundary and location, parcel area, building type, year built, and building square footage. Sorting these data by year built provides the state of development in the watershed each year. Road surface area was estimated by multiplying the road length with the average width of the roads in the watershed (Rogers & DeFee, 2005). Another component of impervious areas is the sidewalk. A majority of the development has sidewalks on both sides of the road. Hence, the road length was doubled as the sidewalk length. The sidewalk area was then estimated by multiplying the length with the average width of sidewalk.

Finally, estimation was made for the driveway impervious area. Previous studies have used the number of garage stalls multiplied by the average width (3 m) of the driveway (Stone, 2004; Stone & Bullen, 2006). However, parcel data for The Woodlands do not provide driveway information. As front yard setback distance was specified by The Woodlands Residential Development Standards: "a garage or garage addition must be set back at least 16 feet (4.88 m) from the side property line" (Community Associations of The Woodlands, 1996, Section 2.1, p. 14), this setback distance was multiplied by the width of a two-stall garage (6 m) to approximate the driveway impervious area, calculated by Equation (14.3):

$$\text{Driveway area } \left(\text{m}^2\right) = \text{Front-yard setback } (\text{m}) \times 3 \text{ m} \times \text{Number of garage stalls} \tag{14.3}$$

This driveway area was multiplied by the total number of parcels in the watershed to estimate the total driveway areas.

Watershed runoff volume

Annual mean runoff depth was calculated for the five water years. Watershed runoff depth (m) is calculated by dividing the total runoff volume (cubic m) by the watershed area (sq m). This method assumes a uniform depth of water falling onto the watershed. In this way, the flow volume is standardized and becomes comparable. The runoff depth was calculated using Equation (14.4):

$$H = \frac{Q_i \times t}{A} \tag{14.4}$$

where H is the watershed annual runoff depth (m); Q_i is the annual mean flow at year i ($m^3 s^{-1}$); t is a constant, 31,536,000 seconds, the total number of seconds in a year; and A (sq m) is the watershed area.

Streamflow response

A daily streamflow response value was created for streamflow-precipitation data pairs when precipitation was recorded (Jennings & Jarnagin, 2002). The streamflow response ($m^3\ s^{-1}\ m^{-1}$) value is calculated by diving mean daily streamflow ($m^3\ s^{-1}$) by daily precipitation (m). "Streamflow response value allows for a unified term for the data pair in which changes in streamflow as a result of variations in precipitation could be comparable for historical data" (Jennings & Jarnagin, 2002, p. 476). The average annual streamflow response value was calculated for each water year.

Precipitation-streamflow correlation

Three sets of correlation analyses were conducted to reflect the watershed characteristics using different drainage systems. The first set of correlation analysis provided an overall comparison of the two watersheds. For water years 1975–1976, correlation analysis was conducted for the watershed status quo condition and the condition in which the dry periods were excluded. For water years 2000–2002, the function of large stormwater detention facilities was assessed.

The second set of correlation analysis was conducted only for water years 2000–2002. The purpose was to compare the flood mitigation effectiveness of different drainage systems together with large stormwater detention facilities. Correlation analysis was conducted on a daily basis for precipitation-streamflow data pairs if precipitation > 0 mm. Precipitation data were further grouped into two categories: > 0 mm and > 6 mm. The first category (> 0 mm) stands for all rainfall events. The second category (> 6 mm) includes moderate and large rainfall events (Jennings & Jarnagin, 2002).

The third set of correlation analysis was also conducted only for water years 2000–2002. It aimed at evaluating flood mitigation effectiveness solely from different drainage systems. Finally, correlation analysis evaluated the daily precipitation-streamflow relationship and the relationship between yesterday's precipitation and today's streamflow (Rogers & DeFee, 2005).

It was found that in water years 2000–2002, Watershed #1 streamflow sometimes did not reach the highest value on the same day as when a large rainfall occurred. A peak flow emerged on the second day. However, this phenomenon was less frequently observed in Watershed #2 in this period. This is perhaps because Watershed #1's open drainage system detained runoff and presented a lag time after rainfall, whereas Watershed #2's conventional drainage system discharged runoff efficiently without detaining it.

Results

Impervious area

Development conditions in Watershed #1 and Watershed #2 are presented in Figure 14.3. By the end of 2002, there were 355 hectares (877 acres) of impervious area in Watershed #1 and 743 hectares (1,835 acres) in Watershed #2. These areas accounted for 15% and 11% of Watershed #1 and Watershed #2 areas, respectively. It is important to note that Watershed #1 contains 93 hectares (203 acres) of The Woodlands Town Center commercial area. This commercial area presents a high percentage of impervious cover and will adversely impact the effectiveness of the open drainage system.

Watershed runoff volume

The annual runoff depths of five specific water years are shown in Figure 14.4. Two trends emerged in this analysis. The first trend was that Watershed #1 has a lower runoff depth than Watershed #2 in each year examined – meaning less runoff volume has been generated from Watershed #1. The second trend was that a noteworthy increase in runoff depth occurred in Watershed #2 in the later phases of development. In the early phases (1975–1976), Watershed #2's runoff depths were around *three* times those of Watershed #1. However, in the later phases (2000–2002), these ratios increased to *five* to *eight* times.

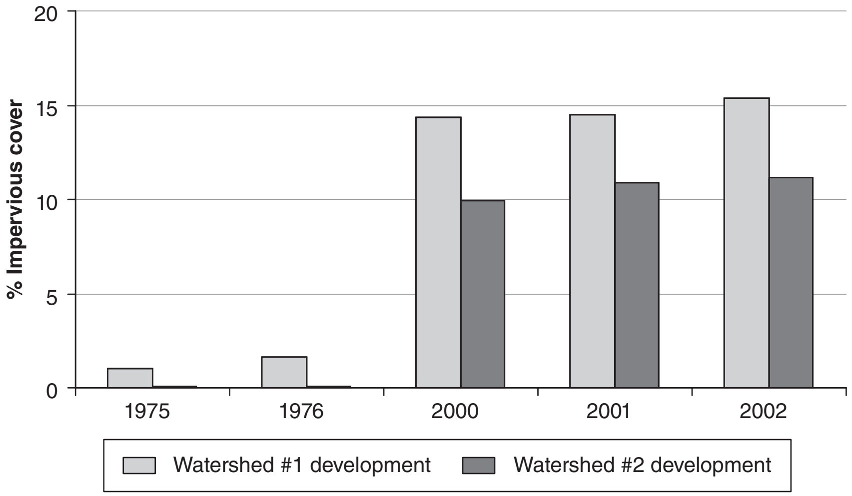

Figure 14.3 Cumulated percentage of impervious area in Watershed #1 (open drainage) and Watershed #2 (conventional drainage).

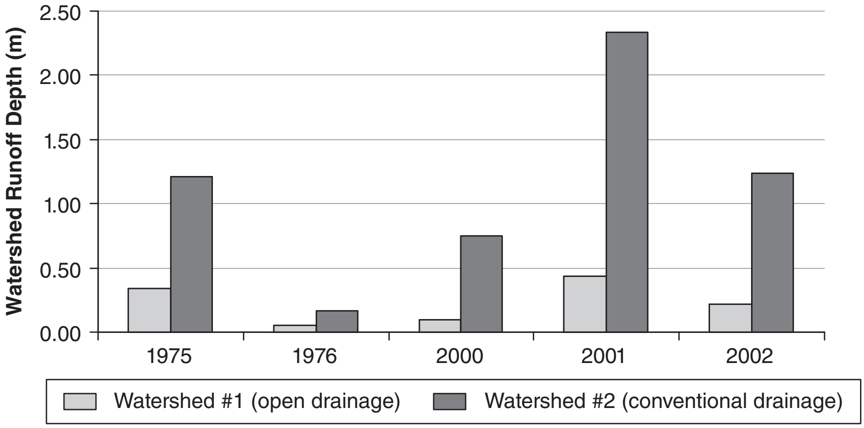

Figure 14.4 Surface runoff depths of Watershed #1 (open drainage) and Watershed #2 (conventional drainage).

Because Watershed #2 has a lower percentage of impervious area than Watershed #1, more runoff volume from Watershed #2 could be attributed to the differences in drainage designs. In Watershed #1, the open drainage system and The Woodlands Lake detained a large amount of water for infiltration and evapotranspiration. Conversely, in Watershed #2, the pipe drainage system facilitates runoff without detaining it – counteracting the detention function provided by the Bear Branch Reservoir.

Streamflow response

Figure 14.5 shows the streamflow response values and the annual precipitation in the two watersheds. Precipitation values were similar in the two watersheds in each year examined. However, the streamflow response values presented differences in the later phases of development. Likewise, two trends emerged in this analysis. The first trend was that the streamflow response values remained low in the early phases in both watersheds. The second trend was that the value increased at a much greater rate in Watershed #2 than in Watershed #1 in the later phases.

In 2002, the Watershed #2 streamflow response value was more than *nine* times that of Watershed #1 – indicating more *flashy* streamflow after development. Given the fact that Watershed #2 has less percentage of impervious area than Watershed #1, thus the conventional drainage system has altered Watershed #2 to be more sensitive in response to rainfall than Watershed #1.

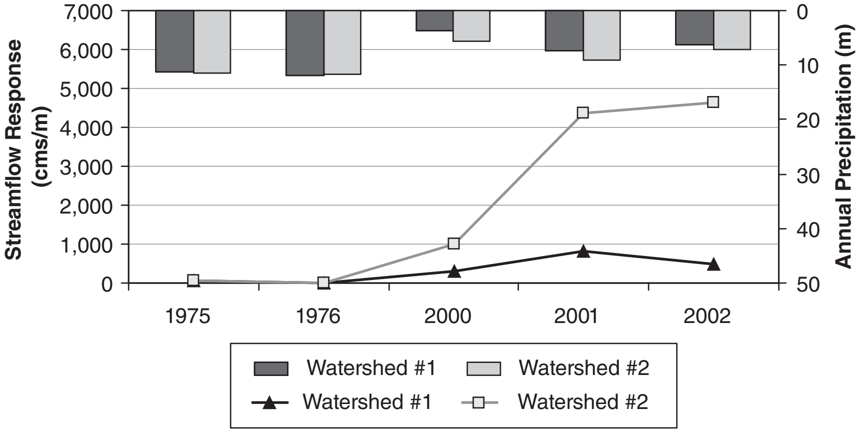

Figure 14.5 Annual precipitation (m) and streamflow response value ($m^3s^{-1}m^{-1}$) of Watershed #1 (open drainage) and Watershed #2 (conventional drainage).

Precipitation-streamflow correlation analysis

Four sets of correlation analyses were conducted and the results are presented in Tables 14.4, 14.5, and 14.6. The first set of precipitation-streamflow correlation analysis was conducted on a daily basis, and Pearson's correlation coefficients (*r*) are summarized in Table 14.4. In the early phases, when both watersheds maintained forest conditions, streamflow and precipitation showed little correlation – low *r* values. Also, there was little variation in correlation between the dry and wet periods.

In the later phases, the correlation remained low in Watershed #1 but increased to be much higher in Watershed #2. Hence, Watershed #1

Table 14.4 Correlation analysis of precipitation (> 0 mm) and daily mean streamflow[a]

Water year	*Watershed*	*Precipitation (> 0 mm)*	
		Correlation coefficient[b]	*Sample number*
1975–1976	#1	0.35	193
Before excluding dry periods	#2	0.26	209
1975–1976	#1	0.35	158
After excluding dry periods	#2	0.39	116
2000–2002	#1	0.17	379
Before excluding lake detention effect	#2	0.48	483
2000–2002	#1	0.10	43
After excluding lake detention effect	#2	0.61	90

[a] Hurricane Allison on 6/9/2001 was excluded as an outlier.
[b] Correlation coefficient: Pearson's coefficient "*r*".

Table 14.5 Correlation analysis of precipitation and streamflow *before* excluding lake/reservoir detention effect[a]

Water year	*Watershed*	*Precipitation*			
		> 0 mm		*> 6 mm*	
		Correlation coefficient[b]	*Sample number*	*Correlation coefficient*[b]	*Sample number*
2000	#1	0.03	98	0.06	19
	#2	0.69	134	0.67	36
2001	#1	0.03	161	0.03	47
	#2	0.36	191	0.24	68
2002	#1	0.42	120	0.38	31
	#2	0.54	156	0.55	53

[a] Hurricane Allison on 6/9/2001 was excluded as an outlier.
[b] Correlation coefficient: Pearson's coefficient "*r*".

stormwater management strategies seemed to be more effective than those of Watershed #2 in mitigating flood. In other words, the open drainage system together with The Woodlands Lake detained water more effectively than did the conventional drainage system and the Bear Branch Reservoir combined. The lake and the reservoir performed a similar detention function. However, the conventional drainage system adversely offset the reservoir's detention effect. After The Woodlands Lake detention effect was excluded, low precipitation-streamflow correlation was still observed in Watershed #1. The open drainage system alone suggested a viable stormwater detention solution.

The second set of analyses included yearly analysis and rainfall intensity categorical analysis, and the correlation coefficients (*r*) are listed in Table 14.5. This set of analyses was conducted only for water years 2000–2002. As mentioned earlier, precipitation-streamflow data pairs were further divided into two categories based on precipitation values > 0 mm and > 6 mm. Similar to Table 14.4 results, Watershed #1 responded to rainfall in a manner similar to its predevelopment forest condition (low *r* values). Conversely, Watershed #2 presented high precipitation-streamflow correlations during 2000–2002 when the conventional drainage system was installed (high *r* values).

Table 14.6 Correlation analysis of precipitation and streamflow *after* excluding the lake/reservoir detention effect[a]

Model	*Watershed*	*Precipitation*			
		> 0 mm		*> 6 mm*	
		Correlation coefficient[b]	*Sample number*	*Correlation coefficient*[b]	*Sample number*
Daily model[c]					
Mean flow	#1	0.11	43	0.32	25
	#2	0.61	90	0.52	65
Max. flow	#1	0.07	43	0.17	25
	#2	0.62	90	0.55	65
Lagged model[d]					
Mean flow	#1	0.42	16	0.30	11
	#2	0.29	44	0.20	36
Max. flow	#1	0.55	16	0.48	11
	#2	0.21	44	0.14	36

[a] Hurricane Allison on 6/9/2001 was excluded as an outlier.

[b] Correlation coefficient: Pearson's coefficient "*r*".

[c] Daily model: $Y = a + bX$. The independent variable is X: precipitation (mm). The dependent variable is Y: streamflow (m^3s^{-1}). Daily mean streamflow and daily maximum streamflow were used as the dependent variable Y.

[d] Simplified lagged model: $Y = a_1 + b_1X_1$. The independent variable is X_1: precipitation of yesterday (mm). The dependent variable is Y: streamflow (m^3s^{-1}). Daily mean streamflow and daily maximum streamflow were used as the dependent variable Y.

The third set of correlation analyses was also conducted only for water years 2000–2002, and the correlation coefficients (*r*) are listed in Table 14.6. This set of analyses aimed at evaluating the flood mitigation effectiveness solely provided by drainage systems. In this analysis, soil was saturated and the detention effects of The Woodlands Lake and the Bear Branch Reservoir were excluded.

Two models were used: the daily model and the simplified lagged model. In the daily model, Watershed #2 showed a higher precipitation-streamflow correlation than Watershed #1 for both rainfall intensities examined, indicating a situation vulnerable to flooding. In contrast, Watershed #1 showed little precipitation-streamflow correlation, suggesting that the open drainage system was effective in detaining runoff.

The simplified lagged model further demonstrated the lag-time effect, since the slope and the flow path length are similar in the two watersheds. In this model, Watershed #1 showed a higher precipitation-streamflow correlation than Watershed #2. This means peak flow was less likely to occur on the same day as when a large rainfall emerged in Watershed #1. In Watershed #1, yesterday's precipitation was a better predictor than today's precipitation for today's streamflow. In Watershed #2, however, yesterday's precipitation and today's streamflow showed little correlation. This means that Watershed #2 discharged runoff faster than Watershed #1 instead of detaining it. This set of analyses showed that when the detention effect of the lake/reservoir was excluded, the open drainage system presented an advantage over the conventional drainage system in mitigating flood.

The fourth set of analyses enumerated precipitation-streamflow correlation coefficients (*r*) as precipitation increases. It provided a comprehensive correlation analysis for all the precipitation-streamflow data pairs. This analysis demonstrated the incremental change of the correlation and minimized the potential bias due to the precipitation intensity thresholds specified (e.g., precipitation > 6 mm indicates a large rainfall).

Figures 14.6 and 14.7 present the scatterplots obtained from the daily model. Figure 14.6 showed that *before* excluding the lake detention effect, *r* values remained low, near zero, in Watershed #1, regardless of the precipitation intensities. In Watershed #2, it was evident that *r* values increased as precipitation increased. Figure 14.7 showed a similar trend; that is, *after* excluding the lake detention effect, *r* values remained low in Watershed #1, but the values increased in Watershed #2 as rainfall intensity increased. Also, comparing conditions before and after excluding the lake detention effect, the correlation became much higher in Figure 14.7 than in Figure 14.6, particularly during a large rainfall.

Discussion

The open drainage system can detain stormwater runoff for infiltration in addition to its drainage function, whereas the conventional drainage system

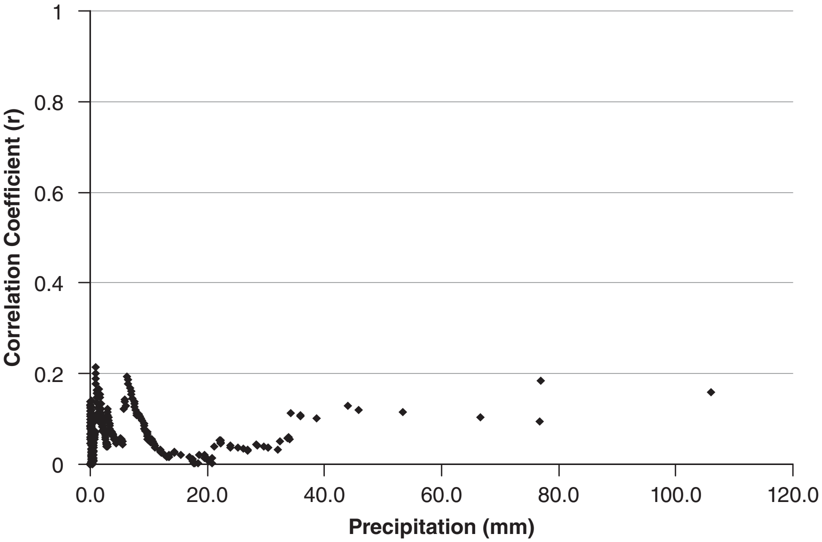

Figure 14.6a Pearson's correlation coefficients (*r*) of precipitation (> 0 mm) and daily mean streamflow during 2000–2002, *before* excluding the lake detention effect. (a) Watershed #1 (open drainage).

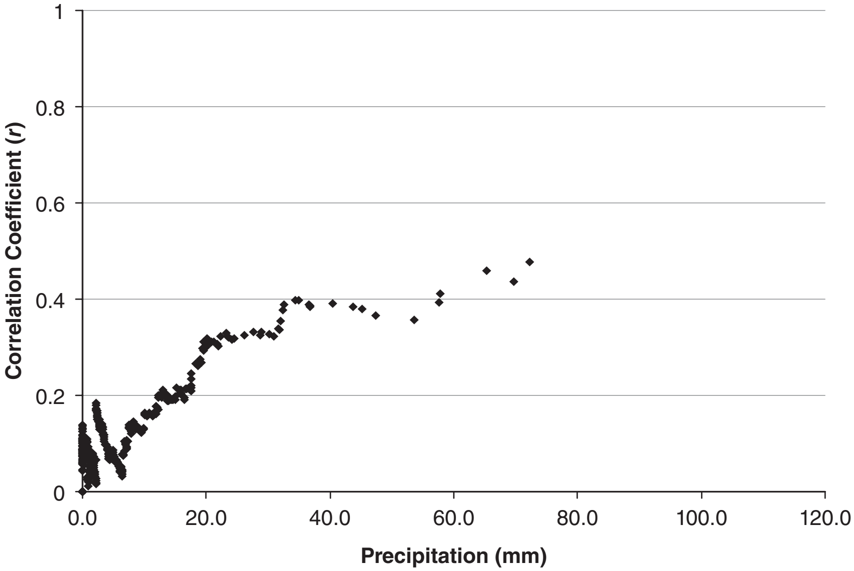

Figure 14.6b Pearson's correlation coefficients (*r*) of precipitation (> 0 mm) and daily mean streamflow during 2000–2002, *before* excluding the lake detention effect. (b) Watershed #2 (conventional drainage).

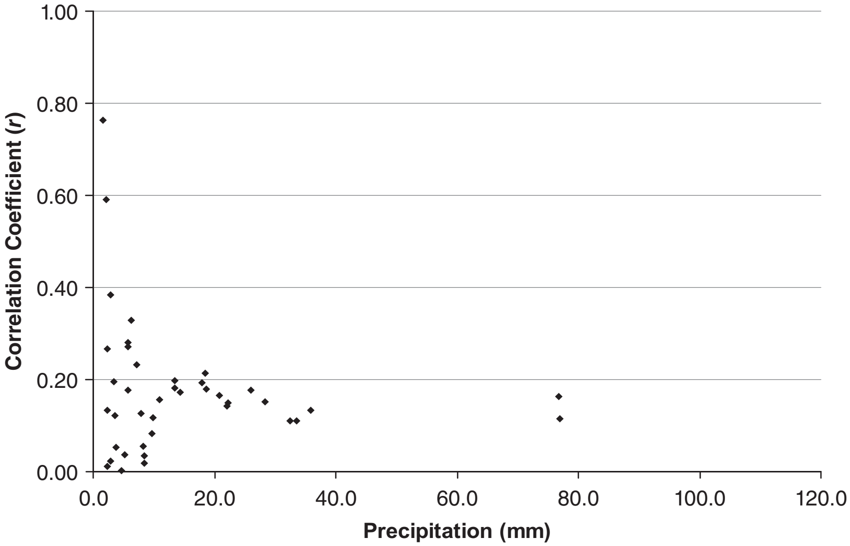

Figure 14.7a Pearson's correlation coefficients (*r*) of precipitation (> 0 mm) and daily mean streamflow during 2000–2002, *after* excluding the lake detention effect. (a) Watershed #1 (open drainage).

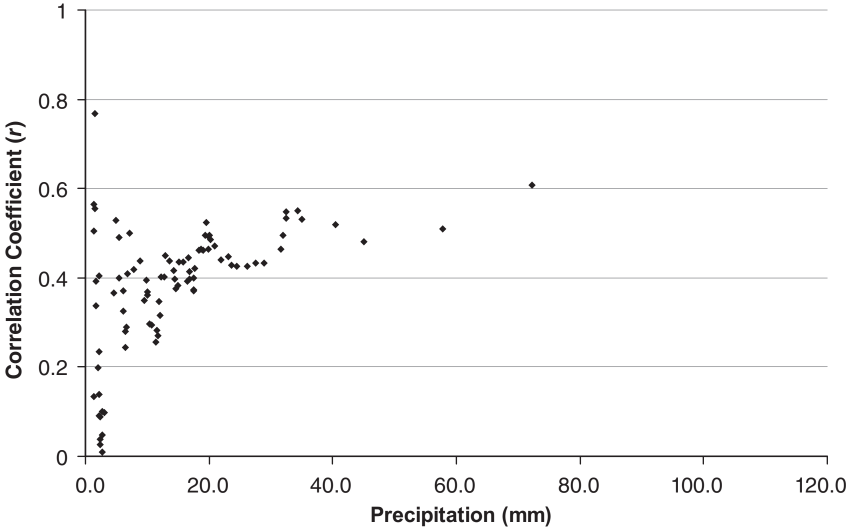

Figure 14.7b Pearson's correlation coefficients (*r*) of precipitation (> 0 mm) and daily mean streamflow during 2000–2002, *after* excluding the lake detention effect. (b) Watershed #2 (conventional drainage).

aims at passing runoff downstream as fast as possible. After development, there was a 26% runoff volume increase in Watershed #1 (open drainage). However, a much greater increase, 110%, was found in Watershed #2 (conventional drainage). Land with high permeable soils (e.g., sandy soils) accounted for 49% of Watershed #1 area and 35% of Watershed #2 area, and by 2002, impervious areas accounted for 15% and 11% of Watershed #1 and Watershed #2 areas, respectively. Intuitively, these differences are not significant enough to engender such a vast difference in runoff (26% versus 110%). Thus, the difference in runoff volume could be largely attributed to the difference between drainage designs. Compared with conventional drainage, open drainage enabled more water to infiltrate and evaporate before discharging downstream.

Streamflow response analysis further illustrated that the conventional drainage watershed presented a high runoff increase per unit of precipitation. Obviously the conventional drainage system has exerted a much greater impact on the natural flow regime than the open drainage watershed. Natural streams became flashy channels in the conventional drainage watershed and suggested a condition prone to flooding. In contrast, in the open drainage watershed, streamflow peaks occurred with a longer lag time than in the conventional drainage watershed. The open drainage watershed responded to rainfall in a manner similar to its forest conditions, in which streamflow did not necessarily increase when it rained. Although the Bear Branch Reservoir helped detain runoff in the conventional drainage watershed, the conventional drainage system efficiently conveyed runoff downstream and muted the detention effect of the reservoir.

Moreover, the yearly correlation analysis showed that the combined effect of the open drainage system and The Woodlands Lake was consistently more effective in detaining water than the conventional drainage system combined with the Bear Branch Reservoir. The Woodlands Lake (92 hectares) and the Bear Branch Reservoir (21 hectares) were designed as flood control devices (U.S. Army Corps of Engineers, 1982). After excluding the lake/reservoir detention effect, a much higher precipitation-streamflow correlation emerged in the conventional drainage watershed, showing the positive flood mitigation function the reservoir could provide and the negative impacts on this function the conventional drainage system could cause. The Woodlands Lake has played an important role in detaining runoff in the open drainage watershed. But even without the lake, the open drainage system maintained a low precipitation-streamflow correlation. Moreover, the lagged model showed the elongated lag time this drainage system could bring.

Prior to the construction of The Woodlands Lake (1985), The Woodlands survived a storm in excess of 100-year levels in 1979 with little property damage (Girling & Kellett, 2005). Although not based on scientific study, it was believed that the open drainage system played a vital role in protecting The Woodlands in this significant event (Morgan & King, 1987; Galatas & Barlow, 2004). Some other storms also help explain the effectiveness of this open drainage system. On September 28, 1987, southern Montgomery County experienced a 130-mm rain. High water and flooding were reported along Panther Creek. The city of Oak Ridge North to the east of The Woodlands and Timber Ridge subdivisions to the south of The Woodlands were flooded. In contrast, no flooding was observed in The Woodlands (NOAA, 1987). In 1994, a 500-year level storm occurred in The Woodlands, with over 890 mm of rain falling within 36 hours. Again, the open drainage system successfully endured this significant event (Galatas & Barlow, 2004).

After The Woodlands took a different approach in drainage design, especially after its ownership was changed in 1997, homeowners started to complain about the flooded streets during large storms (Haut, 2006). On April 2, 2000, The Woodlands had considerable street flooding and many roads became impassable (NOAA, 2000). Again in the 2008 Hurricane Ike, a large territory of The Woodlands was flooded. The western Woodlands, developed with the conventional drainage system, was severely flooded. A number of streets and thoroughfares became impassable after the hurricane (Madere, 2008). However, neighborhoods built with open surface drainage remained safe.

The study also provided some suggestions for planning and design practices. Two issues emerged. The first issue is that location is an important design consideration of developing surface drainage (U.S. EPA, 1999; Villarreal et al., 2004). Open drainage channels in The Woodlands were designed in conjunction with circulation systems, soil characteristics, and site drainage patterns. Check dams were integrated with grading plans to ensure maximum infiltration and groundwater recharge (WMRT, 1973a, 1973c). The second issue is that the combined effect of several BMPs is better than that of a stand-alone BMP (U.S. EPA, 1999). This study showed that open drainage swales could be used as a stand-alone BMP but are more effective if used together with large detention facilities. Also, open drainage swales in The Woodlands demonstrated effectiveness in detaining runoff during large storms, and this finding contributed to the U.S. EPA swale design guidelines.

Limitations

Nevertheless, the research design could not address several confounding factors and presented some limitations. One of the limitations was the Thiessen polygon method used for estimating precipitation. The Thiessen method assumes uniform rainfall within delineated polygons. However, there were cases when flow values increased enormously while no precipitation records were shown. Because of the localized rainfall pattern in Texas, it is possible that a rain occurred within a watershed but was not captured by its nearest weather station. Due to the limitation of the Thiessen polygon method, there is inconsistency in the results of streamflow response analysis and precipitation-streamflow correlation analysis.

Another limitation was the difficulty of fully capturing the impervious area in the watershed. The sum area of building footprints, roads, sidewalks, and driveways provided an approximation of the impervious surface. In this regard, the available data meant to show the general trend of development. Some other components of impervious cover were obscured in the analysis (e.g., parking lot, tot lot playground, and various other pavement areas).

Finally, using watershed as a unit of analysis made it difficult to delineate watersheds that were ideal for the scope of study. On one hand, Watershed #1 includes a large portion of The Woodlands Town Center, a commercial area with large impervious areas. The Town Center shall undermine the effectiveness of the open drainage system demonstrated in the results. On the other hand, Watershed #1 contains less than one-third of the Village of Grogan's Mill, the only village that strictly used McHarg's open drainage design. In short, the effectiveness of the open drainage system was not fully illustrated due to limitations of the research design.

Summary

This chapter evaluates the effectiveness of open surface drainage design in The Woodlands town development. This study provides evidence that the open drainage system effectively mitigates floods while a conventional one does not. The open drainage system generates less runoff volume and increases the lag time to reach peak flow. Therefore, the open drainage system presents a viable alternative to the conventional drainage system in urban development, particularly in the Houston area, where annual hurricanes generate intense precipitation in short durations. Although clay soil will hinder stormwater infiltration, the open drainage swale provides greater storage than the curb-and-gutter drainage system. Moreover, the meandering shape of swales elongates the time for runoff to reach streams.

McHarg's open drainage design mimics the natural hydrologic cycle so that the impact of urban development on the watershed could be minimized. This innovation, however, did not come easily. Cultural preferences sometimes transcend the ecological benefits in the design decision-making process. Such has been the case in The Woodlands when the open drainage system was changed to the conventional drainage one because of its lack of popularity among homeowners (Kutchin, 1998; Galatas & Barlow, 2004). The well-protected pine forest may give homeowners and visitors an impression that this town is developed in harmony with nature, but the less visible ecological values that open drainage could bring are often beyond what the general public could comprehend. It takes time for the general public to value and appreciate the ecological design innovations.

This study also suggests that large detention facilities, such as The Woodlands Lake and the Bear Branch Reservoir, present an effective stormwater management strategy. In addition, using a combination of several BMPs (e.g., open drainage system and The Woodlands Lake) is a better strategy.

Also, the location of the open drainage channels and the detention facilities present important planning and design considerations. McHarg placed the open drainage channels where high permeable soils were available for stormwater infiltration. The Woodlands Lake and the Bear Branch Reservoir were also strategically located to collect runoff from different drainage zones.

15 Safety perception

Background

McHarg's ecological planning approach can provide multifaceted benefits, however, it was discredited for the risk perception when people use the community park spaces (The Woodlands Resident Study). The low perception of safety can partly be attributed to the planning and design approach used in community development. One important aspect that distinguished McHarg's approach from the conventional development approach is that it intended to preserve the original vegetation after development (see Chapter 7). This included the preservation of multilayered woodland vegetation, consisting of more than 50 woody plants (dominantly loblolly pine, *Pinus taeda*) and more than 150 semiwoody, herbaceous vines found on site (WMRT, 1973a, 1973b). The multilayered vegetation was maintained on streets, in community parks, and in individual parcels. As a result, residential development was integrated with the pine forest and commercial development was hidden behind the tree mask (Kutchin, 1998; Forsyth, 2003).

Most residents love trees. But the wild-looking shrubbery understory was viewed by some residents as unpleasant (Kutchin, 1998; Galatas & Barlow, 2004). Further, commercial developers were concerned about the low visibility of developments when viewed from outside. For these reasons, The Woodlands deviated from McHarg's ecological planning approach after development of the first two subdivision villages.[1] Later-built villages shifted back to the conventional preference of manicured landscapes (Girling & Helphand, 1994, Galatas & Barlow, 2004).

Residents' lack of appreciation of the ecological planning approach was further evidenced by the results of multiple years' survey studies conducted in The Woodlands.[2] Starting in 1999, The Woodlands commissioned Creative Consumer Research, a survey company in Stafford, Texas, to conduct a number of survey studies. One important component of these surveys was to determine residents' perceived safety level in community parks and in the neighborhood. Several studies showed that residents in the later-built villages generally feel safer than do residents in the early-built ones (The Woodlands Resident Study). In 1999, 2002, and 2004, the reported safety levels in community parks were significantly different between residents in two villages ($p < 0.05$). These two villages are Grogan's Mill, an early-built village that followed McHarg's ecological planning approach (Figures 15.1 and 15.2), and Alden Bridge, a later-built village that used the conventional planning approach (Figure 15.3). Grogan's Mill received the lowest score on safety perception, whereas Alden Bridge received the highest.

McHarg's ecological planning approach placed a high priority on maintaining the natural pine forest in order to preserve the natural aesthetics, retaining the groundwater table and water quality. During the past few decades, social and economic considerations have been playing a more important role in shaping the community plan. The balance between environmental, social, and economic considerations necessitates more discussions among community planners and managers. This chapter focuses on landscape design of community parks and its impacts on residents' safety perception.

Figure 15.1 A typical neighborhood street view in Grogan's Mill (opened in 1974). Most neighborhood streets have parallel trails that are connected to community parks. Multilayered woodland vegetation was maintained after development. Housing and other developments are hidden by the tree mask. There are few opportunities for penetrating views and there is a lack of natural sunlight along the trails.

(Photograph by Bo Yang).

Figure 15.2 A typical neighborhood park in Grogan's Mill (opened in 1974). Original canopy trees and understory vegetation are maintained, along with sinuous biking and hiking trails. Playground facilities are partly hidden inside the vegetation.

Source: Woodlands commentary special: large parks in The Woodlands. http://woodlandscommentaryspecialsite.blogspot.com/2010/08/major-parks-in-woodlands.html (Image courtesy: Randy Scott. The Woodlands, Texas).

Figure 15.3 A typical neighborhood park in Alden Bridge (opened in 1994). The park contains relatively monotone tree species, little understory vegetation, well-equipped playground facilities, ample sunlight, and good visibility.

(Photograph by Bo Yang).

Literature review

There is a growing body of literature suggesting the social, physical, and psychological benefits that nature can bring to humans (Ulrich, 1984; Kaplan, 1993; Hartig, Evans, Jamner, Davis, & Gärling, 2003; Daniels, 2009; Wells, Evans, & Yang, 2010). Spaces such as community parks and urban greeneries can provide restorative opportunities from stress (Chiesura, 2004; Berto, 2005), add scenic quality to the community (Kaplan, 1993), and enhance residents' satisfaction with nature (Kaplan, 2001; Kaplan & Austin, 2004). According to the Attention Restoration Theory (Kaplan & Kaplan, 1989; Stephen, 1995), people tend to develop attention fatigue when they focus on tasks they have to accomplish. Natural environments such as community parks can provide "soft" natural beauty that generates opportunities for cognitive restoration and recovery from mental fatigue (Herzog, Black, Fountaine, & Knotts, 1997; Hartig et al., 2003).

However, not all community parks are equal in the provision of restoration opportunities. Also, these park spaces may be appreciated in a number of different ways, if they follow different planning approaches. Major planning approaches currently under discussion are ecological and conventional approaches. The former uses ecology as the basis for planning and design and places a high priority on environmental stewardship (McHarg & Steiner, 1998; Ndubisi, 2002). The latter largely adheres to the dominant culture preference of manicured landscapes (e.g., mowed grass) (Nassauer, 1995).

Renowned examples of the ecological planning approach used at a large-scale in community development are found in Birchwood (part of Warrington New Town) in the United Kingdom (U.K.) (Jorgensen, Hitchmough, & Dunnett, 2007) and The Woodlands in the U.S. (McHarg & Steiner, 1998). The 740-ha Birchwood was constructed in the 1970s and 1980s. It used an "ecological woodland" approach that preserved the multilayered original woodland vegetation. Environmental planning goals were articulated at the beginning – this approach meant to contain the natural green infrastructure, preserve the mixed plant communities, and respect the natural processes. The "ecological woodland" approach ceased to be used at this scale in the U.K. in the 1970s (Jorgensen et al., 2007). Following that, this approach drew criticism because of residents' perceived safety risks and insecurity in the community (Thompson, 2000).

Birchwood has its U.S. counterpart in The Woodlands, Texas. As in Birchwood, McHarg's planning approach placed a similar emphasis on protecting the original ecological structure and natural aesthetics (McHarg & Sutton, 1975; WMRT, 1973a, 1973b, 1973c, 1974). Interestingly, The Woodlands residents reported the same safety concern when interacting with the natural woodland landscapes, especially when they use community parks and open greeneries (The Woodlands Resident Study).

Studies have been done on preferred park landscapes. These include penetrating views and scattered and pruned tree groupings without understory

(Kaplan & Kaplan, 1989), and these preferences are in accord with the common practice in the conventional development. In contrast, the ecological planning approach advocates preserving the original vegetation, which often includes dense, wild-looking trees and shrubbery understory. This appearance, however, generally receives low acceptance among the public (Hands & Brown, 2002; Jorgensen, Hitchmough, & Calvert, 2002). Other studies that involved natural woodland landscapes suggested that these wild-looking spaces can provide users with contemplation, solitude, and restoration experiences. However, these same experiences may invite feelings of being unsafe and of insecurity, especially with unkempt shrubbery understory (Kuo, Bacaicoa, & Sullivan, 1998; Kaplan & Kaplan, 1989; Jorgensen et al., 2007).

Generally speaking, the wild-looking landscapes are considered to have high ecological values and can add mystery and a scenic quality to open space environments (Schroeder & Anderson, 1984; Burgess, Harrison, & Limb, 1988; Herzog & Bryce, 2007; Mc Morran, Price, & Warren, 2008). In respect to their restorative effect and public preference, mixed findings were reported. For example, Jorgensen and colleagues showed that the multilayered woodland edge is the least preferred landscaping type to be introduced in a park setting (Jorgensen et al., 2002). Then, Herzog and colleagues suggested that the dense woodland with shrubbery understory provides less restorative potential compared with open natural environments (Herzog, Maguire, & Nebel, 2003). Contrary to these findings, Burgess and colleagues found that local people value multilayered woodland vegetation more than the conventional park setting of isolated trees and mowed lawn (Burgess et al., 1988). However, the commonly accepted norm tends to indicate that wild-looking urban nature setting is untidy and unsafe (Schroeder & Anderson, 1984; Hands & Brown, 2002; Jorgensen et al., 2002).

Safety concerns arise because the dense vegetation appears to be a hiding place for potential attackers and there is a fear of physical and/or sexual assault in this kind of environment (Burgess, 1995; Michael, Hull, & Zahm, 2001). When attacked, the victims may expect little help due to the physical isolation. The greater the amount of vegetation concealment, the more entrapment an individual feels and the higher the risk that is perceived (Michael et al., 2001; Hands & Brown, 2002). For some park users, these fears are overwhelming and prohibit them from visiting. Thus, some parks are rendered underutilized and the benefits they could bring to residents are jeopardized (Burgess, 1995; Burgess et al., 1988; MacNaghten & Urry, 2000; Herzog et al., 2003; Thompson et al., 2004).

Some other studies on multilayered woodland landscapes indicated that the lack of public acceptance is not because of people's inherent dislike of this type of natural landscape. It is because this woodland landscape blocks the long-distance view and does not offer visual penetration into community parks (Jorgensen, 2004). Such has been the case in Birchwood and The Woodlands. Although the "ecological woodland" approach is appreciated by residents with respect to its design intent, the visual concealment poses an adverse impact on residents' perception of safety in park environments.

The spatial arrangement of vegetation also influences visual penetration and plays a role in defining people's safety perception. Schroeder and Anderson (1984) examined people's preferred scenes in respect to the degree of "clumpiness" of tree groups. Results indicated that a preferred situation is where tree canopy coverage is large and trees are separated rather than grouped tightly. In other words, people prefer loosely spaced trees in large masses to tightly spaced trees in small groups. In short, an ideal park landscape situation that provides restorative effect and safe feeling is similar to a savannah, characterized by long lines of sight and scattered tree groupings with limited or cleared understory, with regular maintenance so the area remains free of litter and graffiti (Kaplan & Kaplan, 1989; Schroeder & Anderson, 1984; Schroeder & Orland, 1994).

Finally, other studies have been conducted to link the safety feeling that people experience in their home with the proximity of their home to a park. These studies explored preferred locations to plan park spaces. It is obvious that residents value living close to nature (Coles & Bussey, 2000; Ryan, 2006) but they do not want the wild-looking landscapes to be integrated with their dwellings and they prefer to have orderly, well-kept landscapes nearby (Tartaglia-Kershaw, 1980; Nassauer, 1995; Jorgensen, 2004). Living too close to park spaces may invite too much distraction due to park activities and noise. Conversely, living too far away may prevent residents from being in an area where outdoor activity has little surveillance, keeping them from feeling comfortable. Since most residents visit community parks on foot (Schroeder, 1990; Harrison, Burgess, Dawe, & Millward, 1995), an ideal proximity from home to a park has been identified as 100–400 meters or about a 6- to 8-minute walk (Coles & Bussey, 2000).

Previous studies have identified planning and design variables (e.g., park location and vegetation configuration) that could influence people's perception of safety when using park spaces. Few studies have assessed community parks that are planned according to different planning approaches. Using quantitative methods, this chapter compares park design in two subdivision villages in The Woodlands and cross-validates the results with a series of surveys on residents' safety perception in community parks.

Overall safety perception in early- and later-built villages

Residents' safety perception in the Resident Study was used as a surrogate for public acceptance of McHarg's (WMRT) design. Because social barriers to McHarg's design largely came from residents' lack of appreciation of the naturalistic (or unkempt) appearance of landscapes (Kutchin, 1998; Galatas & Barlow, 2004), presumably the unkempt vegetation was the main reason for anxiety or fear of crime (e.g., low safety perception). Although safety perception is a very limited indicator of well-being, this longitudinal survey dataset would allow a valuable assessment of how residents' appreciation of landscape design changed over time, particularly given the fact that The Woodlands deemphasized its design focus of vegetation preservation in the later phases.

The Woodlands resident survey data were obtained from The Woodlands Resident Study. These surveys consistently show a dichotomy between the early-built and later-built villages in respect to residents' safety level perception (www.thewoodlandstownship-tx.gov). All the eight subdivision villages were divided into two groups to reflect the two different design approaches (McHarg's vs. conventional). For each group and for each survey study year, the average score of the safety perception level was calculated with Equation (15.1):

$$Score_{composite} = \frac{\sum Score_i \cdot N_i}{\sum N} \tag{15.1}$$

where $Score_{composite}$ represents the composite score of the safety level for the two subdivision village groups; $Score_i$ represents the score of the safety level in village i; and N represents the number of interviewees in village i.

For each Woodlands survey study, an average score is calculated for residents' perceived safety level in three community space categories. The results were further grouped into two subsets for comparison (the early- and later-built subdivision villages). The average scores are presented in Table 15.1. Across the three community space categories, residents express higher levels

Table 15.1 Summary of residents' perception of safety on a 1–5 scale in The Woodlands (1 = Not safe, 5 = Very safe) from the past six resident studies.

Year	*Planning method*	*In community parks*	*In neighborhood during day*	*In neighborhood at night*
1999	Ecological	4.04	4.51	3.99
	Conventional	4.28	4.71	4.23
2002	Ecological	4.03	4.53	4.03
	Conventional	4.22	4.66	4.23
2004	Ecological	3.98	4.52	4.09
	Conventional	4.22	4.67	4.29
2005	Ecological	4.14	4.58	4.21
	Conventional	4.22	4.66	4.22
2008	Ecological	4.12	4.58	4.15
	Conventional	4.16	4.57	4.17
2010	Ecological	3.82	4.38	3.85
	Conventional	4.03	4.41	3.89

Notes: (1) For McHarg's ecological design approach, four subdivision villages that fully or partially used his approach were involved in this calculation, including Grogan's Mill, Panther Creek, Cochran's Crossing, and Indian Springs. For the conventional approach, the other four subdivision villages were used for calculation, including Alden Bridge, College Park, Sterling Ridge, and Creekside Park.

(2) Conventional approach scored consistently higher than McHarg's approach. The only exception is in 2008, under In neighborhood during day, McHarg's approach scored slightly higher.

(3) Year 2000 was excluded from this analysis because it used a different rating system and made it difficult to compare with other years' scores.

of safety perception in later-built villages. In contrast, in the early-built villages, residents express safety concerns.

Comparative study of sample sites

Below section provides a detailed comparative analysis of residents' perception of safety in two subdivision villages: Grogan's Mill and Alden Bridge. Across the three community green space categories, the safety levels in Grogan's Mill are significantly lower than those in Alden Bridge ($p < 0.05$).

Study sites

There are 118 parks in The Woodlands. They encompass various functions and serve diverse recreational needs, including social gatherings, sports activities, picnics and parties, wildlife observation, and other general park functions, such as hiking, biking, and contemplation. According to the early ecological planning concept, these community parks belong to a hierarchical open space system that was integrated with community developments, including floodplains of three creeks on site, forest preserve areas, community parks and golf courses, stormwater impoundment sites, and small open space areas on individual lots. This is a multipurpose network for the maintenance of natural drainage, vegetation, and wildlife at all scales of development (WMRT, 1973b).

Original planning guidelines also mandated the preservation of the original pine forest and prohibited clearcutting during construction (WMRT, 1973b). To ensure the minimum clearance of vegetation, a landscape clearance index that specified preservation guidelines was used to preserve vegetation under different soil conditions (see Chapter 7). The objective was to maintain the original runoff recharge capacity of each individual parcel after development (WMRT, 1973b, p. 39). For example, a parcel to be developed was originally covered with pine forest with low recharge soils (e.g., silt loam soils). According to the Index, this parcel could be cleared maximum at 50%. Species with high ecological values were given priorities for preservation. Some advanced technologies at that time were used including analyzing infrared images to identify tree species (WMRT, 1973b).

The Woodlands ownership was changed in 1997 and the new owners did not abide by the original deed restrictions on landscape preservation (Girling & Helphand, 1994). In later-built villages, the revised Landscape Restrictions (Section 10:02) only requires the maintenance of trees that have a diameter of 15 cm or more (measured from a point 60 cm above ground level). More details are specified in the Residential Development Standards, Section 2.7 D on Front Yard Landscaping, stating

> Forty (40) percent of the Front Yard (excluding the portion covered by driveway and walkways) must be trees, shrubbery, flowers, mulch or

> plants other than turf or grass. No trees, shrubbery, plants or vegetation may be removed which would result in the grassed area exceeding 60 percent of the Front Yard.

As a result of this deviation from the original stringent ordinances, a typical image of the front yard landscaping found in later-built villages was a few native trees, trimmed lawns, and often some annuals (Girling & Helphand, 1994). A local landscape architect commented that in a nearby community Kingwood, there seemed to be more natural areas preserved than in the later-built villages in The Woodlands (Girling & Helphand, 1994).

Grogan's Mill was the first subdivision village, opened in 1974. It has an area of 1,748 ha with a population of 13,291. Alden Bridge was opened in 1994 with an area of 1,458 ha and a present population of 21,236 (The Woodlands Development Company, 2010). There are quite a few parks in Grogan's Mill (13) and Alden Bridge (26) that serve diverse functions. However, the planning and design of these parks vary according to different planning approaches. The early planning concept, used in Grogan's Mill, suggested placing parks and greeneries close to homes to create an intimate relationship between human and nature (WMRT, 1973b, 1974). The later planning concept, used in Alden Bridge, was less obvious in this regard, other than meeting with the general community development ordinances.

Analysis

Data

GIS parcel data were obtained from the Montgomery County Appraisal District. Parcel data provide approximate locations of the households, and 1-m resolution aerial photographs were collected from the U.S. Geological Survey (USGS) and Texas Natural Resource Information System (TNRIS) websites. Multiple site visits were conducted to verify the site conditions (vegetation, water body, etc.) in community parks as observed from aerial photographs. Last, resident survey studies were collected from The Woodlands Township (The Woodlands Resident Study).

Data treatment

All parks within the Alden Bridge and Grogan's Mill villages were selected. However, not all the parks contained clear boundaries that could be identified. Alden Bridge contains 26 parks, of which 20 were identifiable. Likewise, in Grogan's Mill, 11 of the 13 parks were identified and analyzed. Park boundaries were digitized using Photoshop image processing software (Clay & Marsh, 2001; Chen, Adimo, & Bao, 2009; Yang & Volkman, 2010). Landscape components in the parks were visually classified into three types: woody (tree), nonwoody (shrub and grass), and water. The digitized park images with landscape classification information were georeferenced in ArcGIS and overlaid with GIS parcel data.

Additionally, parks were classified into three categories based on area: small park (0–1.49 ha), medium-size park (1.5–3.0 ha), and large park (> 3.0 ha). There is a golf course in Grogan's Mill that was excluded in this analysis because the resident survey studies did not specify a separate category for golf course. Also, the golf course is usually accessible to golf players and its landscape design is different from that of community parks in Grogan's Mill.

Two sets of analyses were conducted on park landscapes. The first set of analysis evaluated the distribution of woody vegetation (clumpiness of tree groups) in community parks, using spatial metrics derived from landscape ecology. The second set of analysis examined home-to-park distance, using GIS buffer analysis. Results from these analyses were further compared with The Woodlands residents' studies to see whether the differences in park design correlated with the residents' safety perception.

Analysis #1 – landscape metrics

Three landscape ecology metrics calculated with FRAGSTATS 3.3 (McGarigal, Cushman, Neel, & Ene, 2002) were used: (1) Percentage of Landscape (PLAND), (2) Number of Patches (NP), and (3) Patch Density (PD). In this study, only the woody vegetation was of interest. Formulas and explanations of these metrics are presented in Table 15.2. Landscape components (woody, nonwoody, and water) delineated from previous steps were used to calculate these landscape metrics. PLAND and NP metrics were calculated for each park. The average values of PLAND, NP, and PD were calculated for the three park categories for each village.

Based on an ideal safe park situation of a savannah (Kaplan & Kaplan, 1989; Schroeder & Orland, 1994), woody vegetation "clumpiness" presents meaningful information about its influence on safety perception in community parks. PLAND shows the abundance of trees in parks. NP and PD further explain whether these trees are grouped together or dispersed.

Table 15.2 Landscape metrics used for evaluating landscape structure of woody vegetation (tree) in community parks.

Metric	*Formula*	*Measurement*
Percentage of Landscape (PLAND)	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	Percentage of woody vegetation (%)
Number of Patches (NP)	$NP = n_i$	Total number of woody patch (tree group)
Patch Density (PD)	$PD = \frac{n_i}{A}(10{,}000)(100)$	Number of woody patches divided by total landscape area (#/ha)

For example, if holding the park size constant, the higher the PLAND value, the greater is the tree coverage. Further, given the same PLAND value, the smaller the NP (number of tree groups), the smaller is the PD (density of tree group). Small PD value means trees tend to be clumped in large patches rather than being dispersed in small patches. When trees are clumped, it is not a preferred situation in terms of safety perception.

Analysis #2 – home-to-park proximity

Park boundaries delineated in the previous step were used for buffer analysis. Buffers were created based on park boundaries. A series of buffer zones with a 100-m increment were generated and a maximum of an 800-m buffer distance covered all the households in each village. The 100- to 400-m distance range is of particular interest as it is suggested by Coles and Bussey (2000) as the preferred home-to-park proximity. Based on GIS parcel data, the centroid of each parcel was used as a surrogate for the location of the residence. These centroids were overlaid with the buffer zones so that the number and percentage of households falling into each buffer zone were identified.

Results

Resident survey study

Results of the residents' survey studies on safety perception are presented in Table 15.3. Overall, residents in Grogan's Mill rated their safety levels lower than those of residents in Alden Bridge across the three categories in four resident studies used in this chapter. Especially in 1999, 2002, and 2004, the safety level for Grogan's Mill was rated significantly lower than Alden Bridge.

Landscape metrics

The PLAND, NP, and PD landscape metrics examined the extent to which woody vegetation is clumped or segregated. In addition, these metrics partly reflect the distribution of understory vegetation in Grogan's Mill since site visits showed the mass abundance of understory in community parks and along pathways (see Figures 15.1 and 15.2).

Results of the landscape metrics are presented in Tables 15.4 and 15.5 for Grogan's Mill and Alden Bridge, respectively. Alden Bridge has more parks (20) than Grogan's Mill (11). Of the 20 parks in Alden Bridge, 15 are small parks and many of them are "tot lots," or children's playgrounds. This difference could be attributed to the fact that Alden Bridge has more residents and more children than Grogan's Mill (21,236 vs. 13,291 residents; 6,482 vs. 2,285 children). Tot lot parks contain mainly open lawn and playground facilities, with a few canopy trees and little understory (see Figure 15.3).

Table 15.3 Excerpts from The Woodlands Resident Study on residents' perception of safety in community parks and in the neighborhood. 1 = Do not feel safe at all; 5 = Feel very safe.

		In community parks	*In neighborhood during day*	*In neighborhood at night*
1999	Grogan's Mill (n = 125)	4.03*	4.45*	3.93*
	Alden Bridge (n = 100)	4.28	4.71	4.23
2000	Grogan's Mill (n = 126)	67%	90%	73%
	Alden Bridge (n = 125)	73%	94%	86%
2002	Grogan's Mill (n = 129)	3.93*	4.59	3.92
	Alden Bridge (n = 153)	4.25	4.70	4.26
2004	Grogan's Mill (n = 128)	3.89*	4.06*	4.51*
	Alden Bridge (n = 157)	4.20	4.36	4.73
2005	Grogan's Mill (n = 143)	4.01	4.52	4.11
	Alden Bridge (n = 182)	4.16	4.65	4.24
2008	Grogan's Mill (n = 170)	4.07	4.62	4.17
	Alden Bridge (n = 214)	4.20	4.52	4.24
2010	Grogan's Mill (n = 149)	3.85	4.47	3.94
	Alden Bridge (n = 158)	4.03	4.45	3.92

* Safety levels in Grogan's Mill are significantly lower than Alden Bridge ($p < 0.05$)
Note: In 2000, safety level is reported differently from the other studies. Percentage shows the rated safety level of a "4" or "5."

(Source: The Woodlands Resident Study).

Table 15.4 Community parks in Grogan's Mill (11): park classification and landscape metrics of Percentage of Landscape (PLAND), and Number of Patches (NP) for woody vegetation (tree).

Category	*Park Name*	*Area (ha.)*	*PLAND (%)*	*NP*
Small Park (0–1.49 ha)	Sunset Springs	0.8	69	1
	Cokeberry Pond*	1.2	-	-
	Loggers Hollow	1	92	1
Medium Park (1.5–3.0 ha)	Grogan's Point	1.5	63	1
	Pastoral Pond*	1.5	-	-
	High Oaks	2	71	2
	Tamarac	2	79	1
	Mel Killian	2	100	1
	Maplewood	2	54	9
Large Park (>3.0 ha)	Sawmill	3.5	65	2
	Woodlands Sports	7	15	10

* Cokeberry Pond and Pastoral Pond parks are mostly covered with water surface and do not contain woody canopy vegetation.

Those parks in Alden Bridge were designed consistent with the general preference of penetrating views and scattered tree groups.

The average values of these metrics are listed in Table 15.6. In the small and medium-size categories, it is evident that the PD values of Grogan's Mill are much smaller than those of Alden Bridge. Considering the fact

Table 15.5 Community parks in Alden Bridge (20) and landscape metrics of Percentage of Landscape (PLAND), and Number of Patches (NP) for woody vegetation (tree).

Category	*Park Name*	*Area (ha.)*	*PLAND (%)*	*NP*
Small Park (0–1.49 ha)	Alden Place	0.1	29	1
	Alden Trace	0.1	61	1
	Bethany Bend	0.1	100	2
	Bluff Creek	0.1	100	1
	Cottage Green	0.1	57	1
	Hollylaurel	0.1	82	1
	Maple Glade	0.1	62	1
	Pipers' Green	0.1	71	1
	Wynnoak	0.1	100	1
	Acacia	0.5	76	1
	Larkwood	0.5	77	1
	Pleasant Hill	0.5	25	1
	Spring Hill	0.3	100	1
	Cypress	0.5	55	2
	Sundance	0.5	84	3
Medium Park (1.5–3.0 ha)	Deepdale Pond	1.5	29	4
	Alden Bridge	2.8	73	4
Large Park (>3.0 ha)	Lakeside	4	79	2
	Alden Bridge Sports	4	49	2
	Windvale	4	50	6

Table 15.6 Comparison of landscape metrics of woody vegetation (tree) in community parks in Grogan's Mill and Alden Bridge. PLAND: Percentage of Landscape; NP: Number of Patches; PD: Patch Density.

	Category	*Park No.*	*Avg PLAND (%)*	*Avg NP*	*Avg PD (#/ha)*
Grogan' s Mill	Small Park	3	80	1.0	1.4
Alden Bridge		15	72	1.3	7.5
Grogan' s Mill	Medium Park	6	61	2.3	2.0
Alden Bridge		2	51	4.0	3.2
Grogan' s Mill	Large Park	2	40	6.0	3.6
Alden Bridge		3	60	3.3	1.7

that Grogan's Mill has higher percentages of tree coverage (PLAND), this shows that trees in Grogan's Mill are clumped together, while they tend to be scattered in Alden Bridge. High "clumpiness" means that parks in Grogan's Mill lack penetrating views, a result consistent with the resident survey studies that residents generally did not appreciate parks in Grogan's Mill.

In the large park category, the results are less informative because Grogan's Mill has only two parks and Alden Bridge has only three that fall into this category. Grogan's Mill houses The Woodlands Sports Park, the largest park (7 ha) in this study. Unlike the high percentage of tree coverage found in other parks in Grogan's Mill, this sports park has limited tree coverage (15%) due to the functional needs for a large open space to accommodate soccer and softball games and to provide viewing places. On the other hand, the other large park in Grogan's Mill, Sawmill Park, still contains a high percentage of woody vegetation (65%). Last, the three large parks in Alden Bridge (including a sports park) all contain high percentages of tree coverage.

Overall, the results show that Grogan's Mill parks contain more trees than Alden Bridge and trees are grouped tightly in masses. The abundant and clumped tree groups together with understory vegetation create enough concealment to prohibit penetrating views. Therefore, community parks in Grogan's Mill are less favored compared with those in Alden Bridge. In contrast, Alden Bridge features mostly small parks with transparency that allows vision through the opposite side. This design contributes to a safe feeling in the parks.

Home-to-park proximity

Results of the buffer analysis are presented in Table 15.7. Buffer analysis shows that Alden Bridge has a higher percentage of residents than Grogan's Mill who live in the 100- to 400-m buffer zones,[3] a suggested optimal home-to-park distance range (Coles & Bussey, 2000). Although home-to-park distance only partly contributes to residents' safety feeling in the neighborhood, this result is consistent with the residents' survey studies that revealed that residents in Alden Bridge generally feel safer in the neighborhood than in Grogan's Mill. In contrast, a high percentage of residents in Grogan's Mill live close to community parks (within 100 m). This is in accord with the original planning concept of integrating park spaces with residence (WMRT, 1973a). In Alden Bridge, this concept is not obvious according to this study. Given the fact that Grogan's Mill has only half the number of community parks as Alden Bridge, park accessibility was emphasized more in Grogan's Mill than in Alden Bridge.

Table 15.7 Household in different buffer zones to nearby community parks in Grogan's Mill and Alden Bridge villages (n = number of household).

	<100 m		*100–400 m*		*>400 m*	
	n	*%*	*n*	*%*	*n*	*%*
Grogan's Mill (n = 3,971)	1377	35%	1594	40%	1000	25%
Alden Bridge (n = 6,457)	781	12%	4307	67%	1369	21%

Discussion

This chapter compared woody vegetation structure in community parks and home-to-park proximity in two subdivision villages in The Woodlands. Results show that when following the ecological planning approach, community parks in Grogan's Mill present a higher percentage of woody vegetation with a more clumped spatial structure than in Alden Bridge, which followed the conventional planning approach. In addition, Grogan's Mill has a lower percentage of residents living in the preferred home-to-park distance range. These results are in accord with the residents' self-reported safety level in the past seven resident studies, as well as the overall comparison of safety levels between the early- and later-built villages (see Table 15.1). The results herein are also consistent with findings from previous studies on landscape structure and safety perception (Kaplan & Kaplan, 1989; Jorgensen et al., 2007).

McHarg's approach was developed in a response to the severe flood-prone site condition on the Texas coast. In respect to environmental planning, it is a successful experiment (Spirn, 1984; McHarg & Steiner, 1998; Forsyth, 2002), and The Woodlands received numerous awards for its great success (see Appendix 11). This study indicates that some intricate tradeoffs seem to be necessary between the initial focus on environmental issues and other considerations along the human dimension (e.g., safety perception), to allow more informed and balanced design guidelines.

It is not surprising that the wild-looking natural landscape was not appreciated by the residents. However, some scholars argue that the natural beauty and aesthetics that wild urban nature can provide are of vital importance to urban life (Nash, 1973; Schroeder & Anderson, 1984; Daniels, 2009). As the "father of landscape architecture," Frederick Law Olmsted suggested that natural parks and preserve are valuable sources in urban environments. They help resist "virtual exhaustion," "nervous irritation," and "constitutional depression" (Nash, 1973, p. 155). For example, Olmsted's Central Park in New York has become a valuable resort for the urbanites.

Although the ecological planning approach presents challenges to the cultural preference of manicured landscape, it is a solution that brings multifaceted environmental benefits and some social benefits, such as flood control, wildlife corridor preservation, forest ecosystem protection, and environmental education opportunities, and it is a low-maintenance solution. Further, there are possible design amendments that allow better visual penetration. For example, the understory vegetation could be cleared in trail heads, entrances to parks, and traffic hubs to allow more visibility. In addition, trees could be moderately trimmed to have high canopies and allow more sunlight so as to minimize the current gloomy situation. However, mass pruning of trees and understory is not recommended. After all, the tree mask along collectors and community streets is a hallmark of The Woodlands, and the residents of this new town are proud of this feature.

Park design should also consider park size to serve different populations and community needs. Alden Bridge features a number of small tot lot parks that target the large youth population. Grogan's Mill, on the other hand, planned mainly medium-size and large parks. In a sense, it is a good solution for urban nature exploration, as some studies have shown that park size should be at least 2 ha to absorb the influence from the urban environment (Harrison et al., 1995; Coles & Bussey, 2000). Designers need to consult with residents regarding design and change, taking into account residents' socioeconomic background, family size, and population profile. Large parks are imperative for ecological preserve, habitat protection, and nature exploration. Medium-size and small parks are also important to allow easy access for restoration opportunities and provide good surveillance. Other parks serving overlapping or separate functions such as wildlife corridors, wildlife watching, and environmental education need to be placed and designed to allow minimum site disturbance and to complement other park functions. In summary, the tradeoffs between ecological design and cultural landscape preference shall not only consider the issue of safety but also must take into account various functions and maximize recreational opportunities.

Limitations

Although this study shows consistency with the resident survey studies, there are a few limitations that could not be addressed and need further exploration. First, the two villages studied were built 20 years apart. The age difference may contribute to the reputation of the place, since the crime history in community parks is likely to be different. Built in the 1970s, Grogan's Mill was the first neighborhood. This translates into dated park equipment and infrastructure and older homes and architecture surrounding the parks. These variables could potentially contribute to residents' low safety perception. Alden Bridge was opened in 1994, and nearly the opposite is true. This village has better infrastructure and park equipment than Grogan's Mill. Because of this age difference, future studies need to analyze the historical crime incidents for these two villages to allow more informed comparison. However, the perceived safety levels derived from the survey studies still provide a good indication of people's willingness to visit a particular park.

Second, the analysis on home-to-park distance only partly assessed the safety perception of the category *In neighborhood during the day*. Some other factors may also contribute to residents' safety perception in the neighborhood. For example, in the 2008 survey study, Grogan's Mill was actually rated safer than Alden Bridge in this category (see Table 15.3). The survey also showed that the traffic condition in Grogan's Mill was better than in Alden Bridge. This was because some new villages near Alden Bridge were experiencing intense construction and as a result worsened the traffic conditions in Alden Bridge. Thus, traffic situation may become a more important factor than home-to-park distance when people expressed their safety concern.

Third, the aerial photographs did not allow assessment of the understory vegetation distribution and condition. However, the wild-looking shrubbery understory is an important factor that negatively impacts residents' safety perception. Site visits showed that the understory vegetation was largely maintained in Grogan's Mill and to a much lesser degree in Alden Bridge. Thus, the understory distribution was largely estimated based on the distribution of woody vegetation (see Figure 15.2 example). Due to the difficulty of data availability, this study was unable to quantify the location of understory for better analysis.

Finally, future studies also should consider other design variables that may influence residents' perception of security or preference. For example, some woodland species were found to be favored over another (e.g., broad-leaved versus conifer) (Coles & Bussey, 2000). Also, path design (e.g., linear versus curvilinear) may also influence the perception of "mystery" or insecurity. Last, other variables such as the shape of the park and connectivity to trails and pathways may also influence residents' feelings of safety.

Summary

Findings of this chapter are helpful for community open space planning in choosing park location and management of vegetation. There are many variables that certainly play a role in the effectiveness of a park's safety. This study confirms the commonly accepted norm of a safe park environment that includes large amounts of woody vegetation, regular maintenance, cleared understory, and being free of litter and graffiti. The ecological planning approach used in The Woodlands focuses on environmental stewardship. It can enhance its potential attractiveness by including other dimensions that are also important for park users. Park design needs to balance various considerations such as ecology, safety, and aesthetics. Sometimes those benefits are hard to accomplish simultaneously, but it is not always the case. It is within planners' and designers' ability to create safe and enjoyable park spaces by drawing upon successful experiences from different planning approaches.

Notes

1 Grogan's Mill and Panther Creek are the first two villages that were built according to McHarg's ecological planning approach (Girling & Helphand, 1994; Yang & Li, 2011).

2 Creative Consumer Research conducted telephone interviews with The Woodlands residents. Questions cover the entire spectrum of the community services (e.g., traffic, garbage collection, deed restrictions). This chapter used seven resident studies including 1999, 2000, 2002, 2004, 2005, 2008, and 2010. Certain requirements were established to select interviewees, including (1) participants currently reside in one of the villages in The Woodlands, (2) participants need to be head of household, (3) participants currently reside in a single family dwelling, (4) respondent/family/household members do not work in market research, advertising, or public relations, and (5) respondent/family/household members

has never served on The Woodlands Township Board or been employed by any of The Woodlands Township Associations. Number of interviewees of these studies are 575 (1999), 634 (2000), 727 (2002), 756 (2004), 941 (2005), 1,022 (2008), and 1,050 (2010) (The Woodlands Resident Study).

3 An alternative analysis was conducted that included the golf course in Grogan's Mill as a park. According to this analysis, the percentages of Grogan's Mill residents living in different buffer zones are 36% (< 100 m), 60% (100–400 m), and 4% (> 400 m). For the 100- to 400-m distance range, Grogan's Mill still presents a lower percentage than Alden Bridge (60% vs. 67%). This analysis shows that including the golf course as a park will not change the comparative results.

16 Major players and barriers

Introduction

Chapters 12–15 reviewed design changes in The Woodlands in the past four decades. This chapter extends the understanding of landscape performance to further review the implementation of each planning strategy. It examines the roles of different players (homeowner, developer, designer, and government) during the course of the development, and diagnoses the obstacles that jeopardized McHarg's approach. It also attends to the question why McHarg's approach has not been replicated at such a scale in the current community planning practice.

Design implementation

McHarg's (WMRT) plan was followed in the first subdivision village (Grogan's Mill) and part of the second village (Panther Creek) (Galatas & Barlow, 2004). Although setbacks from the original plan occurred in 1985, The Woodlands remained committed to environmental stewardship and sustainability (Girling & Helphand, 1994). The conventional underground drainage system replaced the natural drainage for carrying stormwater within the neighborhoods, while open drainage was retained in arterial and collector streets. Deed restrictions were less stringent on landscape clearance: only trees that are 6 inches in circumference are strictly protected from removal (The Woodlands Association, 2007).

In 1997, there was a further adjustment to the original plan when George Mitchell sold The Woodlands to Crescent Real Estate Equities and Morgan Stanley Real Estate Fund II (ownership 1997–2003). Development sped up afterward and McHarg's approach was replaced with the conventional approach, which was in particular evidenced in drainage and landscape designs (Figure 16.1) (Clay, 1998; Yang & Li, 2010). According to Roger Galatas, former president of The Woodlands Development Corporation, changes to the original plan were made because of the low market acceptance of the open drainage system and complaints about the commercial developments being masked by trees and largely invisible from the streets. These concerns led the corporation to shift the development emphasis from

Figure 16.1 Drainage and landscape design conditions in The Woodlands before and after ownership change in 1997.

(a1) Subdivisions before 1997: open surface drainage swale with trees preserved

(a2) Subdivisions after 1997: curb-and-gutter drainage with fewer trees replanted

(b1) Creeks before 1997: natural vegetation well preserved

(b2) Creeks after 1997: concrete channel to facilitate runoff

(c1) Ponds before 1997: natural bank with well-preserved vegetation

(c2) Ponds after 1997: manicured lawn with fewer trees replanted ecological stewardship to economic viability (Galatas & Barlow, 2004). The following sections review the design implementation of each land planning strategy described in Chapter 7.

Development location per soil permeability

According to Chapter 12, the principle of preserving permeable soils was not followed after 1985 and the deviation became more pronounced after 1997. Development in The Woodlands can be divided into three phases according to three critical time periods (1972–1984, 1985–1996, and 1997–2005) (see Figures 12.3 and 12.4, and Tables 12.1 and 12.2). During the period of 1972–1985 (Zone I), soils with high permeability (e.g., sandy soils) were given high priority of protection, a reflection of McHarg's concept. However, after 1985 when developing Zones II and III, this concept was not well followed. After 1997 in Zone III development, McHarg's concept was no longer reflected in the development. For instance, in Zone III during 1997–2005, even though the land area of A and B soils (3,981 acres) is only 55% of that of C and D soils (7,904 acre) in this zone, a higher percentage of A and B soils (28%) than C and D soils (23%) was developed. Similar developments that ignored soil permeability also occurred in Zones I and II during the 1997–2005 period. Obviously, McHarg's concept of preserving permeable soils was followed before 1997 but ceased to be adhered to after 1997.

Forest preserve before and after ownership change

As in the early 2000s, 25% of the natural forest was preserved from development, which was considered as a great success following the original McHarg (WMRT) plan (Galatas & Barlow, 2004; Gause, Garvin, & Kellenberg, 2002). This forest preserve included maintenance of 100-year floodplains of the three creeks on site, drainage easements, greenways, and more than 100 parks. From the 1970s to 1997 when Mitchell was leading the development, a total of 9,603 acres were developed (Haut, 2006). Under the new ownership of Crescent and Morgan Stanley, much accelerated development occurred (Table 16.1) (Haut, 2006). For example, within five years (1996–2001), an additional 3,556 acres were developed. By 2001, The Woodlands had converted a total of 4,084 acres of its original forest preserve land into residential, commercial, and various other types of development. In addition, during this same five-year period, The Woodlands gained a substantial amount of grassland, bare land, and developed open space (NOAA, 2000). According to Galatas and Barlow (2004), construction of The Woodlands would be completed probably ten years earlier than what Mitchell originally anticipated.

Shifting from open surface to curb-and-gutter drainage

The third strategy, open surface drainage, was also revised after development of the first two subdivision villages. Open surface drainage was

Table 16.1 Land use land cover change in The Woodlands from 1996 to 2001.

Class	*1996* (acre)	%	*2001* (acre)	%	*Percent change*
Developed	9,603	35.6	13,159	48.7	13.2
Developed open space	908	3.4	1214	4.5	1.1
Cultivated pasture	667	2.5	588	2.2	-0.3
Grassland	356	1.3	733	2.7	1.4
Forest	11,041	40.9	6,957	25.8	-15.1
Scrub/shrub	1,028	3.8	740	2.7	-1.1
Wetlands	5,836	21.6	5,642	20.9	-0.7
Bare land	95	0.4	400	1.5	1.1
Water	330	1.2	336	1.2	0.0

Source: NOAA coastal change analysis program, adapted from (Haut, 2006).

installed along residential streets in Grogan's Mill and part of Panther Creek villages. After that, conventional curb-and-gutter drainage was employed within neighborhoods in later villages. Open drainage was still maintained along major thoroughfares, collector streets, and from residential neighborhoods to major streams (Gause et al., 2002).

However, shifting from open surface drainage to conventional drainage led to more "flashy" streams in The Woodlands (see Figure 14.4). It is evident that the conventional drainage neighborhoods (later phases) generate much higher runoff volumes than do the open surface drainage neighborhoods (early phases), despite the fact that the extent of development in these neighborhoods is similar. Moreover, the open surface drainage neighborhoods (early phases) respond to rainfalls similar to their predevelopment forest conditions. By contrast, the conventional drainage neighborhoods (later phases) present strong precipitation-flow correlations. These correlations become stronger when rainfall intensity increases, suggesting a vulnerability to flooding (see Chapters 8 and 9).

Abandonment of ecological plan led to flooding

Deviations from McHarg's (WMRT) ecological plan have caused greater impacts on the forest environment. The Woodlands experienced flooding in 2000 (NOAA, 2000). During Hurricane Ike in 2008, western Woodlands, which was developed after 1997, was particularly hard-hit, whereas developments completed under McHarg's plans experienced much less damage (Madere, 2008). An initial assessment showed 400–450 homes and a large number of trees suffered substantial damage. Some streets and thoroughfares were flooded and became impassable. Seventeen parks were closed due to hurricane damage, while 15 of them were built after 1997 by the new developers. Grogan's Point, which was

Table 16.2 Significant storm events and flooded locations in The Woodlands and Houston metropolitan region.

Date	*Intensity*	*Flooded location*	*Source*
July 24–25, 1979 (Storm Claudette)	43 inch/24 hrs	Houston (50 km south of Woodlands)	Girling & Kellett, 2005
Sept 28, 1987	5 inch/24 hrs	Oak Ridge North (east to Woodlands); Timber Ridge (southwest to Woodlands)	NOAA, 1987
Oct 16–18, 1994 (Hurricane Rosa)	29 inch/36 hrs	Houston (50 km south of Woodlands)	USGS, 1994; Galatas & Barlow, 2004
April 2, 2000	2 in/6 hrs	Woodlands	NOAA, 2000
Sept 13, 2008 (Hurricane Ike)	4 in/6 hrs	Woodlands (especially western portion, developed by new owners)	Madere, 2008
April 28, 2009	N/A	Woodlands (two subdivision villages, developed by new owners)	K. Carrizal, personal communication, April 22, 2013

Note: The Woodlands experienced no flooding before 1997, whereas it did when McHarg's approach was not followed.

an extension of Phase I (Grogan's Mill) but was developed after 1997, was flooded (Madere, 2008). Similarly in 2009, Grogan's Point and Alden Bridge subdivisions, which were developed by the new developers, experienced flooding.

After open drainage was shifted back to curb-and-gutter drainage, residents began to complain about the flooded streets in heavy rainfalls. In contrast, in Grogan's Mill and Panther Creek subdivision villages, which used open drainage, residents seldom have such complaints (Galatas & Barlow, 2004; Haut, 2006). Table 16.2 compares The Woodlands performance during significant storm events, before and after its ownership change. It is evident that The Woodlands later-built villages became more vulnerable to flooding after the ownership change.

Barriers to follow ecological plan

Although it is almost 50 years since *Design with Nature* made its debut, McHarg's ecological planning approach has not been replicated at a scale such as that in The Woodlands (Steiner, 2008, 2011; Herrington, 2010; Yang & Li, 2016). The ownership change led to the implementation of a different planning approach. Nonetheless it was not the only reason for the deviation of McHarg's (WMRT) plan. Barriers came from each side of the development.

Homeowner (demand)

The main obstacle is homeowners' lack of appreciation of ecological planning innovations. Market studies showed that most homeowners preferred visually appealing conventional stormwater drainage design (e.g., curb-and-gutter street) and open surface drainage does not *look good* (Figure 16.2). The rustic appearance of natural vegetation and unkempt understory are contrary to average American's preference for a manicured lawn (Nassauer, 1995; Nassauer, Wang, & Dayrell, 2009; Yang, Li, Elder, & Wang, 2013). In Phase I development, a typical neighborhood with a lot of 50-feet wide, there were a 20-feet culvert with two head-walls and a 30-feet open surface drainage channel. This channel design posed a challenge to homeowners' preference of typical home landscaping (Kutchin, 1998).

The covenants in the deed restriction required that the understory remain intact. However, quite a few homeowners undermined the ecological concepts by cutting backyard trees and clearing shrubs to expand their manicured lawn areas (Galatas & Barlow, 2004; Forsyth, 2005). Maintenance problems also emerged. When homeowners disliked the open drainage channels they used them as trash dumpsters (Kutchin, 1998). To make things worse, stagnant water in these drainage channels bred mosquitoes in the hot and humid Texas weather (Morgan & King, 1987). Water detention in backyards also received objections. Homeowners complained about excessive runoff in backyards and children playing in mud after rainfalls (Kutchin, 1998; Galatas & Barlow, 2004).

Developer (supplier)

Developers' choices of development are largely influenced by homeowners' preferences. As expected, new developers revised the original plan to meet the market needs. McHarg placed an emphasis on environmental factors in addition to following municipal development ordinances. This required

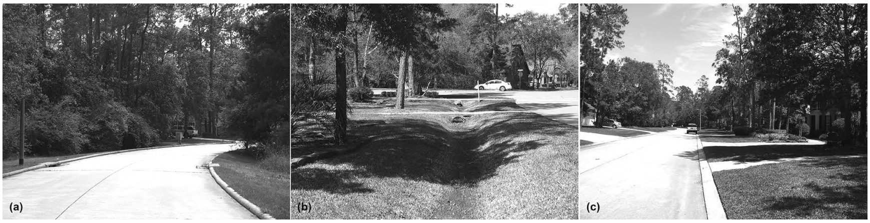

Figure 16.2 Different drainage solutions and landscaping types in The Woodlands, before and after 1997 ownership change.

(a) Unkempt understory (before 1997): homeowners disliked

(b) Rustic open surface drainage channel (before 1997): homeowners disliked

(c) Manicured lawn and curb-and-gutter street (after 1997): homeowners liked additional analysis than the normal "cookie-cutter" planning and design approach would require. Moreover, for new developers McHarg's approach did not indicate tangible profits in the short-term.

Because of the stringent covenants on landscape preservation, some tensions were created between The Woodlands Development Corporation and commercial developers (Galatas & Barlow, 2004). The accepted norm of commercial development is that commercial buildings are intended to be seen from the outside rather than hidden inside by trees and shrubs. For the same reason, the natural vegetation along the floodplains of the major streams was cleared and subjected to regular mowing to increase visibility (Haut, 2006) (see Figure 16.1). In the 1970s, natural preserve was a novel idea in the Houston market. The challenge was not to save trees, because most homeowners love trees. The challenge was that the land available for development thus decreased. As a result, the original land availability analysis was revised to increase land for development in order to increase profit (Kutchin, 1998; Galatas & Barlow, 2004).

Designer (professional service)

Some members in the early design team hesitated to adopt McHarg's innovations and they believed that the market-driven type of service remained the best type of service to provide (Galatas & Barlow, 2004). Moreover, the real estate and marketing professionals thought that McHarg's innovations were sometimes over demanding and unrealistic for the project to be profitable (Malone, 1985; Forsyth, 2005). An example would be the location of the commercial center of Grogan's Mill subdivision village. The center's location was determined largely by environmental suitability studies. It is often used as a critique for the ecological plan with respect to the plan's less successful role in commercial development (Kutchin, 1998).

The accuracy of environmental data (e.g., soil and vegetation) was another concern when preparing the environmental studies. For instance, site topography data at 80-m resolution were not considered as ideal (Kutchin, 1998). Another concern was the ranking of the ecological values of different tree species and, as a result, the design interpretations. Trees of high ecological value were meant to be preserved, but less variation of the tree species was found on site. The relatively arbitrary ranking of the species' ecological values led to constant dialogues regarding the various factors that determined the ranking. For example, if more mature trees are subject to dying, a hard choice needs to be made between mature and young trees (Galatas & Barlow, 2004; Kutchin, 1998; Malone, 1985).

In addition, some members from the early planning team maintained a different opinion from McHarg's (Kutchin, 1998; Galatas & Barlow, 2004). Some of them thought that McHarg's approach worked best at micro-level site design, rather than at macro-level community planning (Galatas & Barlow, 2004). Dissenters regarded McHarg's approach to be helpful when allocating streets and shopping areas at the site-level, whereas for community planning, an alternative approach would be to determine the location of a particular land use first, then to survey environmental information, and to propose designs accordingly. Some real estate professionals further contended that land use location should be determined by economic feasibility analysis instead of by environmental constraints (Galatas & Barlow, 2004; Forsyth, 2005).

For instance, Mitchell's senior in-house urban planner, Robert Heineman, thought that McHarg's approach exhibits some limitations. Heineman was hired by Robert Hartsfield in the summer of 1972 when Hartsfield was head of the planning department. Heineman received an architecture degree from Rice University and later a Master's degree in urban design from Harvard, and he has been involved in The Woodlands development since 1972 (Kutchin, 1998). Heineman noted that the majority of the soils, rather than those in the floodplains, had only moderate recharge capacities (2.5–5 cm). The soil conditions were not as varied as the proposed plan indicated (Galatas & Barlow, 2004).

Government (policy maker)

Barriers to the ecological plan also came from the government. In the typical American planning system, public departments are often too isolated to allow successful private sector innovations (Forsyth, 2005). Government offices generally prefer status quo conditions and the support for private sector innovations is not always available. A more sophisticated public-private partnership in the U.S. has yet to come, particularly in respect to the private sector initiatives (Siemiatycki, 2010). In the current planning system, if The Woodlands were initiated by another normal developer, it will never be as successful as it is today, at least in the environmental planning aspect (Galatas & Barlow, 2004).

In addition to McHarg's planning innovations, The Woodlands' success in environmental planning was also attributed to developer George Mitchell's vision, his sophisticated political network, and his tremendous financial commitment that supported the project (Malone, 1985). First, Mitchell's vision to initiate The Woodlands project was not purely for profits, but rather sought to experiment with a development model with an intent of solving some of America's urban problems (Kutchin, 1998; Malone, 1985). Mitchell did not make much profit from The Woodlands until the mid-1980s, some ten years after its inception (Kutchin, 1998).

Second, Mitchell managed to place The Woodlands in the extraterritorial jurisdiction of Houston in 1971. At that time, Houston logically would not annex The Woodlands because of its low tax base and indebtedness in the early stages of development. This allowed Mitchell to execute McHarg's ecological plan without many obstacles (Morgan & King, 1987).

Third, Mitchell's huge financial commitment made it possible for The Woodlands to muddle through the early stages (Galatas & Barlow, 2004). In the 1960s, Mitchell used his own money to assemble 23,000 acres of land. By 1974, his energy company had invested $28 million in infrastructure and improvement. Again, he provided tremendous financial support when The Woodlands was on the verge of financial disasters during the 1970s' international economic crisis and in the 1980s' Houston economic downturn (Galatas & Barlow, 2004; Kutchin, 1998).

Lacking Mitchell's vision and financial capacity, normal developers rarely could risk the huge upfront investment, let alone the continuous support in hard economic times. For instance, The Woodlands economic specialist Jim McAlister recalled that other members in the development team believed that Mitchell would never quit, even during the economic downturns. The team was encouraged by Mitchell and maintained perseverance to accomplish the project. Among the 13 projects that were funded by HUD, The Woodlands was the only project which has met its financial obligations. In contrast, most developers in the HUD bond gave up quickly when they did not see the light of profit (Kutchin, 1998; Forsyth, 2003).

Discussion

To reiterate, further implementation of McHarg's (WMRT) plan faces the challenge of reconciling the conflict between long-term environmental benefits and short-term economic gains. Despite the fact that McHarg's (WMRT) plan was of vital importance to protect the town in historical significant storm events, the cultural preference of landscape appearance transcended the long-term ecological benefits and led to a greater cost in later flood events. It is true that a wider application of design innovations takes time.

Developers hesitate to make major changes in the way they do business, because a single unpopular development may cause great financial loss. Bankers and others who provide loans to developers are often conservative with respect to innovations (Arendt, 2004; Arendt, Brabec, Dodson, Reid, & Yaro, 1994; Cunningham, 2002). Therefore in most cases, conventional developers tend to follow the framework with which they have had previous success in receiving municipal approval and selling the housing products, for example. When choosing between conventional and more creative approaches to community plat layout and landscape design, developers tend to pick the former because this choice is unlikely a misjudgment of the market. In addition, the current economic system focuses on short-term economic return and tends to jeopardize the long-term environmental benefits (Simon, 1983a, 1983b). This was the case when environmental degradation in the 1960s and 1970s became severe enough that a series of environmental acts came into play (Daniels & Daniels, 2003; Hack, Birch, Sedway, & Silver, 2009).

McHarg's idea of incorporating design with nature set the premise for the planning professionals. His planning innovations, especially in stormwater management, present a precursor of the U.S. EPA's low-impact development (LID) strategy (Coffman 2000; U.S. EPA, 2000). McHarg used soil infiltration capacity as a key variable to guide land use planning in order to achieve the zero-runoff objective. This unique concept has proven to be successful (see Chapters 12 and 13). McHarg's open surface drainage design also demonstrated flood mitigation effectiveness in that runoff regimen retains its forest conditions after subdivision development (see Chapter 14).

Early woes regarding data accuracy ceased to be an issue given today's technology capacities. It was costly to acquire environmental information in the 1970s, whereas currently, high-resolution environmental data are readily accessible through various public agencies. With the aid of GIS, designers can conduct robust spatial analysis and facilitate informed design interpretations. It is also important to note that as a HUD new town project, The Woodlands meant to address urban sprawl problems, which are regional in nature. The project was not limited to solving site-scale design problems, as some members in the early design team have described.

One way to advocate for ecological planning is to provide the performance benefits and evidence of success. McHarg's open drainage design achieved tremendous initial construction savings (e.g., $14 million savings for Phase I). Implementation of his plans brought additional savings to the developer, because further benefits accrued when increased erosion, runoff, and flooding hazards were avoided. These adverse impacts are usually more pronounced if using the conventional planning method (McHarg, 1996). In fact, there are quite a few examples that used open surface drainage in community development. These projects not only showed success in function but also suggested economic viability and public acceptance. A well-known example is Bellevue, Washington. The city planned an open drainage system that was integrated with its open space system in 1994 (Girling & Helphand, 1997). This innovation saved the expensive costs of the conventional pipe drainage system. Like The Woodlands, Bellevue survived storms in excess of 100-year levels in 1984 and 1990 with little property damage (Girling & Kellett, 2005).

Another example that pioneered the open drainage system, but at a smaller scale, is Village Homes in Davis, California (Francis, 2002). In this 60-acre community development, the open drainage system saved nearly $200,000 compared with the conventional drainage system. These savings were substantial enough to pay for most landscape improvement costs (e.g., walkways, gardens, and other landscape amenities) (Corbett & Corbett, 2000). Several residential and commercial developments in Davis have mimicked this drainage design (Francis, 2002). The drainage systems helped protect natural vegetation and habitat because the existing riparian corridors were an important component of the open drainage systems.

Summary

This chapter reviews the evolution of McHarg's ecological planning approach used in The Woodlands. Early success in environmental planning indicates that McHarg's approach met the original planning goal of preserving the forest environment and his approach caused less impact than a conventional approach would have done. The Woodlands ceased to implement parts, if not all, of McHarg's (WMRT) plan, especially after its ownership change in 1997. Barriers came from each side of the development: homeowner (demand), developer (provider), designer (professional service), and government (policy maker). Although the early ecological planning vision was not entirely pursued, "anyone who has ever been involved in a long-term, large-scale planning project can attest to the challenges of sustaining idealism and vision" (Steiner, 2011, p. 81). The Woodlands' environmental planning success in early development was also attributed to developer George Mitchell's personal commitment and financial support, the U.S. Housing and Urban Development's $50 million loan, and the relatively flexible planning system in the 1970s. However, in the current planning and economic systems, it would be a hard undertaking to replicate McHarg's ecological planning approach at this scale.

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Part V

Ecological wisdom and urban resilience

17 McHarg's ecological wisdom

Introduction

McHarg's pioneering efforts in performance assessment is inherent in his unique design process, often known as the McHarg method. Recent literature attributes his ability to do real and permanent good as a manifestation of his ecological wisdom (Gibson, 2016; Steiner, 2016; Xiang, 2014a, 2016, 2017; Yang & Li, 2016). McHarg constantly linked his theory to practice through his extensive involvement in projects. And he substantially refined and expanded his concepts and methods in ecological planning (McHarg & Steiner, 1998; Ndubisi, 2014). This chapter provides briefs on recent development in ecological wisdom and puts McHarg's ecological wisdom in context.

Ecological wisdom

"Wisdom" is defined as "the quality of having experience, knowledge, and good judgment" (Oxford Dictionary of English). As a subset of wisdom, ecological wisdom is a term that enjoys less recognition in the literature. However, it manifests itself widely in terminologies such as nature-inspired design, "green" policy and design, biomimicry, sustainable design and planning, biophilic design, and others (e.g., Beatley, 2000; Benyus, 2002; McDonough & Braungart, 2002; Yeang, 1995). Ecological wisdom is regaining broader recognition, and being proposed for use in socio-ecosystem planning and management for achieving urban resilience and sustainability (Patten & Xiang, 2015).

Resilience refers to the ability of a system to maintain its functions while undergoing disturbance (Holling, 1973; Meerow, Newell, & Stults, 2016). Ecological wisdom enhances city designers' and managers' ability to make the right ethical and political choices in doing (or not doing) certain projects, especially large-scale public projects, for the city's long-term benefits. Ecological wisdom is acquired by incorporating social and ecological knowledge with site-specific history and practical knowledge in developing strategies, tenets, and action plans. Thus, the building of urban resilience can be inspired and guided by ecological wisdom.

There is no unified definition of "ecological wisdom." Norwegian philosopher Arne Naess first put forth the concept of "ecological wisdom" based on his ecocentric personal philosophies, *ecosophies*, combining the root words from ancient Greek *ecos* (household place) and *sophia* (wisdom) (Drengson & Devall, 2010; Naess, Drengson, & Devall, 2010). In his book, *On Ecological Wisdom*, Mr. She specified the definition that "Ecological wisdom is the wisdom for living and survival that is rooted in and developed through the process of human adaptation to the environment" (She, 1996, p. 2). In Xiang's series entries on ecological wisdom, he contended that "Ecological wisdom should include both *ecosophy* and *ecophronesis*, that is, both theoretical and practical wisdom." And "Ecological wisdom research should therefore include practice research, which is different but related to scientific (basic) research and applied research" (Xiang, 2014a, 2014b, 2016, 2017). Last, Yang and colleagues (Yang et al., 2018) provided a working definition of ecological wisdom in the inaugural book of the EcoWISE (Ecological wisdom inspired science and engineering) book series (www.springer.com/series/15217) (Yang & Young, 2018) that:

> Ecological wisdom is a wise person or society's ethic, knowledge, ability, and grit to do the right thing (or not do certain things), in socio-ecosystem planning, design, and management, as manifested in time-honored projects, efficacious policy instruments, and is informed by lessons learned.
>
> (Yang et al., 2018)

In the era of Anthropocene, urban sustainability faces stiff challenges with the coupled effects of human and biophysical changes. Central to ecological wisdom is the understanding of the human and nature relationship. One of the fundamental, ethical questions confronted by design professionals, as well as by those advocating a wise society in general, is to grapple with the relation of human and nature. Sciences and technologies, often considered as the solutions, are developing into increasingly compartmentalized sub-disciplines that lack the holism necessary for tackling sustainability challenges. A deep ecological crisis cannot be alleviated simply through the accumulation and application of scientific knowledge. To effectively tackle a global ecological crisis, we need ecological wisdom (Lu, 2014; She, 1996; Xiang, 2014b, 2016).

Ecological wisdom also encompasses traditional ecological wisdom (TEK) (Wang, Jiang, & Jiao, 2018), presents new thinking (Steiner, 2018), bestow new meanings to aesthetics (Bishop & Xiang, 2018; Cheng, 2018), and builds resilience into community planning and urban design (Liao, Le, & Van, 2016; Wang, Palazzo, & Carper, 2016; Gibson, 2016). Ian McHarg's ecological wisdom is a role model for both *ecosophy* and *ecophronesis* (Xiang, 2014a, 2017). The following section elaborates on the development of his ecological wisdom.

McHarg's ecological wisdom development in context

Wisdom is one's ability to make ethical and good political choices. Wisdom is considered as a personality trait, which is related to knowledge, whereas the acquisition of knowledge does not guarantee the acquisition of wisdom (Gugerell & Riffert, 2011). The same is true for the acquisition of ecological wisdom. In more than 90 projects, as elaborated in *Design with Nature* (e.g., Chapter 10, "Processes as Values"), McHarg seeks the intrinsic carrying capacity of land through a design process that respects, integrates, and facilitates multiple ecosystem processes, functions, and services. Indeed, McHarg's ecological wisdom of following nature's lead in design, does not emerge in vacuum. His education at Harvard University, teaching at the University of Pennsylvania, and 18 years of practice at Wallace McHarg Roberts and Todd (WMRT) culminated in the peak phase of his legendary career.

McHarg pursued joint degrees in landscape architecture and city planning at Harvard in the 1940s. At that time, there was continual separation between the two programs. Most landscape architecture faculty remained focused on small-scale garden and park design, whereas city planning faculty were interested in broad social and environmental issues. McHarg's passion and training in both programs allowed him to embrace diverse planning and design scales when developing his own ecological planning theory and practice, something that most landscape architects at that time were not able to do (McHarg, 1996; Spirn, 2000).

McHarg continued to bridge the separation through his teaching at the University of Pennsylvania. He integrated regional planning and landscape architecture, particularly through his incorporation of environmentalism into studio teaching to achieve a more holistic pedagogical approach (Spirn, 2000). Emphasis was placed on understanding the natural processes. In McHarg's first studio project (Cape Hatteras) in 1956, for instance, students examined the processes of beach formation and erosion, the development of plant communities and animal habitats, and the interactions among them (McHarg, 1996; Spirn, 2000). A number of other case studies were examined in *Design with Nature*, including the Delaware River Basin Study, Interstate 95 in New Jersey, Staten Island Project, and Plan for the Valleys. The case studies demonstrated the imperative of interdisciplinary collaboration, in order to incorporate natural processes (biophysical attributes) and social and cultural issues in the design process (McHarg, 1996; Toth, R., personal communication, July 20, 2014).

Furthermore, McHarg used his department chair position at Penn to hire many natural scientists and social scientists, as well as leading designers on the faculty, to promote interdisciplinary collaboration in design studios, such as Laurie Olin, Robert Hanna, Sir Peter Faulkner Shepheard, Carol Franklin, A. E. Bye, Karl Linn, and others. In 1962, McHarg hired a forester and resource economist, Dr. Nicholas Muhlenberg. Since then, "the biome, the physiographical region, and the river basin provide an indispensable context for the curriculum at Penn" (Spirn, 2000, p. 104).

McHarg taught another noteworthy course, Man and Environment, throughout the 1960s and 1970s, and some of the most distinguished scholars in the environmental era were invited to lecture (McHarg, 2006a), such as Lewis Mumford, who wrote the Introduction to *Design with Nature*, and Eugene Pleasants Odum and Howard Thomas Odum, who heavily influenced McHarg's knowledge of ecosystem ecology. In 1963, eight of the lecturers were Nobel Prize winners (Spirn, 2000). Based on this course, McHarg hosted a CBS television series (The House We Live In) from 1960 through 1961, and invited leading scientists of the time (e.g., Margaret Mead, Loren Eiseley, and Luna Bergere Leopold). The course and the CBS television series facilitated the development of McHarg's theoretical framework and scientific ideas for his book *Design with Nature* and his wisdom in ecological planning and design (McHarg, 1996; Spirn, 2000).

After the CBS television series, McHarg began to gain national recognitions outside the landscape architecture field. Particularly after 1962, McHarg played an increasingly important role in developing the intellectual base and methodological framework for the National Environmental Policy Act (NEPA) (McHarg & Steiner, 1998). McHarg's interdisciplinary approach to ecological planning and his systematic evaluation of the plan formed a standard practice in NEPA, and this is particularly reflected in the Environmental Impact Statement (EIS) (Bass, Herson, & Bogdan, 2001).

In addition to being a successful practitioner, McHarg was a theorist. He developed his own theory of "creative fitting," which explained and validated his nature-led design approach (Herrington, 2010; McHarg, 1996). The inspirations were attributed to the scientific theories of Charles Darwin's The Origin of Species (Darwin, 1859), which suggests that "the surviving organism is fit for the environment" (McHarg, 2007, p. 23), and Lawrence Henderson's The Fitness of the Environment (Henderson, 1913), which indicates that "the actual environment, the actual world, constitutes the fittest possible abode for life . . . this fitting then is essential to survival" (McHarg, 2007, pp. 23–24). In addition to Darwin, Henderson, and the Odums, McHarg's ecological ideas were also influenced by Patrick Geddes, Loren Eiseley, Robert MacArthur, John Phillips, and Jack McCormick, among others.

In accord with his theory of "creative fitting," McHarg provided his definition of ecological design:

> Ecological design follows planning and introduces the subject of form. There should be an intrinsically suitable location, processes with appropriate materials, and forms. Design requires an informed designer with a visual imagination, as well as graphic and creative skills. It selects for creative fitting revealed in intrinsic and expressive form.
>
> (McHarg, 2006b, p. 123)

McHarg's interdisciplinary practice

In 1962, McHarg began to test his ecological planning methods on real clients and projects. Subsequently, his studio at Penn became a place in which to experiment with theories, and McHarg's firm, WMRT, provided a means to test the theories. The types of clients and projects with which McHarg (WMRT) worked were influenced by several federal acts enacted during the environmental era (Table 17.1). The evaluation and mitigation of environmental consequences due to suburban and exurban growth constituted the majority of McHarg's professional work in the 1960s and 1970s (Spirn, 2000; Steiner, 2011). By 1969, Penn's Department of Landscape Architecture and WMRT enjoyed worldwide reputations as a leading landscape architecture program and firm, respectively (McHarg, 1996; Spirn, 2000).

Other lasting contributions that McHarg made are his definition of nature as a process that "is subject to the forces that produce and control the phenomena of the biophysical world" and his statement that places are "only comprehensible in terms of physical and biological evolution" (Herrington, 2010; McHarg, 1969, p. 105). Following this definition of nature, McHarg stated that design process should fit in the natural processes and that, "We have asked Nature to tell Man what it is, in the way of opportunities and of constraints for all prospective land-uses" (McHarg, 2007, p. 44). Because most of McHarg's projects are located in suburban and exurban areas that are low-density and less populous, understanding the natural processes (biophysical attributes) becomes the key to project success.

As a result, nature as a value system and the ecological and natural sciences (the field of ecology in particular) provided the theoretical core for McHarg's ecological planning and design method. His design process is operationalized by the landscape-suitability assessment framework ("layer-cake" model for mapping). The design process starts with a comprehensive ecological inventory, in which natural processes are integrated into planning and design. Ecological factors are superimposed onto the land to determine

Table 17.1 Ian McHarg's (WMRT's) primary project types during 1960s–1970s.

Period	*Primary project type*	*Federal act*
1960s	Rural areas in metropolitan regions impacted by federal highways	Interstate Highway Act 1956
Late 1960s – early 1970s	Planned new communities and resorts (client: private developers)	New Communities Act 1968
Mid 1970s – 1979	Control and direct growth for environmental quality issues (client: public agencies)	National Environmental Policy Act 1969 Clean Water Act 1972

(Spirn, 2000; Steiner, 2011)

its capacity to support human activity and its suitability for a particular type of land use (McHarg & Steiner, 1998). This design process lays out a systematic analytical framework that is instrumental in identifying central design problems of the site, as illustrated in The Woodlands study.

Another important aspect of McHarg's career was that he had extensive involvement in actual planning and community design projects. These opportunities allowed him to constantly link theory to practice and to refine his ideas and methods (McHarg & Steiner, 1998; Schnadelbach, 2001; Steiner, 2004). McHarg's faculty position at Penn allowed him to structure his teaching and practice in a complementary way. During his 18 years with WMRT, the creative tension between theory (Penn teaching) and practice (WMRT) led to exciting innovations in ecological planning and design. A practicing landscape architect is often constrained by the prescribed project scope. In contrast, McHarg's faculty position allowed him to choose problems that he deemed important to examine (Spirn, 2000).

Why McHarg can do real and permanent good

McHarg's idea of incorporating nature into the design process set the premise for the planning and design professionals. His ability to do real and permanent good could be attributed to his knowledge and skill set in planning and design, his broad influence outside the landscape architecture and planning disciplines, and his faculty position at a prestigious academic institution.

McHarg presents core problem-solving skills in ecological design. He is proficient in multiple-scale synthetic thinking and his critical thinking skill-sets allow him to assemble the right colleagues to consult and work with (e.g., his interdisciplinary team approach). He is also capable of interpreting complex ecological data and (re)prioritizing design goals to recast simple(r) design problems.

In addition, McHarg "is among the very few landscape architects since Frederick Law Olmsted Sr. who have commanded widespread notice, respect, and influence outside the design and planning fields" (Spirn, 2000, p. 97). His 1969 book *Design with Nature* is considered as the most influential text in the planning and design discipline in the 20th century. The book was also selected as a finalist of the 1969 National Book Award. Besides his 1960–1961 CBS series ("The House We Live In"), he successfully co-organized the 1970 Earth Day event, in which more than 30,000 people participated (McHarg, 1996). McHarg also appeared frequently on television and in popular press. For instance, he helped produce and starred in the popular 1969 public television documentary "Multiply and Subdue the Earth" (Spirn, 2000).

Previous chapters have suggested that McHarg's ecological wisdom is actionable, defensible, and meaningful, as evidenced in The Woodlands' outstanding landscape performance which is in accord with the performance benchmarks that McHarg (WMRT) projected. McHarg's ecological wisdom of designing with and dwelling in nature allows the performance of real and permanent good for the built environment. It is also important to note that the "secret" of McHarg's ecological wisdom is anchored in his interdisciplinary training and practice, his love of Mother Nature, his creative blending of scientific theories with landscape planning and design, and his strong capacity to promulgate the idea of design-with-nature to the general public.

For The Woodlands project, the significance of the design solution needs to be understood in its historical and site contexts. Its holistic solution is likely a one-of-a-kind plan that tackled wicked problems specific to this particular site. Therefore, this solution may not be directly replicated in another project due to the inherent differences in the design problem(s). Although the plan for The Woodlands is context dependent, a well-articulated, comprehensive design process would lead to the expression and execution of McHarg's ecological wisdom.

Implications for ecological planning

Through revisiting one of McHarg's most successful projects, The Woodlands, it is evident that his ecological wisdom presents a knowledge/skill component, as well as a value system that embraces cultural, personal, and ethical characteristics. McHarg's comprehensive design process would make his ecological wisdom actionable and facilitate the establishment of landscape performance targets. Furthermore, his charismatic personality and superb capability to communicate in layman's language persuaded numerous individuals to accept his ideas (Spirn, 2000). Also, his theory and methodology pervaded the NEPA and then other federal and state environmental management programs (Bass et al., 2001).

In the 1970s, the Ford Foundation provided funds to support ecology at Princeton University, the University of Georgia, and the University of Pennsylvania. Unique aspects at Penn included the integrated, ecology-based new curriculum, and enrollment preference given to candidates with natural science backgrounds. In addition, "a natural scientist faculty was hired, including such luminaries as Ruth Patrick, a 1996 recipient of the National Medal of Science" (McHarg & Steiner, 2006, p. 116). In the following decades, Penn's program produced 15 deans, 38 chairmen and directors, 150 professors, founded 20 new programs worldwide emphasizing ecological planning and design, and helped 1500 graduate students in landscape architecture who employ ecological planning in many academic institutions and government agencies throughout the world (Margulis, Corner, & Hawthorne, 2007; McHarg & Steiner, 2006).

18 Urban resilience and contemporary relevance

Introduction

Resilience in the urban context stands for the ability that a city endures disturbance. For places that are most vulnerable to climate change impacts, building resilience into communities become increasing important (Collier et al., 2013; Michel-Kerjan, 2015; Spaans & Waterhout, 2017). Houston has been warned for years that it is a city built to flood. It is routinely hammered during extreme weather events. Unprecedented storms like the recent Hurricane Harvey (August 2017), overwhelmed the city's flood management system. Harvey is another wake-up call for Houston, while the city's flood-prone situation could be ameliorated through designing with nature. The Woodlands in this case offers a well-researched example of enhancing resilience through performance measures.

Performance in Harvey

McHarg's (WMRT) ecological plan for The Woodlands focused on stormwater management and flood control. The Woodlands performance in Harvey is, once again, a strong testament to the effectiveness of McHarg's approach. In late August 2017, Harvey made landfall in Houston, releasing a harrowing amount of more than 50 inches (1270 mm) of rainfall, which was equivalent to the city's total annual precipitation. Harvey led to at least 107 confirmed deaths. The total damage was estimated at $125 billion, a figure even higher than that caused by Hurricane Katrina in the City of New Orleans in 2005. Harris County Flood Control District officials reported with a deep concern that Harvey actually made the third "500-year" flood in three years in Houston (2015, 2016, and 2017, respectively) (Ingraham, 2017).

Being the fourth largest city in America, Houston is an epitome of urban sprawl while its urban density and impervious area per capita are greater than national averages. In addition to the city's low elevation and flat topography, introduction of impervious surface areas (e.g., road, building), loss of sponge landscapes (e.g., wetland, lake, forest), and construction of modern

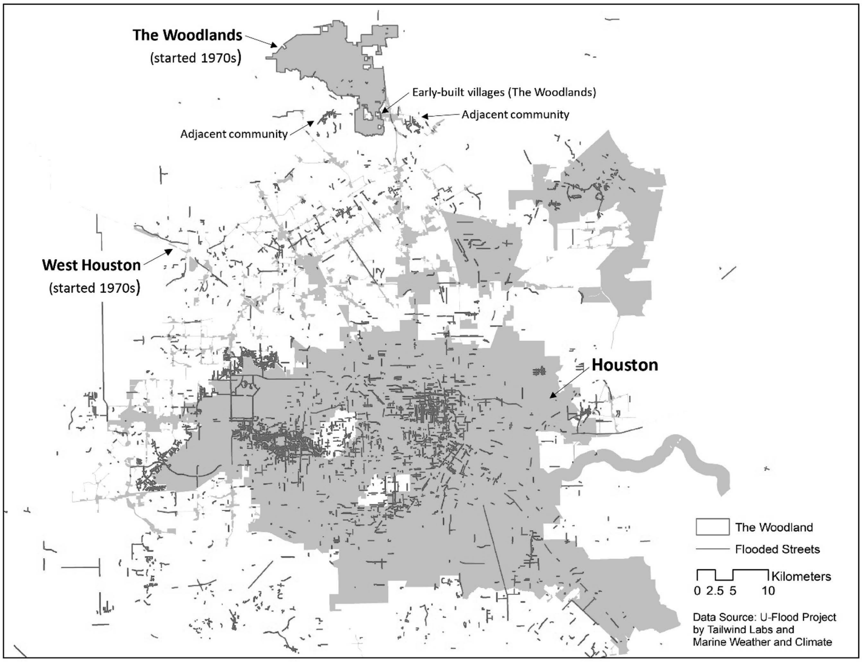

Figure 18.1 Flooded streets in Houston areas after Hurricane Harvey (August 2017).
Data source: U-Flood Project by Tailwind Labs and Marine Weather and Climate.

conveyance system (e.g., channel, underground pipe) alter the timing and velocity of stormwater runoff, resulting in catastrophic flooding events during Harvey (Bogost, 2017; Pigott, 2017).

Part of The Woodlands was affected by Harvey but at a much lesser degree. Figure 18.1 was developed based on the "real-time" dataset of the U-Flood Project, provided by the Galveston-based Tailwind Labs and Marine Weather and Climate (www.marineweatherandclimate.com/projects.html). This figure shows the flooded streets in Houston and the surrounding areas during Harvey. The results are fairly consistent with what was presented in previous chapters – there were very few flooded streets in The Woodlands, and almost none existed in the early-built villages that were more faithful to McHarg's (WMRT) plan. It is evident that The Woodlands demonstrated a greater level of resilience to flood than its adjacent communities and Houston.

Not surprisingly, The Woodlands, especially villages constructed in the first phases, sustained several significant regional storms (e.g., 1979, 1994 Hurricane Rosa, 2001 Tropical Storm Allison, 2008 Hurricane Ike, 2015 Memorial Day flood, 2016 Tax Day flood, 2016 Memorial Day flood, and

2017 Hurricane Harvey). The sharp contrast of flood resilience is a result of The Woodlands' comprehensive ecological plan, which Houston lacks.

Green infrastructure: inspiration from Staten Island and The Woodlands

Another renowned McHargarian project on the spotlight of the current resilience discussion is Staten Island in New York (www.rebuildbydesign.org/our-work/sandy-projects). Although never built according to McHarg's original proposal (Wagner, Merson, & Wentz, 2016), an ecological plan for Staten Island was thoroughly laid out in *Design with Nature* (pp. 103–115). Based on a systematic land suitability analysis, certain areas in the plan were prescribed as "unsuitable" for development. Nevertheless, development occupied these areas, including the scenic coastal swath facing the Atlantic.

In 2012, Superstorm Sandy hard-hit Staten Island, causing widespread flooding and damage. Subsequently, an analysis conducted by landscape architecture professor Neil Korostoff at Pennsylvania State University demonstrated remarkable similarities between areas identified for evacuation by the Federal Emergency Management Agency and places that were refrained from development in the original McHarg proposal (Steiner, Simmons, Gallagher, Ranganathan, & Robertson, 2013; Xiang, 2014a).

In fact, the City of New York has been seeking an alternative, ecology-based approach for flood control and community development (Feuer, 2014; Gumb, Garin, Mehrotra, & Henn, n.d.). The Staten Island Bluebelt Plan is one of these conspicuous programs (www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml). Similar to The Woodlands ecological plan, the Staten Island Bluebelt Plan integrated green infrastructure (e.g., wetlands, waterways, underground sand filters, and other sponge landscapes) for stormwater management, flood control, and water quality improvement. It is a watershed-level, coordinated effort which properly combined the green and gray stormwater infrastructure to enhance urban resilience. McHarg's proposal in *Design with Nature* was inspiring for the development of the Bluebelt Plan (Appleton, 2012; Eisenman, 2005; Gumb, Garin, Mehrotra, & Henn, 2008). Partial implementation of the Bluebelt Plan showed encouraging performance outcomes (Gumb, Rossi, Mehrotra, Deb, & Henn, n.d.)

Mitigating the short-term and long-term effects of climate change necessitates adaptive strategies in planning and design, especially in coastal areas. Given the fact that the changing climate can only make the vulnerable situation even worse, for a case in point, The Woodlands and Staten Island could encourage the City of Houston to consider using green stormwater infrastructure. Although the effects of climate change (or sea-level rise) were not a focus area in the Staten Island or The Woodlands original plan by McHarg, stories from both cases suggest that the ecological approach can enhance urban resilience (Berry & BenDor, 2015; Wagner et al., 2016). On the other hand, deviation from the ecological plan would lead to exorbitant costs.

The Houston region has more master-planned communities than any other metropolitan area in America. This accounts for 25–40% of new home sales. After Harvey, the City of Houston listed "stormwater infrastructure" as a top priority for investment. As a matter of fact, back in 2015, Houston experienced two catastrophic flooding events in May/June (Memorial Day Flood) and October/November (Halloween Flood). Since then, the City has been prioritizing funding to support flood-control infrastructure projects. In particular, the City planned to take this opportunity to invest in green infrastructure projects to "improve resiliency and provide other community benefits such as open space, recreation, water quality, and reduced maintenance" (City of Houston, 2016, p. 52). Perhaps the time has arrived to fuse green stormwater infrastructure with land development patterns in Houston.

Building resilience through performance goals

Design for change and uncertainty is another consideration in order to build resilience into communities. This is because natural environments are not stationary, nor should the design solutions be (Calkins, 2010). Over the past three decades, several overarching recommendations and/or requirements have been specified for designing and planning for uncertainty in urban landscapes (Ndubisi, 2016). A common thread is that more robust monitoring and assessment is needed for designed landscapes. "Specifically, attention should be given the how urban ecosystems can evolve in response to uncertainty, nonlinearity, and abrupt changes, and how resilient landscapes can fulfill their intended goals" (Ndubisi, 2016, p. 199).

The preceding statement is in accord with the fundamental question that landscape performance research intends to answer. With performance goals central to the ecological plan, The Woodlands demonstrated notable accomplishments in the aforementioned recommendations and/or requirements (Table 18.1).

The Woodlands development program over time

The Woodlands was always envisioned as a quintessential community where people can "live, work, play, and learn," and as a model for planned growth. "The Woodlands is not perfect, but [developer] George Mitchell's vision illustrates the practical reality of dreaming big" (Steiner, 2011, p. 85). Although according to an early projection that The Woodlands would be completed some ten years before Mitchell had envisioned, due to the accelerated pace of development (Galatas & Barlow, 2004), Robert Heineman, Vice President of Planning of The Woodlands Development, provided a more optimistic outlook with recent data, that "the current development plan is very consistent with the vision of The Woodlands during Mr. Mitchell's direction." (Heineman, 2014, p. 2). In almost all categories regarding

Table 18.1 Overarching recommendations and/or requirements for building resilience into communities/cities (Ndubisi, 2016), and The Woodlands' practice.

Recommendations and/or Requirements[a]	*The Woodlands' Practice*[b]
(1) Create a first-order organization of space and infrastructure in a landscape and allow the details to be filled in over time.	Green stormwater infrastructure served as the first-order organizing structure of space: maintained forest preserves along major roadways; kept greenbelts besides natural streams; preserved ¼ land as open space in perpetuity; used other green infrastructure strategies (e.g., wetland, riparian corridor, floodplain, drainage swale).
(2) Plan simultaneously for large-scale change and incremental opportunities while employing the "underlying structure" of the landscape (e.g., bedrock geology and hydrology) as the foundation for shaping urban form.	Established an interdisciplinary team for planning and design (e.g., geology, hydrology, limnology); identified linkages between ecological and hydrological processes (water as the agent); development form shaped by the "underlying structure" of landscape, and in turn, facilitated the natural processes.
(3) Target interventions to critical variable in an ecosystem that underpin the effective performance of urban landscapes (e.g., enhance the hydrological flow in flood-prone area using low-impact development strategies).	Critical environmental variable – soil permeability, was used to guide land use locations and densities; 100-year floodplains and forestlands were well preserved for ecosystem services (e.g., heat island mitigation); low-impact development strategies were implemented throughout.
(4) Develop governance structures that strive to handle cross-scale influences (e.g., issue-oriented coalition of governments and watershed management).	Created Drainage Task Force as a coordinated governance structure for watershed management and to resolve drainage issues; established funding and operation mechanisms for environmental monitoring and early warnings of flooding risks.[1]
(5) Adopt design and management processes that nurture reflective learning (e.g., collaborative group processes targeted toward learning).	Employed highly interdisciplinary design processes; management strategies for enhanced communication and feedback, which allow reflective learning opportunities – through traditional and social media, biannual resident surveys, and other platforms for information exchange and group processes that build stronger social ties and sense-of-place.[2]
(6) Establish tight feedback loops and monitor protocols for designed landscapes that connect design intentions seamlessly with ongoing management activities.	Established protocols for long-term environmental monitoring; ongoing assessment of design intentions and landscape performance; allowed for adjustable management regimens and corrective efforts; created efficient feedback loops for management and social programs. [3]

(7) Design and monitor urban landscape using a performance-oriented approach (e.g., establishing performance objectives, as a basis for evaluating project outcomes).	Performance objectives were articulated in the original ecological plan (e.g., zero-runoff objective for sub basins; see Table 7.3 for the list of objectives); performance evaluations have been conducted over the years (see Appendix 12. The Woodlands Literature 1973–2017, for empirical studies).
(8) Design and plan for the larger context of cities, since cities involve highly dependent, interconnected systems whose resilience depends on those of the larger context landscapes, as in regional plans.	Landscape analyses conducted to understand development impacts on the physiographic region (e.g., aquifers underneath Houston), and to enhance regional resilience; provided ample employment opportunities locally, together with multi-modal transportation planning efforts to lower commute trips to Houston.

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[a] adapted from (Ndubisi, 2016).

[b] adapted from (WMRT, 1973a, 1973b, 1973c, 1974; Kutchin, 1998; Galatas & Barlow, 2004; Heineman, 2014; The Woodlands Township, 2018).

Notes:

[1] The Woodlands Township Board initiated the Drainage Task Force in 2016. The task force includes representatives from The Woodlands Joint Powers Agency, The Woodlands Municipal Utility Districts, the San Jacinto River Authority, the Harris County Flood Control District, and the Federal Emergency Management Administration. In addition to the three U.S. Geological Survey (USGS) gauge stations functioning since the 1970s, The Woodlands has an agreement with the USGS to install an additional two gauge stations to monitor flooding risks. Installation and maintenance cost and responsibilities are shared by The Woodlands Township, San Jacinto River Authority (SJRA), USGS, The Woodlands Joint Powers Agency, and Harris County Flood Control District. These environmental monitoring efforts will provide better data for creek levels and streamflow conditions of the community (The Woodlands Township, 2018).

[2] The Woodlands Township continues to expand the venues and platforms to communicate with residents, businesses, as well as visitors. These include not only traditional media such as The Woodlands Community Magazine, but also social media such as Facebook, Twitter, departmental blogs and Instagram. In 2017, a new Facebook page was opened especially for the Parks and Recreation Department. Furthermore, Facebook live videos have been used as a means of communication during several events, such as for Hurricane Harvey updates and recovery (The Woodlands Township, 2018). The Township also conducts biannual surveys of The Woodlands residents to seek feedback on all aspects of community services and residents' satisfaction levels (see Chapter 15). Ten surveys have been conducted since 1999. According to the most recent survey conducted in 2016, residents indicated a high level of satisfaction, and that 90% of the respondents considered the services to be "good" or "very good" value for the money (The Woodlands Township, 2018).

[3] "Established the legal means to develop and enforce development goals through the Covenants, Development Standards, Development Criteria established for each parcel prior to sale, restrictions related to land use, density, and other factors contained in recorded deeds, and by monitoring and enforcing the Standards through the various design review committees" (Heineman, 2014, p. 2).

Table 18.2 Comparisons of 1997 and 2014 projections for select categories of community development in The Woodlands, Texas.

	2014	*1997*
Population	130,800	150,000
Employees	74,045	82,000
Non-residential buildings square footage (MSF)	39.5	41

(Heineman, 2014, p. 2)

community development, the 2014 projections were actually less than Mitchell's projections, prior to the ownership change in 1997. Table 18.2 shows data for a few categories of the development (Heineman, 2014).

Contemporary relevance and prospects

In The Woodlands town development, McHarg's approach was implemented from regional-scale planning to site-scale design. Its development provides an example that bridged the gap between theories of ecology and subdivision planning practices. The ecological wisdom demonstrated through McHarg's design process has immense relevance to urban resilience. Table 18.3 presents three widely discussed McHargarian projects and their implications to contemporary practice (McHarg & Steiner, 1998; Spirn, 2000; Yang, Li, & Li, 2013). Plans for the Valleys and the Potomac River Basin study were conducted in Penn design studios, and The Woodlands plan by WMRT staff (mostly the Penn team). Many innovations by McHarg (WMRT) that were once seen as radical are now common practice. The most noteworthy one is McHarg's landscape-suitability assessment framework ("layer-cake" model) that spearheaded the development of the modern-era Geographic Information System (GIS) (Ndubisi, 2002, 2014). In fact, the computerized soil and vegetation surveys used in The Woodlands represented one of the first actual applications of GIS technology to a built project (McHarg & Steiner, 1998).

Likewise, the "natural" drainage channels in The Woodlands witness their contemporary applications, such as the rain gardens and stormwater planters commonly seen in the green streets in Portland, Seattle, Philadelphia, Kansas City, and other cities. An ongoing master-planned community development adjacent to The Woodlands, Springwoods Village (728 ha), followed several of the WMRT planning/design strategies (e.g., open drainage and forest preservation) (Jost, 2012).[1] The U.S. EPA's low-impact development and green infrastructure design initiatives further promote McHarg's design-with-nature ecological wisdom (Yang, Li, & Huang, 2015).

The Woodlands design team included Narendra Juneja, Jonathan Sutton, Mokun Lokhande, Anne Whiston Spirn, Colin Franklin, Leslie Sauer, and James Veltman. Anne Whiston Spirn went on to have a distinguished

Table 18.3 Selected significant projects of Ian McHarg (WMRT) and their implications to contemporary practice.

Project	*Central theme/major design question*	*WMRT design innovation*	*Impact on contemporary theory or practice*
Plan for the Valleys (1962)	Illustrate consequences of uncontrolled versus planned growth, and potential economic profitability	Integrate graphic presentation and economic analysis; visualize impacts of different built scenarios	Today's land trusts, purchase, and transfer of development rights, performance zoning
Potomac River Basin (1965)	Provide a framework for development (past, present, and future, at multiple landscape scales)	First study to combine the physiographic region and the river basin as the organizing context for ecological planning and design; used most of the methods (overlay and metrics) at the time	Institutionalizes a comprehensive method for ecological inventory; advances GIS method
The Woodlands (1973)	Plan at a flood-prone site coupled with difficult drainage conditions; maintain aquifer levels to prevent Houston high-rise buildings from sinking	A holistic solution of natural drainage system integrating stormwater drainage, flood control, and water quality; link soil permeability to development intensity	One of the first applications of GIS to a built project; precursor of U.S. EPA's LID and GI initiatives; today's "green-street" programs nationwide[1]

[1] U.S. EPA (U.S. Environmental Protection Agency); LID (low-impact development); GI (green infrastructure)

academic career and is currently a professor of landscape architecture and planning at MIT. Members from the WMRT team also founded two prominent professional firms. Colin Franklin and Leslie Sauer founded Andropogon Associates in 1974, and Robert Hanna and Laurie Olin founded Hanna/Olin in 1976 (now OLIN) (Spirn, 1985). Currently, both firms enjoy international reputations and have influential practices. Andropogon, in particular, uses "designing with nature" as the firm's credo, whose many projects feature creative stormwater management techniques (Yang, Li, & Huang, 2015).

Last, although McHarg applied his design process and analytic framework primarily in suburban and exurban settings (see Table 17.1), the process and framework can be extended to urban settings. McHarg's followers inherit his ecological wisdom and further contribute to urban/metropolitan sustainability (Bunster-Ossa, 2014; Hough, 1995; Spirn, 1984). Other scholars build on McHarg's environmental focus and strengthen social, economic, aesthetics, and public health dimensions of sustainability, while advancing theoretical frameworks and actionable agendas, such as Lyle's regenerative design (Lyle, 1999), Nassauer's "cues to care" (Nassauer, 1995; Nassauer, Wang, & Dayrell, 2009), Johnson and Hill's and Steiner's frameworks for ecology and design (Johnson & Hill, 2002; Steiner, 2008, 2011), Ndubisi' sustainable regionalism (Ndubisi, 2008), Musacchio's six *E*s for landscape sustainability (Musacchio, 2009), Pliny Fisk's biophilic design (Kellert, Heerwagen, & Mador, 2011), and the Lady Bird Johnson Wildflower Center's Sustainable Sites Initiative (SITES) (Calkins, 2012; Steiner et al., 2013). In summer 2019, the Department of Landscape Architecture at the University of Pennsylvania will be officially launching The Ian L. McHarg Center (https://mcharg.upenn.edu/), "a nexus of research, teaching, and advocacy for improving the relationship between cities and their landscapes, and processes of urbanization and ecosystems," in the 50th anniversary of the publication of *Design with Nature* (McHarg, 1969). Practitioners continue to apply McHarg's ecological wisdom to actionable agendas in order to tackle many sustainability issues around the world.

Note

1 Land planning and urban design, Design Workshop; architecture, Gensler; engineering, Walter P Moore.

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Appendix 1

Landscape Architecture Foundation (LAF) Case Study Investigation (CSI) research fellows 2011–2018

2018 fellows

- Catherine De Almeida, University of Nebraska
- Lisa DuRussel, RLA, LEED AP, Pennsylvania State University
- Jon Calabria, Alfred Vick, and Brian Orland, University of Georgia
- George Bradley Guy, Assoc AIA, LEED AP BD+C, SEED, Catholic
- Pavlina Ilieva, AIA, Morgan State University

2017 fellows

- Richard Plunz, Columbia University
- Hong Wu, PhD, Pennsylvania State University
- Simon Kilbane and Andrew Toland, University of Technology Sydney
- Taner Ozdil, PhD, ASLA, University of Texas at Arlington
- Shan Jiang, PhD, West Virginia University

2016 fellows

- Charlene LeBleu, FASLA, AICP, Auburn University
- Howard Hahn, RLA, ASLA, Kansas State University
- Nicholas Pevzner, University of Pennsylvania
- Kelly Shannon, PhD, University of Southern California
- Jane Wolff and Elise Shelley, University of Toronto

2015 fellows

- Andrew Fox, PLA, ASLA, North Carolina State University
- Matthew James, Ed.D., South Dakota State University
- M. Elen Deming, PhD, University of Illinois at Urbana-Champaign
- Christopher Sass, PhD, ASLA, University of Kentucky
- Jean Trottier, CSLA, CIP, University of Manitoba
- Allan Shearer, PhD, ASLA, University of Texas at Austin

2014 fellows

- Chris A. Martin, PhD, Arizona State University
- Michele Palmer, Cornell University
- Ebru Ozer, Florida International University
- Mary Pat Mattson, Illinois Institute of Technology
- Brad Collett, University of Tennessee
- Taner R. Ozdil, PhD, University of Texas at Arlington
- James P. Richards, University of Texas at Arlington
- Leena Cho, University of Virginia

2013 fellows

- Maria Bellalta, Boston Architectural College
- Aidan Acker, Boston Architectural College
- M. Elen Deming, PhD, University of Illinois at Urbana-Champaign
- Jinki Kim, PhD, University of Illinois at Urbana-Champaign
- G. Mathias Kondolf, PhD, University of California, Berkeley
- Mary Pat Mattson, Illinois Institute of Technology
- Taner R. Ozdil, PhD, University of Texas at Arlington
- Roxi Thoren, University of Oregon
- Bo Yang, PhD, Utah State University

2012 fellows

- Barry Lehrman, Cal Poly Pomona
- Molly Mehling, PhD, Chatham University
- Jessica Canfield, Kansas State University
- Claudia Goetz Phillips, PhD, Philadelphia University
- Mary Myers, PhD, Temple University
- Ming Han Li, PhD, Texas A&M University
- Bruce Dvorak, Texas A&M University
- Bo Yang, PhD, Utah State University
- Victoria Chanse, PhD, University of Maryland
- Chris Ellis, PhD, University of Maryland
- Byoung-Suk Kweon, PhD, University of Maryland
- Nancy Rottle, University of Washington

2011 fellows

- Jessica Canfield, Kansas State University
- Dennis Jerke, Texas A&M University
- Mary Myers, PhD, Temple University
- Bo Yang, PhD, Utah State University
- Chris Ellis, PhD, University of Michigan

- Byoung-Suk Kweon, PhD, University of Michigan
- Kristina Hill, PhD, University of Virginia
- Nancy Rottle, University of Washington
- Ken Yocom, PhD, University of Washington
- Alexander Robinson, University of Southern California

Appendix 2

Landscape Architecture Foundation education grant recipients and courses (2014–2017)

2017 grant recipients

- **Kelly Curl, Colorado State University**

  Designed Landscapes – Theory and Criticism (BLA Seminar)
- **Catherine De Almeida, University of Nebraska**

  Materiality in Landscape Architecture (BLA Seminar)
- **JeanMarie Hartman, Rutgers University**

  Advanced Plants (MLA Lecture and Lab/Studio)
- **Hope Hui Rising, Washington State University**

  Theory in Landscape Architecture (BLA Seminar)
- **Phillip Zawarus, University of Nevada, Las Vegas**

  Landscape Arch Design III (BLA Studio)

2016 grant recipients

- **Kenneth Brooks, FASLA, FCELA, PLA, Arizona State University**

  Design Research Methods (MLA/Interdisciplinary Research Methods)
- **Brad Collett, ASLA, RLA, LEED AP, University of Tennessee, Knoxville**

  Operative Landscapes (MLA Seminar)
- **Kirk Dimond, MLA, LEED AP, University of Arizona**

  Site Engineering (MLA Site Engineering)
- **Joseph Ragsdale, ASLA, FAAR, California Polytechnic State University, San Luis Obispo**

  Design Theory and Exploration Focus Studio (BLA Studio)

- **Rebekah VanWieren, MLA, MS, Montana State University**

  Advanced Landscape Design Studio: Landscape Design Scenarios for Water Conservation in the Middle Rockies (Landscape Design BS Studio)

2015 grant recipients

- **Kenneth Brooks, FASLA, FCELA, PLA, Arizona State University**

  Advanced Landscape Architecture Studio IV (MLA Studio) and *Special Topic: Design Performance* (MLA Seminar)

- **Ellen Burke, PLA, LEED AP, Cal Poly San Luis Obispo**

  Project Design and Implementation Focus Studio (BLA Studio)

- **Reid Coffman, PhD, Kent State University**

  Urban Ecological Systems (MLA, MArch, MUD Joint-seminar)

- **Yi Luo, PhD, Texas Tech University**

  Landscape Architecture Design Process (BLA Studio and Lecture)

- **Emily Vogler, Rhode Island School of Design**

  Site Analysis and Planning (MLA Seminar)

2014 grant recipients

- **Aidan Ackerman, Boston Architectural College**

  Ecological Analysis & Conceptual Frameworks (MLA Studio)

- **Gary Austin, PLA, University of Idaho**

  Water Conservation Technologies (BSLA Lecture)

- **Kenneth Brooks, FASLA, FCELA, PLA, Arizona State University**

  Advanced Landscape Architecture Studio IV (MLA Studio) and Special Topic: Design Performance (MLA Seminar)

- **Chuo Li, PhD, Mississippi State University**

  Landscape Architecture Graduate Studio II: Health (MLA Studio)

- **Mary Myers, PhD, FASLA, FCELA, Temple University**

  Seminar on Landscape Performance: Focus on Temple University Main Campus Landscape(MLA/BSLA Seminar)

Appendix 3

Accreditation standards for first-professional programs in landscape architecture

Landscape Architectural Accreditation Board
American Society of Landscape Architects 636 Eye Street, N.W. Washington, D.C.
20001–3736
March 2016

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Standard 3: professional curriculum

The first-professional degree curriculum shall include the core knowledge, skills, and applications of landscape architecture.

a ***In addition to the professional curriculum, a first-professional degree program at the bachelor's level shall provide an educational context enriched by other disciplines, including but not limited to liberal and fine arts, natural sciences, and social sciences, as well as opportunities for students to develop other areas of interest.***
b ***In addition to the professional curriculum, a first-professional degree at the master's level shall provide instruction in and application of research and scholarly methods.***
c ***A first-professional degree at the master's level that does not require all students to have an undergraduate degree before receiving the MLA shall meet the requirements for both a and b, above.***

INTENT: Each landscape architecture curriculum shall be designed to achieve the learning goals stated in the mission and specific educational objectives of the program. The curriculum shall encompass both coursework and other co-curricular opportunities intended to develop students' knowledge and skills in landscape architecture.

A **Curricular Expression of the Mission and Objectives.** The program's curriculum shall address and express its mission, goals, and objectives. (This criterion is directed not toward the evaluation of the mission and objectives, but rather toward the way the curriculum is developed and delivered in carrying out the expectations of the mission and objectives.)

Assessment: The program identifies the knowledge, skills, abilities, and values it expects students to possess at graduation.

B **Professional Curriculum.** The program curriculum shall be guided by, but not limited to, coverage of:

History, theory, philosophy, principles, and values

design history design theory criticism
sustainability, resiliency, stewardship health, safety, welfare

Design processes and methodology

critical thinking analysis ideation synthesis
site program
iterative design development design communication

Systems and processes – natural and cultural (related to design, planning, and management)

plants and ecosystems sciences built environment and infrastructure
human factors and social and community systems human health and well-being

Communication and documentation written communication oral communication

visual and graphic communication design and construction documents
numeracy, quantitative problem-solving, and communication community and client engagement

Implementation

construction technology and site engineering site materials
use and management of plants and vegetation policies and regulation

Computer applications and advanced technologies

visualization and modeling
communication (conceptual and construction drawings) geospatial analysis

Assessment and evaluation

site assessment
pre-design analysis landscape performance post-occupancy evaluation
visual and scenic assessment

Professional practice

values ethics practice
construction administration

Research and scholarly methods (for master's-level degree programs)

quantitative and qualitative methods establishing a research hypothesis framing research questions
literature/case study review/precedent review research integrity and protection of human subjects communication of research

Assessment 1: The curriculum addresses the designated subject matter in a sequence that supports the degree program's goals and objectives.
Assessment 2: Student work and other accomplishments demonstrate that the curriculum is providing students with the appropriate content to enter the profession.
Assessment 3: Curriculum and program opportunities enable students to pursue academic interests consistent with institutional requirements and entry into the profession.

C **Syllabi.** Appropriate syllabi shall be maintained for courses.

Assessment 1: Syllabi include educational objectives, course content, and the criteria and methods that will be used to evaluate student performance.

Assessment 2: Syllabi identify the various levels of accomplishment students need to achieve to successfully complete the course and advance in the curriculum.

D **Curriculum Evaluation.** At both the course and curriculum levels, the program shall evaluate how effectively the curriculum is helping students achieve the program's learning objectives in a timely way.

Assessment 1: The program demonstrates and documents ways of:

a. assessing students' achievement of course and program objectives within the length of time to graduation stated by the program;
b. reviewing and improving the effectiveness of instructional methods in curriculum delivery; and
c. maintaining currency with the evolving technologies, methodologies, theories, and values of the profession.

Assessment 2: Students participate in evaluation of the program, courses, and curriculum.

E **Augmentation of Formal Educational Experience.** The program shall provide opportunities for students to participate in co-curricular activities, internships, off-campus studies, research assistantships, or practicum experiences.

Assessment 1: The program provides opportunities for students to augment the formal educational experience and documents students' use of these opportunities.

Assessment 2: The program identifies the objectives of co-curricular activities and evaluates the effectiveness of these opportunities.

Assessment 3: Student participants are given the opportunity to report on their co-curricular experiences to their fellow students.

F **Coursework (Bachelor's Level).** In addition to the professional curriculum, students shall also pursue coursework in other disciplines in accordance with institutional and program requirements.

Assessment: Students take courses in the humanities, arts, technologies, mathematics, natural sciences, social sciences, and/or other disciplines.

G **Areas of Interest (Bachelor's Level).** The program shall provide opportunities for students to pursue special interests.

Assessment 1: The program provides opportunities for students to pursue independent projects, focused electives, optional studios, certificates, minors, and the like.

Assessment 2: Student work incorporates academic experiences reflecting a variety of pursuits beyond the basic curriculum.

H **Research/Scholarly Methods (Master's Level).** The program shall provide an introduction to research and scholarly methods.

Assessment 1: The curriculum provides instruction in research and scholarly methods and their relation to the profession of landscape architecture.

Assessment 2: The program requires that theses or terminal projects exhibit creative and independent thinking and contain a significant research/scholarly component.

Appendix 4

Select landscape performance research projects funded by the National Natural Science Foundation of China (NSFC) (by Province, 2017–2018)

- **Guangzhou**

  Lin, G.-S. (2017). *A study on metrics and methods of social benefits assessment of urban comprehensive parks in Pearl River Delta*. South China University of Technology, Guangzhou, China. Project funded by the National Natural Science Foundation of China.

- **Shanghai**

  Shen, J. (2018). *Study on assessment and evidence-based design method of high performance stormwater landscape*. Tongji University, Shanghai, China. Project funded by the National Natural Science Foundation of China.

  Tao, C. (2018). *Study on the landscape performance evaluation and optimization of community parks in large cities based on health objectives*. Shanghai Jiao Tong University, Shanghai, China. Project funded by the National Natural Science Foundation of China.

- **Wuhan**

  Dai, F. (2017). *Study on urban green infrastructure for reducing particulate air pollution through multi-scale simulation and field monitoring*. Huazhong University of Science & Technology, Wuhan, China. Project funded by the National Natural Science Foundation of China.

  Qiu, H.-F. (2018). *A research of the landscape performance and optimal regulation of urban lake parks based on the coordination of the lake system and the green system: Case study of Wuhan city*. Huazhong Agricultural University, Wuhan, China. Project funded by the National Natural Science Foundation of China.

  Yin, L.-H. (2017). *Spatial form of sponge unit under urban viaducts and its landscape performance*. Huazhong University of Science & Technology, Wuhan, China. Project funded by the National Natural Science Foundation of China.

Note: project listed under the Principal Investigator.

Appendix 5

Select literature on landscape performance

- ***Landscape Research Record*** **(CELA)**

Barth, D., & Carr, M. (2014). Using a Delphi Method to develop criteria for high performance public spaces that contribute to community sustainability. *Landscape Research Record*, *2*, 132–137. Retrieved from http://thecelaorg.ipage.com/wp-content/uploads/lrr-no-2.pdf

Canfield, J., & Yang, B. (2014). Reflections on developing landscape performance case studies. *Landscape Research Record*, *1*, 310–317. Retrieved from www.thecela.org/pdfs/Landscape_Research_Record_No.1.pdf

Li, M-H., Dvorak, B., Luo, Y., & Manskey, J. (2014). "Park Seventeen" residential roof garden: Landscape performance and lessons learned. *Landscape Research Record*, *2*, 148–156. Retrieved from http://thecelaorg.ipage.com/wp-content/uploads/lrr-no-2.pdf

Luo, Y., & Li, M-H. (2013). Do environmental, economic and social benefits always complement each other? A study of landscape performance. *Landscape Research Record*, *1*, *566–577*. Retrieved from www.thecela.org/pdfs/Landscape_Research_Record_No.1.pdf

Luo, Y., & Li, M-H. (2014). How does it change after one year? A comparison of the Landscape Architecture Foundation's published case studies in 2011 and 2012/2013. *Landscape Research Record*, *2*, 138–147. Retrieved from http://thecelaorg.ipage.com/wp-content/uploads/lrr-no-2.pdf

Ozdil, T., Modi, S., & Stewart, T. (2014). A "Texas three-step" landscape performance research: Learning from Buffalo Bayou Promenade, Klyde Warren Park, and UT Dallas Campus Plan. *Landscape Research Record*, *2*, 117–131. Retrieved from http://thecelaorg.ipage.com/wp-content/uploads/lrr-no-2.pdf

Xu, J., Wu, C-Z., & Ma, X-W. (2014). Landscape performance assessment of urban wetland park planning and design: Case study of Wuzhou Wetland Park in China. *Landscape Research Record*, *2*, 106–116. Retrieved from http://thecelaorg.ipage.com/wp-content/uploads/lrr-no-2.pdf

Yang, B., Zhang, Y., & Blackmore, P. (2014). Performance and economic benefits of four streetscape renovations: A comparative case study investigation. *Landscape Research Record*, *1*, 300–309. Retrieved from www.thecela.org/pdfs/Landscape_Research_Record_No.1.pdf

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Appendix 6

Benefits categories for landscape performance assessment (from Landscape Architecture Foundation)

Part 1 Environmental benefits (18)

Land

- Land efficiency/preservation
- Soil creation, preservation, and restoration
- Shoreline protection

Water

- Stormwater management
- Water conservation
- Water quality
- Flood protection
- Water body/groundwater recharge
- Other water

Habitat

- Habitat creation, preservation, and restoration
- Habitat quality
- Populations and species richness

Carbon, Energy, and Air Quality

- Energy use
- Air quality
- Temperature and urban heat island
- Carbon sequestration and avoidance

Materials and Waste

- Reused/recycled materials
- Waste reduction

Part 2 Social benefits (11)

- Recreational and social value
- Cultural preservation
- Health and well-being
- Safety
- Educational value
- Noise mitigation
- Food production
- Scenic quality and views
- Transportation
- Access and equity
- Other social

Part 3 Economic benefits (8)

- Property values
- Operations and maintenance savings
- Construction cost savings
- Job creation
- Visitor spending
- Increased tax revenue
- Economic development
- Other economic

Appendix 7

Select online calculation tools for landscape performance assessment (adapted from Landscape Architecture Foundation's benefits toolkit)

Waste Reduction Model (WARM) v.14

www.epa.gov/warm
U.S. Environmental Protection Agency – 2016
The WARM tool estimates and compares greenhouse gas (GHG) and energy use reductions for different waste management practices. For example, the model can be used to calculate the GHG savings of recycling 1 ton of aluminum cans versus landfilling them.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) v 3.3.3

www.naturalcapitalproject.org/invest/
The Natural Capital Project – 2016
InVEST is a suite of GIS-based models help map and value the goods and services from nature (ecosystem services) that provide benefits to humans. For example, the *InVEST Crop Pollination* model estimates insect pollinator sites, floral resources, and flight ranges for a landscape in order to derive an index of pollinator abundance.

National stormwater calculator

www.epa.gov/water-research/national-stormwater-calculator
U.S. Environmental Protection Agency – 2014
The SWC is a desktop application that accesses national databases for soil, topography, rainfall, and evaporation information in order to estimate the annual amount of rainwater and frequency of runoff from a specific site in the U.S.

i-Tree Streets (v 5.1)

www.itreetools.org/streets/index.php
USDA Forest Service – 2014
i-Tree Streets uses tree inventory data to provide a dollar value for the environmental and aesthetic benefits of trees, including: energy conservation,

air quality improvement, CO_2 reduction, stormwater control, and property value increase.

i-Tree Eco (v 6)

www.itreetools.org/eco/index.php
USDA Forest Service – 2016
i-Tree Eco uses tree measurements and field data from complete inventories or randomly sampled plots to estimate ecosystem services and structural characteristics of the urban or rural forest (such as avoided runoff or air quality benefits).

Automated Geospatial Watershed Assessment (AGWA) Tool v 3.0

www.epa.gov/water-research/automated-geospatial-watershed-assessment-agwa-tool-hydrologic-modeling-and-watershed
U.S. Environmental Protection Agency, University of Arizona, and USDA Agricultural Research Service – 2016
The AGWA is a GIS-based tool for analyzing watershed water quantity and quality in order to provide qualitative estimates of runoff and erosion relative to landscape change.

The value of green infrastructure: a guide to recognizing its economic, social, and environmental benefits

www.cnt.org/publications/the-value-of-green-infrastructure-a-guide-to-recognizing-its-economic-environmental-and
American Rivers and Center for Neighborhood Technology – 2011
A publication that aims to provide an economic value for the numerous benefits provided by green infrastructure (defined here as a network of decentralized stormwater management practices – such as green roofs, trees, rain gardens, and permeable pavers).

Long-term hydrologic impact analysis

https://engineering.purdue.edu/mapserve/LTHIA7/lthianew/tool.php
Local Government Environmental Assistance Network – 2011
The L-THIA model uses 30-plus years of precipitation data for the U.S. in order to estimate changes in recharge, runoff, and nonpoint source pollution resulting from past or proposed development.

Recycled content (ReCon) tool

https://www3.epa.gov/warm/ReCon_home.html
U.S. Environmental Protection Agency – 2010

The ReCon calculator estimates the greenhouse gas (GHG) emission and energy benefits associated with increasing the recycled content of materials purchased or manufactured. For example, ReCon can estimate the GHG emissions and energy benefits of purchasing office paper with 35% recycled content instead of 25%.

Rainwater harvesting calculator

https://ecology.wa.gov/Water-Shorelines/Water-supply/Water-recovery-solutions/Rainwater-collection

State of Washington Department of Ecology – 2010

This Excel-based calculator uses rainfall data in 29 Washington State communities to help residents size rainwater harvesting systems based on based on roof size and intended use.

SPAW field & pond hydrology model

https://hrsl.ba.ars.usda.gov/SPAW/Index.htm

USDA Agricultural Research Service and Washington State University Department of Biological Systems Engineering – 2009

The SPAW (Soil-Plant-Air-Water) is a daily water budgeting model for agricultural landscapes as well as ponds – such as wetland ponds, lagoons, or reservoirs.

Vegetable garden value calculator

www.plangarden.com/app/vegetable_value/

Plangarden – 2009

This online calculator uses the inputs of produce type and planted area to provide an output of total pounds grown and market value of individual or multiple crops.

National stormwater management calculator

http://greenvalues.cnt.org/national/calculator.php

Center for Neighborhood Technology – 2009

The National Green Values Calculator is a web-based tool for quickly comparing the performance, costs, and benefits of green infrastructure to conventional stormwater practices for a single site.

Recycling and reusing landscape waste cost calculator

https://archive.epa.gov/wastes/conserve/tools/greenscapes/web/html/index-2.html

U.S. Environmental Protection Agency – 2008

This Microsoft Excel-based calculator provides one-, three-, six-, and ten-year cost estimates for handling hardscape and landscape wastes (concrete and asphalt, brick, lumber, and yard waste) in four scenarios regarding reuse, recycle, and disposal.

Construction carbon calculator

http://buildcarbonneutral.org
Lady Bird Johnson Wildflower Center and Mithun – 2007
This online calculator estimates the embodied energy and subsequent carbon amounts released during construction for a project's structures and site.

Decking cost calculator

https://archive.epa.gov/wastes/conserve/tools/greenscapes/web/html/index-2.html
U.S. Environmental Protection Agency – 2007
This Microsoft Excel-based calculator compares the initial, annual, and life-span costs of building a new deck with the four most common traditional decking construction materials versus building with recycled plastic or recycled wood/plastic composite lumber.

Resource conserving landscaping cost calculator

https://archive.epa.gov/wastes/conserve/tools/greenscapes/web/html/index-2.html
U.S. Environmental Protection Agency – 2007
This Microsoft Excel-based calculator compares the initial and annual cost of converting conventional landscapes to retrofit landscapes that require less irrigation and produce less waste.

Sub-surface drip irrigation cost calculator

https://archive.epa.gov/wastes/conserve/tools/greenscapes/web/html/index-2.html
U.S. Environmental Protection Agency – 2006
This Microsoft Excel-based calculator compares the high and low costs (and water use) of a sub-surface drip irrigation system versus conventional sprinkler irrigation.

Erosion control calculator

https://archive.epa.gov/wastes/conserve/tools/greenscapes/web/html/index-2.html
U.S. Environmental Protection Agency – 2006

This Microsoft Excel-based calculator compares the cost of using environmentally beneficial compost filter berms or compost filter socks for erosion control versus the conventional silt fences.

Biotope Area Factor (BAF)

www.berlin.de/senuvk/umwelt/landschaftsplanung/bff/en/bff_berechnung.shtml

The BAF is a scoring formula to promote green infrastructure practices and protection of biotopes and species for new development in the city of Berlin, Germany. The model applies weighted scores to various surface types according to "ecological effectiveness" and uses these to then calculate the BAF for a given land area.

City biodiversity index

www.cbd.int/subnational/partners-and-initiatives/city-biodiversity-index

The City Biodiversity Index (or Singapore Index) is a quantitative self-assessment tool for monitoring and evaluating biodiversity in cities.

Appendix 8

Landscape performance project list (published by the Landscape Architecture Foundation, as of 2017)

Part 1 Projects by state (in U.S.)

Alabama

Samford Park at Toomer's Corner
Railroad Park

Arizona

Phoenix Civic Space Park
George "Doc" Cavalliere Park
Yuma East Wetlands, Phases 1 and 2
Underwood Family Sonoran Landscape Laboratory

California

Tassajara Creek Restoration
Napa River Flood Protection Project (1998–2012)
Tujunga Wash Greenway and Stream Restoration Project
Park Avenue/U.S. 50, Phase 1 Redevelopment
Frontier Project
Elmer Avenue Neighborhood Retrofit
Port of Los Angeles Wilmington Waterfront Park
Baldwin Hills Scenic Overlook
Malibu Lumber Yard
Cavallo Point

Colorado

Riverside Ranch
Capitol Valley Ranch

Cascade Garden
Cherry Creek North Improvements and Fillmore Plaza
Westerly Creek at Stapleton

Connecticut

Kroon Hall, Yale School of Forestry and Environmental Studies

Florida

Pompano Beach Boulevard Streetscape and Dune Restoration
1100 Block of Lincoln Road Mall
Nova Southeastern University Oceanographic Center: Phase I Landscape
Old Collier Golf Club

Georgia

Atlanta BeltLine Eastside Trail
1315 Peachtree Street

Illinois

Mary Bartelme Park
Palmisano Park/Stearns Quarry
The Morton Arboretum: Meadow Lake & Permeable Main Parking Lot
Sarah E. Goode STEM Academy
Boneyard Creek Restoration: Scott Park and the Second Street Detention Basin
One Drop At A Time
Advocate Lutheran General Hospital Patient Tower
63rd Street Beach, Jackson Park
Chicago Botanic Garden Lake Shoreline Enhancements
Chicago Museum of Science and Industry Smart Home
Millennium Park
Gary Comer Youth Center
Uptown Normal Circle and Streetscape
Ravinia Festival South Parking Lot
The Lurie Garden at Millennium Park

Indiana

Carmel Clay Central Park
Portage Lakefront and Riverwalk

Iowa

Charles City Permeable Streetscape Phase 1

Kentucky

Loch Norse Commons at Northern Kentucky University
University of Kentucky College of Agriculture Alumni Plaza

Massachusetts

Watch Factory, Phases 1 and 2
Central Wharf Plaza

Michigan

Ann Arbor Municipal Center
William G. Milliken State Park, Phase 2 Lowland Park
Kresge Foundation Headquarters
Ruth Mott Foundation Gilkey Creek Relocation and Restoration
Crosswinds Marsh Wetland Interpretive Preserve

Missouri

South Grand Boulevard Great Streets Initiative
Swope Campus Parking Lot and Entry Plaza
Middle Blue River Basin Green Solutions Pilot Project

New Jersey

The Willow School

New Mexico

Pete V. Domenici U.S. Courthouse Landscape Retrofit
High Desert Community

New York

EcoVillage at Ithaca
Buffalo Public School #305 McKinley High School
Brian C. Nevin Welcome Center, Cornell Plantations
Dutch Kills Green
Teardrop Park
Avalon Park and Preserve

North Carolina

Charlotte Brody Discovery Garden

Oregon

Randall Children's Hospital
Simon and Helen Director Park

Pennsylvania

Pennswood Village Regional Stormwater Management System
Black Rock Sanctuary
Thomas Jefferson University Lubert Plaza
Salvation Army Kroc Community Center
Cusano Environmental Education Center
Chester Arthur Schoolyard

Tennessee

Renaissance Park

Texas

The George W. Bush Presidential Center
Sundance Square Plaza
AT&T Performing Arts Center: Sammons Park
Klyde Warren Park
University of Texas at Dallas Landscape Enhancements
Buffalo Bayou Promenade
Blue Hole Regional Park
Park Seventeen Roof Garden
The Shops at Park Lane

Utah

Daybreak Community

Virginia

James Madison University Bioscience Building Landscape
Meadow Creek Stream Restoration
Thomas Jefferson Visitor Center and Smith Education Center at Monticello
Richmond Canal Walk
The Dell at the University of Virginia

Washington

Olympic Sculpture Park
Magnuson Park Wetlands and Active Recreation
Snoqualmie Falls Upper Park
Seattle Children's PlayGarden
Zoomazium at Woodland Park Zoo
Taylor 28
Thornton Creek Water Quality Channel

Washington DC

U.S. Coast Guard Headquarters
Canal Park
Sidwell Friends Middle School
The Avenue
Brent Elementary Schoolyard Greening: Phase 1
ASLA Headquarters Green Roof

Wisconsin

Erie Street Plaza
Menomonee Valley Redevelopment and Community Park

Part 2 International projects

Australia

Sydney Olympic Millennium Parklands

Canada

Sherbourne Common
HTO Park
Corktown Common

China

Tangshan Nanhu Eco-city Central Park
Beijing Olympic Forest Park
Shanghai Houtan Park
Tianjin Qiaoyuan Park: The Adaptation Palettes

Italy

Castiglion del Bosco

South Korea

Cheonggyecheon Stream Restoration Project

Appendix 9

Metrics for social benefit assessment

(1) Recreational and social value

Promotes facility use and quality of experience

Potential metrics

Number of visitors to the site

- Direct observation, including population counts and surveys.
- Consult visitation/use records from local agency, group, or institution that may already collect such data.

Number or Percent of Visitors Engaged in Recreational or Social Activities

- Direct observation, including population counts and surveys.
- Public Space/Public Life (PSPL) survey methods.

Quality of the visitor experience

- Conduct surveys of visitors to determine the quality and nature of their recreational activities.

Extent of facility use

- Consult construction documents to assess the number and extent of facilities that directly support active and passive recreation. Such facilities may include recreational trails, sports fields, clubhouses, etc. Compare this with observation or survey data to determine the extent of use compared to capacity, which could be expressed as amount of time facilities are used, or percentage of capacity of use at given times.
- Direct observation, including population counts and surveys.
- Public Space/Public Life (PSPL) survey methods.

(2) Cultural preservation

Retains or restores culturally significant features, areas, practices, or views

Potential metrics

Area or quantity of culturally valuable elements protected or enhanced (area or percent of site preserved; or number of elements protected)

- Reference local records, project documents, etc., to identify areas and elements deemed valuable/significant by agencies or governments, including religious, tribal, or cultural preservation groups. Utilize aerial photographs, GIS analyses, or other tools to quantify spatial extent. Compare pre- and post-construction conditions.

Qualitative experience of individuals who use the space

- Conduct surveys of visitors to determine the quality and nature of their experience as it relates to the cultural features or aspects of the site.
- Visual assessments can be performed to better understand the effect of culturally significant areas on visitor perceptions.
- Compile and analyze data from local sources, agencies or governments, including religious, tribal, or cultural preservation groups.

Quantity of cultural goods produced

- Estimate the number of culturally significant goods produced from the landscape (such as the bottles of wine or blocks of cheese), which are the result of site preservation, restoration, or enhancement.

(3) Health and well-being

Improves physical health, mental health, or quality of life

Potential metrics

Change in Mood or Level of Satisfaction

- Survey methods including focus groups.
- Analysis of secondary data compiled by a client, site manager, or other third party. Post-occupancy evaluations can be especially helpful.

Physical Health Indicators (e.g., increase in frequency of exercise)

- Conduct surveys of visitors, either in person or indirectly.
- Compile data from third parties regarding decreases in acute-asthma related events or other health incidents that can be clearly tied to the landscape in question.

Improved Quality of Life

- Conduct surveys of visitors, either in person or indirectly.
- Spatial analysis can be performed to assess the design's opportunities for relaxation and respite.

(4) Safety

Improves safety or reduces crime

Potential metrics

Reduction in traffic or pedestrian accidents due to design elements

- Analysis of accident data from local government or Department of Transportation.
- Comparison between the design intervention and other similar sites.

Reduction in traffic speed

- Review construction documents to identify features such as narrowing lanes, urban street trees, or traffic circles that are known to reduce traffic speed.
- Conduct a site visit to assess the current traffic speed and compare it with speeds recorded prior to the design intervention.

Reduction in Crime

- Analysis of statistics from local government or police department.

Perceptions of Safety

- Conduct surveys of visitors, either in person or indirectly.
- Use pictures of the site to conduct a remote survey on perceptions of safety.

(5) Educational value

Enables, promotes, or encourages educational goals

Potential metrics

Number of people attending educational events or programs onsite

- Analysis of secondary data from client, land manager, or affiliated educational group.
- Direct observation, including population counts and surveys.

Number of people accessing educational material (online or as part of curriculum)

- Analysis of data pertaining to access of affiliated educational material.
- Analysis of curricula or teaching materials.

Perceptions of educational value

- Conduct surveys of visitors, either in person or indirectly, asking about their perceptions of educational value/experience.

Increased comprehension of sustainability or design concepts

- Conduct surveys of visitors, either in person or indirectly, that test understanding of basic concepts presented onsite.

Extent of facility use

- Consult construction documents to assess the number and extent of facilities that directly support educational use. Such facilities may include amphitheaters, nature trails, interpretative signage, etc. Compare this with observation or survey data to determine the extent of use compared to capacity, which could be expressed as amount of time facilities are used, or percentage of capacity of use at given times.
- Direct observation, including population counts, estimates of time spent at a site, and surveys.
- Public Space/Public Life (PSPL) survey methods.

(6) Noise mitigation

Reduces or eliminates unwanted sound

Potential metrics

Reduced onsite noise levels

- Measure the decibel levels onsite using a sound level meter and compare with pre-construction levels.
- Analyze and report data from a secondary source such as a consultant or municipality.

Reduction in perception of undesirable noise

- Conduct surveys onsite that note perceived noise levels and participant location. This metric is useful when undesirable noise is not actually reduced but is mitigated by adding desirable noises, such as the sound of leaves in the wind or falling water.

(7) Food production

Supports the sustainable production of food

Potential metrics

Volume of food produced

- Analyze secondary data available from the client, land manager or other source.
- Determine the areas devoted to different types of food and use the Vegetable Garden Value Calculator (plandgarden.com) to assess rough volumes produced.

Number of meals provided/people fed

- Analyze secondary data available from the client, land manager, or other source.

Dollar value of food produced

- Analyze secondary data available from the client, land manager, or other source.
- Estimate value using the Vegetable Garden Value Calculator.
- Use local food prices from a grocery store or farmers' market to estimate price of food produced.

(8) Scenic quality and views

Creates or preserves desirable sight lines or improves the visual quality of a landscape

Potential metrics

Change in score on a visual quality scale

- Use the U.S. Forest Service Visual Quality Assessment.
- Use or develop a Travel Route Rating such as that used by the Tahoe Regional Planning Agency or other local entity.

Percent of unwanted views screened or desirable views retained

- Digital photography and computer software to determine relative size of views.
- Traditional photography and planimeters to determine relative size of views.
- 3-D simulation using computer-aided design software.

Perception of improved aesthetic

- Survey visitors to determine their perceptions of the visual quality of the site.
- Survey experts in the field to determine their perceptions of the visual quality of the site.

(9) Transportation

Improves or encourages walkability, public transit use, and/or other sustainable transit modes

Potential metrics

Increase in bicycle, pedestrian, or public transit use

- Direct observation, including counts and surveys.

- Compile and analyze data from an agency such as the Department of Transportation.

Reduction in automobile miles driven

- Consult actual traffic count data from a Department of Transportation or other agency.
- Direct observation, including counts and surveys.
- Determine decreased need for private car transportation to key locations.

Increased connections, especially trails and bike lanes

- Consult construction documents to identify new off-site connections.

(10) Access and equity

Improves or encourages visitation and equal access to a site

Potential metrics

Increased access to parkland or recreational facilities for underserved populations

- Utilize spatial mapping techniques such as map overlays or GIS software to determine under-served areas and populations.
- Consult applicable government or agency records regarding community locations and populations that may face inequality of access.

Improved access for those with disabilities

- Consult construction documents to ascertain use of universal design or other disabled-friendly techniques or features.
- Consult client or land manager records to determine number of users with disabilities.

Number of visitors or students to the site

- Consult applicable agency, group, or institutional records.
- Direct observation, including counts and surveys.

Amount of volunteer opportunities

- Consult applicable agency, group, or institutional records.

Reference

Canfield, J., Yang, B., Keane, T., Whitlow, H., Burgess, K., & Koudounas, A. (in press). *Landscape performance: A guide for metric selection*. Washington, DC: Landscape Architecture Foundation.

Appendix 10

Metrics for economic benefit assessment

(1) Property values

Increases value of adjacent properties

Potential metrics

Increase in property value of adjacent or nearby properties

- Consult municipal property tax records to compare assessed value of one or more buildings within an established vicinity of the site before and after project completion.
- Consult municipal property tax records to compare assessed value of one or one properties within an established vicinity to the site to similar properties further from the site.

Increase in sales price for adjacent or nearby properties

- Consult municipal or online real estate databases of sales prices.

Increase in rents for adjacent residential or commercial properties

- Comparison of rent charges in adjacent or nearby residential or commercial properties before and after the landscape intervention.

(2) Operations and maintenance savings

Reduces life cycle costs/increases long-term savings

Potential metrics

Reduction in heating and cooling costs

- Compare heating and cooling bills from before and after the implementation of a landscape design.
- Compare heating and cooling bills from the property with similar properties that have not had a landscape intervention.

- Use local energy costs to convert energy savings into cost savings. See Energy Use section for useful energy use calculating tools.

Reduction in irrigation or potable water costs

- Compare use of water on the site to use on a similar site without a sustainable design.
- Compare water bills from before and after design implementation.
- Calculate water savings and use local water costs to determine cost savings. See Water Conservation section for useful methods.

Reduction in maintenance costs, including mowing, fertilizer, or labor

- Compare actual maintenance costs of the site to those prior to the design intervention, or to a similar reference site.
- Compare actual or estimated maintenance costs to a comparative traditional-type site design.

Value of volunteer hours

- Multiply typical value of an hour of labor by the total number of volunteer hours to obtain a value of volunteer contributions.

(3) Construction cost savings

Reduces expenses associated with implementation

Potential metrics

Reduced hauling and/or dumping costs

- Record the amount of material reused onsite that does not need to be hauled away. See also Reused/Recycled Materials section and Waste Reduction sections.
- Calculate potential savings associated with avoiding dumping fees by reusing materials.

Reduction in materials cost

- Calculate the savings realized from using alternative/sustainable materials.

Reduced installation cost

- Calculate the savings associated with installing green infrastructure instead of traditional infrastructure.

Reduced earthworks cost

- Consult construction documents to assess the cut/fill operations and determine the savings associated with eliminating purchase and transport of fill to the site, or determine savings from reducing off-site disposal of cut.

(4) Job creation

Increases jobs as part of the site construction and/or completed design.

Potential metrics

Number of permanent jobs created directly for the site

- Consult public data, client records, or other sources to determine the number of park staff, event staff, or other employees that rely directly on the landscape project for their jobs.

Number of temporary jobs created

- Landscape development often creates temporary jobs, particularly in construction. Numbers of jobs or of man-hours can be available from the construction contractor(s).

(5) Visitor spending

Increases spending of visitors to the site

Potential metrics

Revenue or net revenue generated by entry fees

- Review of visitor counts or other collected data sources.
- Interviews with staff and other personnel who keep records of visitation.

Revenue or net revenue generated through sales

- Review sales records from cafes, gift shops, and other retail establishments affiliated with the project in question.

Revenue or net revenue generated through rentals

- Review rental records from rental establishments affiliated with the project.

General visitor spending

- For well-known sites, review and analyze data reflected total visitor spending in the city or region.

(6) Increased tax base/revenue

Increases revenue for the local municipality

Potential metrics

Increase in property tax revenue

- Government records can be consulted to ascertain the before and after development amounts of tax revenue collected.

Projected revenue increase

- Projected tax revenue can be estimated by calculating square footage of different types of space and extrapolating taxes based on those types.
- Projected tax revenue can be estimated by calculating square footage of different types of space and extrapolating taxes based on those types.

(7) Economic development

Provides economic benefits to adjacent properties

Potential metrics

Amount of investment or number of projects catalyzed

- Calculate the amount of investment or determine the number of secondary projects realized because the main project in question provided a catalytic benefit such as flood protection or brownfield remediation.

Increase in retail sales

- Obtain retail sales information from public records or through contacting private businesses to determine increases after landscape project.

Increase in office, commercial, or residential space or units

- Mapping or consultation of commercial or municipal records can lead to a determination of the extent that development has increased.
- A count of new commercial business directly adjacent to the site or in the larger neighborhood can be performed if there is evidence that the landscape design contributed in a significant way to the establishment of the businesses.

Increase in occupancy/Decrease in residential or commercial vacancies

- Consult records to determine if vacancy rates decreased or occupancy rates increased for both commercial and residential spaces following the completion of the landscape project.

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Appendix 11

The Woodlands Major Awards of Excellence (select list on planning and design, 1974–2016)

2016

- Lone Star Programming Award by Texas Recreation and Parks Society
- Innovations in Parks and Design Award by Texas Recreation and Parks Society
- National Night Out (first in the state of Texas) by the National Association of Town Watch
- National Night Out (second in the nation) by the National Association of Town Watch

2015

- National Landscape Award of Excellence by the Professional Landcare Network (PLANET)

2014

- Communicator Award of Distinction by Academy of Interactive and Visual Arts
- Community Based Crime Prevention Program of the Year by the International Society of Crime Prevention Practitioners (ISCPP)
- National Night Out (fourth in the nation) by the National Association of Town Watch

2013

- Community Based Crime Prevention Program of the Year by the International Society of Crime Prevention Practitioners (ISCPP)
- National Night Out (ninth in the nation) by the National Association of Town Watch

2010

- Outstanding Park/Facility Design Award by Southwest Region of the National Recreation and Park Association
- Master Planned Community of the Year by Greater Houston Builders Association
- Landscape Design of the Year by Greater Houston Builders Association

2009

- Landmark Award by the Houston Business Journal
- Environmental Planning Award by American Planning Association, Texas Chapter
- Recreation Facility Award by Texas Recreation and Park Society
- Park Design Excellence Award by Texas Recreation and Park Society
- Maintenance Award by Texas Recreation and Park Society
- Certified Audubon Cooperative Sanctuary by Audubon Cooperative Sanctuary System

2008

- Corporate Conservation Leadership Award by the Nature Conservancy of Texas
- Silver Spur Award by Texas Public Relations Association
- Tree Preservation Award by The Park People

2007

- Community of the Year by Greater Houston Builders Association
- Humanitarian of the Year by Greater Houston Builders Association

2006

- Community of the Year by Greater Houston Builders Association

2005

- Honor Award by the American Institute of Architects

2004

- Environmental Impact Award by the North Houston Association
- Certified Audubon Cooperative Sanctuary

2003

- Nations in Bloom Gold Award by the international Nations in Bloom Competition (The Netherlands)
- Nations in Bloom Second Place Overall Award by the international Nations in Bloom Competition (The Netherlands)
- Landmark Award (Best Multiuse Project Sale) by the Houston Business Journal
- Landmark Award (Best Medical Project) by the Houston Business Journal
- Community of the Year by Greater Houston Builders Association
- Humanitarian of the Year by Greater Houston Builders Association
- Honor Award by the American Society of Landscape Architects, Texas Chapter

2002

- Commercial Award by Texas Recreation and Parks Society
- Landmark Award by the Houston Business Journal
- Grand Award by Greater Houston Builders Association
- Drum Major Award by Martin Luther King Drum Major Award Committee

2001

- Grand Award by Greater Houston Builders Association

1999

- Developer of the Year by Greater Houston Builders Association

1997

- Environmental Achievement Award by Texas Association of Nurserymen

1994

- Award of Excellence by Urban Land Institute

1993

- FIABCI Prix D’Excellence World Premier Real Estate Award by FIABCI

1991

- Texas Urban Forestry Award by Texas Forest Service & Texas Urban Forestry Council
- The Legacy Award by Houston Business Journal

- Beautification Award by South Montgomery County Chamber of Commerce

1990

- Texas Urban Forestry Award by Texas Forest Service & Texas Urban Forestry Council
- Harris B. Lieberman "Developer of the Year Award" by Greater Houston Builders Association

1989

- The Lorax Award by Lorax Award for Business
- Urban Forestry Award by Greater Houston Galveston Urban Forestry Council

1986

- Award of Distinguished Achievement by Houston Chapter of The American Institute of Architects, Municipal Arts Commission, and The American Society of Landscape Architects

1984

- Award of Distinguished Achievement by The Houston Chapter of The American Institute of Architects, Municipal Arts Commission, and The American Society of Landscape Architects

1983

- Developer Merchandising of the Year by Greater Houston Builders Association

1981

- Award of Distinguished Achievement by Houston Chapter of The American Institute of Architects

1978

- Environment in Commercial by American Industrial Properties

1975

- Community Quality of Life Award presented by Environmental Monthly for creating quality of life in The Woodlands community

1974

- Better Environmental Award by American Society of Landscape Architects
- Annual Environment Honor Award by Environmental Monthly
- Design Award by Sixth Annual Biennial HUD (Department of Housing and Urban Development) Awards

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