STORMWATER EVALUATION AND SITE ASSESSMENT
—A Multidisciplinary Approach for Stormwater Best Management Practices (BMPs)

by

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Abstract

Stormwater management is typically approached from different perspectives by practicing professionals. As such, stormwater planning/design is not always completed as a multi-disciplinary coalition of experts using holistic and synergistic methods.

For a number of years, engineers and design professionals, particularly landscape architects, have been employing various strategies and techniques to address on-site stormwater management in terms of water quality and quantity. There is increasing awareness that in order to create solutions that are effective over both the short and long-term a landscape architect's approach needs to account for the health, safety and welfare perspectives carried by engineers, the unique aspects of particular project sites, their surroundings and bio-regional context, as well as the perceptions of clients, other key stakeholders, and the broader public.

This research investigates the various criteria integral to developing an analytic framework for ecologically-appropriate stormwater planning/design (Sustainable Stormwater Evaluation and Site Assessment or SSWESA). SSWESA is proposed as a type of decision-tree for site analysis of sustainable systems pertaining to stormwater. Using the SSWESA process is expected to help researchers and professionals make better planning and design decisions as they select and implement appropriate best management practices (BMPs) for a given site and context.

My intent in developing SSWESA is to help designers assess existing and potential stormwater functions at the site scale in order to promote sustainable planning and design based upon the important principle: "First, do no harm". It is also my intent to promote further research related to sustainability by providing references and sources from experts in the various fields related to ecologically-based stormwater management.

A review of the literature related to ecological factors relevant to low impact stormwater management assisted in the development and refinement of the criteria for stormwater assessment and evaluation. In this report, the SSWESA framework is tested on a public school property in Manhattan, Kansas to demonstrate how the framework is applied and to understand the questions and issues that arise from its use.

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Dedication

To Daddy, Amma, Pravs, and Lance kutty

and,

in memoriam:

Paati.

Preface

Landscape Architects have increasingly used stormwater best management practices (BMPs) and employed low-impact development (LID) concepts in their land development plans and site designs. Nevertheless, conventional approaches to stormwater management (moving water quickly off of paved and turf grass surfaces) still dominate the urban landscape and most new residential, commercial, and institutional developments. Engineers, who in many instances collaborate with landscape architects on BMP and LID designs, seek to minimize nuisances, risks, and hazards associated with storm events. In most instances, engineers have sought to convey surface water runoff into well-defined conveyance systems (for example, pipes and concrete-lined channels) and holding systems (primarily, detention or retention ponds).

Both professions (landscape architects and engineers) tell a story with the methods they choose to use. Landscape architects typically seek to “fit” or relate plans and designs to the particular place for which they are designing (bio-regionally and site specific), but frequently allow aesthetic concerns to trump ecological factors. On the other hand, engineers are inclined to use readily quantifiable methods that make it easy to verify precisely how much water can be conveyed or stored at particular locations, for a given storm event of a given amount and duration. As a result, landscape architects and engineers frequently seek to address stormwater management issues employing different overarching goals and using different approaches and techniques.

What is the optimal approach to effective site assessment for design and selection of stormwater BMPs? How do we, as designers, engineers, and researchers, best assess a site’s potential to address stormwater quality issues to lead us towards sustainable stormwater management design decisions? What are the criteria that must be taken into account in order to design and engineer stormwater management systems in an integrated, sustainable, and holistic manner? And, how do designers and engineers apply these ideas to various urban planning/design projects?

This thesis seeks to reveal how designers and engineers can effectively address the dynamic natural and cultural systems and variables that are associated with individual sites. A primary objective of the research is to further the understanding of site processes so that landscape architects and engineers can work collaboratively to create systems that meet all or at least a good portion of water quality requirements, needs, and interests.

"Rainwater must be considered a resource, not a waste product. Stormwater is most effectively managed on site at the source." (Pennypacker & Echols, 2008, 2).

CHAPTER 1 - Introduction

Research Intent, Objective, and Goals

Research Intent

The principal intent of this thesis is to **further research regarding ecologically-based stormwater management systems.** The primary focus of my research has been to better understand the interrelationships between hydrology, soils, and vegetation—and how these three factors influence stormwater runoff and management. In doing so, I have studied the different approaches to stormwater collection, treatment and management, drawing upon the insights provided by the fields of Biology, Engineering, Fluvial Systems and Hydraulics, Plant Science and Ecology, Soil Chemistry, Geology and Geomorphology, Pollution Prevention and Control, Sustainable Urbanism, Landscape Architecture, and Design Aesthetics.

Research Objective

It is posited that each discipline provides important ways to more comprehensively understand and respond to a site and its larger context, and that an overall Sustainable Stormwater Evaluation and Site Assessment (SSWESA) process could be invaluable for thinking about and selecting place-appropriate stormwater management tools and techniques such as stormwater Best Management Practices (BMPs). It is suggested that a **design decision matrix** could provide an invaluable framework for stormwater management assessment, and offer a platform for performing a more in-depth analysis of the systems associated with a site and its surroundings. My overall objective has been to create and test an analytic framework for ecologically-appropriate stormwater planning/design, which can then be applied to project sites in urbanizing areas and that can subsequently be critiqued, refined, and/or adapted.

Research Goals

The researcher, with the aid of the SSWESA framework, intends to promote a way to fuse the study of interrelated on-site variables, thus aiding planners, designers, and engineers as they work together on land-planning projects and issues. Such investigative analyses should lead to “successful designs” for effective **urban stormwater management**, built upon the foundation of meaningful **site-scale analysis**. It is hoped that SSWESA will serve as a robust template for designers, engineers, and researchers as they investigate site variables that pertain to stormwater management.

The primary intent of this research endeavor is two-fold:

- To further the understanding of the various natural and cultural systems influencing a site’s stormwater systems—and to offer sources and ideas for further research.
- To help educate stakeholders and practicing professionals involved in any project about the interrelated functions of hydrology, soils, and vegetation—thus enabling stakeholders, practitioners, and researchers a common platform for discussing and debating appropriate, place-based stormwater solutions.

Research Methodology

Searching and Understanding the Literature

I have explored books and publications by authors in their respective fields of expertise, searching for data and information on which to base land planning/design criteria related to stormwater management. This search expanded my knowledge of hydrology, soils, vegetation, and other site-specific and human factors. Essential ideas related to stormwater management were gathered, reviewed, and documented.

Offering a Synthesis

Elements and principles pertaining to each site factor under the headings of hydrology, soils, and vegetation were studied in some detail and a set of assessment criteria developed to frame and set the stage for a thorough analysis of urban stormwater systems. Interconnections among specific sub-factors (for example, soil structure, porosity, and infiltrative capacity) were studied and grouped together into three categories: physical, chemical, and biological. The final assessment framework is composed of a generally hierarchical set of factors, with each factor linked directly or indirectly to the three primary criteria for ecological site analysis: hydrology, soils, and vegetation.

Developing a Sustainable Stormwater Evaluation & Site Assessment (SSWESA) Framework

The Sustainable Stormwater Assessment and Site Assessment framework is a concise, graphic summary of factors that pertain to stormwater functions on a site. The SSWESA framework is intended as a decision support tool for landscape architects, engineers, and designers looking to make planning and design decisions that are sustainable, and for all other professionals who seek to prepare site plans supported by stormwater analyses that focus on ecological function.

Testing the SSWESA Framework

A site was chosen to demonstrate SSWESA's applicability to institutional properties such as schools, parks, and corporate headquarters. Design guidelines are outlined as part of the results to demonstrate the usefulness of SSWESA for designers working at the site scale in urban settings. The site chosen for the SSWESA application and the subsequent conceptual design work was Eisenhower Middle School in Manhattan, Kansas.

Products/Results/Findings and Expected Outcome of the Research

A conceptual site design was developed to explore the ideas gleaned from the literature review and test the SSWESA framework at the scale of an urban site. For this thesis, the site constraints and individual context associated with a middle school property were evaluated through a preliminary analysis using SSWESA as a primary guide. It is hoped that a more through investigation based upon findings in this thesis will be made for the school. It is also hoped that designers and engineers will use key ideas from this thesis to deepen and help guide their land planning/design and development work.

Targeted readers of this study

- Researchers wanting sources for in-depth study of the various factors critical to stormwater management and design.
- Planning, design, and engineering professionals who need an assessment tool to evaluate sites before they recommend specific design solutions (including BMPs).

Overview of the Document

The chapters following this Introduction include: Background, Literature Review, Site Application of SSWESA, and Conclusions.

Chapter 2, Background, presents a general introduction of stormwater management from the perspectives of various practitioners and design professionals within the field. After this, an outline of recent activities associated with stormwater management in the United States is discussed. Finally, three implemented projects are briefly discussed. Project precedents chosen include the 10th@Hoyt Courtyard in Portland, Oregon; the Stata Center Outwash Basin within the MIT campus in Cambridge, Massachusetts; and Stephen Epler Hall, which is part of Portland State University in Portland, Oregon. These projects were selected based on three attributes: stormwater functions (ecology), design and aesthetics (art), and education. Since Eisenhower Middle School has been chosen as the application site, I felt it was appropriate to look at site-scale designs in urban areas that provide opportunities for learning and enjoyment.

Chapter 3, Literature Review, provides a detailed discussion of the factors that are included within the Sustainable Stormwater and Site Assessment (SSWESA) under the headings: hydrology, soils, and vegetation. As each factor is discussed, the relation to stormwater management is also discussed. A synthesis of what was learned from the literature is explained at the end of the chapter and serves as a foundation for SSWESA framework. Stormwater Best Management Practices (BMPs) and a final set of guidelines are discussed and can be used during application of the framework at the site-scale.

Chapter 4, Site Application of SSWESA, includes a discussion of the process by which SSWESA is applied at the Eisenhower Middle School (EMS) site in Manhattan, Kansas. Hydrology, soils, and vegetation are discussed in detail, along with a brief analysis of the site's socio-cultural variables. A summary analysis and SSWESA charts are presented at the end of each section of the chapter. Problems and issues are identified with regards to stormwater management, and suggested design ideas (in the form of a list of guidelines and conceptual master plan) are briefly discussed. A conceptual site design for stormwater management improvements is presented at the end of the chapter, with sketches and brief explanations of design elements that could potentially be implemented on the EMS property.

Chapter 5, Conclusions, presents parting thoughts about the thesis and includes discussion about the possibilities for further research in relation to sustainable stormwater management in urban landscapes.

CHAPTER 2 - Background — Urban Stormwater Management

Stormwater Management and Water Quality

Stuart Echols and Eliza Pennypacker have this to say in an article about stormwater: *"When Landscape architects hear the term "stormwater management," what springs to mind: A regulatory demand? A system of pipes and ponds designed to be unobtrusive? Whatever the response, thanks to revisions to the Clean Water Act, virtually every landscape architect must address stormwater management in virtually every project." (2006, 1)*

The Clean Water Act of 1972 highlighted the importance of surface water quality protection in the United States. Since its inception and passage, landscape architects have become increasingly concerned with incorporating stormwater strategies in urban areas that not only "solve stormwater issues" but also create usable and attractive spaces. Landscape architects are particularly concerned with "place-making strategies", and rightfully so. This place-making aspect of site design is particularly important and is considered as a broader part of the SSWESA process.

Although landscape architects generally desire to fit their designs to the unique characteristics of sites and regions, most lack sufficient knowledge of hydrology, soils, vegetation, and dynamic ecological systems to do so in a manner that allows for the creation of integrated places. Complementing applied research by landscape architects, engineers, and scientists such as Ferguson (1998), Patchett (1999), Sorvig (2000), Urbonas (2001), Shaw & Schmidt (2003), Holman-Dodds (2006), Lubick (2006), Schnieder & McCuen (2006), Trimbath (2006), Echols (2007), Hogan & Walbridge (2007), and many others, this thesis creates an inventory list to guide urban stormwater planning/design. Strategies and guidelines specific to stormwater-related site assessment and design are also outlined herein.

Stormwater Functions as Defined by Primary Participants

Engineers

Engineers may define function as exactly that—meeting required functional (including health, safety, and regulatory) conditions. The method or approach used here is very scientific and premeditated. Purposeful calculations and modeling data are employed to assure that human health and safety are considered during all aspects of the analysis.

Pros: Engineers generally seek to achieve a standard measure of safety—determined by keeping certain numbers within a range understood as efficient and safe, such as runoff rates (measured in cubic feet per second, or cfs) and runoff volumes (measured in inches or feet over acres). Flooding is generally kept in check, except when major storms overwhelm the designed and implemented infrastructure and associated land uses in urban and rural settings.

Cons: Often, numbers can be too assumptive and 'over-designing' can occur—for example, a channel section designed for a 25-year or a 50- year storm event and resultant peak flows, is wasteful for smaller storms such as a 1- year or 2- year storm event—and may transport the water off the site too quickly (causing problems such as lower water tables and droughty soils, and the silting in of channels, ponds, and retention areas).

Standardized designs result from being too rigid and too efficient—these designs are not typically based on cultural perspectives or with a sense of place and community pride. Materials and methods tend to involve repetition or redundancy—in many cases, the innate lay of the land and integral processes of ecosystems on a site are removed, altered, or ignored—leading to long-term degradation of natural resources.

Landscape Architects

Landscape Architects typically consider natural functions and processes, although project budgets often prohibit or discourage in-depth assessment of important variables. For landscape architects, considering the environmental and regional context is an important part of project/site analysis. Aesthetic design is seen as integral to site planning/design in landscape architecture.

Pros: Each site is uniquely handled, with its individual set of processes and functions. For example, a project site in Manhattan, Kansas will be evaluated differently than a site in Blacksburg, Virginia or any other region. Designs are innovative and visually appealing, and usually have distinct cultural connotations and connections, thus providing an element of identity within the community.

Cons: Not a lot of emphasis is placed on quantitative statistics or being extremely precise when using formulae and equations for runoff calculations. Design is often “conceptual” and “artistic,” usually relating more to aesthetics and the experience of people—with strict functional assessments often seen as less important than having a strong idea, theme or concept. For example, while plant biodiversity may be of high value in a rain-garden due to its capacity to support a more diverse set of wildlife and its ability to improve the prospects for pollutant treatment and/or erosion control, a diverse plant palette may not be seen as desirable due to “aesthetic considerations” and other “formal design qualities.”

Regulatory Boards

USEPA defines function in stormwater management as addressing flood prevention and protecting the health, safety, and welfare of people while satisfying specific minimum standards for water quality. Other regulatory authorities and boards typically involved in stormwater management oversight of sites include local agencies as well as state, city, or county officials.

The Public

The public is strongly influenced by the processes and results associated with site planning and design. As users of the site, people typically expect to encounter few to no risks or problems due to stormwater, and for many landowners this frequently includes a desire for clean water, protection from flooding of structures and basements, and no “unkempt” look. Moreover, site users wish to readily understand and appreciate the design (simplicity and cleanliness in terms of how a landscape looks has become the standard for most residential, commercial, and corporate landscapes in the United States). Because it is property owners who oversee the maintenance and management of landscapes, a high level of acceptance from the public is considered a good measure of the success of the stormwater management methods employed.

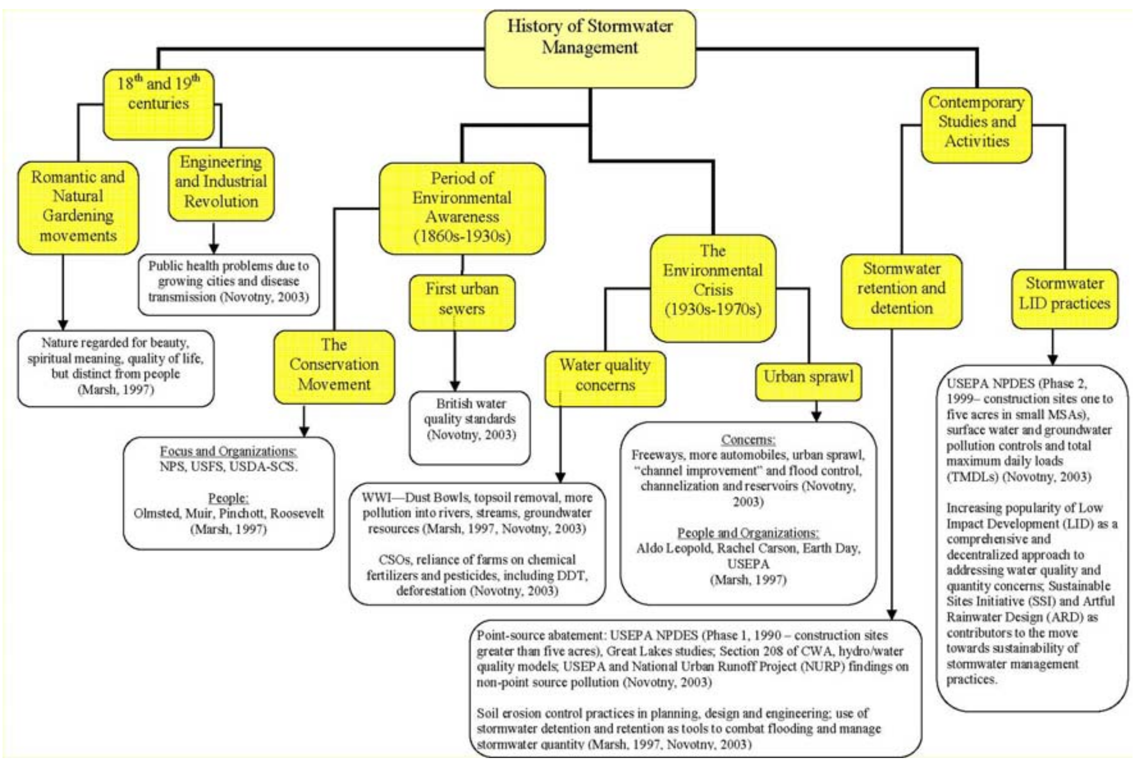
In short, aesthetic conventions are upheld consistently with regard to the local culture and perceptions. For example, naturalized stormwater management design may be supported in Portland, Oregon, Chicago, Illinois, or Cambridge, Massachusetts but such designs might be poorly received in other suburban and urban settings because of a lack of acceptance for this new type of urban aesthetic or the maintenance practices they entail (people cannot simply mow the turf to keep a "clean and green" appearance).

Historical Context: An Sketch Highlighting Selected Events

Stormwater management has evolved through the ages, with landscape architects and planners and engineers involved in developing several of the modern stormwater management BMPs and other practices. Fig.2.1 illustrates the various events that make up the history of stormwater management. Four eras are succinctly depicted in the figure:

1. 18th and 19th Centuries
2. Period of Environmental Awareness (1860s-1930s)
3. The Environmental Crisis (1930s-1970s)
4. Contemporary Studies and Activities

Figure 2.1 Sketch illustrating timeline of events related to stormwater management.



Contemporary Studies: Place-making using Rainwater Art

Information on stormwater design precedents is drawn from Echols and Pennypacker (2006; 2008a). These three urban stormwater management projects sought to integrate the design of stormwater functions, aesthetics, and education, and I believe they do so with some success.

10th@Hoyt Courtyard, Portland, Oregon *(Case Study #1).*

Design by Steve Koch, ASLA

"Artful rainwater design", as coined in the article, "Art for Rain's Sake" (Echols & Pennypacker, 2006, 2) consists of a set of several strategically-placed site elements that convey and treat stormwater. These elements are not simply functional; they also have a place in the site and are part of a larger "placemaking" context. These artistic rainwater elements serve as place markers in an overall setting where the flow of water is indicated clearly, and where site users, similar to students and visitors on the EMS site, can be brought to understand the concepts involved in the arrangement of these stormwater BMPs or design elements, with a clear representation of alternatives to the efficient but frequently degrading "roof-to-drain" approach depicted in figures 2.2 and 2.3.

Figure 2.2 Sketch illustrating the system in the 10th@Hoyt Courtyard, Portland OR. (Source: Echols & Pennypacker, 2006).

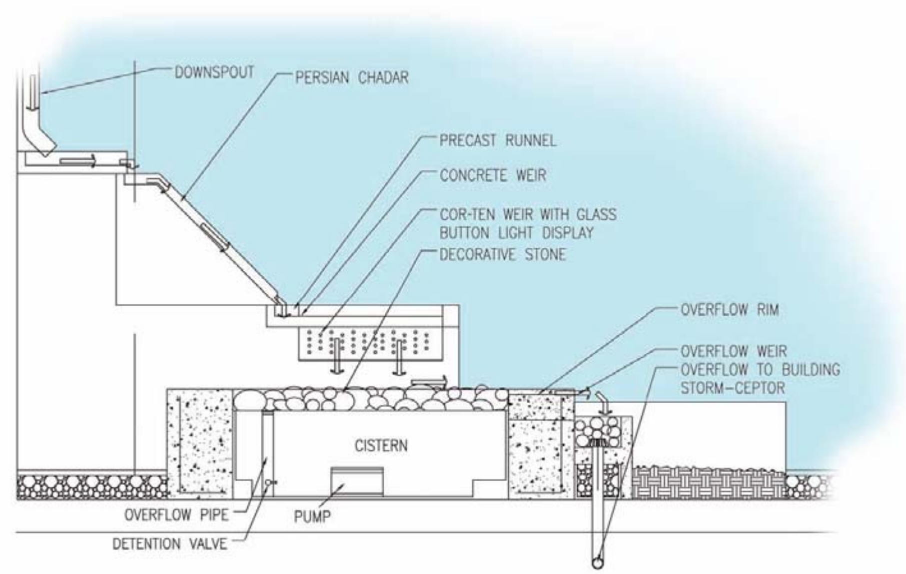


Figure 2.3 Rainwater is conveyed from building roofs to river rock basins through downspouts and runnels—10th@Hoyt Courtyard

(Source: Echols & Pennypacker, 2006).

With the 10^{th}@Hoyt Courtyard design in Portland, Oregon, Steve Koch has visualized a system of continuous conveyance of rainwater using innovative elements such as vertical stepped runnels, artfully designed downspouts that drain into runnels and stepped aqueducts, and river-rock-filled basins or smaller cisterns (Refer to figures 2.2 and 2.3). Eventually, all the runoff water from the roof drain flows into an underground cistern with a 4,000 gallon capacity to store the water for up to 30 hours at a time. While most of this water is released slowly (controlled and operated by a valve) to the city stormwater system, some of the water detained in the cistern is recycled and pumped back up for use in the fountains within the courtyard.

The “chutes and ladders” system of conveying the rainwater on this site is highly intriguing to the viewer. Although benches and courtyard spaces flank this artful rainwater system and provide inward-oriented, relaxing spots, the users of this particular space are primarily compelled to move around to observe the progress of the stormwater from one structure to another (during the occurrence of a major rain-event).

Axial sightlines, geometry, and safety considerations are a part of the concept behind this novel design. Overall, according to the authors’ reviews and observations, the layout and implementation has proved to be a great success by clearly revealing the way the system functions and engages the site users.

However, Echols and Pennypacker find a critical element missing from the design—lack of site structures and elements to improve water quality treatment. The system is primarily designed to convey the stormwater through the varied structures. The travel path—from the building roofs, through the downspouts, and into to the rock basins—intrigue and excite users by telling at least part of the story about the hydrologic cycle. On the other hand, if more elements could have been incorporated for treating the water as it moves, for watering the planting beds with the captured rainwater, for reducing the velocity of water as it infiltrates through planting beds composed of native plants and healthy soils, the design would have been a benchmark for conveying more complete educational understandings regarding rainwater and its associated ecological and cultural functions.

A greater number of stormwater BMPs (such as swales, bio-retention cells, and other elements), placed at strategic points along the system, would have added more to visitor and resident education, and dispelled the question of where the water goes after it secretly enters the cistern and underground detention area beneath the rock basins (see Fig. 2.4). On the other hand, the element of mystery might very well appeal to a good portion of residents and other visitors to the site, and is certainly to be appreciated. Moreover, the recycling of the water back through the building for secondary uses (such as water fountains) might be good reason for the absence of obvious visual elements clearly revealing the destination of the stormwater after the water falls into the rock basins (for safety reasons, it may be better not to reveal how water is recycled).

Figure 2.4 Intriguing system of structures that convey stormwater—10th@Hoyt Courtyard

(Source: Echols & Pennypacker, 2006).

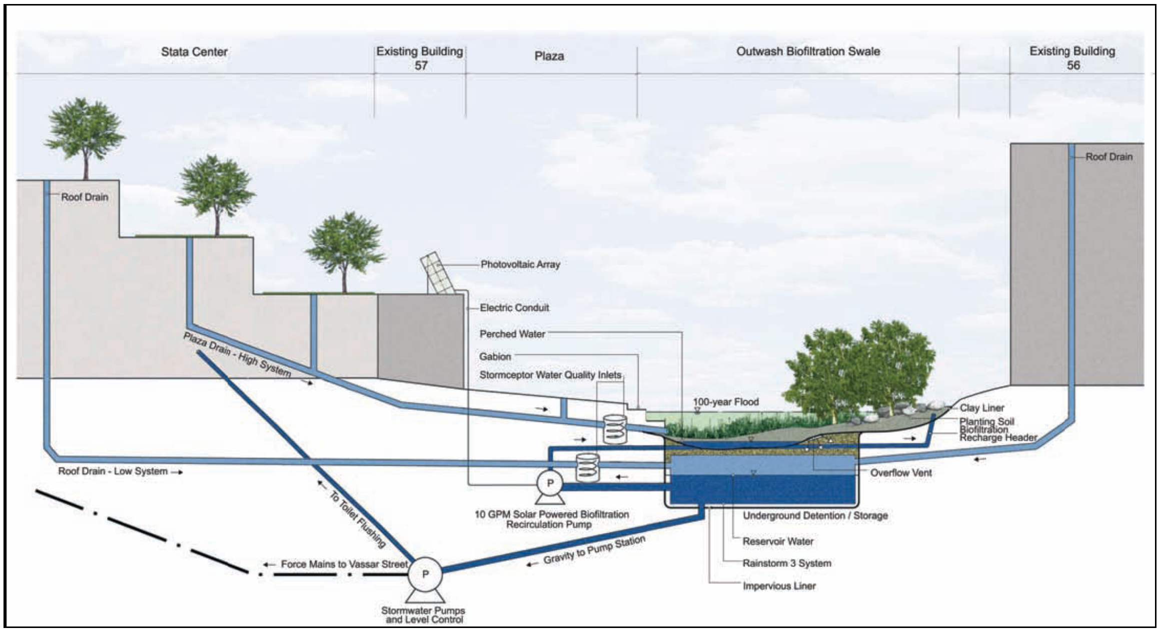
Stata Center Outwash Basin, MIT Campus, Cambridge, Massachusetts

(Case Study #2).

Design by Olin Partnership in collaboration with Judith Nitsch Engineering

The second review is from a stormwater system at the Massachusetts Institute of Technology campus in Cambridge, Massachusetts. This system has a more organic concept to it, and consists of a "river's edge" swale, which is rock-filled and essentially dry, except in the event of very large storms (see Fig. 2.5).

Figure 2.5 Subterranean stormwater management system—MIT's Stata Center (Source: Echols & Pennypacker, 2006).



In direct contrast to the system at 10^{th}@Hoyt Courtyard in Portland (refer to Case Study #1), the Stata Center rainwater system is almost entirely functional beneath the surface. Surface water in the basin is almost entirely invisible except during 100-year storm events. Roof drains convey water directly to the underground detention/ storage chamber, while a network of pipes and conduits convey water directly underground. Recirculation pumps recycle water back up to the surface for reuse in water cisterns and toilets within the buildings, and an impervious layer beneath the subterranean detention chamber aids in storage of water.

Only in the presence of larger storms (for example, 100-year-plus storm events) does the Outwash Bio-filtration Swale carry water above the ground—and when this happens stormwater is readily visible (see Fig. 2.5).

Figure 2.6 Landscape mounds and boulders—MIT's Stata Center
(Source: Echols & Pennypacker, 2006).

The design addresses a variety of stormwater functions such as detention, filtration, and rainwater harvesting. However, the storytelling is not as obvious as it is with the 10th@Hoyt Courtyard design, where stormwater conveyance is clearly revealed Although aesthetically pleasing (Fig. 2.6), the educational element is largely absent in this design project, and visitors are likely unaware of the complex rainwater interactions that occur just beneath the surface.

The steel bridge (Fig. 2.7), the natural edge of the dry river bed, and the native plantings are all elements that give form to this partially naturalized stormwater system. However, the disconnection between site elements that are readily visible and the hidden subterranean elements point to a "backstage effect" for hydrologic processes, where things are not as they seem. Except in the case of larger storm events, this disconnect exists and site users are likely unaware of the stormwater management processes occurring beneath their feet.

Figure 2.7 Steel bridge over the "river"—MIT's Stata Center

(Source: Echols & Pennypacker, 2006).

***Stephen Epler Hall, Portland State University** (Case Study #3).*

By Mithūn and Atlas Landscape Architecture

The final review is from a project implemented at Portland State University in Portland, Oregon. An interesting combination of design elements have been incorporated as part of this stormwater project, a discussion of which follows.

Figure 2.8 Stormwater system layout—Stephen Epler Hall, Portland State University

(Source: Echols & Pennypacker, 2008).

Legend: "1": Sunken basins filled with plants (bio-paddies)

"2": Raised concrete basins filled with river rock

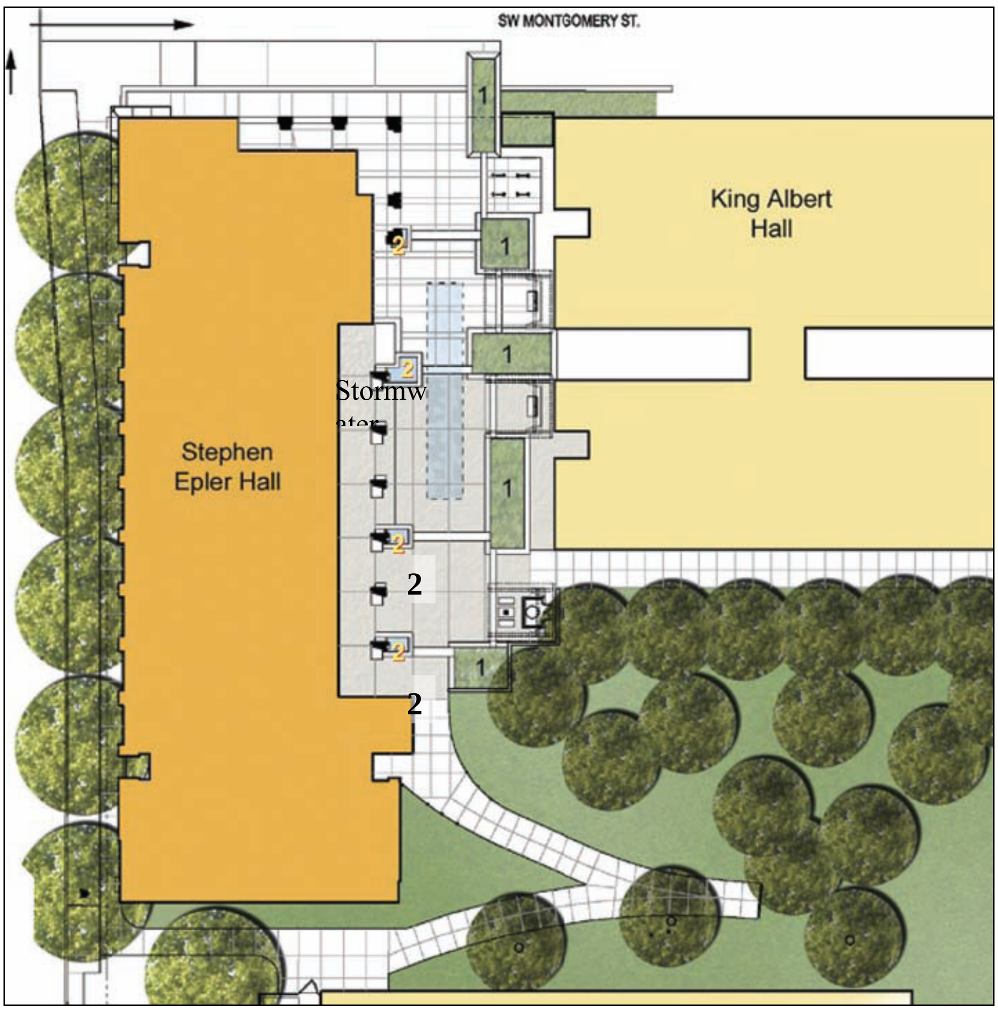


Figure 2.9 A: Picture of rainwater plaza. B. granite runnel and rock basin detail—Stephen Epler Hall, Portland State Univ.

(Source: Echols & Pennypacker, 2008).

A. B.

In the case of the rainwater plaza in Stephen Epler Hall at Portland State University, there is a generous mix of the design/aesthetic element as well as the educational factor concerning the stormwater functions that take place on the site. Similar to design concepts in Case Study #1 (10th@Hoyt Courtyard), there are travel paths for the rainwater that are designated as part of the design. Stormwater flows down via downspouts from the roof and collects in the rock basins located directly below. Thereafter, the water moves just beneath the ground, through surface runnels and empties into the planted basins or "biopaddies." These sunken basins are planted with sedges for water treatment, which help in processing and treatment of the stormwater. All of the basins are laid along a slope (to match the grade of the site), which helps water to drain into the next biopaddy via runnels during times of storm overflow. This way, the plaza stays dry (see figures 2.8 and 2.9).

Such a design is highly educational with respect to all aspects of stormwater function, as well as from an aesthetic perspective. Bio-filtration, phytoremediation, flood control, stormwater conveyance—are functions that the design accounts for and makes readily visible.

Thus far, in addition to a discussion of the context for urban stormwater management, this thesis has provided some insight into the design and aesthetic considerations as evidenced from the reviews of three project case studies. The following chapters of this document provide a review and analysis of a site from a functional perspective, with particular focus on the natural characteristics of hydrology, soils, and vegetation.

Chapter 3—the Literature Review, explores various aspects related to the near surface water cycle, soil structure, function and health, and vegetation. These are essential site components that need to be understood in order for designers and engineers to make better decisions from an ecological planning and design perspective. At the outset, the Literature Review discusses the importance of knowing the bioregional context for a site or project.

CHAPTER 3 - Literature Review — Sustainable Stormwater Management

This chapter reviews site assessment factors (ecological and socio-cultural) as they relate to stormwater management. Functions corresponding with Best Management Practices (BMPs) are also discussed. The descriptions provided are not exhaustive, and are meant as a starting point for referencing resources related to topics discussed in the following sections.

The chapter begins with a discussion of ecoregions since factors at the ecoregion scale (especially macroclimate, physiography, and ecological communities) serve as the context within which ecologically-based stormwater management decisions are made. Site context is then discussed in terms of site location and characteristics. Site variables, which include socio-cultural and ecological factors, are then described in some detail, with a synthesis of ideas provided. Finally, BMP functions are discussed in relation to their tolerance and treatment/uptake ability with regards to specific pollutants and water quality treatment.

Ecoregion and Site Context

The US Environmental Protection Agency (EPA, www.epa.gov, accessed February 2008) defines an ecoregion to "denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources."

The World Wildlife Fund (WWF; www.worldwildlife.org, accessed February 2008) classification defines an ecoregion as "a large area of land or water that contains a geographically distinct assemblage of natural communities that: 1. Share a large majority of their species and ecological dynamics; 2. Share similar environmental conditions, and; 3. Interact ecologically in ways that are critical for their long-term persistence."

According to WWF, the boundaries of an ecoregion approximate the original extent of the natural communities prior to any major recent disruptions or changes. WWF has identified 825 terrestrial ecoregions and approximately 450 freshwater ecoregions across the Earth.

The primary purpose of studying an ecoregion is to gain an understanding of the site with respect to its context. Knowledge of ecoregions aids analysis of the regional characteristics and environmental conditions with which the site is associated.

Regional characteristics

Landscape ecology and ecoregions

In recent times, planning and engineering have lost sight of landscape changes and in many instances; there has been little or no regard for landforms, drainage systems, or ecosystems. Over the past 50 years, urbanization and development have been established using "cookie-cutter" models regardless of the natural diversity that exists as a part of the site and its surrounding landscape. Too frequently, stormwater ordinances were not designed to fit a unique landscape setting, but borrowed from other traditional precedents that are already existent in other areas.

Importance of physiography and ecoregions

Composite patterns of landscape processes define physiographic regions. Ecoregion-level processes operate within a range of systems that include climatic systems, drainage systems, geologic systems, geomorphic systems and other land use systems and processes. An ecoregion, along with its processes and boundaries, is ever-changing and acts upon terrestrial systems across intersecting timelines (Marsh, 1997).

Physiographic provinces

Regional geology sets the structural division for determining these provinces or areas. A physiographic region is larger, with smaller physiographic provinces making up a single region (Craul & Craul, 2006; Marsh, 1997). These regions are defined based upon similar patterns of vegetation, soils, runoff, climate characteristics, etc.

Ecosystem classification

(definitions are adapted from USEPA, 2008).

Level I (USEPA): Level I ecological regions in North America include: Arctic Cordillera, Tundra, Taiga, Hudson Plains, Northern Forests, Northwestern Forested Mountains, Marine West Coast Forests, Eastern Temperate Forests, Great Plains, North American Deserts, Mediterranean California, Southern Semi-Arid Highlands, Temperate Sierras, Tropical Dry Forests and Tropical Wet Forests. This broad classification provides a general sense of macroclimate and vegetation (Fig. 3.1.A).

As briefly discussed in the Introduction, the primary focus of this thesis has been to better understand the interrelationships between hydrology, soils, and vegetation on a site. All these factors are entirely dependent upon and are more readily identified based on the ecoregion to which the site specifically belongs. Climatic conditions, rainfall, and other forms of precipitation and runoff characteristics have a direct influence on the natural processes and functions that occur at the site level.

Level II (USEPA): Level II ecological regions are 50 in number and give a more specific understanding of the ecological context than the Level I ecological divisions. Level II ecoregions can be studied in greater depth at a sub-continental level (Fig. 3.1.B).

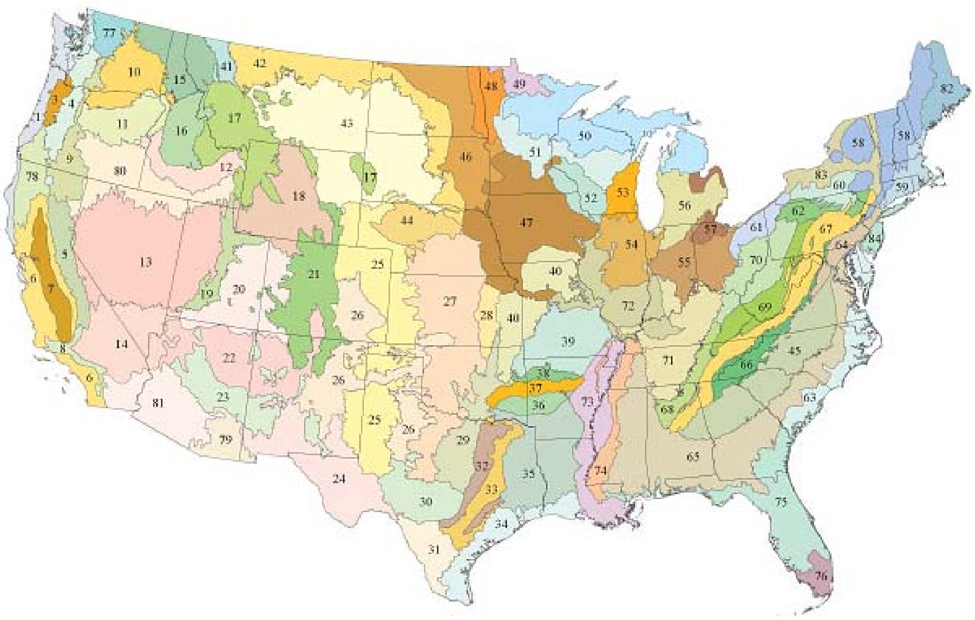
Level III (USEPA): The North American continent is, at present, divided into 182 Level III ecological regions, and the Coterminous United States into 84 ecoregions. Smaller and more detailed, the ecoregions at this level augment decision-making processes at a regional scale. Local ordinances and planning strategies are better defined at this scale (Fig. 3.1.C). Manhattan, Kansas lies within the Flint Hills Ecoregion, an area historically dominated by tallgrass prairie with strands of wooded riparian corridors.

Figure 3.1 Ecoregions of North America

A) Level I Ecoregions, B) Level II Ecoregions, C) Level III Ecoregions (Source: US EPA, 2008).

A) Level I Ecoregions of North America.

B) Level II Ecoregions of North America.



C) Level III Ecoregions of North America.

Site location and local watershed context

Watersheds, subwatersheds, and smaller drainage basins within which a site is located need to be carefully examined. Important characteristics and features that should be considered by designers and engineers include stream/river networks and reaches, major and minor drainage ways, position within the watershed or drainage basin (upper, mid-level, or lower; within the collection zone, conveyance zone, or floodway), regional and local climate (including temperature extremes and monthly rainfall patterns), and existing stormwater management policies and regulations within the state, region, metropolitan area, and/or locality (Marsh, 1997).

For more information on specific hydrological characteristics of a watershed, refer to the 'Hydrology' sections in chapters 3 and 4.

Site characteristics

Land-Use/Land Cover

Knowing what currently protects, renews, or degrades water, soils, and living organisms (plant and animal) is essential to designers and engineers—and that which dominates all other factors is land-use and land cover (including the amounts and locations of buildings, streets, parking lots, parks and natural areas, agriculture, industry, etc.).

Slope and Landform

Caused by differences in soil composition, parent materials, geomorphology, geologic processes, and slopes account for the creation of landforms on a site and strongly influence (and are influenced by) hydrology and vegetation. Deposition and erosion continually alter landforms and slopes (Bloom, 1978), although these processes can stabilized in well-designed urban landscapes.

Slopes and landform are a very important aspect for consideration when planning site-specific stormwater management designs. Stormwater BMPs require careful location and design with respect to slope because of specific functions that may be involved. For example, detention and retention ponds require steeper side slopes (to contain the amount of water desired) and even, flat bottomed slopes. Swales require a slope of 1-2 percent to be most effective for conveyance combined with infiltration.

Aspect

Aspect refers to the direction that the slopes face. This is particularly important for plant selection as well as considerations based on shade and aesthetic effects. Solar aspects that face to the north are typically ideal for creating comfortable outdoor spaces during the summer (in hot temperate climates such as central Kansas) and support a number of different plant species than south-facing aspects. Even minor changes in aspect can make a significant difference in hydrology, soil moisture, and the composition of vegetation.

Stormwater-related Site Variables

Socio-Cultural Factors

Apart from the specific ecological considerations and issues related to hydrology, soils, and vegetation (considered in some depth later in this chapter), there are other site-specific factors and constraints that are important to investigate in relation to each particular project site. The relevance of these factors is specific to each project site and its context.

History of the site, including construction history

The history of the site is a significant factor and needs to be researched. Specifically, alterations to topography, soils, hydrology, and vegetation need to be considered (including use of the site for agriculture or other land management practices that may have changed or disrupted key elements related to stormwater infiltration and surface water runoff).

Construction history is a particularly important consideration for urban sites—and affects stormwater design and planting decisions in terms of soil type, soil disturbance/compaction, and soil properties such as permeability. Knowledge of existing conditions with respect to soil contamination is vital in relation to pollutant uptake and treatment (Craul & Craul, 2006).

Furthermore, use of different construction practices and materials on a site may prompt an analysis of different techniques or types of soil treatment while planning for the site. Knowing the type, magnitude, and number of mining, construction, or other industrial or urban development activities makes a huge difference to designers and engineers. For example, if heavy equipment was used then soil compaction is generally a given and will likely influence the structural and infiltrative properties of the soils involved.

Existing and proposed structures and BMPs

The location of existing structures and buildings (included paved areas for parking, roads, walkways, and other uses) are obviously critical to stormwater planning/design and engineering. Proposals for new buildings on a site and consideration (or lack thereof) of low-impact development (or LID) practices should be carefully studied. Adjacent land uses should also be considered, especially if water flows from these adjacent areas.

If existing structures are located upstream or upslope, and are within the same drainage area, stormwater management plans must account for the hydrological contributions of these features. If a certain design character exists on-site or in the neighboring area, then a closer look at stormwater management procedures associated with these sites and structures may lead to more in-depth analysis and incorporation of a similar set of design strategies for the proposed design (if the existing stormwater management practices are well-suited to the project site) or distinctly different approaches (if existing stormwater management practices are inappropriate in regards to improving water quality and quantity).

Green technologies that support culturally and ecologically appropriate stormwater management in the landscape should be duly considered during the process of planning for the site. Consideration of stormwater management practices that already exist will influence the selection and implementation of stormwater management tools and techniques by evaluating these practices as useful in meeting project goals or not.

Sustainable site development initiatives should be considered, drawing ideas from authors such as Ferguson (1994, 1998), Thompson and Sorvig (2007), Echols (2007), ASLA (2008), and local or regional BMP manuals and databases (for example, see the International Stormwater BMP Database at: www.bmpdatabase.org).

Existing built areas and impervious surfaces could be sources of concern on the site with regards to future development. Retrofits of existing conditions may be necessary before or in company with new design approaches (Schueler, et al., 2007), and retrofits may be mandated for some projects.

For example, the Energy Independence and Security Act of 2007 requires that: "The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet to use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow" (http://www.epa.gov/water/waternews/2007/071231.html).

Future development, utilities, education, and aesthetics

Examples of factors that need to be considered during the design and planning stage for stormwater management on-site include:

- Future structures/buildings, paved areas, and other land use changes influencing the site.
- Utilities (including stormwater lines). Utilities are especially important to consider while planning for stormwater BMPs, particularly BMPs that require excavation depths greater than two or three feet. In some instances, the relocation of utility lines may be cost prohibitive.
- Education and aesthetics. These aspects need to be addressed in designs to make stormwater BMPs aesthetically pleasing and valued to site users as well as to those who responsible to care for them. Echols & Pennypacker (2006, 2008a) suggest including recognizable and aesthetically pleasing visual cues in formulating and implementing designs.

Ecological Factors

A healthy combination of hydrology, soils, and vegetation on a site will sustain well-functioning sites and systems. Since this paper primarily focuses on water quality, an understanding of stormwater pollution and its causes (briefly mentioned in Chapter 2) is particularly relevant. Understanding the interrelations among the natural or ecological site factors (hydrology, soils, and vegetation) contributes to understanding the processes that affect the health of a site. Stormwater functions and processes on a site are affected by each of these factors, and the purpose of the following sections is to focus on and underscore the relevance of each sub-factor in contributing to stormwater management and managing water quality on a site.

As noted in the preliminary report for the Sustainable Sites Initiative: “Water on the site can be managed to imitate natural water cycling, vegetation can be used strategically to cool the area and filter water, and soils can be restored to support healthy vegetation and filter pollutants” (ASLA, 2007, 8). In the recently released *Sustainable Sites Initiative: Guidelines and Performance Benchmarks* (ASLA, 2008, 84), on-site cleansing of water is to be supported by granting sustainability credits or points for effective and ecologically-based on-site stormwater management (see Table 3.1).

Table 3.1 Summary chart of guidelines for on-site water cleansing
(Source: ASLA, 2008).

INTENT	REQUIREMENT
Treat water runoff on-site to improve downstream water quality.	<u>Low point value:</u> Treat 70 percent of average annual runoff volume for the entire site for pollutants of concern.
	<u>Mid-point value:</u> Treat 80 percent of the average annual runoff volume for the entire site for pollutants of concern.
	<u>High point value:</u> Treat 90 percent or more of average annual runoff volume for the entire site for the pollutants of concern OR site performs at the level of the site’s natural ecosystem curve number.
	<u>Additional point(s):</u> Site meets credit requirements using soil- and vegetation-based systems to the maximum extent practicable.

Hydrology

3.1 Hydrology— Physical (Site processes)

Hydrology and infiltration

In general, water infiltrates and percolates into the ground and then flows slowly toward stream channels and finally into wetlands, lakes, or the ocean. Factors that affect the capacity of water to infiltrate include soil permeability and infiltration capacity, soil texture, and extent of compaction due to urbanization processes (Novotny, 2003). Therefore, it is crucial to conserve and maintain the zones that induce groundwater recharge and contribute to a stream's water supply, particularly during the dry weather (McHarg, 1969). Lowering infiltration capacity of the soil can occur because of the removal of vegetation (Ferguson, 1994) for construction purposes, or because of other reasons such as inhibiting soil properties or lack of water in the soil due to, for example, bedrock layer close to topsoil surface or the presence of hard clay pan soil structure (Ferguson, 1994). Furthermore, processes such as soil compaction and exfiltration (the seepage of sewage into water systems or into surrounding soils) can disrupt the drainage processes within the soil layers and thus yield larger storm volumes than existed prior to development (Ferguson, 1994).

In urban areas, an increase in the impervious areas and channelization (straightening of natural channels, reducing surface friction by using smooth channels with concrete lining, and increasing channel depths) increases the efficiency of the water routing systems away from the site so that stormwater runoff rates, temperatures, and flow velocities are dramatically increased. This causes faster accumulation of rainwater in downstream areas which produces high flood peaks and frequently eroding streambanks and downcutting streams.

Detrimental effects of flooding

Increased overbank flooding leads to disruption of life and property in urban areas such as flooding of basements, damage to buildings, property, and infrastructure. Storage capacities of hydraulic structures—pipes, culverts, bridges, etc. are overburdened (Dunne & Leopold, 1978). Furthermore, natural channels are eroded and are enlarged (broadened or deepened) in response to heavy flooding.

Understanding hydrology is central to effectively managing stormwater on a site. Every issue and concern is linked to hydrology, with soils and vegetation also playing a critical role. On-site hydrological functions are described below, in Table 3.2.

Table 3.2 On-site hydrologic functions and values
(Source: ASLA, 2007).

Hydrologic functions and values			
Water supply regulation	Water quality purification	Provision of Biological Habitat	Provision of Recreational Opportunities

1. **Water supply regulation.** When ecosystems are intact, and impervious surfaces minimal, the water cycle (precipitation, infiltration, capture by plant biomass, surface and channel storage, evapotranspiration, and groundwater storage) remains fully functional. Rainfall is transpired and absorbed or adsorbed through the soils and vegetation and is evaporated into the air or enters the groundwater. "For example, at the latitude and climate of Wisconsin, approximately 70 percent of the total annual precipitation evaporates or is transpired by vegetation, 17 percent enters groundwater, and 13 percent becomes stream flow" (ASLA, 2007, 11). However, as the extent of pervious areas decreases on the site with new construction, roads, buildings, and other paving, runoff increases and base flow to the groundwater and water table decreases proportionately (Holman-Dodds et al., 2003).

2. **Water quality purification.** Stormwater runoff treatment and water quality improvement is made possible via filtration and infiltration through vegetation into soils (Ferguson, 1994). Uptake and absorptive abilities of plants and particular soil types and textures are factors considered for necessary hydrological processes like infiltration and pollutant adsorption (EPA, 2008). Treatment abilities are compromised when soil compaction occurs and other soil properties are altered (such as composition or texture changes). These changes in specific site characteristics adversely affect water retention and water quality (Ferguson, 1994, Holman-Dodds et al., 2003)

3. **Provision of biological habitat.** Water provides habitat conditions—on site and in waterways. Water nourishes soils and vegetation in uplands and wetlands. "At least 45,000 described species rely on freshwater habitats, including 12,500 fishes, almost 5,000 mollusks, 5,700 amphibian species, and numerous other reptiles, insects, plants, and mammals" (SSI, 2007, 11). Apart from provision of habitat and cover, water also supplies food and acts as an area for breeding grounds for marine and coastal organisms. Furthermore, on-site hydrological features or presence of water provide environments conducive for non-aquatic habitat and species' growth. Moths, butterflies, hummingbirds, tadpoles/frogs, and earthworms are all indicative of healthy hydrological conditions (Shaw & Schmidt, 2003). When water quality is compromised, habitat conditions can be altered severely (see section on "sources of water quality impairment").

4. **Provision of recreational opportunities.** Fishing and swimming are water-specific sports that healthy streams and lakes can be used for. "Approximately 40 percent of surveyed rivers, lakes, and estuaries were not clean enough to meet basic uses such as fishing and swimming in 1996" (SSI, 2007, 11). On-site wetlands, ponds, and other water features also function as aesthetic elements in the landscape, and serve as spaces for recreation to site users. Hydrological amenities can double as pleasing design features (see section on "artful rainwater case studies" in Chapter 2) and help attract visitors on an everyday basis. Such design elements, while conserving habitat areas and on-site vegetation, also adds intrinsic and economic value to the property.

<u>Urbanization and the Urban Hydrological Cycle</u>

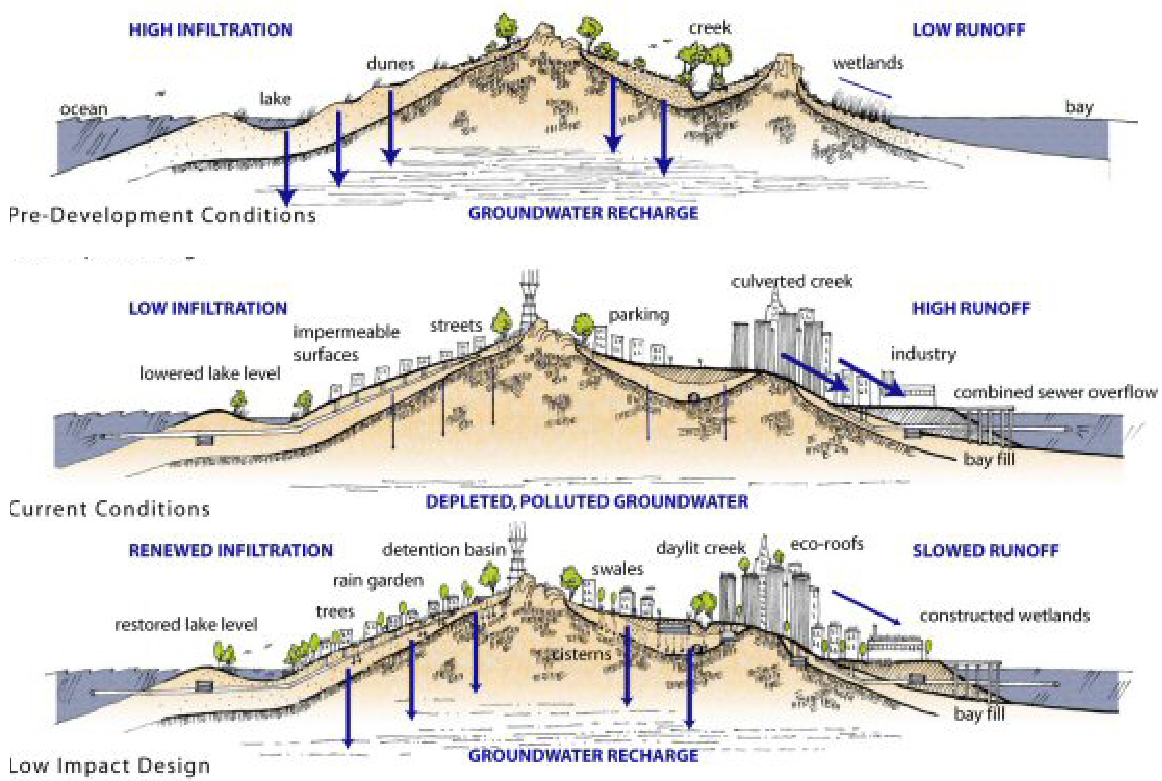
Urbanization and poor land use planning, design, and construction practices have severely affected the natural and biotic integrity of water quality and stream habitat. The correlation of negative effects on a stream or waterbody to the amount of urbanization within its surrounding watershed is readily apparent (Miltner et. al., 2003). Fig.3.2 provides a graphic summary of urban hydrological processes based on three stages of planning:

1. High Infiltration (Pre-development hydrology)
2. Low Infiltration (Post-development and conventional pipes)
3. Renewed Infiltration (Stormwater Management: Low-Impact Development)

Apart from significant increases in runoff quantities created by the amount of impervious cover, modern changes in land uses typically include increased connectivity—the alteration of the conveyance of water by means of piped systems. Recent studies involving roadway and other urban runoff have indicated high levels of pollutants, including heavy metals and suspended solids in stormwater (Davis et. al., 2001).

Figure 3.2 Urban Hydrological Processes

(Source: San Francisco Public Utilities Commission, www.sfwater.org, 2008).

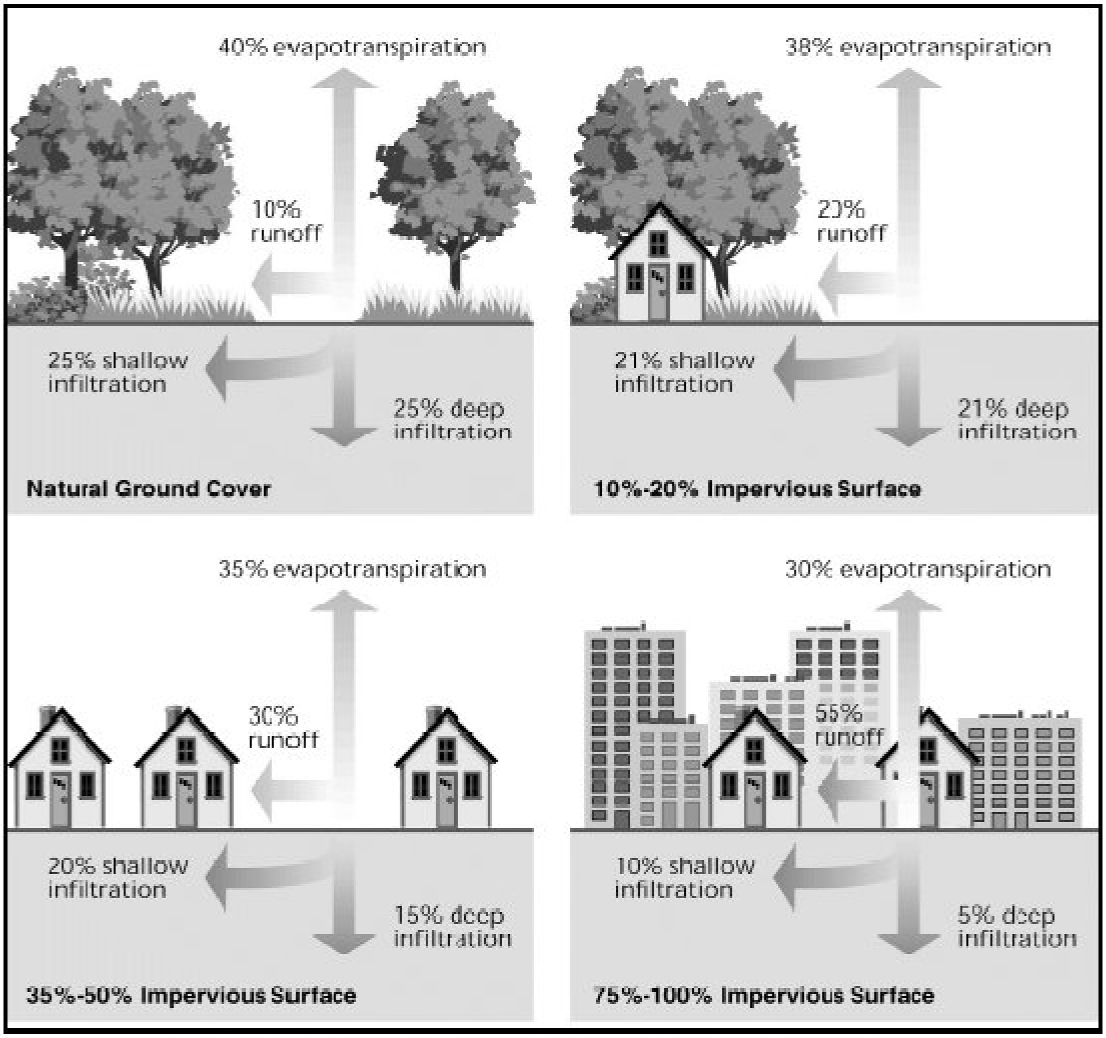


<u>Increase in impervious cover and corresponding effects on stormwater</u>

Research and monitoring effects have constantly reiterated some basic facts about the effects of increased impervious cover in urban areas. As the amount of pervious surfaces decreases, the infiltration capacity of the area also decreases (Ferguson, 1994), and there is a resultant increase in runoff volumes, and correspondingly, an increase in pollutants in the water (EPA, 2008) (see Fig.3.3).

Figure 3.3 Land cover changes and effects of impervious cover on hydrological process and runoff

(Source: Minnesota Urban Small Sites BMP Manual, 2001).



Design storm for water quality

Different rainfall regimes have varying effects on runoff due to stormwater, and on groundwater and recharge. Larger storms with a larger return-interval (for example, 50-year or 100-year storm events) are typically flood-producing events, where the hydrology affected is due in most part to the volume of runoff generated during these large rainfall events. However, in many regions, the percentage of annual rainfall from large storm events is small, and so is their contribution to cumulative pollutant loads (Echols, 2007). This concern has resulted in an emphasis on controlling rainfall runoff from more frequent, smaller (first-flush) rain events since these smaller storm events cumulatively have a larger contribution to annual rainfall, groundwater recharge, and water quality (Roesner, 1991) (see figures 3.4.A, 3.4.B, and 3.4.C). First-flush runoff defined as the volume of stormwater that transports the bulk of pollutants and particulate matter (Echols, 2007), which usually occurs during smaller storms (typically within a two-year return interval).

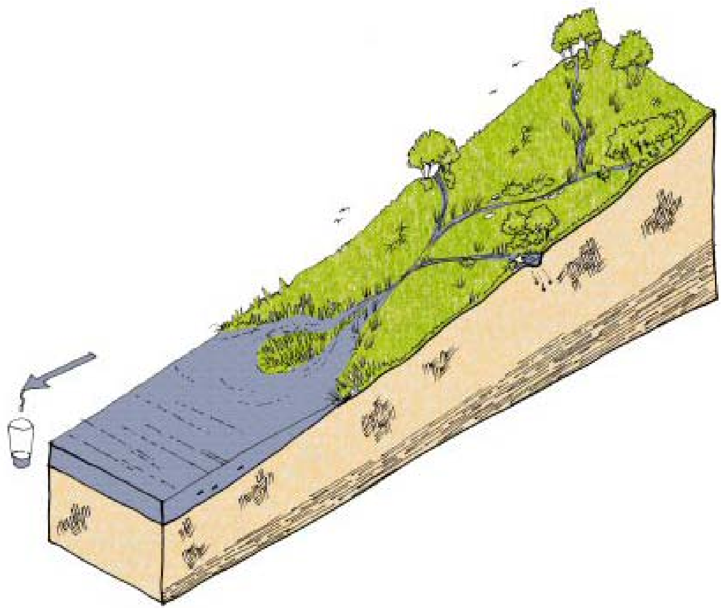
Total volume and peak rates of runoff from the land surface are increased by urbanization and the increased velocities in the channels decrease the lag time between rainfall and runoff. If the lag time of a hydrograph of fixed volume is decreased, the peak rate must increase to keep the volume constant (Dunne et al., 1978) (see Fig.3.5).

Treating stormwater runoff at the source

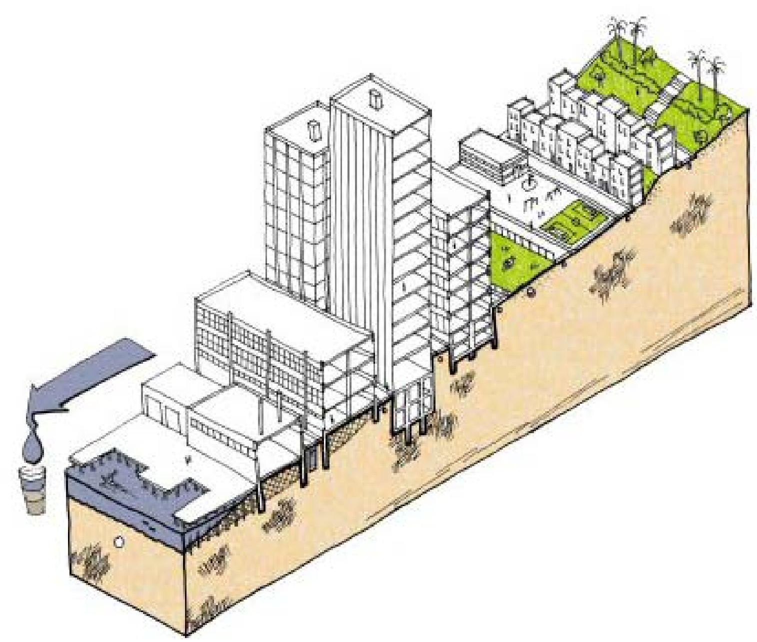
Natural hydrological processes are typically in balance as intact ecosystems manage rainfall through evapotranspiration, infiltration, and runoff. Variation in precipitation levels due to regional and climatic differences may cause distinctions in the way these three processes occur (Ferguson, 1998). However, these variations are, nevertheless, critical to maintaining ecosystem health and biodiversity while keeping natural dynamic processes integral to the site (Ferguson, 1998).

Figure 3.4 Effect of land cover changes on stormwater runoff

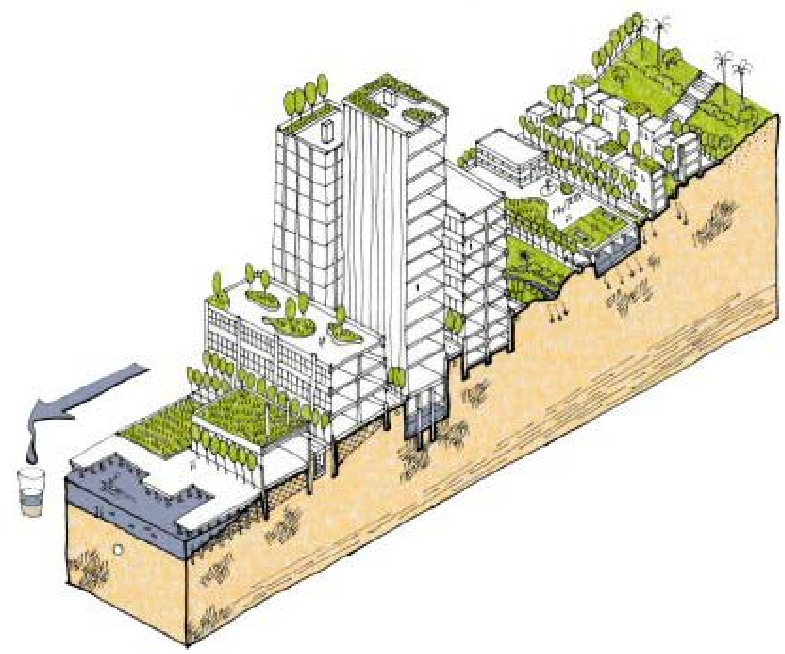
A) Predevelopment conditions B) Post-development conditions C) Post-development conditions with BMPs/LID in place (Source: San Francisco Public Utilities Commission, 2008, accessed at www.sfwater.org).



A) Predevelopment conditions.



B) Post-development conditions.

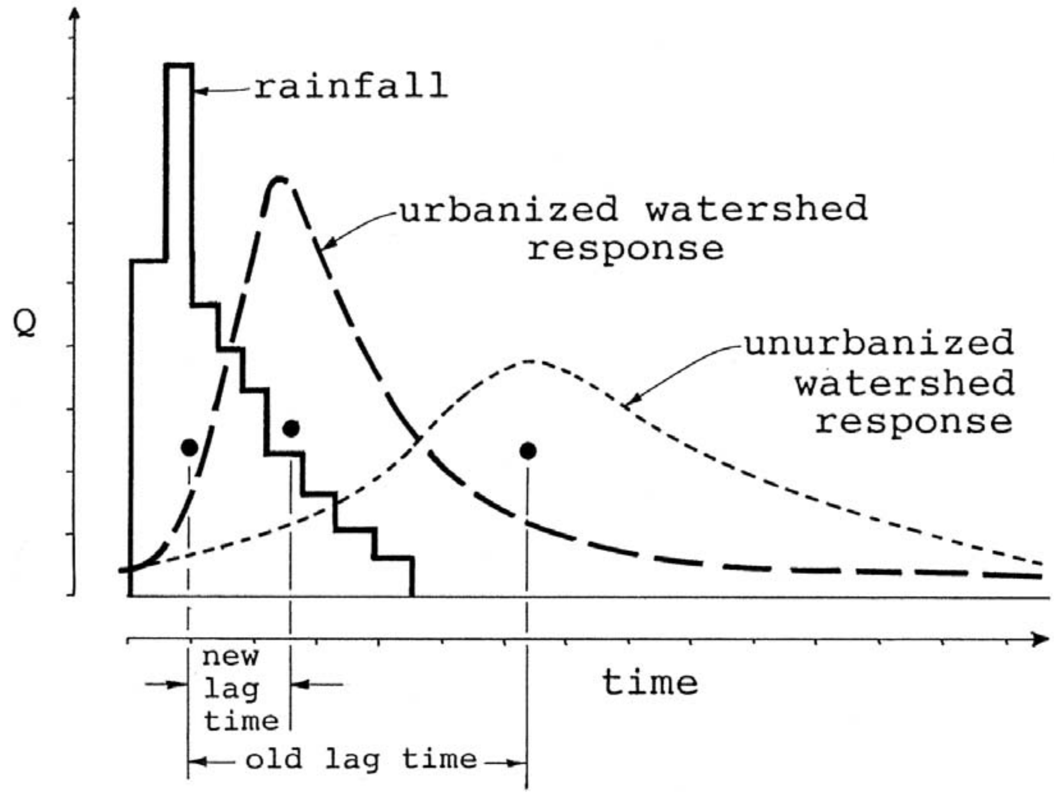


C) Post-development conditions with BMPs/LID in place.

Figure 3.5 Storm hydrograph: peak runoff and changes in lag time

(Before and after urbanization. “Q” denotes the stormwater discharge in cfs)

(Source: Leopold, 1968).



According to Stephens et al., 2007: “Drainage engineers have traditionally thought in terms of flow rates rather than volumes. In fact, at the site level, we need to focus on how much rainfall volume has fallen, how to capture the excess, and what to do with it” (455).

Detrimental effects of urbanization include a decrease in the lag time post-urbanization. Increases in quantities and rates of stormwater runoff are also common. The discharge curve in urbanized streams is higher and steeper for urban streams than for non-urbanized streams due to faster and greater runoff (see Fig. 3.5). Common stormwater management practices include “after-the-fact” treatment methods, when the crux of the issue caused by urbanization is reduced infiltration and ET or evapotranspiration rates, and not excess runoff (Ferguson, 1998). Far from aiding natural processes, urbanization tends to impede healthy ecosystems (Stephens et al., 2007, Echols, 2007). To maintain healthy ecosystems on site and affected water bodies downstream, the most effective method would be to emulate natural processes, and not focus on prevention of localized flooding and protection of property (DeBarry, 2004, Echols, 2007, Stephens et al. 2007).

Land use and density

Changes in land use and density determine runoff characteristics in developed urban areas. Land use and land cover can be mapped using relief overlays, or mapping systems such as GIS (Geographic Information Systems) which can help in making well-informed land planning decisions, both at site and regional scales.

Two aspects of land use, 1) density and 2) surface cover and type (impervious and pervious surfaces), are typically the primary criteria that define the volume and rate of stormwater runoff (EPA, 2008).

Figure 3.6 A: Connected impervious areas, and B: Disconnected impervious areas (Source: EPA, 2008)


A.


B.

In addition to directly connected impervious cover (for example, impermeable parking lots that drain directly to storm sewers and then to streams), the Water Science and Technology Board (WSTB) classifies impervious cover into two additional categories:

1. Effective Impervious Areas are areas that drain directly into the urban stormwater system through pipes and drains, with flow lengths of less than 5 to 20 feet over pervious areas, depending on slope and surface characteristics (Gregory et al., 2005; Sutherland, 2000).

2. Disconnected Impervious Areas (or non-connected impervious areas) are areas that drain into stormwater drains, but travel considerable lengths over pervious surfaces before entering storm sewer systems.

An in-depth discussion of stormwater Best Management Practices (BMPs) based on pervious and impervious areas is provided within sections 3.11 and 3.12 of this chapter.

3.2 Hydrology—Physical (Stream and Structural conditions)

It is critical to understand, at least through visual observances, the state of streams or river channels that are affected by stormwater runoff conditions off a site. Runoff from upland areas affects the volumes, rates, and velocities of water conveyed in water bodies that are impacted by sites. Physical conditions such as structure and morphology are also affected by stormwater runoff rates and volumes.

Channel pattern and structure

Channel conditions such as stream pattern, profile, and dimensions must remain in a balanced state in order for the channel to retain its stability. These channel conditions and stream characteristics, including the state and characteristics of the floodplain, are criteria that need to be studied in relation to streams or waterways. Potential disadvantages resulting from channel modification are listed in Table 3.3.

Table 3.3 List of potential costs or disadvantages of channel alteration
(Source: Dunne & Leopold, 1978).

Potential costs or disadvantages of channel alteration			
Channel instability	Erosion, sediment aggradation/degradation	Change in stream & habitat conditions	Aesthetic degradation and channel alteration

Channel stability and flow, and riparian vegetation

A stable system usually consists of pools and riffles, formed by constant, natural processes of aggradation and degradation and channel topography. Channel patterns vary from (1) relatively straight and non-meandering to (2) ribbon-like, meandering patterns that vary in depths, point bars and sinuosity (curvature and inflection changes) and to (3) braided, individual channel formations separated by islands (Dunne and Leopold, 1978). Slopes, soil and bed conditions, rapid changes in bank cutting, lateral migration (horizontal alteration or movement of the stream) and scouring (or erosion) are some of the aspects that are to be understood while performing a visual analysis of stream and waterbody conditions (Dunne and Leopold, 1978). Comparisons between pre and post-urbanization stream conditions (with the aid of aerial and site photographs and maps) will help in determining, to an extent, the nature and cause of structural changes in streams.

3.3 Hydrology—Bio-chemical (Pollutants, water quality and habitat conditions)

Originally, all water pollution was nonpoint or diffuse in nature. It became "point" pollution when people in urban and industrial areas collected urban runoff and wastewater and brought it, at great expense, to one point for disposal (Gaffney, 1988).

Point sources and nonpoint sources of water pollution

The Clean Water Act categorized different types of pollutants as either point or nonpoint sources:

- **Point Sources** include pipe-borne effluents as well as sources identifiable to their point of discharge.
- **Nonpoint Sources** comprise everything else, from the land, atmosphere and subterranean surfaces, driven by meteorological events and difficult to identify and measure (Novotny, 2003).

Shortly after the conception of the Clean Water Act (and Water Pollution Control Act amendments) in 1972, the implications became far-reaching. Section 208 of the Clean Water Act served to greatly increase land planning efforts, calling for state-wide reports about water pollution levels in lakes, streams, and other water bodies.

USEPA funded several watershed and pollutant modeling tools such as Hydrological Simulation Program—Fortran (HSP-F), Storm Water Management Model (SWMM), Critical Ecosystem Assessment Model (CrEAM). Still, much progress was needed in the water quality arena because penalties for noncompliance and incentives for treatment existed for point sources, but no immediate enforcement tools were in place for nonpoint sources.

In the 1980s, however, enforcement practices and laws changed by the National Urban Runoff Project (NURP), where the research objectives included—

- Research and investigation into the types, similarities, and differences among the various components of urban runoff, analyzed at different urban locations.
- Establishment of evaluation criteria for various management practices related to pollution control as a result of urban runoff (Novotny, 2003).

NURP findings included—

- High concentrations of toxic metals and toxic organic chemicals were present in urban runoff.
- Contamination by coliforms and pathogenic bacteria and viruses were present in urban runoff.
- High quantities of sediment were present in urban runoff.

<u>Sources of water quality impairment</u>

US EPA identifies leading sources of water quality impairment (see Table 3.4). Depending on the type of land use activities, the source and type of runoff affecting different water bodies are ranked accordingly.

Table 3.4 Sources of water quality impairment

(Source: US EPA Water Quality Inventory, 2008).

Rank	Rivers	Lakes	Estuaries
1	Agriculture	Agriculture	Urban runoff
2	Municipal point sources	Municipal point sources	Municipal point sources
3	Stream/Habitat changes	Urban runoff	Agriculture

Table 3.5 Stormwater pollutants

(Source: Adapted from Table 1.1 in Urban Stormwater: Best Practice Environmental Management Guidelines CSIRO, 1999).

Pollutant	**Effect**	**Urban source**
Sediment	Reduces the amount of light in the water available for plant growth and thereby reducing the supply of food for other organisms. Can clog and damage sensitive tissues such as the gills of fish. Can suffocate organisms which live on or in the bed of lakes and streams by forming thick deposits when this suspended material settles out.	• Land surface erosion • Pavement and vehicle wear • Building and construction sites • Spillage, illegal discharge • Organic matter (for example leaf litter, grass) • Car washing • Weathering of buildings/structures • Atmospheric deposition.
Nutrients	An increase of nutrients in water stimulates the growth of aquatic plants. This causes excessive growth of aquatic weeds and algae that may choke lakes and streams and lead to dramatic daily fluctuations in dissolved oxygen levels.	• Organic matter • Fertilizer • Sewer overflows, septic tank leaks • Animal feces • Detergents (car washing) • Atmospheric deposition • Spillage, illegal discharge.
Oxygen demanding substances	Oxygen is used up more quickly than it can diffuse into the water from the atmosphere. The resulting drop in oxygen levels may then be sufficient to kill fish and other aquatic organisms. If all the oxygen in the water is used up, unpleasant odors can result.	• Organic matter decay • Atmospheric deposition • Sewer overflows, septic tank leaks • Animal feces • Spillage, illegal discharges.
pH acidity	Increased acidity damages some plant growth and animals, and may irreparably alter soil conditions.	• Atmospheric deposition • Spillage, illegal discharge • Organic matter decay • Erosion of roofing material.

Micro-organisms	Contain very high numbers of bacteria and viruses. Some of these organisms can cause illnesses, including hepatitis and gastroenteritis.	• Animal feces • Sewer overflows, septic tank leaks • Organic matter decay.
Toxic organics	Can poison living organisms or damage their life processes.	• Pesticides • Herbicides • Spillage, illegal discharge • Sewer overflows, septic tank leaks.
Heavy metals	Poison living organisms or damage their life processes in some other way. Persists in the environment for a long time.	• Atmospheric deposition • Vehicle wear • Sewer overflows, septic tank leaks • Weathering of buildings, structures • Spillage, illegal discharges.
Gross pollutants (litter and debris)	Unsightly. Animals can eat and choke on this material.	• Pedestrians and vehicles • Waste collection systems • Leaf-fall from trees • Lawn clippings • Spills and accidents.
Oils, detergents and shampoos (surfactants)	Highly toxic poison to fish and other aquatic life.	• Asphalt pavements • Spillage, illegal discharges • Leaks from vehicles • Car washing • Organic matter.
Increased water temperature	High temperatures are lethal to fish and other aquatic organisms. Elevated water temperatures stimulate the growth of nuisance plants and algae. This and other effects can lead to decreased levels of dissolved oxygen which can threaten other aquatic life.	• Runoff from impervious surfaces (pavements, rooftops, etc.) • Removal of riparian vegetation.

Table 3.5 (continued). Stormwater pollutants.

Major types of NPS pollution

Urban stormwater is a huge source of excess nutrients (Hogan and Walbridge, 2006), as well as pollutants such as sediment, trash, oil, and grease (Hope et al. 2004, Schueler, 1987). Nonpoint source water pollution can be a result of increased runoff volumes, density in urban areas, removal of vegetation, and sediment accumulation:

- Increased runoff volumes generate greater pollutant loads. For example, "in response to an 18 percent increase in urban area in a watershed near Indianapolis, Indiana, between 1973 and 1991, annual average runoff volume increased by 80 percent, and average annual loads for lead, copper, and zinc increased by more than 50 percent" (Gaffield, et al., 2003).
- Urban development in denser areas may contribute to less runoff than lower density neighborhoods, primarily because construction of these lower density developments disturbs soils over larger land areas, accelerating the transport of sediment loads into downstream water bodies.
- Stripping protective vegetation cover off the soil surface has been found to accelerate soil erosion to a rate of up to 40, 000 times higher than before the soil was disturbed (Gaffield et al., 2003).
- Accumulated sediment can harbor large populations of pathogens, particularly bacteria (Galli, 1991).

Sediment and other debris in water

Although sediment load is a natural character of waterways and stream flow patterns, a "detrimental increase" in sediment loads is defined as that which negatively affects the water quality and habitat contained within the streams (Dunne and Leopold, 1978).

Sediment and other debris concentrations can be assessed through turbidity tests on site and in detail by the use of laboratory tests on concentration levels and amounts. Sediment, upon settling, can smother and reduce survival rate of fish-eggs and bury bottom-dwelling insects (Horner et. al 1994, Schueler, 1987).

Pollutant amounts and concentrations are increased due to varying contributing sources: Pathogens and fecal coliforms are contributed by biological impairment, often from Combined Sewer Overflows (CSOs) or confined animal feedlots (see Table 3.6 listing causes and categories of waterbody impairment). Excess nutrients and sediment are also conveyed by runoff from agricultural land surfaces or large areas of turf grass (where chemicals such as fertilizers are heavily used and erosion is highly likely because of little or no land cover—see discussion on vegetation).

Table 3.6 Categories of Impairment requiring CWA action
(Source: WSTB, 2008).

Cause of Impairment	Number of waterbodies	Percent of the total
Mercury	8,555	14%
Pathogens	8,526	14%
Sediment	6,689	11%
Metals (other than mercury)	6,389	11%
Nutrients	5,654	10%
Oxygen depletion	4,568	8%
pH	3,389	6%
Biological integrity impairment	2,866	5%
Temperature	2,854	5%
Habitat alteration	2,220	4%
PCBs	2,081	3%
Turbidity	2,050	3%
Cause unknown	1,356	2%
Pesticides	1,322	2%
Salinity/TDS/chlorides	996	2%

Habitat susceptibilities

A detailed study of habitat conditions within and surrounding waterbodies and streams would be necessary to make a complete assessment of all the species that are susceptible to adverse habitat alterations, however, typical consequences of channel alteration and stream disturbance add to specific "habitat stressors" within biological systems. Some habitat stressors include: hydro-geomorphic alterations to low-order streams, increases in stream temperatures and flow rates, and channel destabilization (Miltner, et. al., 2003). Such stressors have been found to severely affect biological communities when impervious cover within a watershed reaches 8 to 20 percent and water quality and habitat conditions are irreparably compromised when the percent of impervious cover within the watershed reaches 25 to 60 percent (Novotny, 2003, Miltner, et. al., 2003).

Understanding the effect of a combination of habitat stressors (or factors detrimental to plants and wildlife growth conditions) will help develop regulatory and planning standards for urban streams. For example, some habitat stressors from an analysis of Ohio streams and lakes and fish studies related to susceptibilities are outlined below (Source: EPA, 1988).

- Habitat or hydrologic alteration,
- Industrial pollution,
- Pollution, chiefly organic,
- Limited zoogeographic distribution within the region/state,
- Sedimentation, and,
- Temperature.

Water temperature

Temperature increase is also a negative effect of reduction in pervious surfaces. Urbanization and consequent changes in hydrologic flow patterns, including increased runoff from site surfaces, lead to (1) increase in water temperature due to higher water velocities and flow rates (Hogan and Walbridge, 2006), which, in turn, leads to (2) severe eutrophication and adverse impacts on aquatic life (Galli, 1991).

Thermal impact of urbanization could possibly be sources of degraded environmental quality of water bodies and habitat. High levels of temperature fluctuations are indicated by the effect of several factors:

- Heated runoff from impervious surfaces,
- Removal of riparian vegetation, and,
- Widening of stream channels.

Reduction in groundwater inflow to streams affect water temperature accordingly (Arrington, Ventura, Norman, Roa-Espinosa, 2003). Streams are classified according to position within the reach as well as temperature ranges into three categories:

1. Cold-water streams (less than 21 degrees C), which are typically headwater streams;
2. Cool-water (~27 degrees C); and
3. Warm-water (33-35 degrees C) streams, which are typically downstream reaches (Arrington, et. al., 2003).

Aquatic plant and animal toxicity

Criteria delineated for the protection and conservation of aquatic animals usually protect aquatic plants. In some cases requiring more information about plant susceptibilities to specific pollutants, additional plant testing may be advisable or required for specific BMP vegetation and analyses.

Some chemicals with fairly sensitive plant values are listed below (EPA, 2008; Novotny, 2003).

- Aluminum
- Arsenic (III)
- Cadmium
- Chloride
- Chromium (VI)
- Cyanide, and,
- Selenium (VI).

3.4 Hydrology—Summary of factors

Critical hydrological factors and processes that need to be looked at include:

1. Physical factors
    a. On-site conditions and processes
        i. Type of land cover and imperviousness surface
        ii. Design storms (for water quality and quantity)
        iii. Runoff characteristics, drainage patterns and existing infrastructure, surface infiltration
    b. Stream and structural conditions
        i. Channel pattern and structure
        ii. Channel stability, flow, and riparian vegetation
2. Biochemical factors: Pollutants, water quality, and habitat conditions
    a. Point sources and NPS of water pollution
    b. Sources of water quality impairment connected to land uses
    c. Pollutant types and concentrations

Soils

3.4 Soil history and geomorphology

Understanding the history and geomorphic formations of a site or region through time are important from a planning or design perspective. As such, it is important to have knowledge of the geological substrate as it influences soil processes such as physical and chemical weathering and also impacts the soil structure and thereby, stormwater processes such as infiltration and adsorption.

3.5 Soil physico-chemical properties

In general, soils are made of soil separates such as silt, sand, and clay—which make up the structure and govern the soil texture.

Sand particles form the largest soil separates and range between 2 and 0.05 mm in diameter. Sand particles are classified according to sizes, with the smallest being 'very fine sand' to the largest classified as 'very coarse sand'. Easily eroded by water and wind, sand particles have very little nutrition content in their structure and thus contribute little to plant health, but provide space for air.

Silt, which is smaller in size than sand, has an approximate diameter of 0.05 to 0.002 mm (Harpstead, Sauer, Bennett, 2001). Easily transported by water and wind flows, the process of 'silting in' occurs when the flow stops and the suspended silt material drops down.

Clay has the smallest particles with characteristics that are essentially different from sand and silt in that the structure is sticky and platy (Harpstead et. al., 2001) and it lends the most surface area to the soil.

3.6 Soil properties and stormwater

The following soil assessment factors are based on the soil properties and characteristics relevant to stormwater functions. Available water capacity, infiltration, and chemical factors such as hydraulic conductivity, bulk density, and soil compaction are briefly discussed in the following sections.

Available Water Capacity (AWC) of the soil represents the water which plants can extract from the soil (Winter, 1974). As the soil reservoir decreases, soil suction decreases, soil water potential is reduced, and water is not as readily available for plant uptake. However, these properties vary according to the soil mixtures and composition, as well as vegetative cover and type. With heavy soils such as clay or loam, the total amount of water held within the soil particles is high, but so is the amount of unavailable water (Winter, 1974). For horticultural values, the critical feature is not the water-holding capacity, but the available water capacity of the soil structure.

The influence of soil structure and texture on available water capacity is important to understand. Structure is influenced by a variety of factors: size and shape of particles (as defined by 'soil texture') as well as external matter such as plant root content- which includes dead roots, and additions to the soil such as peat, mulch, manure, etc (Rendig et al., 1989; Winter, 1974).

Water Infiltration Rate is the rate at which water enters a soil (Harpstead et. al., 2001) and is easily ascertained by field tests that include a double-ring infiltrometer (which is a set of two concentric cylinders) thrust into the soil surface. Because water moves laterally as well as downward, this method helps determine only the downward movement of water, where the outer cylinder is kept constantly saturated. Infiltration rate is governed primarily by the soil particle size (texture) (Rendig et. al., 1989); in medium sand, it may be about 600 mm per hour, in a medium loam about 40, and in a clay only about 20 mm per hour (less than an inch).

Hydraulic Conductivity, Bulk Density, and Porosity of a soil influence infiltration rates in the soil. Hydraulic conductivity (or permeability), defined as the mass flow of water within the soil, typically ranges from less than 50 mm per day in a clay up to 10 m per day in a coarse sand soil (Winter, 1974).

Porosity is the ratio or percentage of pore space in the soil (Harpstead et. al., 2001). Weathering, mixing of soils, and loosening by other means are processes that typically lead to formation of pore spaces within the soil structure, and thus provide a place for movement and storage of air and water. The importance of differences in pore spaces is critical to a better understanding of porosity as it influences water movement and infiltration rates. According to Kirkham (2005), and Linden et al (1991), pore spaces that are smaller (between 0.2 and 75 μm) are important for aiding water retention within the soil structure, macropores (between 75 μm and 10 mm) are highly critical to infiltration properties. Macropores drain out water and let air move in (Harpstead et. al., 2001), which helps with retaining pore spaces and osmotic movement of water and air. It is therefore desirable to have proportionate amounts of small and large pores in soils.

Soil Compaction defines how loose or tight a soil is with respect to its density (Harpstead et. al., 2001) and this measure includes both the soil particles as well as the amount of pore spaces among them. During compaction, the amount of pore space is reduced, and the weight of a given volume of soil is increased. Some soils such as clay pan have densely compacted layers that have a high bulk density, which then restricts water movement and plant root penetration (Rendig et al., 1989; Winter, 1974; Harpstead et. al., 2001). Compaction is also caused by other factors such as use of heavy machinery and construction activities such as tamping of soil, that in turn reduce the soil infiltration capacity. Gregory et. al (2006) states that there are drastic alterations in bulk densities of soils irrespective of whether light or heavy compaction occurred. Increase in bulk densities causes significant decrease in infiltration rates and water movement within the soils that were tested. Reduction in topsoil (caused by stripping processes during and after construction) has also been found to severely reduce infiltrative properties of soil and diminishes soil health in multiple ways.

Permeability and infiltration factors are essential while planning for stormwater BMPs and determining soil and vegetation requirements, as they influence the amount of water being held above and below ground. Performing an analysis of the soil characteristics will help in planning for stormwater management as these properties directly influence infiltration and stormwater runoff processes on site.

3.6 Soil health—Soil tilth and Faunal health

Soil health is based on a number of factors including:

1. Humus and other organic content within the soils, particularly in the topsoil layer, plant residue such as dead roots.
2. Soil tilth.
3. Faunal health.

Humus and other Organic Content are often used as indicators of soil health since they play a significant role in soil structure. Pore spaces are maximized by the break up of soil particles, which encourages aggregate-formation- a combination of clay and humus and clusters of mineral grains (Harpstead et. al., 2001). Aggregates are critical to promoting root penetration, and enhancing infiltrative capacity of the soil. According to Harpstead et. al (2001), water storage is greater in well-aggregated soils than in poorly aggregated soils. This is due to the fact that soil has a definitive 'particle-pore' texture that is indicative of looser soils. Therefore, humus promotes water availability in soils. Soil core tests or the use of shovels to assess grab samples will help ascertain the organic layer or humus content within the soil section. Typically, the topsoil layer, which is usually richest in organic matter and nutrient content lies within the top 5 to 20 inches of soil structure (Rendig et al., 1989; Winter, 1974).

Humus content and organic matter can be readily observed through simple visual analysis by examining the top six inches (approx.) of the soil profile. Presence of root matter and other organic debris will help ascertain the soil structure and biota and conditions for vegetation growth.

Organic content, particularly humus content, is also affected by root residue within the soils. Typically, pigmentation of humus is darker in grassland and prairie soils than in forested areas. Moreover, the humus in prairie areas and grasslands is derived from root residue as plants grow and expand their root structure, whereas in forested areas, leaf litter is typically the main contributor to humus content. Humus in grassland soils is greater in content than humus in forests because of greater density of plants as well as the fibrous nature of the roots and residue that is caused by the mix of many different deep and shallow rooted species (Winter, 1974; Harpstead et. al., 2001).

Color is also usually indicative of the nature of humus and chemicals present- such as the quantity and chemical form of iron present. *Munsell color charts* depict the range of colors that are typically used to differentiate between the surface colors. Furthermore, red typically indicates more iron content and less hydration (water content in soil pores). Gray colors indicate wetter, less drained soils. Yellow colors usually mean the soil has less oxidation and are drier soils (Harpstead et. al., 2001). A general indicator is that the darker the pigmentation, the greater the root residue and thus, greater the increase in infiltration and water-holding capacities (Winter, 1974; Harpstead et. al., 2001; Rendig et al., 1989).

Vegetative content such as humus greatly influences the infiltrative capacities within soil particles. Roots break up the soil particles and add macropores which increase water-holding capacity within soil pores.

<u>Soil Tilth</u> is affected by a group of interrelated factors such as texture, porosity, and composition. For effective water infiltration and ease of root penetration, the soil should maintain good soil tilth. Soil tilth can be qualitatively assessed by employing a simple "crumble-test" and if it is determined that the soil has a non-cloddy texture and is not too dry or wet, it can be inferred that the soil exhibits good tilth characteristics (Harpstead et. al., 2001; Rendig et al., 1989). When a soil demonstrates a good level of aggregation, the effect on infiltrative properties and soil health is generally good as a result of increased pore spaces and a mixture of sandy clay within the soil composition. Cloddy soil aggregates is an indicator of high clay content (Harpstead et. al., 2001).

<u>Faunal Health:</u> Soil biota and mycorrhizae are essential for improvement of soil health. According to ecologists and scientists, organisms such as earthworms are considered as important parts of the soil content and are often qualitatively determined using charts and rapid visual species counts. Earthworms and other organisms promote soil fertility by burrowing through the soil (Ransom, Rice, Todd, Wehmueller, 1998). The differences in burrow types give an indication of the type of earthworm species—and also indicate the types of tests that need to be performed within the soil layers. A typical sampling depth in the tallgrass prairie region would be 15 to 20 cm (6 to 8 inches), usually within the topsoil, as this is where organic content would be present (Ransom et. al., 1998).

The greater the diversity of species within the soil, the better is the soil health due to the beneficial attributes of soil organisms, particularly macro-invertebrates, affecting soil fertility and nutrient cycling. Earthworms digest and excrete aggregates and minerals back into the soil profile, which contribute to the organic content and result in increase of macropores. Increase in macropores enhances the water-holding capacity of the soil and soil health in terms of plant growth and root activity, which in turn positively impacts infiltration of water through the soil (Ransom et. al., 1998).

It has been found that earthworms impact in a significant way the rates at which water is transmitted through the soil profile. Results of different studies conducted by Edwards (2004), Shipitalo and Butt (1999), Weiler and Naef (2003) agree on observations of higher rates of water infiltration through earthworm burrows than through the surrounding soil profile and layers.

3.7 Soils—Summary of factors

In conclusion, critical soil factors and processes that need to be looked at include:

1. Physico-chemical
    a. Soil history and geomorphology of the site and region
    b. Soil structure and composition (sand/silt/clay)
    c. Soil properties
        i. Infiltration rate
        ii. Available water capacity, hydraulic conductivity
        iii. Bulk density, porosity, compaction
2. Biological: Soil health
    a. Humus and other organic content
        i. Humus
        ii. Topsoil color
        iii. Root residue and vegetative content
    b. Soil tilth
    c. Faunal health
        i. Earthworms and burrows
        ii. Soil mycorrhizae

Moreover, the key differences between greenfield (undeveloped) and brownfield (urban retrofits or redevelopments) should be noted in regards to soils. Refer to figures 3.2, 3.3, and 3.4 with respect to soil changes or differences in response to:

1. Land use type;
2. Impervious cover (extent and influence); and
3. Post-urbanization soil compaction and soil mixes.

Vegetation

3.7 Vegetation and Land Cover

Land cover is a valid indicator of on-site vegetation and is easy to assess visually. Aerial maps are commonly used to provide a good visual aid to determining the extent of tree growth on site, the amount of impervious cover, and the extent to which stormwater practices might be planned as part of the site and its surrounding features based on existing and proposed vegetation plantings.

A study conducted in Sacramento, California revealed results that clearly indicated the effects of types of tree cover in urban areas (Fig.3.7). Tree types and canopy differences showed corresponding changes in rainfall absorption, and consequently, changes in runoff from the ground surfaces.

Figure 3.7 Role of tree cover in urban areas

(The picture on the right is an older medium-density neighborhood compared to the neighborhood on the left) (Source: WSTB, 2008).

Assessment of vegetation on the site can be two-fold: 1) assessment of existing vegetation types and health, and 2) assessment of stormwater-related site conditions for the planning of vegetation.

3.8. Existing Vegetation and Plant Health

Density and diversity of plant types are important factors for assessing the vegetation on the site. The following sections describe the importance of density and diversity of plant species as they relate to stormwater functions and processes.

Plant Density

According to Holman-Dodds (2006), denser stands of vegetation, especially grasses and forbs, are effective in acting as a physical barrier, and serve as an impediment to the flow of sediments as water travels over the vegetated surface. Furthermore, lack of erosion and soil stability are also indicated by the presence of dense planting—as plants help stabilize soil particles and bind them in place.

Plant Diversity

Diversity within the plant community on the site helps in multiple ways. First, varied vegetation with different root sizes, types, and lengths are beneficial to soil infiltration and organic soil content—differences in water absorption exist, which gives the site with greater biodiversity a much more thorough water and mineral absorption than sites with very little plant diversity (Weaver, 1958). Also, some plants tolerate frequent drying (low water and flood levels) compared to other plant types that take more fluctuations in water and inundation levels. These differences in tolerances reflect on decisions made for different areas on site such as wetlands or uplands. Leaf, fruit, and cambial growth are all suppressed due to flooding in some plants (Shaw & Schmidt, 2003). Although these detrimental effects are commonly associated with plants that are intolerant to flooding, other plants have developed different adaptations to the conditions presented by flooding events; these adaptations include development of adventitious roots and aerenchyma tissue (where the root and stem tissues are permeated with large intercellular spaces for better oxygen transport), and by means of several metabolic adaptations (Shaw & Schmidt, 2003). An in-depth study of on-site flooding history and typical water levels will aid in choosing the vegetation that are tolerant to such conditions.

Frequent, shorter storms have been generally found to be more conducive to maintaining species diversity in created wetlands. Prolonged flooding, on the other hand, has been a major cause of seed and plant mortality, since flooding restricts oxygen availability for emergent plants and their establishment.

On the other hand, prolonged low inundation levels also severely restrict the growth of plants and wetland vegetation. With consistently low water levels, wetland species-emergents and aquatic flora community typically get replaced by perennial grasses and forbs. Huston's (1979) 'dynamic-equilibrium model of species diversity' proposes that higher diversity is found where there exists intermediate levels of disturbance, and low diversity typically exists where high or low levels of disturbance exist (Shaw & Schmidt, 2003).

According to the USDA (1997), an ideal way to assess the health of on-site vegetation is to observe not only the richness and biomass apparent in the existing plants, but to also assess by visual observation, the proportion of dead/dying plants in the area, and the vigor and growth patterns of existing vegetation. A diverse mix of young and mature trees and plants will indicate a balance in the growth and establishment of species on site, which will contribute to better overall health of the vegetation, and hence of the soil and site health.

Although invasive plants may initially increase diversity, invasive species can ultimately reduce diversity and in some cases change the chemistry and hydrology of soils (Patchett & Wilhelm, 2008). For example, as noted by David Chandler (pers. comm., 2008) and others, Eastern red cedar (*Juniperous virginia*) is known to create monocultural stands over a 20-40 year period of time in areas that were previously tall grass prairie, reducing biological diversity and creating hydrophobic soils (soils that shed greater amounts of water across the surface rather than absorbing or infiltrating water due to a change in soil chemistry). Species such as bush honeysuckle (Lonicera sp.) and buckthorn (Rhamnus sp.) frequently shade out grasses and forbs and as a result can also increase surface water runoff and sheet erosion (Patchett & Wilhelm, 2008).

In the case of turf grass areas (prominent in urban and suburban settings), root depths are influenced by management practices. Shorter mow patterns (cutting grass very short) restrict turf grass root depths to a mere few inches, while longer roots result from longer mow patterns (Weaver, 1958).

3.9 Assessment of site conditions for proposed vegetation

Other factors that play a crucial role in planning for vegetation are outlined in the following sections.

Sediment and Erosion

Various studies have generally shown that sediment and erosion are detrimental to plant health. With runoff being the primary contributor of sediment to sites, results from studies have established that the accumulation of sediment and silt over time leads to a decrease in plant productivity (Weaver, 1958; Shaw & Schmidt, 2003). Other studies have shown the detrimental effects on root density (by up to 50 percent) and on seed germination (Shaw & Schmidt, 2003). Species with large seeds were found to have greater resistance to sediment accumulation (Shaw & Schmidt, 2003).

Wetland shrub species as well as native, deep-rooted prairie vegetation have displayed maximum resistance to erosive action of stormwater flows and high velocities of runoff, with some specific Midwest examples being switchgrass *(Panicum virgatum),* big bluestem *(Andropogon gerardii),* indiangrass *(Sorghastrum nutans),* and prairie cordgrass *(Spartina pectinata)* (Shaw, 2000; Shaw & Schmidt, 2003). Such species that are native to the Flint Hills ecosystem should be matched with appropriate stormwater practices on site. *Panicum virgatum* has also been shown to infiltrate water at a significant rate (Bharati, Lee, Isenhart & Schultz, 2002), with a five-year-old planting showing the ability to infiltrate more than 7.5 inches of rainfall per hour (Patchett & Wilhelm, 2008).

Pollutants, Toxins, and Nutrient Uptake

Increasing numbers of studies in phytoremediation and wastewater management are proving more beneficial to expanding our knowledge of the ability of plants to absorb nutrients and pollutants within their structures. Species such as rushes, cattails, and reeds have been found to have pollutant concentrations within their cell structure or plant tissue, with absorption amounts dependent on the plant or root density available for uptake and species ability to absorb these nutrients (Shaw & Schmidt, 2003). In response to increasing concerns on the adverse effects of such high pollutant concentrations on the dependent flora and fauna in the particular stormwater BMP, experiments and monitoring have shown that pollutant concentrations are typically greater in roots than in shoots (Shaw & Schmidt, 2003). This would be a concern for using wetlands and other stormwater BMPs for pollution control where root-foraging wildlife is to be protected from potential harm.

Research at Montana State University shows that plant systems perform more effectively with respect to water treatment when exposed to colder, near-freezing temperatures (Shaw & Schmidt, 2003). Colder temperature treatments (~ 36 degrees F) have been found to remove nitrogen and organic carbon from the water (Shaw & Schmidt, 2003, Weaver, 1958). Species such as bulrushes and sedges are considered to be most effective in nutrient uptake.

<u>Specific urban tolerances</u>

Salt: Several studies have expanded on the effects of salt on plant mortality and adaptation. Some species such as blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) are plants with greater resistance to salinity. Warm-season grasses are found to survive salt from roads. Warm-season grasses germinate late in the season, decreasing the impact of sodium chloride (salt) concentrations due in part to the effect of spring rains (Shaw & Schmidt, 2003). Salt concentrations were recorded as highest within 3 feet closest to the roads, and diminished quickly as the distance increased up to 30 feet. Plant survival was reported to be satisfactory at 10 feet without causing any stress in the plants (Shaw, 2000, Shaw & Schmidt, 2003).

Turbidity: Flooding combined with turbid conditions often leads to plant mortality during and immediately after a storm event, especially with sensitive species requiring clean water for proper survival and growth. Turbidity reduces the functions of photosynthesis in plants by limiting sunlight penetration to the leaves (Shaw, 2000). Fully submerged plants in turbid water declined in numbers rapidly, whereas plants with some parts and leaves above the water surface survived at a better rate. Sediment loading on stormwater systems is a significant source of turbidity in water bodies (Shaw & Schmidt, 2003). A few species such as reed canary grass and cattails have been found to be tolerant of turbid water conditions, and other species should be investigated for their respective tolerances before incorporating them into planting designs for a stormwater management plan.

Apart from the aforementioned stormwater-related concerns and issues that need to be investigated when vegetation is proposed for a site following detailed site and stormwater analysis, invasive species and the potential effect of herbivores and pests should be carefully considered while planning for stormwater management planting plans.

3.10 Vegetation—Summary of factors

Critical vegetation factors and processes that need to be looked at include:

1. Vegetation and land cover
2. Existing vegetation including invasive species and plant health
    d. Plant density
    e. Plant diversity
3. Assessment of site conditions for proposed vegetation
    d. Sediment and erosion
    e. Pollutants, toxins, and nutrient uptake
    f. Specific urban tolerances
        i. Salt
        ii. Turbidity

A discussion of stormwater BMPs follows this discussion of ecological site variables. The descriptions of these BMPs are based on site characteristics and functions as they relate to stormwater processes.

Stormwater Best Management Practices (BMPs)

3.11. A review of stormwater BMPs

Stormwater Best Management Practices (BMPs) are closely tied to functions affected by hydrology, soils, and vegetation. It is important to carefully consider the most appropriate BMP type for a desired location and selected stormwater function, based on existing site characteristics and their appropriateness in addressing water quantity and quality issues.

Typical considerations during the BMP selection process include catchment-specific factors such as soil type (Scholes et al., 2008), available space (EPA, 2008), capacity of BMP to store precipitation and runoff water associated with a design storm event (based on sizing and runoff calculations), cost, operation, and maintenance requirements (Holman-Dodds, 2006, Scholes et al., 2008).

A variety of approaches and guidelines exist for selecting BMPs for a particular site. BMPs are frequently discussed in relation to techniques for achieving Low Impact Development (LID). Selected LID-related websites (accessed January 8, 2009) include:

1. http://www.epa.gov/nps/lid/
2. http://www.cwp.org/
3. http://www.lowimpactdevelopment.org/
4. http://www.wbdg.org/resources/lidtech.php
5. http://greentopeka.org/
6. http://www.artfulrainwaterdesign.net/projects/
7. http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf
8. http://www.portlandonline.com/shared/cfm/image.cfm?id=41627
9. http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/541
10. http://water.lgc.org/urban-stormwater-management
11. http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf
12. www.epa.gov/owow/nps/lid/costs07/documents/reducingstormwatercosts.pdf
13. http://www.co.san-diego.ca.us/dplu/docs/LID-Literature-Index.pdf
    http://www.epa.gov/owm/mtb/living_machine.pdf
14. http://www.toddecological.com/ecomachines.html

Pollutant-removal potentials for specific BMPs are rarely used as the sole criteria for BMP selection; however, pollutant-removal is an important factor for consideration. When considering specific pollutant-BMP interactions, the descriptions of several BMPs are outlined below (descriptions adapted from Holman-Dodds, 2006, Scholes et. al., 2008). For additional discussions of stormwater BMPs and the Low Impact Development approach to stormwater management refer to Jones (2004; http://www.cenews.com/article.asp?id=211). In selecting the appropriate BMP to address watershed and site-specific stormwater management concerns, it is important to understand the purpose or goal of each BMP.

- ***Cisterns and rain barrels:*** Containers used to capture and hold a portion of precipitation (especially off rooftops).
- ***Filter drains:*** Graveled trench systems where stormwater can drain through the gravel to be collected in a pipe, unplanted.
- ***Porous asphalt:*** Open graded powdered or crushed stone with binder, high void ratio, no geotextile liner present.
- ***Porous paving:*** Continuous surface with high void content, porous blocks or solid blocks with adjoining infiltration spaces, an associated reservoir structure provides storage, no geotextile liner present.
- ***Filter strip:*** Grassed or vegetated strip of ground that stormwater flows across.
- ***Vegetated swales:*** Vegetated broad shallow channels for transporting water.
- ***Soakaways:*** Underground chamber or rock-filled volume, stormwater soaks into the ground via the base and sides, unplanted.
- ***Infiltration trench:*** A long thin soakaway, unplanted.
- ***Infiltration basin:*** Detains stormwater above ground which then soaks away into the ground through a vegetated or rock base.
- ***Sedimentation tank:*** Symmetrical concrete structure containing appropriate depth of water to assist the settling of suspended solids under quiescent conditions.
- ***Retention ponds:*** Contain some water at all times and retains incoming stormwater, frequently with vegetated margins.
- ***Detention basins:*** Dry most of the time and able to store rainwater during wet conditions, often a grassed surface.

- ***Extended detention basin:*** Dry most of the time and able to store rainwater during wet conditions for up to 24 hours, grassed surface and may have a low basal marsh.
- ***Lagoon or sediment basin:*** Pond designed for the settlement of suspended solids, fringing vegetation can sometimes occur.
- ***Constructed wetlands:*** Vegetated system with extended retention time.
  - Sub-surface flow (SSF): Typically contain a gravel substrate, planted with reeds, through which the water flows.
  - Surface flow (SF): Typically contain a soil substrate, planted with reeds, over which the water flows.

3.11. BMP Processes and Specific Removal Functions

Structural BMPs can be classified according to their fundamental unit processes such as settling, phytoremediation, adsorption, etc. Tables 3.7.A., 3.7.B, and 3.8 all illustrate these processes and functions according to function, type, and pollutant and vegetation characteristics.

The tables below list the relative potential of each BMP to remove the pollutant under consideration. Depending on the pollutant mechanism to: 1) directly remove the pollutant from the water column, or 2) indirectly contribute to the removal of a pollutant, the pollutant removal processes into two categories (Scholes et al., 2008).

1) Direct removal
    a. Adsorption to substrate
    b. Settling
    c. Microbial degradation
    d. Filtration
    e. Volatilization
    f. Photolysis
    g. Plant uptake
2) Indirect removal
    a. Precipitation
    b. Adsorption to suspended solids

1. Adsorption to substrate (or adsorption to suspended solids)

Adsorption to substrate refers to the physico-chemical adherence of pollutants to an artificial substrate (for example, the gravel matrix of a filter drain), a natural substrate (for example, vegetation within a swale) or an introduced substrate (for example, sediment deposited within a detention pond) (Scholes et al., 2008).

Substrate adsorption is influenced by factors such as the particulate surface area and surface composition.

BMPs listed below are most suited to the substrate adsorption process because of the close contact between stormwater and substrate surface during infiltration (Scholes et al., 2008):

- Filter drains
- Porous paving
- Sub-surface flow (SSF) constructed wetlands
- Infiltration basins
- Soakaways
- Infiltration trenches

2. Settling

Settling is defined as the vertical movement of suspended sediment particles to the base of a water column (Ellis et. al., 2004, Scholes et al., 2008) and is influenced by retention time of quiescent water volume within the BMP system (Scholes et al., 2008).

BMPs listed below are most suited to the settling process because of the extended retention time and higher volumes and surface areas (Scholes et al., 2008):

- Retention ponds
- Infiltration basins
- Extended detention basins

3. Microbial degradation

Microbial degradation is assisted by the availability of nutrients and “attachment sites” within a BMP, and where aerobic and anaerobic processes are enhanced by a high level of contact between stormwater and substrate material (Scholes et al., 2008).

BMPs listed below are most suited to the microbial degradation process because of the diversity of microbial attachment sites and prolonged contact of stormwater with microbial population (Scholes et al., 2008):

- SSF constructed wetlands
- Infiltration basins

4. Filtration

Filtration processes operate by the mechanism where a physical sieve facilitates removal of pollutant particles as they pass through a porous substrate or hydraulic barrier (Scholes et al., 2008).

BMPs listed below are most suited to the filtration process because of surface filtration and low pore size of surface material or sieve (Scholes et al., 2008):

- Porous paving
- Porous asphalt

5. Volatilization and Photolysis

The processes of volatilization and photolysis are both influenced by surface exposure and are only different in that volatilization requires direct exposure to sunlight, whereas photolysis can occur from the open spaces or pores within a BMP structure (Scholes et al., 2008).

BMPs listed below are most suited to the photolytic degradation process because of large surface areas and associated retention times, slow infiltration into surfacing material, and unrestricted exposure of stormwater to sunlight (Scholes et al., 2008):

- Filter strips
- Swales
- Infiltration basins
- Retention ponds
- Detention basins
- Extended detention basins

BMPs listed below are most suited to the volatilization process because of optimization of stormwater exposure times and surface area exposure to wind or ambient pressure differentials (Scholes et al., 2008):

- Extended detention basins
- Detention basins
- Retention ponds
- Infiltration basins
- SF constructed wetlands and swales

6. Plant uptake

Presence of terrestrial or aquatic vegetation provides a medium and potential for plant uptake processes to occur (Scholes et al., 2008), and therefore is non-existent in BMPs without any vegetation.

BMPs listed below are most suited to the plant uptake process because of high pollutant bioaccumulation by cell tissue and increased contact between stormwater and the root systems of terrestrial and/or aquatic macrophytes (Scholes et al., 2008):

- SSF constructed wetlands
- SF constructed wetlands

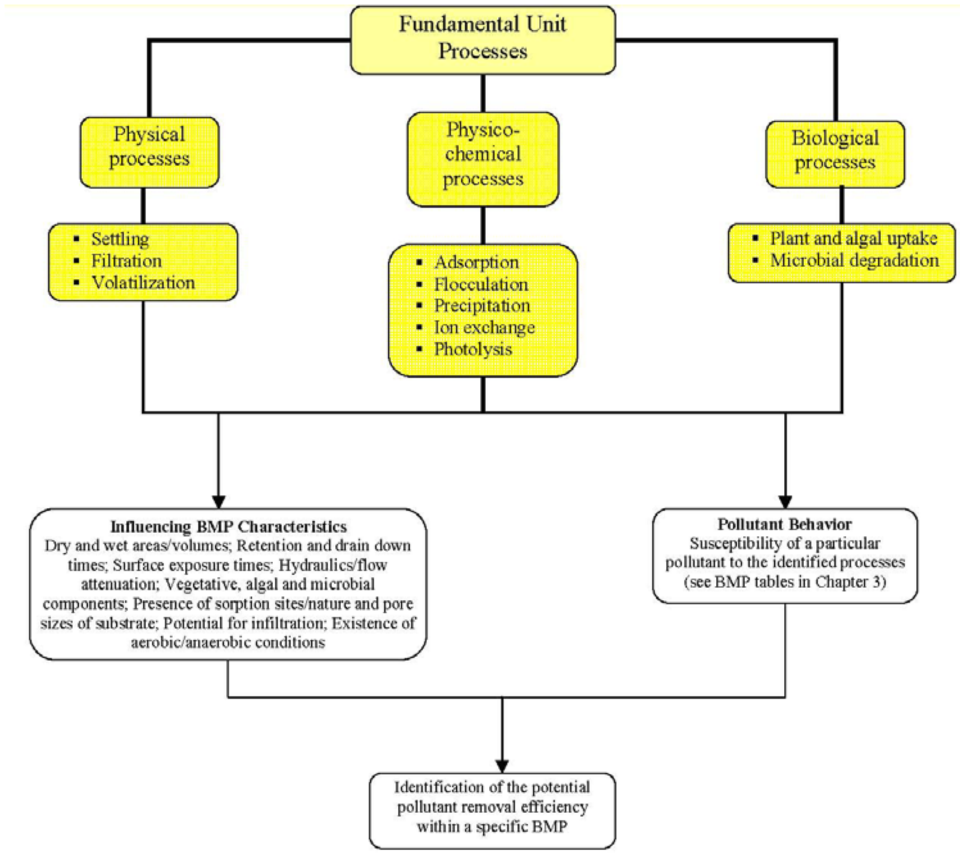
7. Precipitation

Precipitation is mainly influenced by temperature variations and/or chemical composition of water. Still, as opposed to turbulent water conditions facilitate the ease of precipitation as a pollutant removal process (Scholes et al, 2008).

Fig.3.8. is a summary diagram illustrating the various stormwater processes that have been discussed in previous sections in relation to BMP characteristics.

Figure 3.8 Fundamental unit processes in relation to BMP characteristics & pollutant behavior

(Source: Scholes et al., 2008).



3.12. Relative importance of pollutant removal processes in BMPs.

Scholes et. al (2008, 4) initiated the prioritization approach and designated relative importance of each removal mechanism within specific BMPs in the following ranking and priority:

1. High importance (considered as a dominant removal process within the BMP),
2. Medium importance (a process that contributes significantly to overall BMP pollutant removal capability),
3. Low importance (a process that makes a relatively small contribution to pollutant removal, or
4. Not applicable (a process that is not relevant to a particular BMP function).

Table 3.7 Relative importance of specific stormwater processes in BMPs

A) Substrate adsorption, settling, and microbial degradation processes, B) Filtration, Plant uptake, Volatilization, Photolysis processes.

(Source: Scholes et al., 2008).

BMPs	Substrate adsorption	Settling	Microbial degradation
Cisterns/rain barrels	NA	Med/high	NA
Filter drain	Med/high	Low/med	Med
Porous asphalt	Low/med	Low	Low
Porous paving	High	Low/med	Med
Filter strip	Med	Low	Low/med
Vegetated swales	Med	Low/med	Low/med
Soakaways	Med/high	Low/med	Med
Infiltration trench	Med/high	Low/med	Med
Infiltration basin	High	High	High
Sedimentation tank	Low	Med/high	Low
Retention ponds	Low/med	High	Med
Detention basins	Med	Med/high	Low/med
Extended detention basin	Med	High	Med
Lagoons/sediment basin	Low/med	Med/high	Low
Subsurface flow (SSF) constructed wetlands	Med/high	Med	High
Surface flow (SF) constructed wetlands	Med	Med	Med

A) Substrate adsorption, settling, and microbial degradation processes.

BMPs	Filtration	Plant uptake	Volatilization	Photolysis
Cisterns/rain barrels	NA	NA	Med	High
Filter drain	Med	Low	Low	NA
Porous asphalt	High	NA	Low	Low
Porous paving	High	Low	Low	NA
Filter strip	Low/med	Med	Low/med	Low/med
Vegetated swales	Med	Med	Med	Low/med
Soakaways	Med/high	Low	Low	NA
Infiltration trench	Med/high	Low	Low	NA
Infiltration basin	Med/high	Low/med	Med	Low/med
Sedimentation tank	NA	NA	Low	Low
Retention ponds	Low	Low	Med	Low/med
Detention basins	Low	Low	Med	Low/med
Extended detention basin	Low	Low	Med	Low/med
Lagoons/sediment basin	Low	Low	Low/med	Low
Subsurface flow (SSF) constructed wetlands	Med/high	Med/high	Low/med	Low
Surface flow (SF) constructed wetlands	Med	Med	Med	Low

B) Filtration, Plant uptake, Volatilization, Photolysis processes.

Table 3.8 Potential for BMP processes to remove TSS, BOD, COD, nitrates, phosphates, and fecal coliforms

(Source: Scholes et al., 2008).

BMPs	TSS	BOD	COD	Nitrates	Phosphates	Fecal coliforms
Adsorption	Med	Med	Low/med	Low	High	Med
Settling	High	Med	Med	Low	High	High
Microbial degradation	Low	Med	Low/med	Low	Low	Low/med
Filtration	High	Med	Med	Low	High	High
Volatilization	NA	Low	Low	NA	NA	NA
Photolysis	NA	Low	Low	NA	NA	Low/med
Plant uptake	NA	Med	Low/med	High	High	NA

While NPDES regulations and other EPA and local/regional water quality standards exist to promote water quality in urban areas, there is frequently limited information and time available to meet the exact required measures satisfactorily. With availability of more reliable monitoring and experimentation techniques in stormwater applications, there has been an increase in education and implementation of sustainable, site-specific strategies in the planning/design/engineering projects. Evaluation matrices such as seen in tables 3.7.A., 3.7.B., and 3.8 could be expanded further to include scoring methods and then used as tools for facilitating better design and engineering stormwater management for any site.

SSWESA and Eisenhower Middle School site application

The discussion on Hydrology, Soils, and Vegetation and the final SSWESA framework is the primary instrument utilized in the Site Application. The following chapter (Chapter 4) is a detailed discussion of the site application of SSWESA and the proposed stormwater management design.

CHAPTER 4 - Synthesis and Site Application

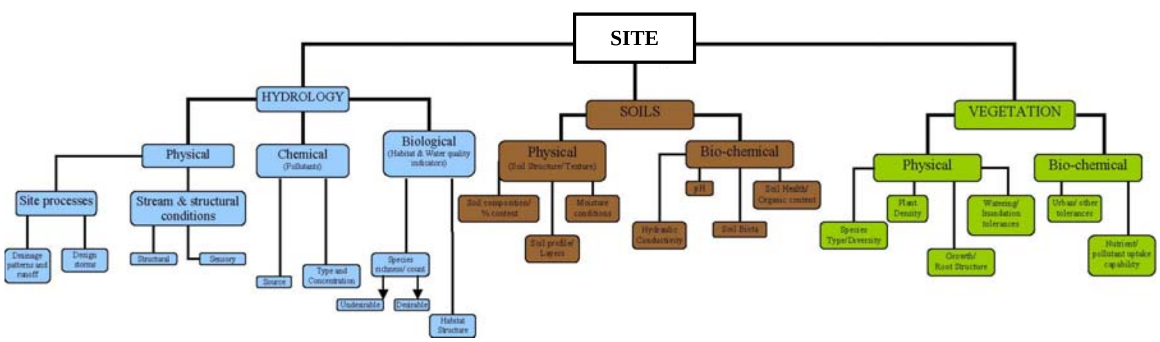
Synthesis: The SSWESA Framework

The following sections provide a review of points discussed in the literature review. The SSWESA framework is the primary product of the research, and site application and design details are based on conclusions realized from this assessment. The guidelines listed on the initial pages of this chapter summarize important steps within the assessment process (Fig. 4.1 is a graphic representation of the SSWESA framework).

Figure 4.1 SSWESA Framework.

SITE/ DRAINAGE AREA/ WATERSHED CHARACTERISTICS
[Size ___________ (acres)]

LAND USE/COVER	IMPERVIOUS FACTOR	HISTORICAL & OTHER SITE FACTORS
☐ Residential ___(%) _____________ (ac.)	☐ < 10% (Natural/ near-natural conditions)	☐ Geomorphic history
☐ Light commercial___(%) _____________ (ac.)	☐ 16-25% (Mild impervious)	☐ Antecedent moisture/ flooding conditions
☐ Agricultural ___(%) _____________ (ac.)	☐ 26-75% (Medium—medium-high impervious)	☐ Environmental/ecological conditions & history
☐ Wild/ Natural area___(%) _____________ (ac.)	☐ >75% (Highly impervious)	
☐ Water ___(%) _____________ (ac.)		



The SSWESA framework is hierarchically explained below:

1. **Socio-cultural factors and site context**
    a. ***Ecoregion and watershed characteristics***
    b. ***Land use/land cover***
    c. ***Impervious factor***
    d. ***Historical and other site factors***
2. **Site-specific ecological factors**
    a. ***Hydrology***
        i. Site hydrology
            1. Physical
            2. Chemical
            3. Biological
        ii. Stream or water body conditions
            1. Physical
            2. Chemical
            3. Biological
    b. ***Soils***
        i. Physical
        ii. Biochemical
    c. ***Vegetation***
        i. Physical
        ii. Biochemical

Guidelines for assessment of site factors: Site Context

Determine which **ecoregion** the site is located in and seek to understand and document key information about the **climate, geology, land use history, and the types of soils, vegetation, and ecosystems** that exist within the ecoregion and how these elements and systems relate to the site. Study and make notes on **watershed size and characteristics**, including **surface water and land cover interrelationships**. Look particularly at the following factors:

1. Map **land use/land cover** (noting areas, sizes, and type of land cover and vegetation) on and in areas immediately surrounding the site. If off-site areas do (or are projected to) contribute stormwater runoff to the site, map land use/land cover for these areas.
2. Estimate percent **impervious cover** (study existing materials and surfaces and note areas and level [degrees] of imperviousness) for relevant on- and off-site areas.
3. Note areas that form **mini-watersheds** or **drainage areas** on or near the site (i.e., streams or other water bodies, storm inlets, surface drains, etc.).
4. Note **existing stormwater management tools and techniques being used in surrounding areas** (including storm drains or inlets, ditches, vegetated swales, wetlands, naturalized areas and their composition, detention and retention areas, ponds, bio-retention areas, etc.). Note, map, and evaluate sources of runoff from off-site areas that likely influence stormwater movements and water quality on the site.
5. Use **regional climatic and rainfall data and maps** to estimate total stormwater runoff and rates/velocities for the storm event(s) to be designed for.
6. Note existing **utilities and infrastructure** on or near the site, particularly those elements/features that would likely influence on-site stormwater management.

Guidelines for assessment of site factors: Hydrology

Analysis of hydrological conditions: (Refer Fig. 4.5)

1. Note **existing stormwater management tools and techniques on the site** (including storm drains or inlets, ditches, vegetated swales, wetlands, naturalized areas and their composition, detention and retention areas, ponds, bio-retention areas, etc.). Note, map, and evaluate **all sources and movements of runoff on-site**.

2. As applicable, study on-site or adjacent **stream structure**, and note changes in recent history, particularly since development of urbanized conditions. Specific stream measurements such as pool/riffle count, sinuosity, and channel dimensions can often help in classification and analysis of stream structure and pattern.
3. As applicable, observe and document **detrimental changes to aquatic habitat and water quality**, both visually and through other methods such as test samples. Erosion, excessive sedimentation, algae growth, foul odors or turbidity, the absence of log jams and similar structures are indicators of loss of habitat and water quality.
4. As applicable, record **water temperatures**, accounting for seasonal and diurnal variations, at sources of runoff and resultant temperatures in water bodies or stream reaches. Classify and attribute reasons for observed temperature changes.
5. As applicable, identify, with the help of visual aids and charts, a cross-section of **macrophytes and macro-invertebrates** in the water. Average the results over a few collected samples or areas within the reach. Refer to citizen science protocols for testing water quality.
6. Isolate and classify the **water quality and quantity impacts** according to the existing hydrological conditions in the water, and try to pinpoint the sources of the issues and problems/concerns identified. Identify and list all existing and potential effects on stormwater quality. Note: **Detailed lab-tests and scientific analysis** can also help with the field tests and observations in determining factors for analysis such as macro-invertebrate species count and richness and pollutant concentrations. Some of the field samples should be tested and/or assessed in different seasons. For example, during winter, there is rarely baseflow present in streams, so gauge samples should be taken after every thunderstorm, and these samples should be monitored regularly (weekly, monthly, and on an annual basis—as often as time and budgets allow). Similarly, pollutant discharges often increase tremendously immediately after a water quality storm event (usually 1-year or 2-year storm over a 1-hour period).
7. **Perform a final summary analysis of all hydrological conditions studied, examined through field observations, and realized through lab tests and/or measurements. Note potential ways to address these effects or concerns.**

Guidelines for assessment of site factors: <u>Soils</u>

<u>Analysis of soil conditions:</u> (Refer Fig. 4.12)

1. Understand and study (using soil maps and USDA-NRCS websoil survey data viewer tools) the **existing soil conditions and classifications**. Recognize that for many urban sites, especially where development activities have occurred or altered, or where farming activities have been previously undertaken, that soils have been altered. The type and level of disturbance to soils is a critical factor which must not be overlooked.
2. From the soil structure, content, and soil profile analysis, identify **critical soil properties** (for example, hydraulic conductivity, infiltration rates, pH, etc.) and corresponding functions and values that need to be considered for planning for handling and treating stormwater.
3. **Soil cores and infiltration tests** can be used to document existing site conditions, and are especially important if sites have been previously developed or disturbed.
4. Make an assessment of **soil health** by observing variables such as root/organic residue in the soil, indicating areas of water puddling or low points on the site, existing floristic biodiversity and macro-faunal health, etc.
5. Identify and list all existing and potential effects on **soil permeability** (infiltration capacity) according to the existing soil conditions on the site, and try to pinpoint the sources of the issues identified.
6. **Perform a final summary analysis of all soil conditions studied, examined through field observations, and realized through lab tests and/or measurements. Identify and list all existing and potential effects on stormwater quality. Note potential ways to address these effects or concerns.**

Guidelines for assessment of site factors: <u>Vegetation</u>

<u>Analysis of vegetation conditions:</u> (Refer Fig. 4.14)

1. Document visually apparent conditions such as **plant density** and **species types**. Note physical stratification (horizontal layering as well as vertical layering). Note maturity in age and/or size/width/height of dominant or important species.

2. Document plant or vegetation **biodiversity** by recording species present and noting the approximate **percentages of dominant species among native and invasive** vegetation on the site.
3. Identify and list all **existing and potential effects** according to the existing vegetation conditions on the site, and try to pinpoint the sources of the issues identified.
4. **Perform a final summary analysis of all the vegetation conditions studied, examined through field observations, and realized through lab tests and/or measurements. Identify and list all existing and potential effects on stormwater quality. Note potential ways to address these effects or concerns.**
5. **Match plant palettes native to the ecoregion according to critical stormwater characteristics observed on site (including soil type, drought and soil moisture tolerances, tolerances to standing water, sun/shade tolerances and conditions, pollutant tolerances, and pollutant uptake capability).**
6. **In accordance with the issues and concerns identified with hydrology and soils analyses, match concerns regarding on-site vegetation and proposed vegetation (for example, provision of shade trees to reduce and moderate water runoff temperatures, sedges to help with phytoremediation/pollutant uptake, etc).**

In general, there are typically two types of sites for which design and planning are developed, “greenfield” and “brownfield” sites:

1. Greenfields: these are undeveloped sites where virtually no construction has taken place, but where agricultural practices may have occurred (including plowing, clearing and harvesting of vegetation and the creation of drainage tiles and/or ditches).
2. Brownfields: sites that have been previously developed (with roads, buildings, and/or other urban infrastructure).

Both types of sites can be prime locations for the implementation of urban stormwater retrofits to mitigate the negative effects of urbanization and corresponding stormwater effects.

Site Application of SSWESA for Improved Water Quality—

Eisenhower Middle School in Manhattan, Kansas

Methods

While SSWESA is generally applicable for any site with relation to its stormwater functions and processes, the framework is more amenable to working with urban retrofits, such as the Eisenhower Middle School site in Manhattan, Kansas.

A site was chosen to apply the SSWESA framework and look at design possibilities *and* to help integrate stormwater management practices on the site. The goal is to propose effective strategies for optimizing Best Management Practices (BMPs) at the site-scale. Since this thesis paper primarily focuses on BMPs for water *quality*, an appropriate design storm event was chosen, and the SSWESA framework was applied to analyze the natural site variables—hydrology, soils, and vegetation—and the interactions among them.

Although the SSWESA framework is broad enough to be adapted and then applied to any site, a deeper understanding of site-specific processes and hydrological background is essential to analyzing the connections among stormwater variables that occur on a particular site. A closer look at these natural stormwater variables or factors is made possible by working on an area that is part of a larger, encompassing watershed. The Eisenhower Middle School site (hereafter referred to as EMS) is over 30 acres in size and is sufficiently complex to explore a range of site conditions and to also propose some design guidelines for stormwater BMPs.

Background information

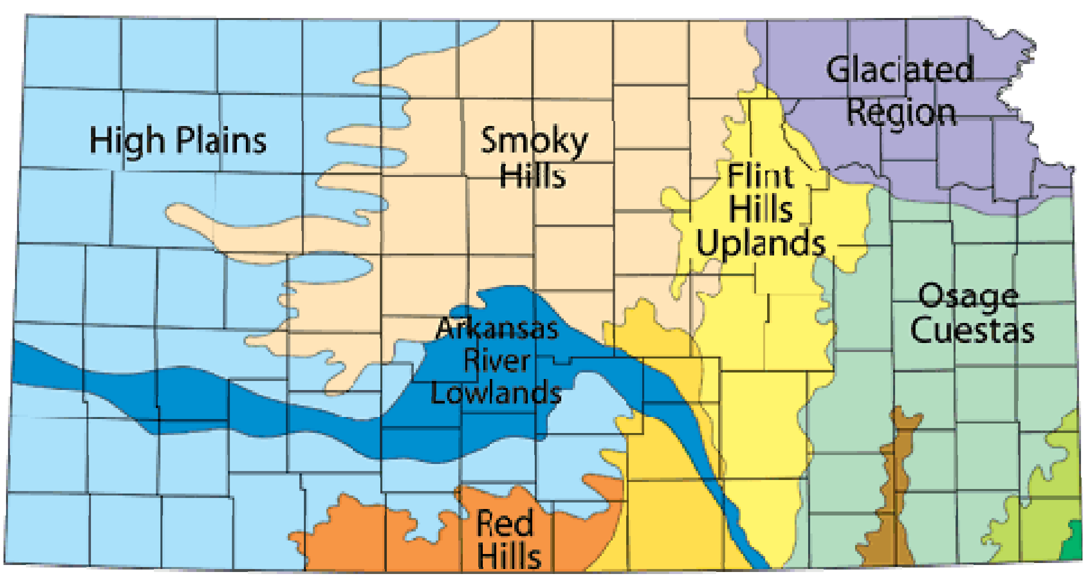
Ecoregion

The site lies within the Flint Hills Ecoregion which is part of a diverse prairie system. The following characteristics are particular to this ecoregion (as described by the EPA and shown in Fig. 4.2). [See: http://www.epa.gov/wed/pages/ecoregions/ksne_eco.htm]

> Physiography: Undulating to rolling hills, cuestas, cherty limestone, and shale outcrops. Perennial streams and springs common.
>
> Geology: Cherty and clayey residuum. Interbedded cherty Permian limestone and shale. Some limited glacial drift in the northeast corner of region.
>
> Potential Natural Vegetation: Tallgrass prairie: big bluestem, little bluestem, switchgrass, and Indiangrass.
>
> Land Use and Land Cover: Rangeland with extensive cattle grazing. Some limited areas of cropland agriculture along the river valleys and in areas with little relief.

Figure 4.2 Ecoregions of Kansas and the Flint Hills ecoregion

(Source: www.kansasnativeplantsociety.org, February 2007).



Urban Use and History

EMS is located south of Marlatt Avenue and is approximately 31.4 acres in size. There are a variety of land use types and urban land cover types surrounding the site. As a traditionally designed public school property, the middle school and its grounds are a favorable location for a public demonstration of stormwater planning/design strategies.

Encompassing watershed and surrounding land use patterns

Marlatt Waterway is a channel that runs on the south side of Marlatt Avenue, beginning at the intersection of Tuttle Creek Boulevard and Marlatt Avenue and ending where the channel crosses under Casement Road to the south and east (refer to Fig.4.3 for location map). Marlatt Waterway carries stormwater runoff from two separate watersheds: North Watershed and Stadium Watershed. There are several reaches within each watershed identified on regional and area maps (see Fig.4.4). The headwaters of the Marlatt Waterway are in the North Watershed, while the outlet into the Big Blue River is in the Stadium Watershed (HWS, 2007a).

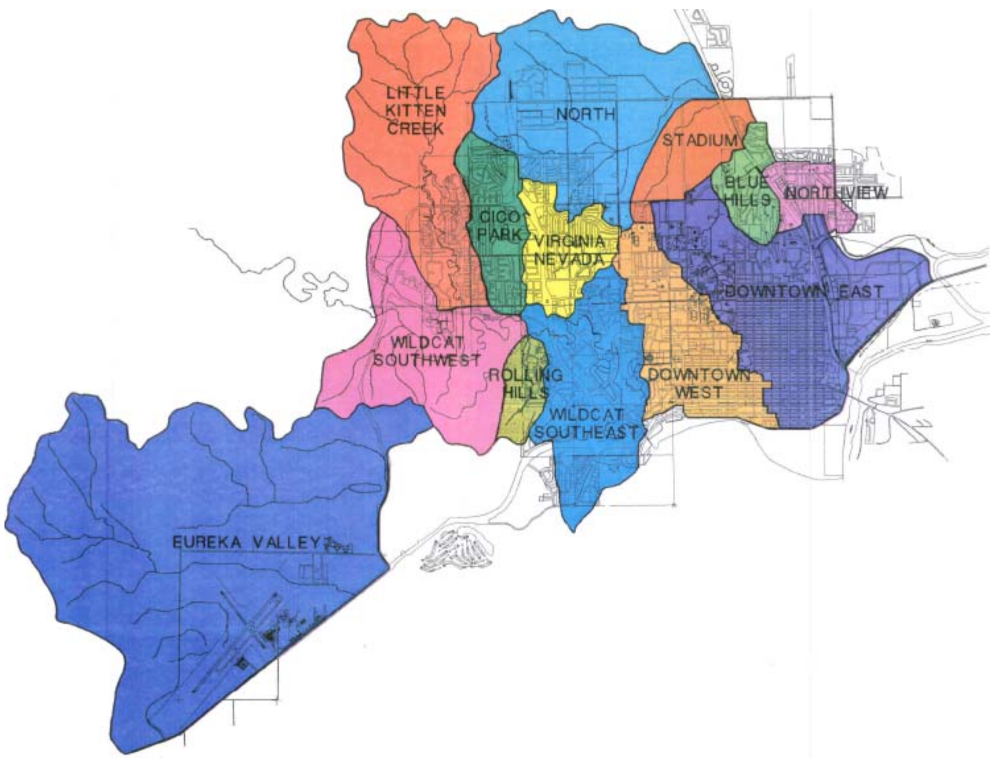
Figure 4.3 Eisenhower Middle School site location map

(Source: Provided by Jen Hancock, HWS, February 2007).

Stadium Watershed

The drainage area for the Stadium Watershed covers 614 acres (0.96 square miles). Its headwaters are located on the south side of Kimball at the KSU Stadium parking lot, extending further north and east to Casement Road and Marlatt Avenue. Land cover within this watershed includes roadways, parking lots, agricultural fields (both row crops and pasture), and structures of various sizes. Presently agricultural and urban runoffs enter the Marlatt Waterway.

Figure 4.4 Marlatt Waterway watershed map
(Source: HWS, February 2007).



Current land use within the two contributing watersheds

Current land use of the two contributing watersheds is mostly under agriculture and owned or managed by Kansas State University. As indicated by the Comprehensive Land Use Plan, agriculture is likely to be continued in the near future, although the comprehensive plan is zoned for residential and neighborhood commercial development west of College Avenue.

Immediately adjacent to Marlatt Waterway along the south side of Marlatt Avenue is a residential development and Eisenhower Middle School. There is very limited commercial business in the area. Slopes within the two watersheds are typically flat (less than one to two percent) but there are some rolling hills with five to ten percent slopes. In contrast, the EMS site is generally very flat, with slopes ranging from less than one to two percent.

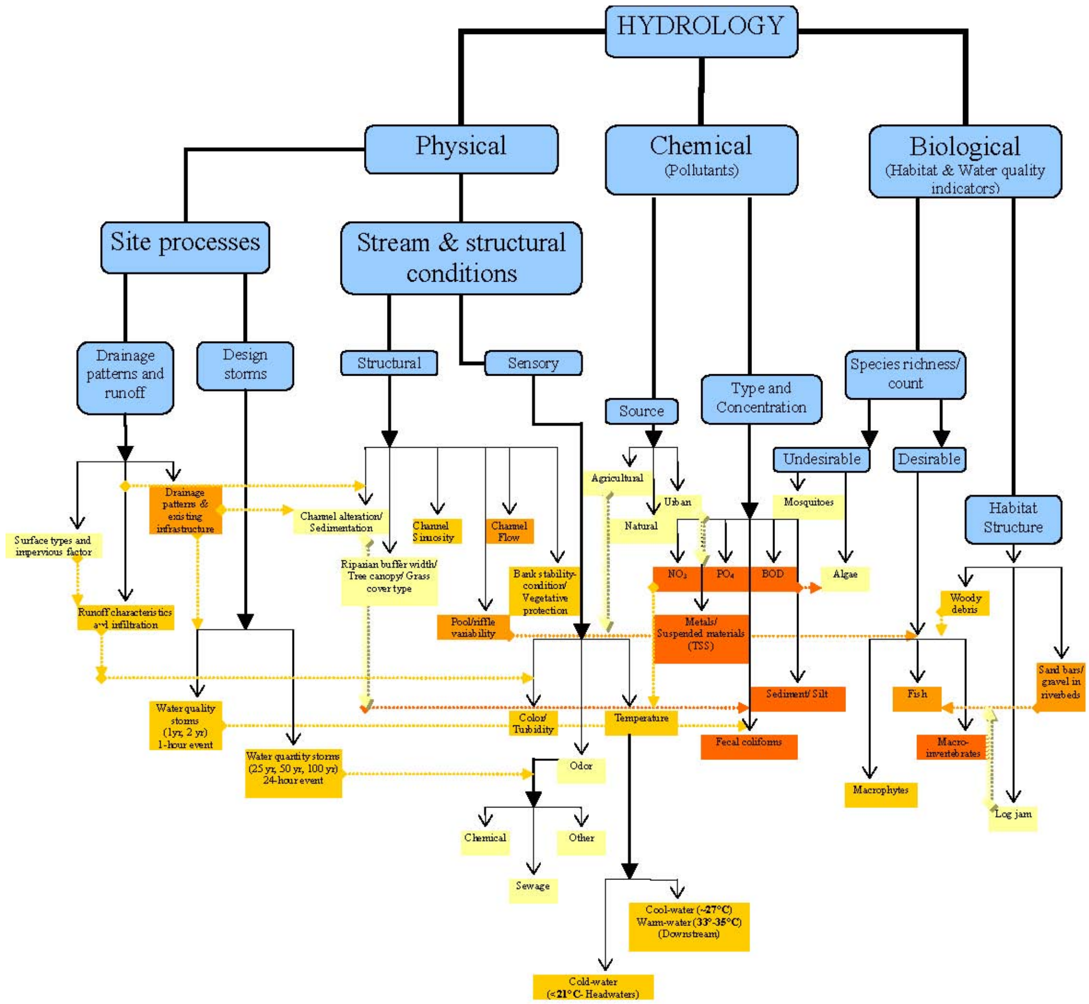
SSWESA—Hydrology

The following section includes descriptions of the hydrology relating to the EMS site and a discussion of the Marlatt Waterway. Much of the information about the Marlatt Waterway is drawn from the *Stormwater Management Master Plan* (*SWMMP*), prepared by HWS (2007b). HWS, in association with the City of Manhattan, authored the SWMMP document which is based on drainage reports from 1995.

A SSWESA analysis of hydrological factors related to the Marlatt Waterway is provided first since this discussion indicates why stormwater retrofits are needed within the contributing watersheds. A SSWESA analysis of hydrological factors on the EMS site is then presented.

Figure 4.5 depicts the SSWESA framework related to hydrology. A general note about SSWESA analysis charts will be helpful for the reader: The colors indicated within the text boxes represent the expected difficulty level for planners and designers (ranging from light yellow to dark orange). The darker the color, the greater is the need for specialized expertise and testing, which should preferably be carried out with consultation of engineers and ecologists. To complete a preliminary or rapid assessment of a site, the factors indicated with a light yellow color can be readily be examined, and if needs be, further detailed tests can then be conducted. For example, knowledge about runoff sources and non-point source pollution literature would give some idea about the types of pollutants found in the stormwater runoff; however, further testing will probably be required to pinpoint specific pollutant types and concentrations.

Figure 4.5 Hydrology analysis chart—SSWESA



Marlatt Waterway drainage patterns

The 1995 *SWMMP* and drainage report data indicated the following: the Marlatt Waterway had more than adequate capacity for the existing peak flows; no reports of drainage problems were received from residents within the area; and, other potential inadequacies (such as erosion, channel degradation, reduction in water quality) affected few, if any, homes or businesses in the area, considering the small amount of development in the two watersheds (HWS, 2007b).

Marlatt Waterway was analyzed under steady-flow conditions at 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year storm intervals, “to determine where the channel capacity currently fails" (HWS, 2007a). From the data collected, it is evident that three of six reaches within the Stadium Watershed (including Marlatt Waterway—refer to the highlighted part of Table 4.1) have less carrying capacity than a ten-year storm (usually the recommended minimum storm event to be designed for in order to protect stream-morphology conditions).

Table 4.1 Existing system performance—Stadium Watershed

(Source: Adapted from Table IV-27 from SWMMP drainage study, HWS, 2007).

REACH	CAPACITY	PEAK FLOWS					
NO.	(C.F.S.)	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
12000	3600	1257	2080	2780	3886	4508	5259
12003	2324	1250	2067	2761	3862	4484	5229
12005	61	25	44	59	82	101	120
12010	450	21	38	52	72	89	106
12015	1191	161	281	380	532	659	792
12020	132	110	184	244	333	406	482

As reported in the *SWMMP*, information for Reach 12003 (adjacent to EMS) describes pertinent peak flow values for this section of the Marlatt Waterway. According to Table 4.1, Reach 12003 has a carrying capacity of **2,324 cubic feet per second (cfs)**. Peak flow for a 100-year 24-hour design storm is **5,229 cfs**. Based on this information, the waterway is currently able to handle smaller storms based on its capacity (the 2-year and 5-year storms). However, the 10-year storm event (which typically influences stream morphology), and larger floods such as the 50-year or 100-year events, have a detrimental effect on the stream (HWS 2007a). The take-home lesson is that there is an overwhelming need to handle and treat water at the source of runoff specific to individual sites such as the Eisenhower Middle School property.

Existing watershed and channel conditions (HEC-RAS analyses)

The hydraulics within the Marlatt Waterway was modeled using the HEC-RAS (Hydrologic Engineering Center – River Analysis System).

Station and elevation data for the profiles were assigned by HWS using LiDAR (Light Detection and Ranging) in conjunction with QT (Quick Terrain) Modeler from the City of

Manhattan (see Figs. 4.6, 4.7 and 4.8). Boundary lines were approximated by HWS using survey data and plat information, and helped determine the areas of ineffectiveness, and overflow areas within the site. From station profiles and dimensions, LiDAR data helps analyze single-dimensional models such as sections and elevation data for the purpose of looking at channel patterns, thus helping engineers and designers identify problems related to water quantity.

Figure 4.6 Marlatt Waterway LIDAR images (aerial map)
(Source: HWS drainage reports, 2007).

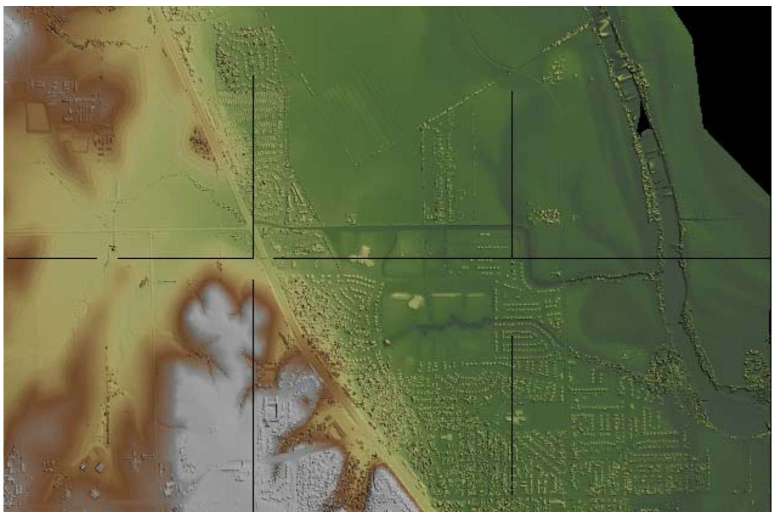


Figure 4.7 Marlatt Waterway LiDAR images (EMS in the background, looking downstream from an aerial perspective)
(Source: HWS drainage reports, 2007).

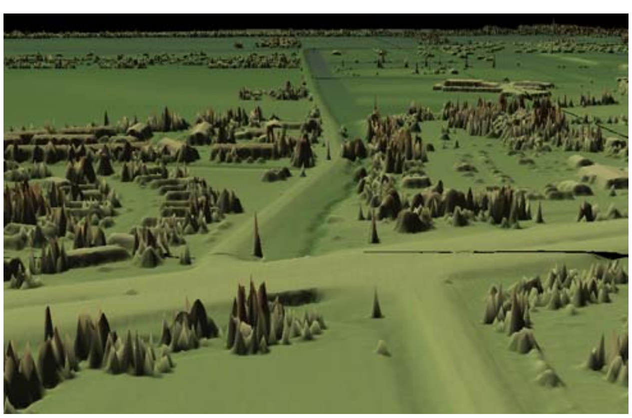
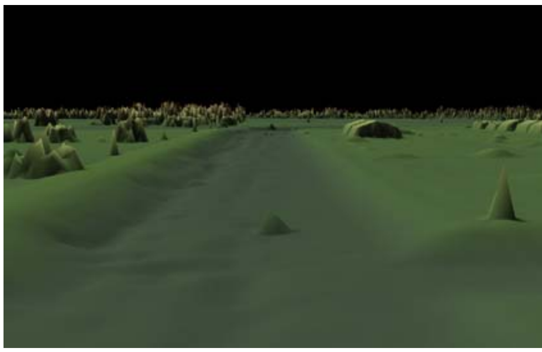
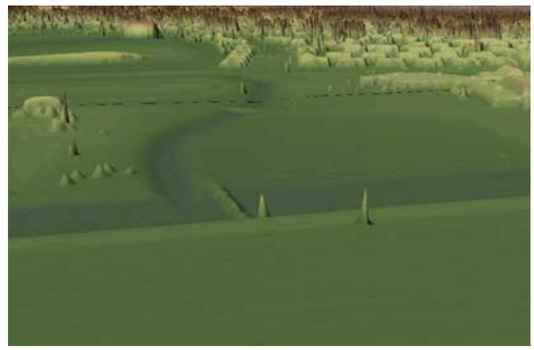


Figure 4.8 Marlatt Waterway LiDAR images

(A: Looking east, downstream. B: Aerial image of EMS site, looking south, with the middle school building at the upper right). (Source: HWS drainage reports, 2007). Note: Information provided is based on 100-year simulation; darkened areas are projected water levels with a 100-year storm event.


A.


B.

HWS found, from the data analyses of the waterway that three types of situations exist:

1. Flow occurs outside the streambanks and outside the drainage easement.
2. Flow occurs within the streambanks but outside the drainage easement.
3. Flow occurs within the streambanks and within the drainage easement.

These flooding events are important to understand in relation to the EMS site because the resulting channel conditions and poor water quality create a habitat where invasive species such as the troublesome reed canary grass (*Phalaris arundinacea*) thrive, and where water is pushed into the drainage swales on or adjacent to EMS. Although reed canary grass is used by wildlife for nesting and escape cover, helps control erosion, and has good nutrient uptake (USDA-NRCS 2002; http://plants.usda.gov/factsheet/pdf/fs_phar3.pdf) it creates monotypic stands of vegetation and is very difficult to control. It has also been shown to reduce the abundance of some small mammal populations (http://www.winona.edu/NAPC/Abstracts/Bade_Abstract_Bade.pdf), a number of which prefer native wetland vegetation.

The following points provide a summary of the post-urbanization conditions of Marlatt Waterway.

Physical (stream) conditions

As can be seen in the images below (Fig. 4.9: Images 1-6) the existing channel displays the following characteristics:

1. The channel is almost perfectly straight, due to excessive down-cutting and channelization (refer to images 1 and 2). This reduces channel sinuosity (essential for a more diverse habitat and stream structure, including diversity in stream velocity and rates of flow).
2. Has a low rate of flow, causing excessive sedimentation further downstream and resulting in braided channels (refer to image 3), incised banks, high turbidity, and increased flooding. The area south of the waterway is frequently prone to flooding due to channel sedimentation and increased runoff from new development and other surrounding land uses.
3. Exposed manhole cones (refer to image 4) and bank instability result from erosion and degradation of the channel (images 5 and 6 illustrate the effect of having a limited buffer between the channel and the proposed development).

Figure 4.9 Existing waterway and conditions
(Source: Drainage Report, HWS, 2007).


Image 1: Headwaters of channel looking upstream.


Image 2: Looking downstream from bridge in Image 1.


Image 3: Widest and flattest part of channel.


Image 4: Exposed manhole cone shows depth of erosion since its installation (date currently unknown).


Image 5: First major bend in channel. Based on evidence of grading, a new house is proposed for this site with limited buffer zone between the channel and structure.


Image 6: Channel erosion that has occurred beyond the boundaries of upstream residential development.

Nutrient and pollutant load sources

Water quality within the Marlatt Waterway, as well as further upstream, has been greatly affected by less than adequate stormwater management practices on agricultural and urban lands. These undesirable changes are made more noticeable due to recent residential development along the Marlatt Waterway. The existing waterway is being polluted with sediments, fertilizers, and other contaminants from nearby land uses (playfields, residential development, and agricultural runoff). The pollutants affecting water quality within the Marlatt Waterway can be classified and corrected as follows:

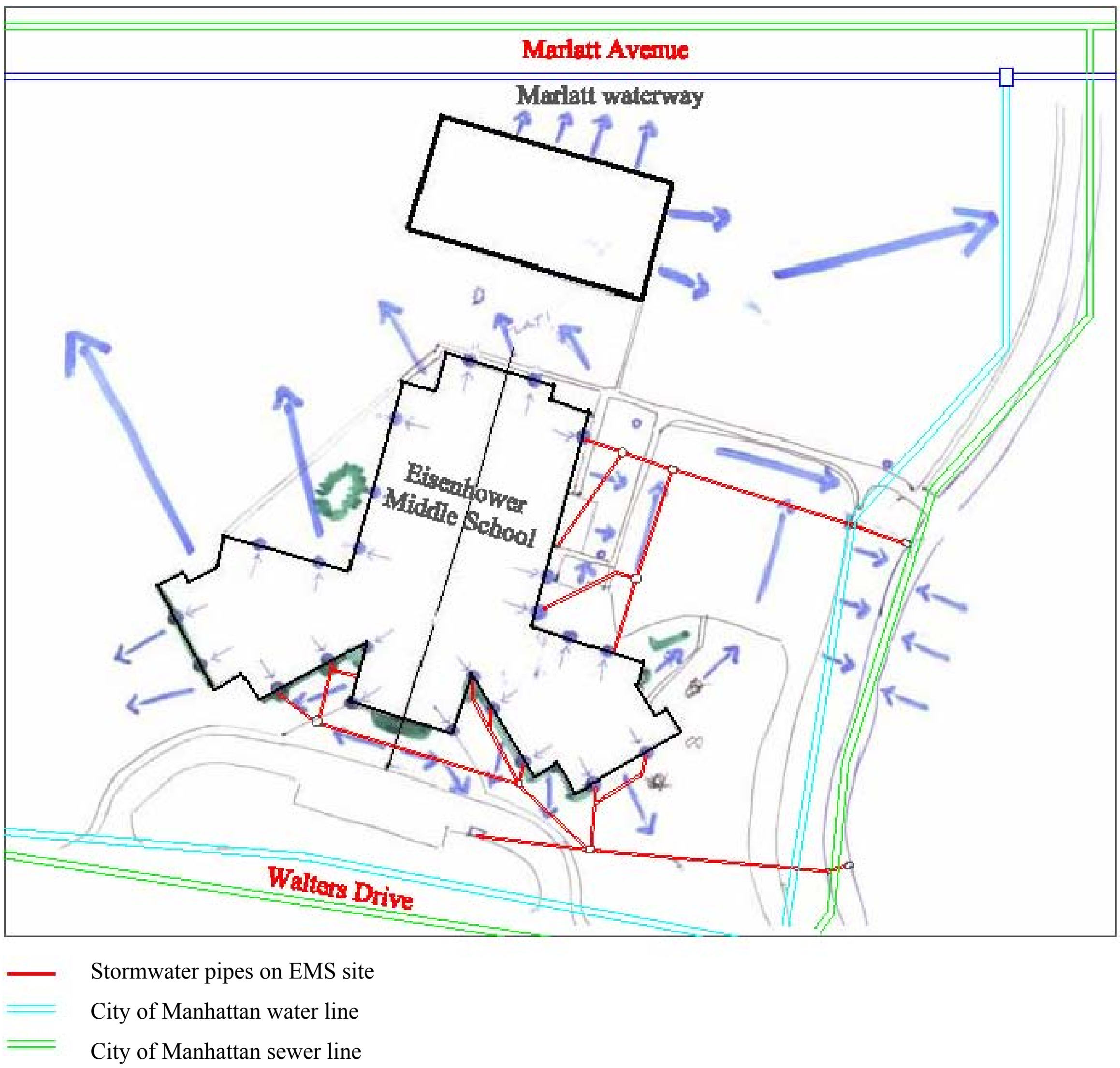
1. Nitrates (from having to regularly maintain the turf grass surfaces on the EMS property and the common use of herbicides and pesticides on a number of sites within the watershed). ***Potential solutions: Altering mowing practices and increasing the plant diversity on the site will result in improved site conditions (in terms of stormwater management and water quality). Increases in infiltration will reduce runoff and sediment into the waterway.***
2. Sediment/silt content (from bare soil and eroding turf grass areas that have very short-rooted vegetation). ***Potential solutions: Providing naturalized planting areas with deeper rooted vegetation and adequate riparian buffer will facilitate improved hydrological processes, and reduce sediment content, primarily caused by removal of topsoil.***
3. Floating debris from paved surfaces such as roads and parking lots. ***Potential solutions: Reducing litter requires more rigorous environmental education and personal stewardship, which could be facilitated by have the opportunity to teach students by example (thus making connections) at institutions such as Eisenhower Middle School.***

Drainage and runoff patterns on the EMS site

The EMS site is primarily divided into two drainage areas or sub-watersheds: the southeastern half that abuts Walters Drive has drain lines and storm sewer inlets that lead to: 1) the concrete-lined channel that runs along the east of the site and eventually drains into Marlatt Waterway, and 2) the storm inlet located on the southern side of Walters Drive, across from the entrance to the school site. The northern half is a partly disconnected system with respect to the roof downspouts, storm drains and inlets. Eventually (by a combination of surface flow and one or two storm pipes) the runoff enters a broad swale and then into a vegetated, finger-like swale (initially composed of turf grass and then by naturalized wetland vegetation) at the northwestern edge of the site. Finally, stormwater runoff drains into the Marlatt Waterway (see initial analysis diagram Fig.4.10).

Figure 4.10 Existing waterway and conditions

(Source: EMS Site Development Plans and On-Site Observations by the Author).

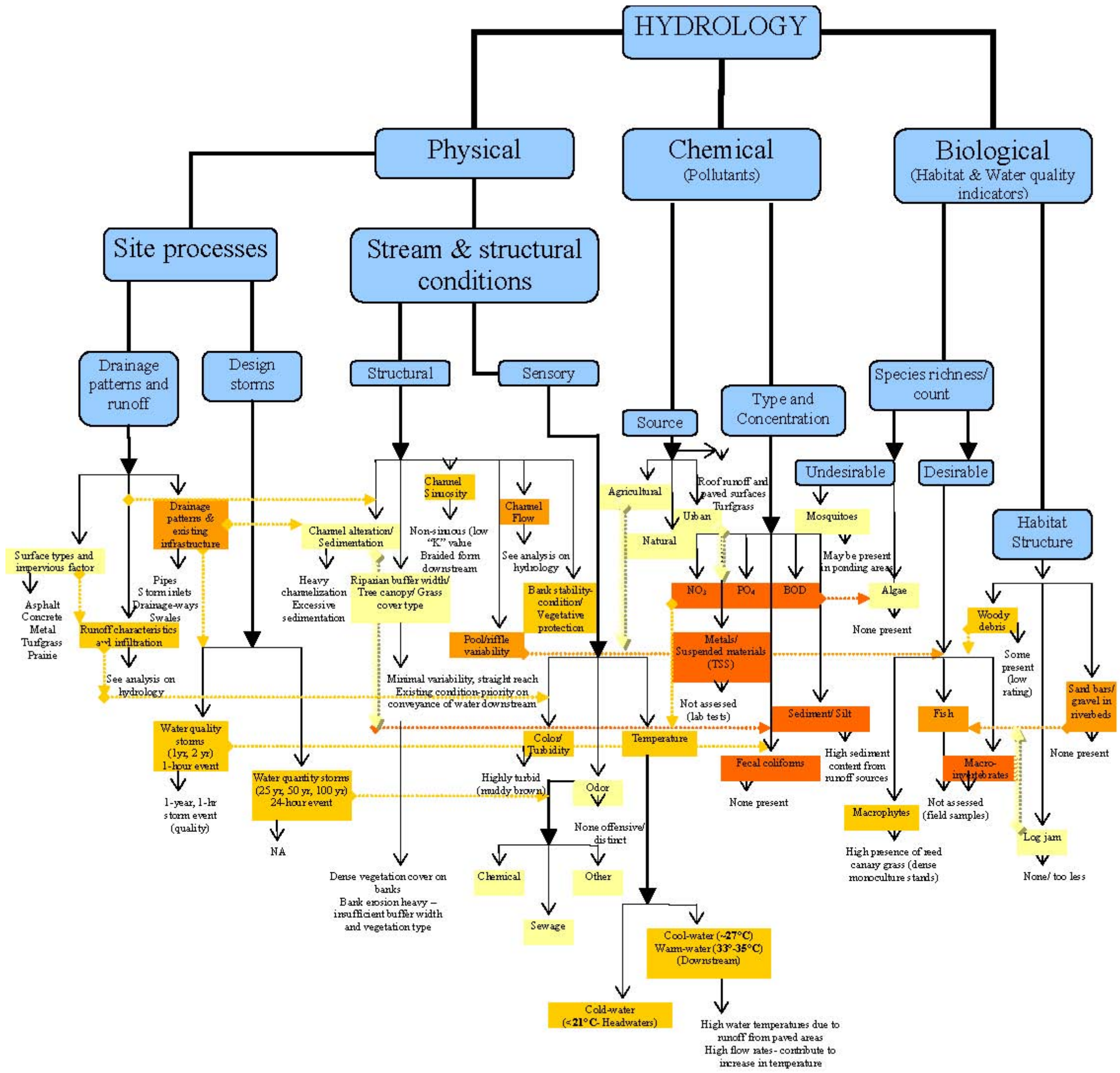


North ^

Figure 4.10 depicts stormwater runoff on the site. A concrete ditch originates at the housing area south of the EMS site and runs north until it drains into the Marlatt Waterway. The parking lot and service area on the east side of the school and the tennis courts on the north side of the school drain into the concrete-lined channel between EMS and the adjacent recreation fields—the parking lot by means of a storm drain and the tennis court by sheet/surface flow.

SSWESA Hydrology Summary: To summarize, the SSWESA analysis chart is altered with the analysis included (see Fig. 4.11). The main concerns and issues related to the site hydrology are identified as follows: 1) reduce concentrations of pollutants which are of immediate concern: Sediment/silt, Nitrogen (N), and Phosphorus (P), 2) improve water quality on a micro-level. Marlatt Waterway is impacted by runoff from many different sites located along its length, and the best way to improve water quality is by operating at the specific site level.

Figure 4.11 Final Analysis—SSWESA Hydrology



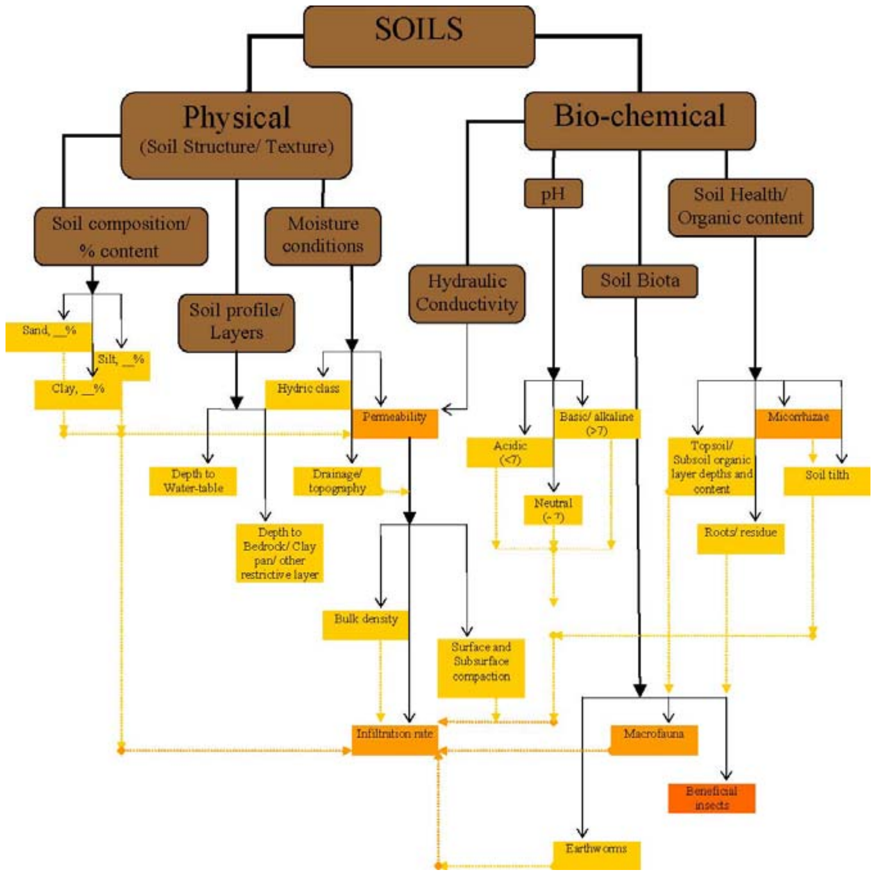
SSWESA Soils

The following section presents soil information obtained from a review of site soils using the USDA-NRCS Web Soil Survey application (http://websoilsurvey.nrcs.usda.gov/app/). This Internet tool helps identify existing (or historic) soils and allows designers and engineers a way to quickly complete a preliminary analysis of soils on a site.

Although the data is listed as current information and official soil reports from the Riley County, Kansas Web Soil Survey (hereafter referred to as WSS), it can be safely assumed that considerable urbanization and corresponding compaction and modification of soils have occurred on the site. This idea is confirmed by looking at the aerial photography associated with the WSS and the 1994 engineering drawings for the EMS site. Soils on the site have been altered significantly through the process of site development and construction of the school, play fields, parking lots, and other infrastructure. Prior to school construction, the soils were influenced by farming practices such as plowing and tilling.

Figure 4.12 highlights the relationships among the various factors concerning physical and bio-chemical properties of soils on a site.

Figure 4.12 Soils Analysis chart—SSWESA



Physical properties

The soils on the EMS site were originally comprised of the Chase silt-clay loam type. It is assumed that these soils were manipulated through the excavation and grading processes associated with the school construction but that the original properties still have some relevance for stormwater management. Chase silt-clay loam soils are known to be finely grained soils, made up of Sand (20%), Silt (49%), and Clay (31%). The depth to water-table was likely two to four feet (on average), on the pre-development property. Original soils were fine-textured, with a topsoil layer to a depth of seven to 14 inches approximately. The depth to bedrock or clay pan or other restrictive layer was greater than 60 inches (five feet).

With respect to water movement, soils on the EMS site had a low tendency of water ponding, which typically occurred only in depressions on the site. Permeability of the EMS site is rated "moderately low." Under fully-saturated conditions (during and immediately after a rainstorm event) the infiltration rate on the EMS site is classified under "Group C"—which indicates slow infiltration rates. (Note that "infiltration group classification" is different from the general soil type classification, where the latter is based on surface type and imperviousness, and level of urbanization). Several factors contribute to this low infiltration rate of water on the site:

Intrinsic site factors

i. Pre-EMS development *topographic conditions* did not aid water movement; the site was relatively flat with slopes ranging at one percent (1%) on an average—these were poorly drained soils. However, there are swales and stormwater pipes on the site that presently transport water away from the building.
ii. *Permeability* was low, partially due to the fine-textured soils that restrict water movement within the pores of the soil structure, and partially due to compaction.
iii. *Moist bulk density* of the soil type played an important role in water movement. Normal bulk density values are based on soil type and content, and for the EMS soils, normal values should range between 1.2 and 1.35. From the WSS, the moist bulk density values were found to be normal, with an increase for certain places within the soil layering or structure. On average, the values were between 1.3 and 1.45. Values greater than 1.4 indicate restriction in water movement and signify some limitations related to vegetative root penetration.

Extrinsic site factors

i. Surface runoff on the existing EMS site is very high (as indicated by the runoff calculations described in the latter part of Chapter 4).
ii. Although the rating for surface and subsurface compaction is shown to be "low to none" in the original soil reports, the significant changes in land use or surface types and corresponding increase in rooftops and paving on the EMS site have created more highly compacted soils. Construction activities have definitely altered the soil properties. Soil core samples and lab tests would be needed to establish current conditions. An increase in root biomass (over that of existing turf grass, regularly clipped close to the surface) would improve permeability of existing soils.

Bio-chemical properties

As discussed in Chapter 3, there are important biological and chemical properties that affect site hydrology. Soils and vegetation influence the way stormwater is handled and treated and thus, must be closely looked at in relation to a site context. Some of the important factors associated with the EMS site are listed below.

Soil chemistry

i. According to the WSS*, pH values* for the site are neutral to slightly acidic, and the values range between 5.6 and 8.4. Low pH values often indicate that the soils are good for anionic adsorption (adsorption of *phosphates*, *nitrates,* etc). Vegetation selected for BMP designs should reflect pH tolerances of each species.
ii. *Saturated Hydraulic Conductivity* (SHC) is another crucial element for consideration. SHC is a measure of water movement within the pore spaces. On the EMS site, the SHC is between 1.41 and 4.23 (rated as "moderate"), which is adequate for the soil infiltration processes.
iii. *Cation Exchange Capacity* (CEC) is influenced by the soil's clay content, and is shown to be "moderate" on the EMS site. This indicates that there is an adequate presence of elements such as Calcium (Ca), Potassium (K), Magnesium (Mg) which aid plant propagation and growth. Thus, there is no need for the use of fertilizers or soil supplements at EMS.

Soil biology

i. *Soil Biota:* This factor has not been determined due to time constraints and the absence of technical expertise, but it is viewed as important to understanding stormwater infiltration. A visual analysis of the site lends some understanding of soil biota. Where naturalized vegetation exists, it is more likely that improvements in soil biota occur (over turf grass soils).
ii. *Organic soil content or soil health:* From the soil analyses and reports obtained from WSS, the soil profile and associated layers were studied. Original topsoil depths ranged from seven inches at the shallowest part of site to fourteen inches at the

deepest. There was a high content of organic matter in the soil profile, indicated by the composition of roots and residue. Site grading would have altered organic soils and likely reduced both soil biota and soil health.

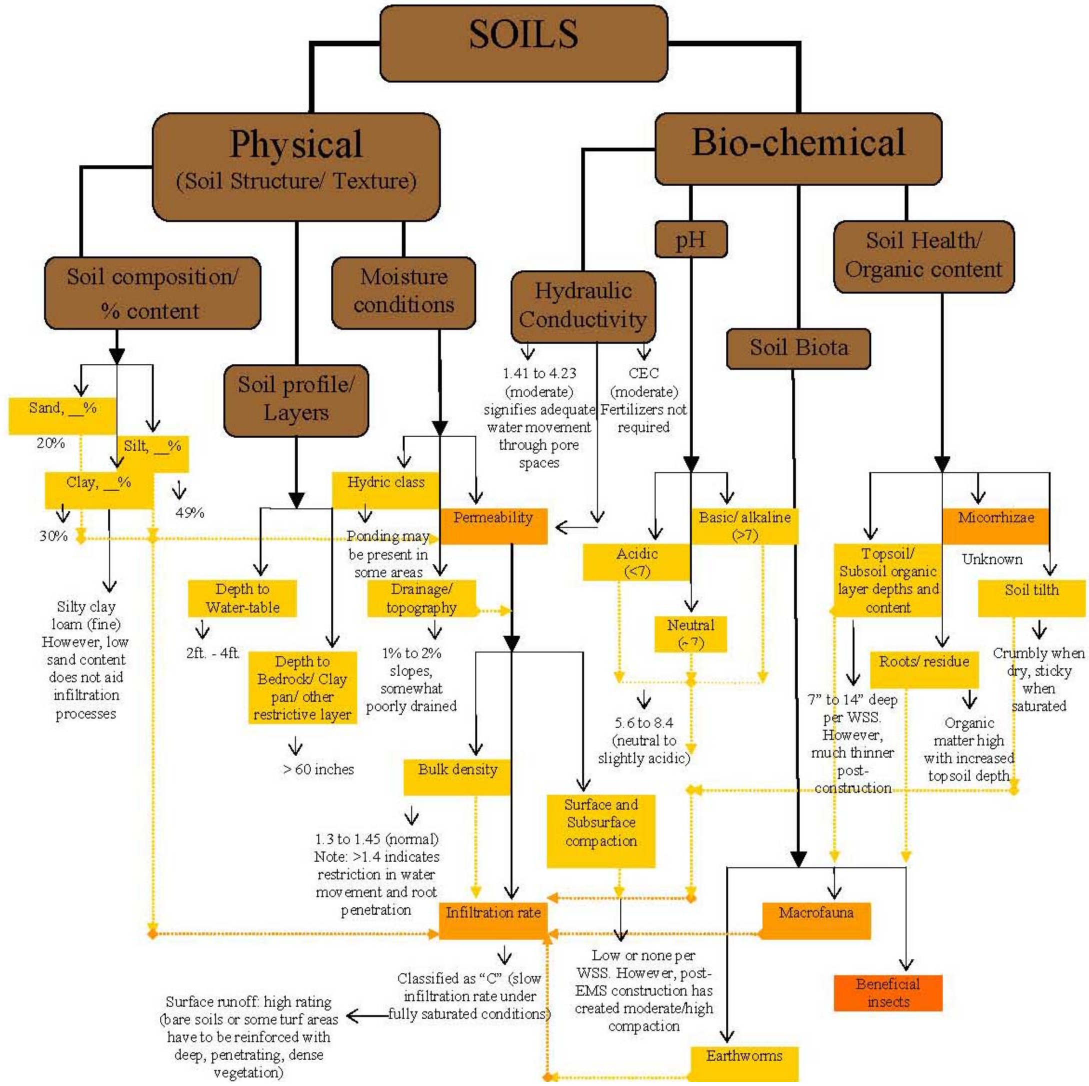
iii. *Soil tilth*, assessed in 2008 by the author, was found to be good on the EMS site, as easily ascertained by observing the texture of the soil, which further indicates the favorability of the soil for plant growth, soil aeration, and ensures proper infiltration of water. Soil mycorrhizae should be determined and analyzed to give a better understanding of soil health.

SSWESA Soils Summary Chart

To summarize, the SSWESA analysis chart is deepened by the analysis (see Fig. 4.13). The main priorities related to soils on the EMS site are identified as follows:

1. Promote infiltration (and where appropriate, temporary ponding) by loosening existing soils, creating raingardens that have a range of deep-rooted native plants, mowing non-playfield areas so that blades of grass are at least four inches in height, and increasing the extent of vegetated (naturalized) swales.
2. Increase pollutant adsorption by the soils by capitalizing on the low pH values and clayey content of the original Chase silt-clay loam.
3. Increase beneficial soil properties while simultaneously limiting soil compaction on site.

Figure 4.13 Final Analysis—SSWESA Soils

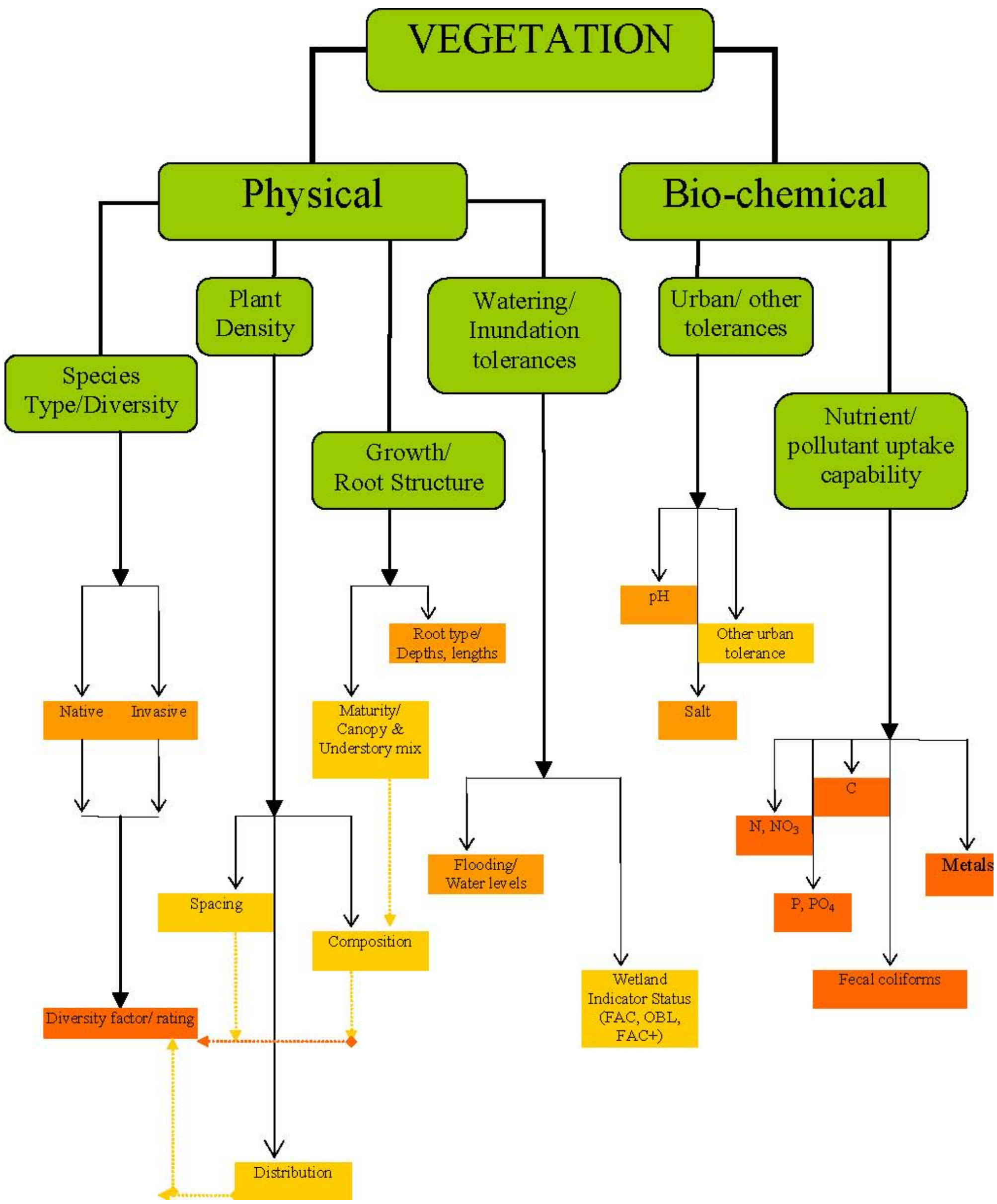


SSWESA Vegetation

Vegetation analysis

The type of vegetation on a site strongly influences stormwater management and also directly influences habitat and water quality. Figure 4.14 highlights the relationships among the various factors concerning physical and bio-chemical properties of plants.

Figure 4.14 Vegetation Analysis chart—SSWESA



Vigorous plant growth and propagation, and the establishment of a diverse mix of species within a site, are conducive to good soil structure and health and improved water quality.

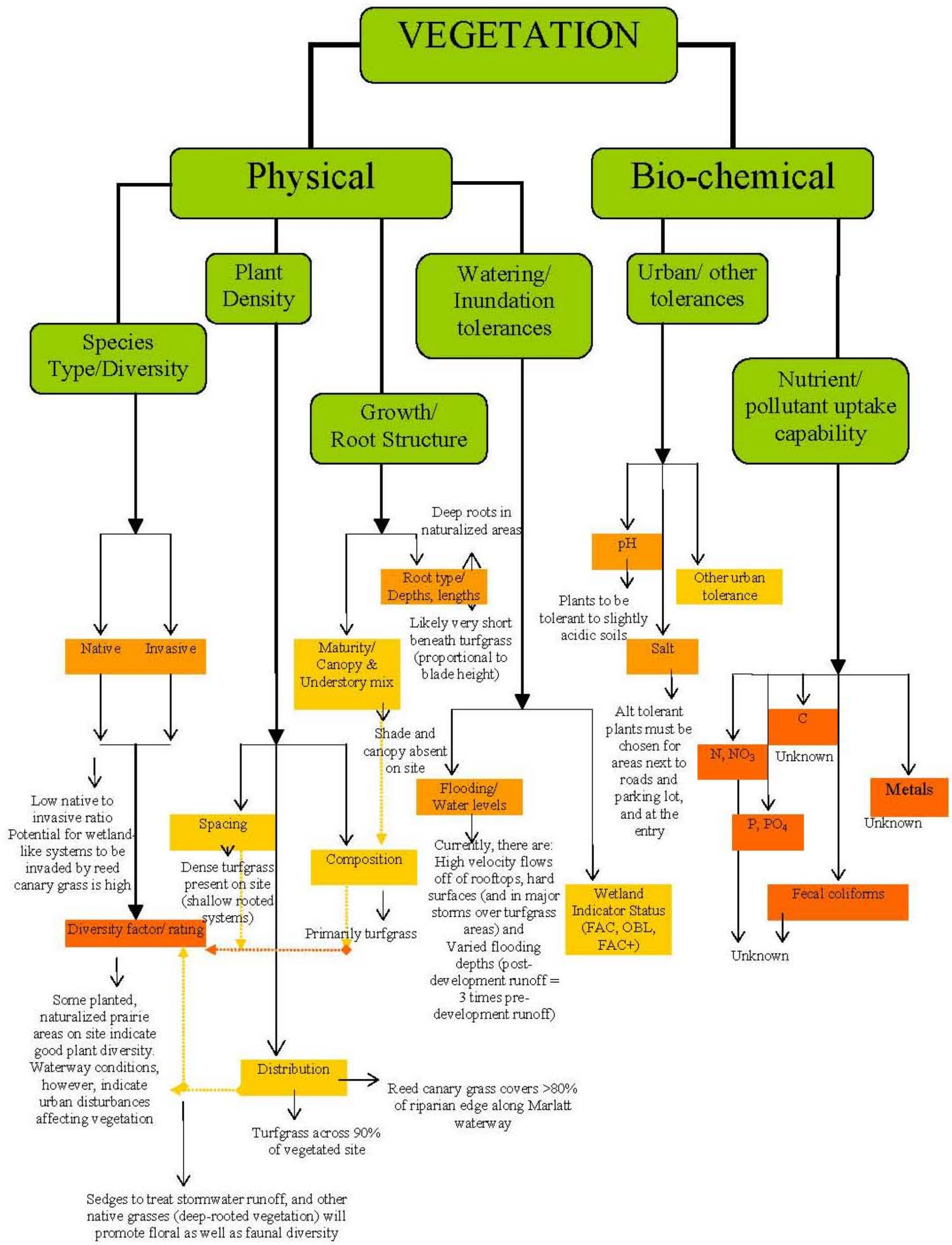
SSWESA Vegetation Summary Chart

A site visit to study the vegetation was essential to understanding site systems at EMS. Most of the site is covered with closely clipped or mowed turf grass, and soils would likely have been compacted during site grading and construction (in addition to subsequent mowing and use/impact by youngsters walking, playing, and running on turf grass). Vegetated swales (some simply turf grass and some with naturalized vegetation) feed into the Marlatt Waterway. Wetland vegetation is growing on top of the concrete-lined swales between EMS and the City of Manhattan recreation fields as sediments have accumulated and seeds and propagules established. Although they do not need to, city personnel are likely removing these wetland plants as part of normal maintenance practices.

The main priorities related to vegetation on the EMS site are as follows (Fig. 4.15):

1. Promote greater plant diversity.
2. Establish plants that will effectively address stormwater management issues related to the hydrology and soils.
    a. Promote soil infiltration and water permeability through establishment of deeper-rooted, native grasses and other plants.
    b. Reduce surface water temperature, flow rates, and velocities of stormwater runoff by moving rainwater through vegetative cover.
    c. Suggest alternatives to current vegetative cover on the EMS site—which, at present includes monoculture stands of reed canary grass near the Marlatt Waterway, and large areas of high-maintenance, shallow-rooted turf grass.
    d. Use plants in creative ways to filter and evapo-transpire rooftop runoff before it moves into stormwater pipes or vegetated swales.
3. Create a planting plan that would be favorable aesthetically *and* from an educational standpoint—and that would address issues such as safety, long-term maintenance, and interactive use by children, educators, and visitors.

Figure 4.15 Final Analysis—SSWESA Vegetation



When selecting plants for the EMS site, the following functions should be achieved:

- Tolerance to temporary inundation or fluctuations in water levels due to dry/wet cycles.
- Density and spacing of vegetation to act as a physical barrier against the erosive forces of concentrated runoff.
- Ability of selected plants to absorb (uptake) pollutants.
- Potential for vegetated areas on site to serve as social gathering places (gardens, play areas) and for educational purposes (community education on stormwater management using BMPs and curricular use of rain-gardens and other features in science and art classes for middle school students and teachers).

Following the discussion of stormwater runoff calculations (below), the conceptual design for stormwater management improvements is described.

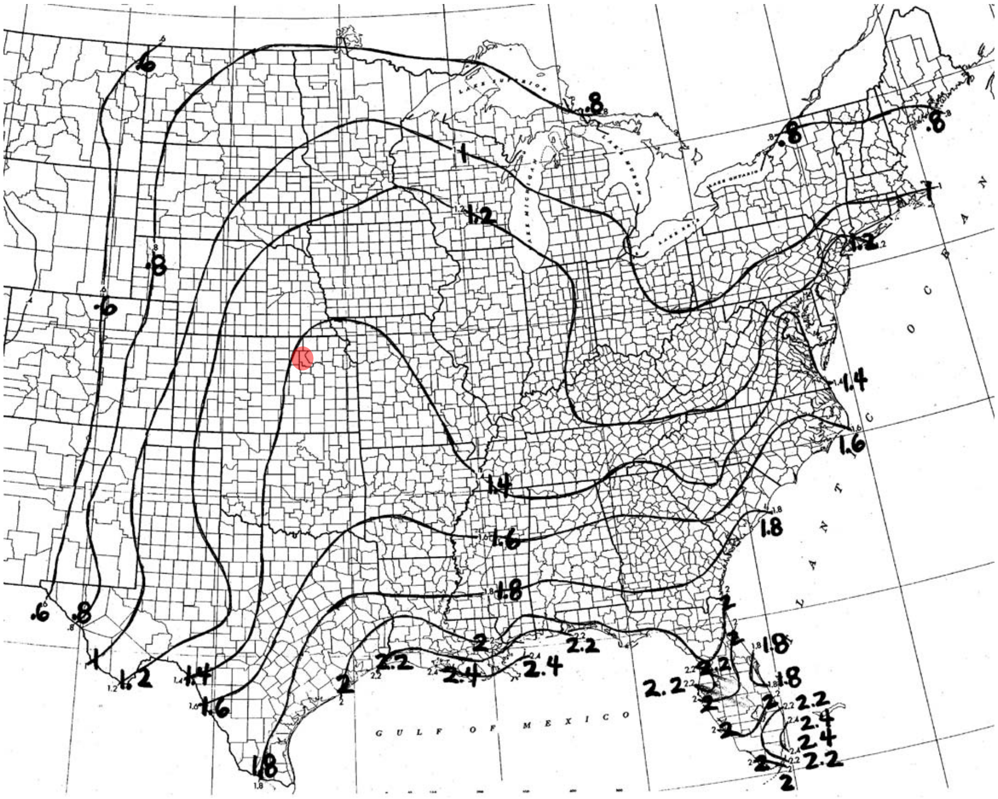
Runoff Calculations (water-quality storm event)—
Eisenhower Middle School in Manhattan, Kansas

The one-inch, one-hour storm event

To determine the rainstorm event for predicting runoff calculations for water quality a design storm of 1.4 inches was chosen, which corresponds with the one-hour storm with the one-year return interval. The one-year storm was selected since these storms happen with some frequency (typically one or more times a year). Rounding to 1.4 inches makes it easier to show and follow the calculations contained in the following section of Chapter 4 (see Fig.4.16).

Figure 4.16 1-year 1-hour Rainfall data

(Source: National Oceanic and Atmospheric Administration, www.noaa.gov, 2008).



To estimate runoff calculations, the TR-55 SCS Curve Number Method (1985) is followed, and the rainfall in inches is assumed to be 1.4. The soil classification and hydrologic group is categorized as 'D', which represents silty-clay loam soil type (see Table 4.2).

Table 4.2 Hydrologic Soil Classification (HSG) Group

(Source: Urban Hydrology for Small Watersheds, 1986).

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

The method

After determining the Hydrologic Soil Group (HSG), the curve numbers are defined for each surface type. The cover descriptions are arrived at from considering a combination of factors such as land use type, surface treatment (grass, natural, bare earth, paving) and hydrologic condition. Runoff calculations are calculated using the curve number method to estimate the rainfall in inches. This will help in design of stormwater management BMP facilities given a volume of rainfall, instead of rates as usually calculated from TR-55 modeling methods. Fig. 4.17 illustrates the rainfall calculation process using the NRCS TR-55 Curve Number Method. (Refer also to figures 4.18, 4.19, and 4.20).

Figure 4.17 Runoff curve number (CN) and Rainfall data

(Source: Adapted from Worksheet-2, TR-55, Urban Hydrology for Small Watersheds, 1986).

Project Eisenhower Middle School	By AP	Date 8-24-08
Location Marlatt Avenue, Manhattan KS 66502	Checked	Date

Check one: ☐ Present ☒ Developed

1. Runoff curve number

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 2-2	CN 1/ Figure 2-3	CN 1/ Figure 2-4	Area ☒ acres ☐ mi² ☐ %	Product of CN x area
D (silty clay loam)	Roofs- Concrete/ Aluminum (almost fully impervious)	98			3.09	302.82
D (silty clay loam)	Parking- Asphalt/ Concrete	98			6.95	681.10
D (silty clay loam)	Grass cover (good surface condition)	80			21.65	1732.00
				Totals ➡	31.69	2715.92

1/ Use only one CN source per line

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{2715.92}{31.69} = 85.7$; Use CN ➡ 86

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	1.0		
Rainfall, P (24-hour)	in	1.4		
Runoff, Q (Use P and CN with table 2-1, figure 2-1, or equations 2-3 and 2-4)	in	0.43		

Figure 4.18 Runoff curve number (CN): Solution of Runoff Equation

(Source: Adapted from Fig.2.1, TR-55, Urban Hydrology for Small Watersheds, 1986).

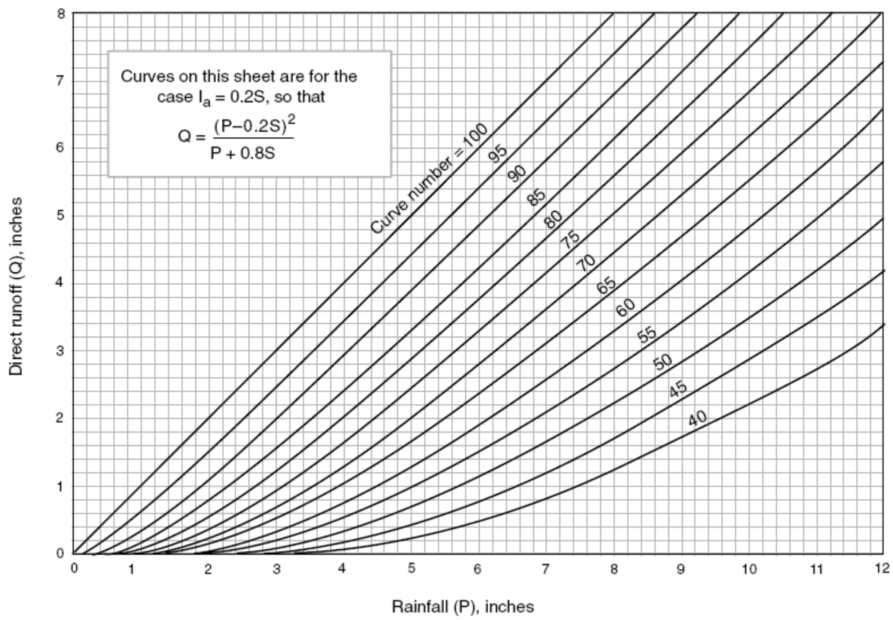


Figure 4.19 Runoff depth for selected Curve Numbers (CNs) and Rainfall Amounts

(Source: Adapted from Table 2.1, TR-55, Urban Hydrology for Small Watersheds, 1986).

Rainfall	Runoff depth for curve number of—												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

Figure 4.20 Runoff curve numbers for urban areas

(Source: Adapted from Table 2-2a, TR-55, Urban Hydrology for Small Watersheds, 1986).

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Runoff volume (cu.ft.) = [Runoff (inches)/12] x site area (sq.ft.)

= (0.43/12) x (31.69 x 43,560) = **49,464.92 cu.ft.**

Assuming an average depth of one foot (since the site is a middle school, deeper rain-gardens and other temporary detention would have to be re-examined for safety as part of the design considerations). In order to capture the 1.4 inch storm event, the area to be allocated for BMP designs would measure approximately **<u>250 feet x 200 feet.</u>**

Sustainable Stormwater Management Concept Design for EMS

Design proposal

To make the site effective in addressing stormwater management, aesthetics, and educational opportunities a variety of concepts were considered for the BMP design. The following ideas express the core values addressed by the design (Fig. 4.21):

1. A “treatment train” BMP method has been proposed to address the issues and concerns discussed previously. A series of strategically placed BMPs will help slow down stormwater runoff rates and velocities from the site.
2. To appeal to the end users of the site (especially teachers, students, and parents), a series of inter-connecting stormwater planters, rain-gardens, and vegetated swales are proposed as part of the stormwater treatment process.
3. Stormwater conveyance creates a “disconnected-connectivity” system—water flow processes occur primarily at the ground surface with stormwater being held by the soils and vegetation. Runnels and pipes direct the water through the series of BMPs.
4. Native grasses and shade trees are incorporated into the planting plan to help promote infiltrative properties of the soils, and to decrease the temperature of urban runoff.
5. The proposed vegetated areas shown as stormwater planters and formal rain-garden designs highlight the built structure—the building corners and edges sharply contrast with the curvilinear forms of vegetated swales and more informal rain-garden shown on the planting plan, providing clearly defined edges and spaces on the EMS site.
6. Maintenance issues and cost are critical at a site like Eisenhower Middle School, where regular watering and upkeep are very difficult without a full-time maintenance crew. To give this factor due consideration, areas of turf grass are retained only where necessary, such as for playfields and other practice lawns *and* for aesthetic or safety reasons (for example, near Walters Drive and a few other locations). Ease of mowing along edges of new BMPs is considered essential.
7. Mow strips and stone liners are incorporated within the design details to accentuate the aesthetic element in the BMP designs. Either mowing or burning of prairie and meadow type vegetation will enable these areas to be readily maintained. Carefully

done, burning is an excellent way to maintain native vegetation and is employed in urban settings such as Ann Arbor, Michigan and the greater-Chicago area.

Figure 4.21 Conceptual Stormwater Management Plan for EMS.

North ^

Concluding thoughts about the design of BMPs for EMS

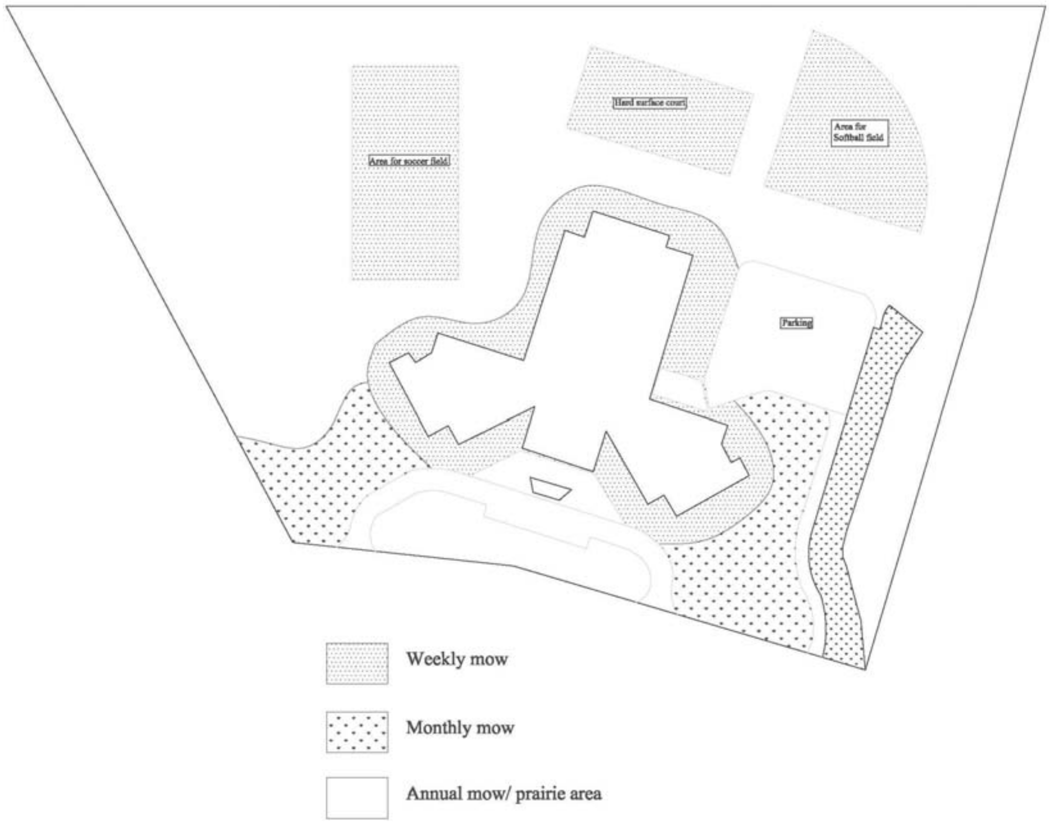
The EMS site was selected for an application that involves the following stormwater management considerations:

1. Ecological stormwater functions;
2. Design aesthetics and "artful rainwater" concepts; and
3. Education about stormwater for site users: including students, instructors/teachers, visitors, parents, local residents and other visitors.

Economic feasibility and ease of maintenance/management are important considerations that must be planned for during design of the EMS site. While it is very important to consider the concept of effectively educating the site users about rainwater functions and processes, short- and long-term cost effectiveness is crucial to school management. Irrigation and mowing considerations affect this site and the application of stormwater BMPs. Intensive weeding of native plantings is kept to a minimum with the proposed design by creating vegetative systems that can be readily mowed or burned at the end of each growing season (or early in the spring if the winter effect of prairie and/or meadow is desired) *and* by filling stormwater planters with just a few hardy and visually recognizable species.

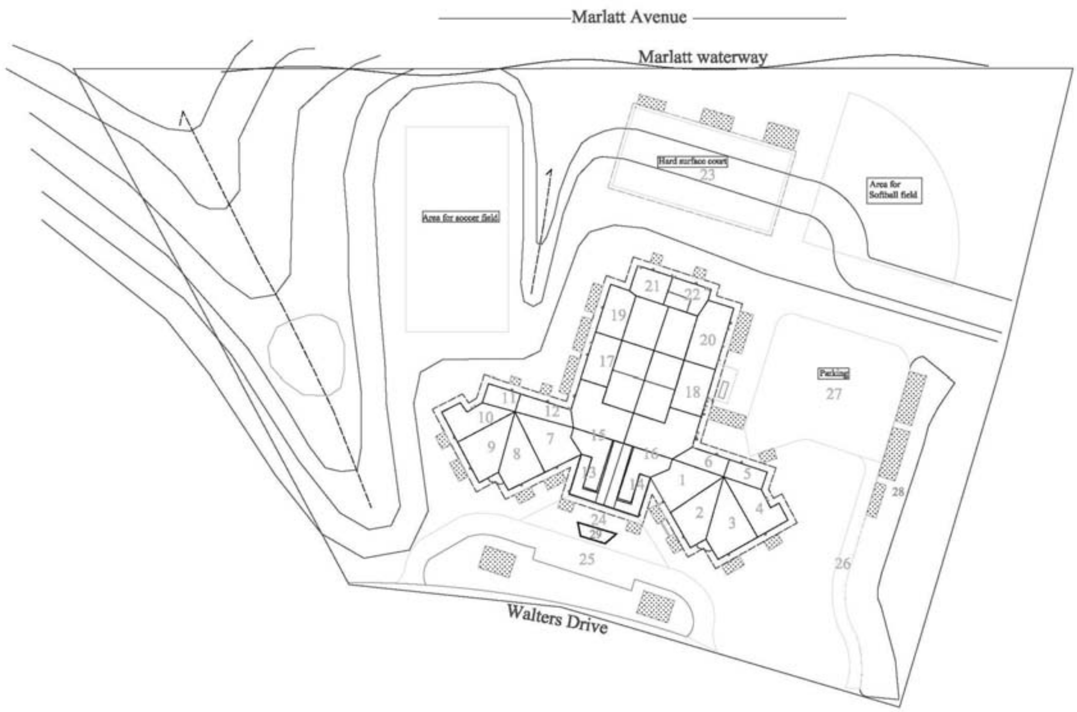
Figure 4.22 illustrates the mow patterns that are proposed as part of the maintenance plan, and are classified into three tiers according to their time cycles (weekly, monthly, and annual).

Figure 4.22 Maintenance plan with suggested mowing patterns.



North ^

Figure 4.23 Conceptual Stormwater Management Plan for EMS, with area designations for post-BMP stormwater calculations.



North ^

Pre-BMP runoff

Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (0.43/12) x (31.69 x 43,560)

= **49,464.92 cu.ft.**

As noted earlier, assuming one foot depth for BMPs, the total area to be allocated for BMP designs would need to be approximately 250 x 200 feet to capture the 1.4 inch storm event.

Post-BMP runoff

Below are the post-BMP stormwater calculations, using the Conceptual Stormwater Management Plan (see Figure 4.23) as a guide. Twenty-nine (29) areas were designated as possible locations for stormwater BMPs. The total volume for the 29 areas is 19,972.37 cubic feet (~20,000 cu.ft.).

1. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (4053.98) = **398.64 cu.ft.**

2. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (3679.03) = **361.77 cu.ft.**

3. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (4608.42) = **453.16 cu.ft.**

4. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (3460.30) = **340.26 cu.ft.**

5. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (1587.23) = **156.08 cu.ft.**

6. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (1807.38) = **177.73 cu.ft.**

7. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (4379.27) = **430.63 cu.ft.**

8. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (3946.06) = **388.03 cu.ft.**

9. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
   = (1.18/12) x (4301.06) = **422.94 cu.ft.**

10. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (3109.63) = **305.78 cu.ft.**

11. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (1416.47) = **139.29 cu.ft.**

12. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (2146.93) = **211.11 cu.ft.**

13. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (2921.76) = **287.31 cu.ft.**

14. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (2921.76) = **287.31 cu.ft.**

15. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (8040.85) = **790.68 cu.ft.**

16. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (8440.58) = **829.99 cu.ft.**

17. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (7586.82) = **746.04 cu.ft.**

18. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (7993.35) = **786.01 cu.ft.**

19. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (6366.54) = **626.04 cu.ft.**

20. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)
= (1.18/12) x (7526.99) = **740.15 cu.ft.**

21. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (2296.81) = **225.85 cu.ft.**

22. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (2512.40) = **247.05 cu.ft.**

23. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (28800) = **2832.00 cu.ft.**

24. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (9588.89) = **942.91 cu.ft.**

25. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (20167.49) = **1983.14 cu.ft.**

26. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (6840.91) = **672.69 cu.ft.**

27. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (1.18/12) x (37276.30) = **3665.50 cu.ft.**

28. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

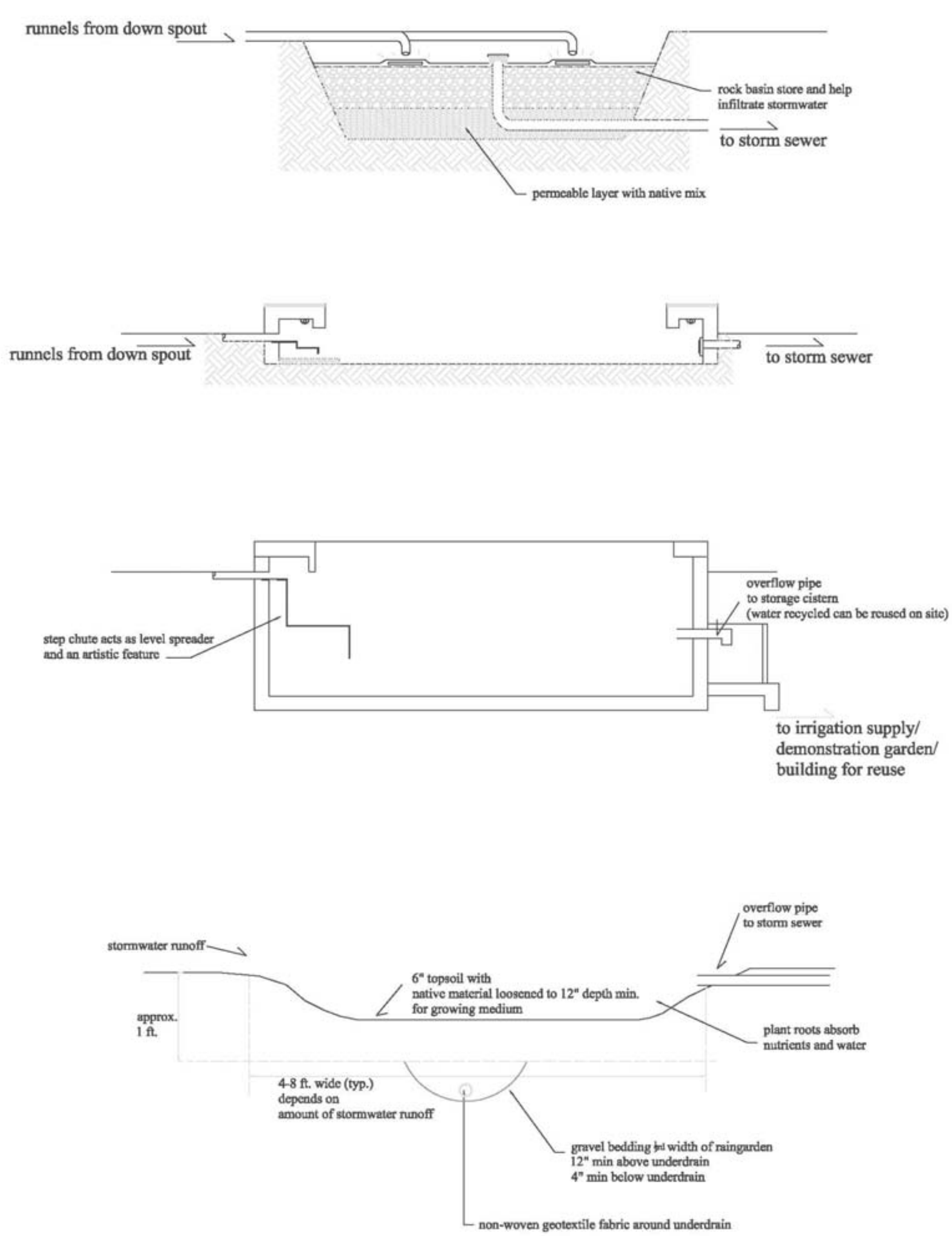
= (0.24/12) x (25399.20) = **507.98 cu.ft.**

29. Runoff volume (cu.ft). = [Runoff (inches)/12] x site area (sft.)

= (0.24/12) x (814.88) = **16.30 cu.ft.**

Figure 4.24 Cross-Sections depicting possible BMPs associated with the Stormwater Management Plan for EMS.

<u>From top to bottom:</u> Section A) Stormwater planter with rock basin, splash pads, and under-drain; Section B) Stormwater planter with vegetation; Section C) Stormwater planter with storage cistern; Section D) Bioswale or raingarden with under-drain. (Note that in some locations an under-drain may not be necessary beneath a rain-garden).



CHAPTER 5 - Conclusions and Lessons Learned

Most landscape architects and other professionals associated with site planning and design processes operate in multi-disciplinary ways as they seek to implement of site-specific, eco-sensitive strategies. However, there still exists definite initiative for and a lack of focus on different techniques that could be realized by promoting more innovative technologies. Meg Calkins (2004) attributes this want of pioneering to several factors, of which *lack of knowledge* and *time available for research and in-depth site analysis* are of primary importance related to the issues discussed in this thesis.

The purpose of the SSWESA framework and literature review discussed herein is to provide students of landscape architecture and designers interested in stormwater management a starting point for understanding the interconnections among the key ecological factors of hydrology, soils, and vegetation on a site. Realizing the different processes and factors that form a site will help landscape architects and designers promote sustainable methods and techniques within the realm of ecological design practice.

Limitations of the Thesis

The SSWESA framework proposed, being fairly comprehensive in its scope, has not been completely tested during the site application process discussed in this thesis. This has been due to the lack of time and expertise involving certain specific tests, particularly concerning biological and chemical aspects associated with hydrology, soils, and vegetation. These same conditions or limits will influence the use of SSWESA by professionals. As such, additional research should be undertaken to focus professionals on the most essential attributes and to create a clearer hierarchy related to the attributes and how they should be used during the design process.

As a preliminary attempt to establish a hierarchy the following idea was suggested. A site assessment using SSWESA can be rapid (addressing attributes shown in light yellow) to in-depth (addressing attributes shown in dark orange) based on the level of analysis that is required for the project. This idea needs to be deepened by additional research and testing.

The most important insight learned during the research process is that experts in other fields must be regularly consulted in order to apply the SSWESA framework in a meaningful way. Designers should not try to design complex stormwater management systems in isolation.

Discussions for Further Research

Although there is a continual increase in awareness and implementation of sustainable stormwater management practices, there is a need for a greater depth of awareness of specific site factors as they relate to hydrological processes and stormwater BMPs.

Everett M. Rogers (pioneer of the "Diffusion of Innovations" theory) posits that "an innovation (or in the case of ecological design, a strategy) is more likely to be adopted if it: is perceived to have relative advantage; is easily tried; can be observed somewhere else; is compatible with existing methods; or is perceived to be relatively simple" (Calkins, 2004, 1, quoting Rogers, 1995).

This thesis presents a method of assimilating information as can be readily observed or tested through various methods associated with site analysis, planning, and design.

> *Often it is the designer who, after much information gathering, initiates use of an innovation/strategy (Calkins, 2004, 4).*

Future research on similar ideas to those presented herein can use the themes and topics in this thesis as a starting point for further exploration of stormwater management technologies. The author and this research explicitly encourage the development of more detailed methods of site analysis for the practice of sustainable stormwater management, such as preparing a more rigorous hierarchy of site factors (a hierarchy and associated process that can be used in a cursory or more detailed manner depending upon the nature of the design project).

A more in-depth compilation of sources and references using expert interviews, books, and journals is also possible. In addition, a scoring matrix that enables designers and engineers to complete a stormwater evaluation for a site could be developed.

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