ASLA

LATIS

Landscape Architecture Technical Information Series

A LANDSCAPE PERFORMANCE + METRICS PRIMER FOR LANDSCAPE ARCHITECTS:

MEASURING LANDSCAPE PERFORMANCE ON THE GROUND

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A Landscape Performance + Metrics Primer for Landscape Architects:

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Cover Photo

Students measure the infiltration rate of a rain garden soil on NC State University's campus. (Credit: Emily McCoy)

Publisher's Note

The American Society of Landscape Architects publishes the Landscape Architecture Technical Information Series (LATIS) to encourage professionals to share specialized expertise relating to landscape architecture. ASLA considers LATIS papers to be important contributions to a necessary and ongoing dialogue within a large and diverse community of landscape architecture researchers and practitioners. ASLA oversees a rigorous peer review process for all LATIS papers to ensure accuracy of content. Each author offers a unique perspective on the practice area covered, reflecting his or her portfolio of professional experiences.

Abstract

Landscape architecture is at a pivotal moment in its history as a discipline, where design practice is becoming more reflective, adaptive, and scholarly. As the need for sustainable design grows, it has become imperative that professionals put their work under analytical review and set higher standards for their work to perform environmentally, socially, and economically. The field looks more to the integration of research and scholarly inquiry in design as a solution to this growing need for high-performance landscapes.

While the concept of landscape performance assessment is gaining attention within the field, the availability of time, resources, and technical expertise remains an obstacle for many designers in evaluating built work. More in-depth research investigations are best left to academics and scientists, but methods exist that every landscape architect can use to assess the performance of their own work for use throughout the planning, design, construction, and post-occupancy phases. This paper aims to provide an introduction to these metrics and methods that can be applied in the field. Less emphasis is placed on models and web-based calculators, which are available through resources such as the Landscape Architecture Foundation.

Feedback on this LATIS and on the series in general should be sent to LATIS@asla.org or send comments to ASLA, c/o Professional Practice Manager, 636 Eye Street NW, Washington DC 20001. ASLA welcomes suggestions for future LATIS topics that will broaden awareness of new and/or rapidly evolving practice areas within landscape architecture and enhance technical proficiency for practicing in these areas.

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Introduction

Why Measure?

> *"Landscape performance can be defined as a measure of the effectiveness with which landscape solutions fulfill their intended purpose and contribute to sustainability."* – Landscape Architecture Foundation

As populations continue to increase and urbanize,[1] cities are placing increasing pressure on both built and natural systems to deliver social and ecosystem services to meet basic human needs for present and future generations. Built environments can thus either become catalysts of environmental and social degradation or canvases for the regeneration of our socio-ecological systems. At the nexus of these two trajectories lies designers, engineers, planners, and developers who make decisions every day that affect the quality and distribution of spaces in our built environment. The weight of these decisions requires thoughtful care and should be pursued with confidence through well-informed, evidence-based practice.

Despite the responsibility the built environment demands from designers, planners, engineers, and developers, a widespread culture of indifference exists toward a critical analysis of the measurable impact of built work (Chen, Miller, Clements, and Kim, 2017; Chong, Martin, and Brandt, 2010; Brown and Corry, 2011). Luckily, leaders in the field are advancing landscape performance metrics. These include the Landscape Architecture Foundation and green building rating programs that advocate for high sustainability standards and performance monitoring, such as the Sustainable Sites Initiative (SITES) and the Living Building Challenge. Rating systems are being increasingly embraced by owners, clients, and designers on projects. These rating programs are beginning to deemphasize simple point-counting decision making with a focus on products rather than process, and instead are emphasizing a holistic, system-based approach to design, including consideration for landscape context and proven sustainability performance.

Although performance-based design and metrics have gained significant attention within the design disciplines, inaction is still rampant throughout the profession. The data are decentralized and scarce, and there are very few standardized methods for data collection. A lack of solid information about the performance of our built environment is debilitating, where current landscape architecture practice is "still based on beliefs rather than facts" (Brown and Corry, 2011). We, as a profession, are still unclear about the extent to which our designs are maximizing their contribution to the health of societies and our environment. A resilient trajectory for the landscape architecture profession requires that we take a more analytical look at built landscapes and learn from successes and failures through the lens of their ability to provide ecosystem and social services[2]—in other words,

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1 Urbanization is defined as a densely developed territory that contains 50,000 or more people (US Census Bureau, 2016).

2 Social services are added in addition to ecosystem services to accentuate the cultural and social value of

performing at a high level of design excellence socially, environmentally, economically, and aesthetically. It is now time to lead with field-tested confidence and become more “scholarly practitioners” (Deming and Swaffield, 2011).

While the concept of landscape performance is gaining attention within the field, the availability of time, resources, and technical expertise remains an obstacle for many designers. More in-depth research investigations are best left to academics and scientists, but methods exist that every landscape architect can use to assess the sustainability—economic, socio-cultural, environmental and aesthetic—and performance of their own work for use throughout the planning, design, and construction phases. This paper aims to introduce to these metrics and methods that can be applied in the field.

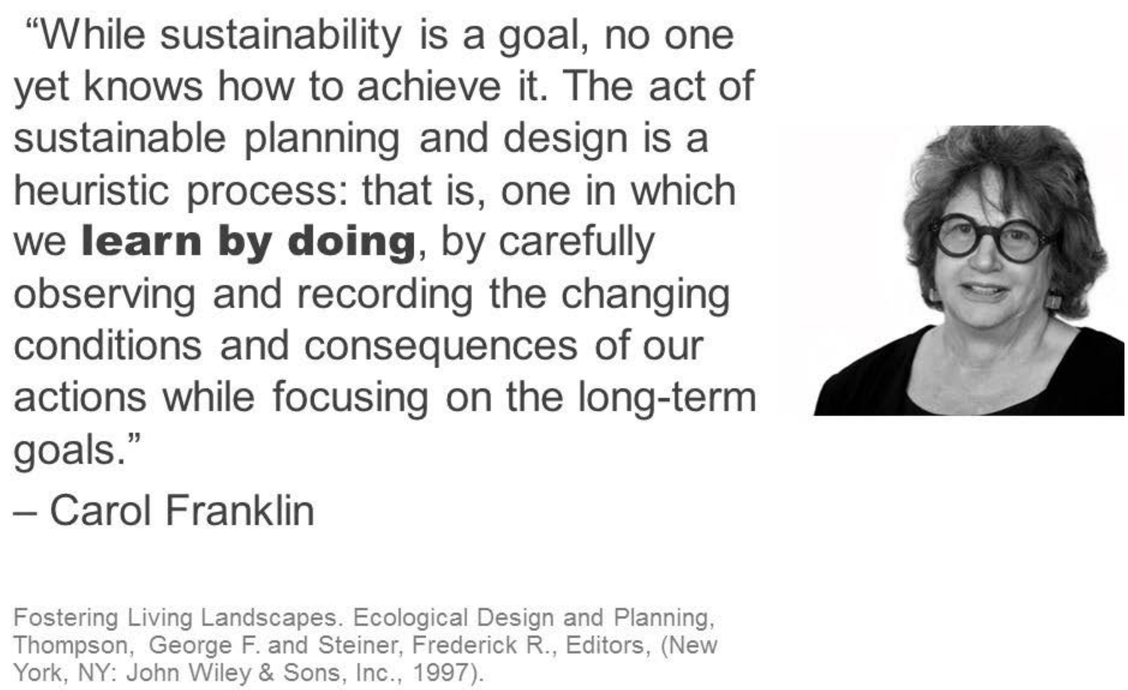

Figure 1. Why Measure? (Credit: Emily McCoy)

COMMUNICATING THE VALUE OF SUSTAINABLE LANDSCAPE ARCHITECTURE

> *“There is increasing evidence suggesting that mental health and emotional stability of populations may be profoundly influenced by frustrating aspects of an urban, biologically artificial environment. It seems likely that we are genetically programmed to a natural habitat of clean air and a varied landscape, like any other*

landscape architecture projects that may not always fall under the definition of an “ecosystem service,” such as community building through a collaborative public process or the influence of a man-made material like a sculpture or historical relic. Ecosystem services can create cultural services, but cultural services do not always fall under the definition of ecosystem services.

> *mammal. The specific physiological reactions to natural beauty and diversity, to the shapes and colors of nature, especially green, to the motions and sounds of other animals, we do not comprehend and are reluctant to include in studies of environmental quality. Yet it is evident that in our daily lives nature must be thought of not as a luxury to be made available if possible, but as part of our inherent indispensable biological need."* – Fredrick Law Olmsted (Todd, 1982)

The quality of human life relies on the ecosystem and the social services our natural and built systems provide. Within the built environment, these services are increasingly being diminished, yet they are desperately needed. Landscape architecture is a profession that has focused on ecosystem and social services since its inception through a commitment to protecting the health, safety, and welfare of the public. However, since the early 2000s, there has been a focus globally on quantifying ecosystem and social services and using data to communicate the value of outdoor spaces, both built and wild. This quantification not only helps convey the multifaceted value of sustainable design, but also supports public policy decision-making and aids in weighing the challenges and opportunities of different development scenarios. This primer is meant to help designers and others easily quantify the impact of landscape architecture projects, assess if a site is meeting its intended goals, and define the measurable contribution a project is providing in ecosystem and social services. The methods discussed can be employed at various stages in the design process— collecting baseline data of a reference site or a project site pre-construction, during construction, or post-occupancy.

Paper Organization

The primer is organized by six broad landscape performance methods categories, rather than the performance benefits themselves. The categories include, 1) Weather, Microclimate, Air Quality, and Sound; 2) Soils and Amendments; 3) Water; 4) Vegetation; 5) Society and Culture; and 6) Economics. Within each of these sections, methods and techniques are described regarding how to measure different aspects of each of these categories, yet many of the methods can be combined to measure one or more performance benefits. For example, to measure a site's ability to sequester carbon, you may need to employ methods and techniques that measure weather, microclimate, vegetation, and economics, depending on your goals. This organization allows for easy navigation of the techniques and tools for measurement, instead of being rigidly prescriptive of how to measure each performance benefit. The matrix of performance benefits below gives guidance on suggested methods for each benefit (See Figure 2 Summary of Performance Benefits and Parameters Used to Measure).

Additionally, each landscape performance method category is divided into the following sections:

- Description of the significance of measuring the parameter (Why Measure?),

- Performance benefits associated with each parameter (Performance Benefits),

- Methods for collecting parameter data (Methods of Assessment),

- Discussion of a few performance benefit considerations (Performance Benefit Considerations).

The methods and tools presented are not comprehensive, but rather curated from those most popularly identified in the reference literature for use in quantifying landscape benefits for environmental, socio-cultural, and economic performance; the methods and tools are also the most easily replicable and cost-effective. It should be understood that this primer does not explore the detailed methodology for how one might assess a performance benefit, but simply offers the tools or methods to assess performance benefits. General guidance is provided on how to use the tool or method. For more in-depth information, it is recommended to consult peer-reviewed journals or contact the manufacturers of certain tools or the authors of the methods or models.

Some of the sources of the referenced landscape performance categories and methods include:

- The Economics of Ecosystems and Biodiversity Initiative (TEEB, 2012).

- Urban Ecosystem Services (Gómez-Baggethun et al. 2013).

- An Empirical Review of Cultural Ecosystem Service Indicators (Hernández-Morcillo, Plieninger, and Bieling, 2013).

- Supplying Urban Ecosystem Services Through Multifunctional Green Infrastructure in the United States (Lovell and Taylor, 2013).

- Ecosystems and Human Well-Being: A Framework for Assessment (Millennium Ecosystem Assessment, 2005).

- Regulation of Landscape Architecture and the Protection of Public Health, Safety, and Welfare (Schatz and Lafayette, 2003).

- SITES v2 Rating System for Sustainable Land Design and Development (Sustainable Sites Initiative, 2014).

Table 1. Summary of Performance Benefits and Methods Used to Measure

		PRIMARY LANDSCAPE PERFORMANCE METHODS TO USE[3]	Weather, Microclimate, Air Quality, Sound	Soils and Amendments	Water	Vegetation	Social	Economic
PERFORMANCE BENEFIT								
Environmental	General environmental health	Vegetation						
		Soil						
		Acoustic quality						
		Air quality						
	Sustainable water use and management	Stormwater management (quantity and quality)						
		Irrigation management (quantity and quality)						
		Blackwater management (quantity and quality)						
	Carbon footprint	Sequestration						
		Emissions reduction						
	Urban heat island	Surface temperature reduction						
		Air temperature reduction						
		Reduce building energy consumption						
	Soil health	Erosion control						
		Soil formation/ enhancement						
		Nutrient cycling						
		Pollution reduction						
	Ecological resiliency, biodiversity, and habitat	Habitat quality and biodiversity						
		Biomass/Net primary production						

3 Other methods may be necessary depending on the study

		PRIMARY LANDSCAPE PERFORMANCE METHODS TO USE	Weather, Microclimate, Air Quality, Sound	Soils and Amendments	Water	Vegetation	Social	Economic
Environmental	Ecological resiliency, biodiversity, and habitat	Heterogeneity in planting (functional groups)	■			■		
		Rate of recovery from stress or disturbance	■		■	■		
		Drought resilience	■	■	■	■		
		Heat resilience	■	■		■		
		Fire resilience	■	■		■		
		Flooding resilience		■	■	■		
		Landslide resilience		■	■	■		
Society and Culture	Human comfort		■	■	■	■	■	■
	Preference		■	■	■	■	■	■
	Accessibility						■	
	Physical activity and health						■	
	Well-being		■	■	■	■	■	
	Education and cognitive development						■	
	Safety and perceptions of safety					■	■	■
	Community building						■	■
	Beauty, inspiration, and Visual quality				■	■	■	■
	Social and environmental justice		■	■	■	■	■	
	Spiritual enrichment						■	
	Sense of place					■	■	

		PRIMARY LANDSCAPE PERFORMANCE METHODS TO USE	Weather, Microclimate, Air Quality, Sound	Soils and Amendments	Water	Vegetation	Social	Economic
Society and Culture	Cultural heritage, relevance, and history					■	■	
	Freedom, choice, and democratic space						■	
	Stakeholder needs and programmatic needs						■	■
	Cultural resiliency	Multifunctionality	■	■	■	■	■	■
		Social capital and social diversity					■	■
Economics and Asset Management	Economic catalyst and revenue generation	Products				■		■
		Services	■	■	■			■
	Cost savings/ avoidance	Materials	■	■				■
		Asset management and sustainable site maintenance	■	■	■	■	■	■

BIG AND SMALL TOOLS FOR SUSTAINABLE LANDSCAPE ARCHITECTURE

A myriad of tools exist that assess or help achieve a landscape's overall performance and effectiveness. "Big" tools are those that focus on larger, regional scales and beyond, such as geographic information systems; remote sensing; models that predict performance based on a synthesis of primary research; and policy. "Small" tools are those that are relevant at smaller scales, such as a site scale. These tools can be the products of site design decisions that help achieve high performance, such as material choice or design of system processes, the processes of design, or the tools used to assess the performance of a site in the field.

This primer focuses on "small tools" that are available to professionals to measure landscape performance in the field at the site scale and how that information can be used to improve design and management of the landscape to maintain or improve performance over time. The methods presented are intended to accommodate those professionals who understand the need to evaluate past, present and future work, but are limited by time, budget, training or access to scientific methodologies. Specifically, this paper seeks to offer efficient and well-tested methods to assess the soil, vegetation, water, human use, and economics of the landscape and their contribution to social and ecosystem services.

Figure 2. BIG and Small Tool Examples (Credit: Emily McCoy)

DESIGN THINKING AND THE SCIENTIFIC METHOD

This primer is not meant to be a robust description of methods or methodologies for scientific research, but rather it borrows from the process of the scientific method while serving the goals of design thinking—solution-based approaches to design problems. The scientific method is a step-by-step process that relies on observation, formulation of hypotheses, predictions, experimentation, data analysis, and conclusions, which are described as the acceptance or rejection of the hypotheses. In most landscape architecture projects, however, robust experimentation with comprehensively identified variables and controls is not feasible since most projects are open systems with a vast, uncontrollable array of possible variables.

The basis of this primer accepts wider varieties of experimentation, as outlined by Ansell and Bartenberger (2014), which are not exclusive to controlled experimentation and are accepted as being necessary for transdisciplinary, environmental problem-solving. This primer also borrows from design thinking strategies, which are traditionally more iterative than the scientific method and accepts the additions of ideation, prototype building, and adaptive feedback to the scientific method. Although controlled experimentation and proving statistical confidence are often unrealistic for the practitioner to implement due to time and financial constraints, practitioners can use the scientific method without controlled experimentation, complemented with the processes of design thinking such as prototyping. This allows practitioners to solve design problems and help researchers identify future research questions for more rigorous scientific inquiry. Establishing critical research topics can support future evidence-based design and identify ways to improve landscape performance through the design and post-occupancy life of a project, whether through improvements to standard practices or changes in landscape management strategies.

Concerted efforts to collect data pertinent to landscape architecture issues can support systems such as those in the citizen science movement that may result in "open, networked, and trans-disciplinary" systems that facilitate "science-society-policy interactions," leading to "more democratic research, based on evidence-informed decision making," and thus becoming advocacy tools for improving the health, safety, and welfare of our built environment (Socientize Consortium, 2014).

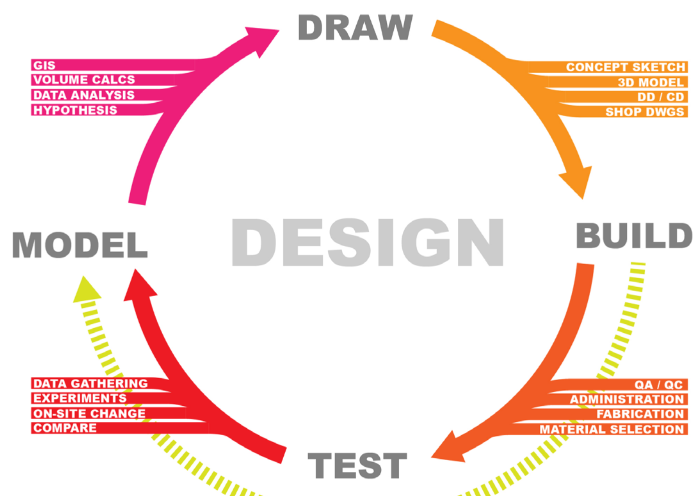

Figure 3. Design—Research—Observe Feedback Loop (Credit: Andropogon Associates)

DETERMINING WHAT AND HOW TO MEASURE AT THE SITE SCALE

The research process begins with first establishing a research topic or question and then creating a plan for the research investigation. The plan for a research project will largely depend on the nature of the research topic, in addition to personal values and the standards an intended audience holds. These values are described in many different ways in the literature. Creswell (2009, 6) calls these values "worldviews," and he silos them into two groups: quantitative and qualitative. However, others have "fuzzier" ways of describing these worldviews. Joroff and Morse (1980) offer a continuum ranging from observation to quantitative laboratory research. Wang and Groat (2002) offer tripartite "systems of inquiry"—postpositivism, naturalism, and emancipatory.

The range of systems of inquiry and their reliance on explaining the world with numbers or words traditionally has created tension between "real" research and "pseudo" research, thus, the "little-r" and "big-R" claims and critiques in explaining research endeavors. As Deming and Swaffield (2011) point out, within the design fields, this system of inquiry will always be dependent on the research topic itself. Their position is not to adopt one school of thought, but rather to use a mixed-method approach due to the nature of landscape architecture as a discipline—a unification of art and science. For social investigations, it is typical to use a mixed methods approach, one using accepted methods in qualitative and quantitative research.

IDENTIFY THE GOAL

This primer can be used at various stages of the design process, from pre-design (programming) to post-occupancy, on one site or to compare multiple sites, and within multiple time scales. Before embarking on a landscape performance monitoring effort, whether it be a one-day site visit or a multi-year study, it is essential to (1) establish the investigation's goals (2) devise a plan that determines what and how to measure and (3) determine during which stages of the process the investigation should be conducted. The desire to answer a question about how a site performs should drive the goal of the monitoring effort. This desire may also be useful in guiding a design decision or collecting baseline information for a later study (pre-design and pre-construction), observing the implementation of a project as it is being constructed, evaluating a design after the project is complete (post-occupancy evaluation), or troubleshooting an issue on the site (adaptive management).

The earlier in the process site investigation goals and landscape performance inquiries can be established, the easier it is to integrate an investigation into the design process and product, and the more accurate or significant your findings will be.

Possible reasons to conduct a field investigation include:

- Educating the greater design community through a larger inquiry, such as a case study investigation with an academic partner, or to fulfill a sustainability rating system requirement, such as SITES

- Informing the design or construction process to maintain or improve project goals (e.g., use of vegetation test plots with different green roof media before final documentation or testing of compaction rates of soil before planting)

- Informing the ongoing management of a landscape to maintain goals or improve performance (e.g., monitoring accumulation of de-icing salts in a planting bed or tracking the irrigation schedule for efficiency or impact on vegetation health)

- Improving design drawing standards, details, and specifications within a professional practice after construction (e.g., revision of acceptable soil specification thresholds for organic matter content based on planting type, or the review of a material type for further use)

- Assessing the assumptions made during the design process and thus testing a design hypothesis, which can later be used to make changes to the design to improve performance, or be applied to similar projects (e.g., varying the organic matter content of a soil and assessing its impact on weed pressure, or assessing the preferred seating configurations in a urban plaza)

In identifying a goal for a site-scale field investigation, it is critical to first assess the usefulness of such an investigation. Is there a problem that needs to be solved? Is this investigation critical for the performance of the site? Is this information unknown to the profession, to your practice, to the site manager, or to the design team? Has anyone else investigated this topic? A review of existing literature is always a critical step in assessing the usefulness of an investigation, although you will likely find that there are few studies out there that reflect the exact conditions of your site or have similar questions. Peer-reviewed journal articles are increasingly becoming available to the general public for free, although it can still be frustrating to find such articles without access to a university library. Online search engines specifically for peer-reviewed journals, such as Google Scholar, or university library websites are great places to start.

CONSIDER REGIONAL ISSUES AND CONTEXT

Some investigation topics are selected for their ability to provide information that may be valuable to promoting the health, safety, and welfare of the public within the context of the site. For example, what are the most cost-effective or best methods for promoting biodiversity for steep slope protection in a landslide prone community? Or, what are the most effective tools for soliciting feedback about programmatic desires in a community that may be less likely to have free time for a community meeting or access to a personal computer? Often, this level of investigation can create unique partnerships with groups that have similar goals and can expand the amount of resources available for a project. This information can also be used as an advocacy tool to inform policy and better promote health, safety, and welfare.

MATCHING THE METHOD TO THE QUESTION

Matching a method (how the information will be collected) to the level of investigation typically involves a compromise between accuracy, precision, training, available time, and cost. The aim of this publication is to assist landscape architects in analyzing their own work with low-cost methods and tools. For more robust studies, it is advisable to conduct a literature review to assess the gaps in current knowledge. This lets you be completely sure that your question cannot be answered through existing research and helps you to discover what methods experts are using to conduct similar investigations, and to understand their limitations. Since landscape architecture is a synthesis of the arts and sciences, there is a large breadth of appropriate research methods that often require a mixed-method approach (e.g., the use of qualitative and quantitative methods). In general, consulting experts in the field of your investigation, such as a psychologist for human behavior assessments, proves advantageous in identifying appropriate research methods.

Weather, Microclimate, Air Quality, and Sound

WHY MEASURE?

Landscapes are open systems that often rely on the mitigation of harsh environmental situations to appeal to the human user and to promote health, safety, and welfare for all life. Landscape architects do not have the luxury of using robust mechanical systems or architectural features to make a space more comfortable or healthier, such as can be done in a building. We must work with existing conditions and proposed elements to make an outdoor space comfortable, safe, and desirable for humans, while balancing other demands. With unprecedented rising global temperatures, mitigating the urban heat island is not only essential for human comfort, but also for mitigating energy demands in an urban environment, which can help reduce the impact of the urban heat island.

PERFORMANCE BENEFITS

Weather (conditions of the atmosphere) and microclimate (the average weather for an area over a period of time) information can be the starting points in forming a design response to a space and the building blocks of a landscape performance investigation, whether it involves monitoring stormwater flow or assessing human comfort and use of a space. Atmospheric conditions, particularly air quality, surface temperatures, and air temperatures, are especially important to consider and track in response to environmental variables within an urban context, as climate change, the urban heat island, and air quality are some of the most important challenges for quality of life today. Beyond the atmosphere, acoustic quality is also an important consideration for design—the impact of the sound of birdsong versus a diesel truck can have profound effects on cognitive function, although not always apparent.

Weather, microclimate, air quality, and acoustic quality data can be gathered through secondary sources or field instruments that are increasingly becoming less expensive and more accurate. These parameters are especially important in evaluating some of the following performance benefits:

- Human comfort and preferences
- Physical activity
- General vegetation health
- Irrigation management
- Stormwater management
- Blackwater management
- Urban heat island effect
- Air quality
- Ecological resilience
- Landscape management practices

METHODS FOR ASSESSMENT

Utilizing weather, microclimate, air quality, and acoustic quality data collected on your site is always preferable to using data collected off-site, as there can be significant variations between sites that may be only a few miles away from one another. In some cases, inaccurate climate data can make other types of site data less significant. For example, some pressure transducers used to measure water fluctuations do not collect barometric pressure, which is used in correcting the data, and requires input from an outside source.

WEATHER, MICROCLIMATE, AIR QUALITY

On-site weather stations with data loggers are the best method for continuous monitoring of site atmospheric conditions, such as temperature, wind, rainfall, humidity, barometric pressure, and solar radiance. However, they can be costly. Many of these weather stations can be accessed wirelessly and online; however, be aware of hosting companies that make data download difficult, as they sometimes will charge a fee for exporting raw data. Some irrigation systems are capable of logging climatic data and could be specified during project documentation if it is determined that the site will be the subject of an investigation or part of an adaptive management regime.

Small, handheld devices are less expensive options for shorter periods of data collection for atmospheric and acoustic quality data; however, they take a limited number of measurements. Handheld devices can measure multiple parameters at once, but typically are only used while in the field for collecting point data. Small data loggers can be left in the field collecting continuous data over time, but they measure only a few parameters, such as temperature and humidity. There are also devices that can be attached to a smartphone or tablet that measure parameters such as decibel levels, temperature, humidity, light, wind, and air quality.

The least accurate (unless located on your site), but least costly method of collecting weather and microclimatic data is downloading daily, monthly, or yearly atmospheric data from an online resource such as your state climate office, NOAA, or Weather Underground. Additionally, there are services that will customize weather data for you for a fee.

ACOUSTICS

Acoustic data can be collected onsite with handheld meters or modeled-based on predicted sound levels extracted from existing research. Smartphone apps do exist to assess sound, but handheld meters are the most accurate and typically cost between $30 and $700. Sound meters with data loggers are more expensive, but help track sound over time more accurately. If you cannot afford a version with a data logger, consider videotaping the screen of the sound meter to capture not only the audio of the sound measured, but also the decibel changes over time so that these metrics can be recorded at a later date at defined intervals (e.g., every 10 seconds).

When collecting or modeling sound data, it is important to not only measure the quantity of the sound as decibel levels, but also to qualify the sounds being measured. Qualifying parameters can be categorized as desirable sounds (rain, water, birds) or undesirable (vehicles, industrial operations), or as natural sounds (biophony and geophony) versus human sounds (anthropophony). On-site interviews can be coupled with the data collection of decibel levels to assess these qualitative aspects of sound and individual perceptions and preferences. Physical characteristics of the environment should also be recorded, such as landforms, solid masses, and weather conditions on your site when collecting acoustic data, as sound can travel in non-linear pathways based on physical elements that may block, dissipate, or reverberate sound. Other factors to record are the sound frequency and sound level variance, as high frequencies and high variance can be more noticeable to the human ear.

Table 2. Typical A-Weighted Sound Levels of Common Sounds (Credit: Bollard and Brennan, Inc., 2004)

TYPICAL A-WEIGHTED SOUND LEVELS OF COMMON SOUNDS (decibels)	COMMON SOUND
130	Threshold of pain
120	Jet aircraft take-off at 100 feet
90	Bulldozer at 50 feet
80	Diesel locomotive at 300 feet
70	Commercial jet aircraft interior during flight
60	Normal conversation speech at 5–10 feet
50	Open office background level
40	Background level within a residence
30	Soft whisper at 2 feet
20	Interior of recording studio

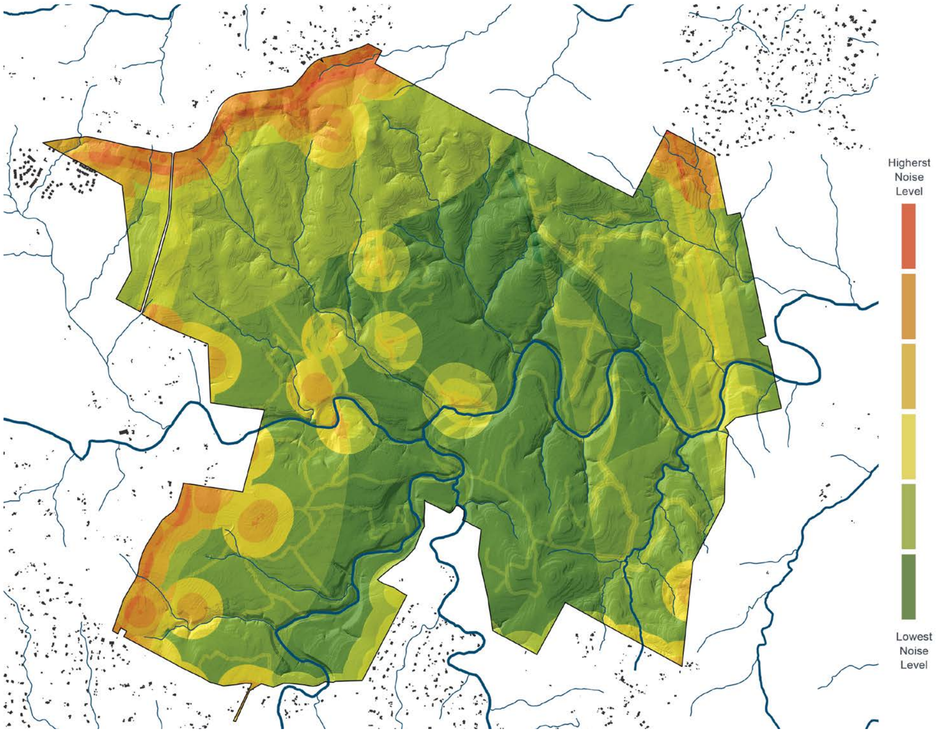

Figure 4. Soundscape Map Created from a GIS-Model (Credit: Andropogon Associates)

WEATHER, MICROCLIMATE, AIR QUALITY, AND ACOUSTIC QUALITY DATA SOURCES

Table 3. Basic Tools and Parameters Measured

TOOL	TYPICAL PARAMETER(S) MEASURED[4]
Infrared Thermometer (IR)	• Surface temperature
Thermal Camera—field	• Surface temperature •Air temperature
Thermal Camera—remote sensing	• Surface temperature
Weather Stations and Small Wireless Data Loggers	• Absolute pressure • Air temperature • Air velocity • Barometric pressure • Carbon dioxide • Carbon monoxide • Dew point • Dust

4 Tool may measure more parameters than mentioned.

TOOL	TYPICAL PARAMETER(S) MEASURED
Weather Stations and Small Wireless Data Loggers	• Hydrogen sulfide • Light intensity • Nitrogen dioxide • Ozone • Particles • Rainfall • Relative humidity (RH) • Soil temperature • Solar radiation • Sulfur dioxide • Surface temperature • Volatile Organic Compounds (VOCs) • Wind speed and direction
Handheld Meters and Smartphone Adapters and Add-ons	• Air temperature • Relative humidity • Carbon monoxide • Nitrogen dioxide • Decibel level (sound) • Audio frequency (sound)

Table 4. Basic Data Sources Summary

DATA SOURCES	ACCURACY AND PRECISION	RELATIVE COST	TECHNICAL EXPERTISE REQUIRED	ADVANTAGES	LIMITATIONS
Infrared Thermometer (IR)	Low to Medium	Low	Low	• Quick readings • Low cost • Portable	• Only takes measurements over small areas • Collects data only while in the field (point data) • Data may have to be recorded manually depending on type
Handheld Thermal Camera	Medium to High	Medium to High	Medium	• Takes measurement over larger areas than an IR thermometer • Produces images that help with data visualization and area comparisons	• Costly • Requires some training • Collects data only while in the field (point data)
Weather Station with data loggers	Medium to High	High	Medium to High	• Continuous data collection • Can be made accessible online • Gathers real-time data from your site • Can record multiple parameters	• Costly • Must be secured to avoid vandalism • May require manual downloads of data if not connected to the internet

DATA SOURCES	ACCURACY AND PRECISION	RELATIVE COST	TECHNICAL EXPERTISE REQUIRED	ADVANTAGES	LIMITATIONS
Handheld Meters and Smartphone Adapters and Add-ons	Low to Medium	Low to Medium	Low	• Low cost • Portable	• Collects data only while in the field (point data) • Calibration should be employed for accuracy
Small Wireless Data Loggers	Medium	Medium	Medium	• Low cost • Portable • Collects continuous data • Small and light-weight enough to be placed easily in difficult locations	• Limited parameters measured • Can be subjected to vandalism or damage • Data storage or battery life may be limited
Secondary Weather Data from Online Sources	High to Low, depending on data source and proximity to your site	Low	Low	• Data is easily accessible • Lowest cost if free online	• Actual weather data may be different than your site • Units of measurement may need to be converted based on your investigation

DATA SOURCES	ACCURACY AND PRECISION	RELATIVE COST	TECHNICAL EXPERTISE REQUIRED	ADVANTAGES	LIMITATIONS
Remote Sensing Data (e.g., thermal cameras)	Medium to Low (depends on resolution)	Low (if publically available)	Low	• Low cost and easily accessible • May show data over multiple years, although it is commonly point data • Can easily be uploaded into (GIS) programs for further analysis as raster images	• Only useful at larger scale, typical resolution is 30 meters • Typically only collects point data
Other common landscape technologies, such as irrigation systems with weather stations	Medium to Low	Low (if already installed) to High	Medium	• May already be a project element (no need to purchase extra equipment) • Data can be viewed easily in relationship to other parameters, such as irrigation usage • Collects continuous data	• Access to data may be difficult (may require site visits to download) or expensive (may require internet access for easy access) • Parameters measured may be limited

PERFORMANCE BENEFIT CONSIDERATIONS

The Urban Heat Island Effect

The urban heat island (UHI) effect is a growing concern in cities, where on warm days, dense urban areas can be 3˚F–8˚F warmer than nearby rural areas causing increased energy demand, poor air quality, thermal discomfort, loss of life, and increased carbon dioxide emissions (McPherson, 1994). This warming can also have ecological impacts on life forms, such as plants and insects, which have narrow ranges of acceptable temperatures. Understanding how to maximize the contribution landscapes can make to significantly reducing the impacts of the UHI effect can be an important topic of study, as it is often cited as one the major concerns of this century. Strategies that landscape designers can employ to mitigate and thus reduce the secondary effects of urban heat islands, include increasing surface albedo (the proportion of light or radiation that is reflected from a surface) with light colors, increasing vegetated areas (and thus, evapotranspiration) adding water elements, and the addition of shade, whether it be with trees or structures.

Below are common mitigation strategies, also known as smart surfaces, that can be employed to mitigate the UHI effect within the realm of landscape architecture. The effectiveness of these mitigation strategies in different contexts can be the topic of a UHI landscape performance investigation.

- Green roofs and walls, green roof irrigation, and blue roofs
- Cool pavements (high albedo, smooth texture)
- Vegetation, including shade trees
- Shade structures

Some information is already known about the impact of a few of the common mitigation strategies on the UHI at the city and site scale. For example, it has been proven that some parks can reduce cooling loads by 10 percent (Yu and Hien, 2006) and can reduce air temperatures by 1.2˚C (Kikegawa et al., 2006) in an urban environment. However, there is still little known about the long-term human and ecological impacts of UHI and how to mitigate these impacts. Some topics that may be of interest to landscape architects when assessing built work and the impact of landscapes in mitigating UHI include:

- Long-term changes in surface temperature on different material types and shaded surfaces
- Differences in shaded surfaces and high albedo pavements
- Differences in a pavement material’s solar reflectance index (SRI) rating and actual performance in the field

- Long-term health of different vegetation types and species for "peak load landscaping" (planting specifically located to provide shade during the time of peak energy demands) (McPherson, 1994)
- Transpiration rates of vegetation and their impact on cooling
- Susceptibility to pests and disease due to changes in temperatures
- Human comfort throughout the seasons
- Building energy consumption, planting strategies, and cost-benefit analyses
- Green roof impacts and variations in green roof types
- Impact of wind tunnels and air movement
- Impact of different architectural glass types and other building materials on UHI
- Balancing tree shading and pollution dispersion along "canyon" streets

To measure the impact of the UHI effect, ambient temperatures and surface temperatures must be measured. Two of the most common instruments to measure surface temperatures are infrared thermometers and thermal cameras. Infrared thermometers are point-and-shoot devices that take measurements as snapshots in time over small areas. Thermal cameras can take measurements over longer periods for larger areas and create images that help assess changes over time, but they are more costly. Usually, these temperature measurements are taken with other measurements such as light intensity with light meters in order to understand the relationship of air and surface temperature with sun exposure.

This information can also be used to assess human comfort. The University of California Berkeley's Center for the Built Environment has a helpful online tool to assess human thermal comfort of an indoor space. Although the tool was developed in accordance with ASHRAE Standard 55-2013 (Thermal Environmental Conditions for Human Occupancy), it can also be used for outdoor environments. Some of the inputs needed for the tool are air temperature, mean radiant temperature, air speed, humidity, metabolic rate (human activity type or the energy being used), and clothing type.

Other methods that can collect continuous measurements over longer periods are temperature loggers that can be left on a site, or other landscape technologies such as irrigation systems that also track soil temperature. Theft and vandalism are always concerns when using these devices, especially wireless devices, but they can be secured to limit theft.

Lastly, thermal data can be downloaded from the USGS, which is collected with satellite imagery. This data is relatively easy to download, but only reads temperature at a 30m x 30m resolution. Consequently, this data is only useful for large-scale projects.

For more information about the UHI effect and the latest research on mitigating its impact, the EPA's UHI effect website is a great starting place for additional information.[5]

5 U.S. Environmental Protection Agency. 2018. "Heat Islands." https://www.epa.gov/heat-islands

Soils and Amendments

WHY MEASURE?

As a landscape architect, understanding a soil's properties are very useful in:

- Determining the overall health of a soil
- Understanding the changes of a soil over time in response to inputs (foot traffic, de-icing salts, fertilizers, other amendments, etc.)
- Assessing a soil's ability to hold and infiltrate water
- Determining a soil's ability to support healthy plants
- Devising a strategy to amend a soil to support healthy plants
- Trouble-shooting a site performance problem
- Designing or modifying a specification of a performance-based soil to meet design goals, whether for maintaining a specific plant palette with minimal input, stormwater infiltration, moisture retention, to resist compaction, or to provide structural stability
- Understanding the effectiveness of a management strategy

Soil is the foundation for the health of all living things in the landscape. As such, soil health is closely tied to overall ecosystem health and resilience, and is particularly challenging in the urban environment (Pavao-Zuckerman, 2008). This matrix under our feet that plays a key role in sustaining life, influences water and air quality, and supports human health and well-being. It is a mix of air, water, organisms, decomposing organic matter, and mineral particles of sand, silt, and clay. The threads that weave this matrix together and give life to the soil are tiny microorganisms not visible to the naked eye, such as fungi and bacteria. These microorganisms support vegetation in the landscape and help give soil its unique properties. The amount of nutrients that can be mobilized by soil microorganisms can be considerable, comprising a significant portion of the stable nutrient pool.

PERFORMANCE BENEFITS

Soil health, particularly in the urban landscape or a landscape which is heavily used, can be one of the most important drivers of landscape performance, directly influencing plant health and stormwater management, and indirectly influencing human comfort, aesthetic value, and building energy consumption. Soil health can be the cause of plant deaths or outbreaks of pest and disease, where it may appear the problem is simply with the plant itself. Due to the soil's influence on overall landscape performance, it is critical for landscape architects to understand soil properties throughout the life of a project.

Before design, it is important to assess the existing soil, and then, if needed, to provide informed guidance through specifications and drawings, proposing a soil to meet the project's goals. Throughout the construction process, it is also critical to ensure that the contractor follows these carefully crafted soil requirements. To understand the effectiveness and evolution of a soil in meeting the project's goals over the long term, it's also important to track how the soils change overtime in response to human use or management of the site. This information can then be used to modify management of the landscape or future soil specifications in anticipation of how these inputs may influence site performance over time. The methods outlined in this primer are useful in assessing and tracking soil performance and are applicable at all stages of design and construction.

Figure 5. Soil during Construction: Engineered soil being placed at Shoemaker Green, University of Pennsylvania, Philadelphia (Credit: Andropogon Associates)

Soil parameters are especially important in evaluating some of these performance benefits:

- Vegetation health
- Soil health
- Stormwater management (quantity and quality)
- Irrigation management (quantity and quality)
- Blackwater management (quantity and quality)
- Carbon sequestration
- Emissions reduction
- Surface temperature reduction
- Erosion control
- Soil formation and enhancement
- Nutrient cycling
- Pollution reduction
- Habitat quality and biodiversity
- Biomass and net primary production
- Revenue generation
- Material cost savings
- Asset management and sustainable site maintenance

Soil properties that affect landscape performance, also known as soil indicators, are divided into physical, chemical, and biological characteristics. These can be carefully measured in the lab or monitored in the field before, during, and after construction. This multi-dimensional analysis of a soil can provide insight into the health of the soil and its ability to perform, helping troubleshoot an underlying problem of soil and plant health. Below are common parameters of physical, chemical and biological soil properties, as well as a summary of some soil issues that may be encountered in landscape architecture projects. Also included are parameters which may be assessed to troubleshoot the problem and solutions.

PHYSICAL

The physical properties of soil offer an important first glimpse of a soil's unique qualities. They can give insight into how much compaction a soil can withstand, its ability to supply water for plants, infiltrate water, and contribute to soil erosion and sedimentation, as well as its ability to support specific plant types and human uses.

Table 5. Common Physical Indicators of Soil Health (USDA, 2001)

PHYSICAL SOIL PROPERTIES	RELATIONSHIP TO SOIL HEALTH
Hydraulic conductivity (K) and infiltration rate	• Describes movement of water through soil
Particle size distribution and texture	• Contributes to the ability of a soil to retain and transport water and nutrients • Effects the health of microorganisms • Influences soil erosion
Penetration resistance, porosity, and bulk density	• Important for measuring compaction • Important for understanding water movement
Rooting depth	• Gives insight into plant health and compaction
Water holding capacity, soil moisture, and plant available water	• Shows water storage potential and water availability

CHEMICAL

The chemical attributes of soil are important for understanding a soil's ability to support healthy plants. This information is useful before design in order to propose plant types that will succeed in the existing soil of the site, understand if there are any toxic concentrations of elements in the soil, and recognize amendments the soil may need to sustain healthy plants over the long term.

Table 6. Common Chemical Indicators of Soil Health (USDA, 2001)

CHEMICAL SOIL PROPERTIES	RELATIONSHIP TO SOIL HEALTH
Acidity or Alkalinity (pH)	• Impacts plant health and nutrient availability
Cation Exchange Capacity (ability of the soil to retain positively charged ions)	• Indicator of soil fertility
Electrical conductivity (EC)	• Effects plant and microorganism health • Can indicate management issues withsynthetic fertilizers or de-icing salts
Macronutrients and micronutrients	• Indicator of soil fertility

SOIL BIOLOGY

Quantitative and qualitative analysis of soil biology is an often overlooked parameter of overall soil health. Bacteria and fungi are the Earth's primary decomposers. As the two primary decomposers, they are critically important in the nutrient cycling process that immobilizes needed nutrients for plant uptake. The amount of nitrogen, phosphorous, and potassium, and other nutrients immobilized in bacterial and fungal biomass can be considerable, from several micrograms to milligrams of biomass, comprising a significant portion of the stable nutrient pool. Other organisms, such as beneficial nematodes, protozoa, arthropods, and mycorrhizae also play critical roles in nutrient cycling and availability, and all play a role in overall soil health. Proposing biologically rich soil amendments, such as compost and compost teas, are particularly important in engineered soils that tend to be composed mostly of sand and have little organic matter.

Table 7. Common Biological Indicators of Soil Health (USDA, 2001)

BIOLOGICAL SOIL PROPERTIES	RELATIONSHIP TO SOIL HEALTH
Soil organic matter (SOM)	• Indicator of soil fertility, structure, stability, nutrient retention, soil erosion, and available water capacity
Microbial biomass carbon (C) and nitrogen (N)	• Indicator of soil fertility • Indicator of soil structure
Potentially mineralizable nitrogen	• Indicator of soil fertility
Soil respiration [6]	• Indicator soil biodiversity. Measures microbial activity as CO_2 , but does not differentiate beneficial organisms from harmful ones and can vary depending on season, time of day, soil type, and time since last disturbance • May be useful for studies of carbon sequestration
Dry weight	• An indicator of soil moisture
Bacteria—active and total	• Indicator of soil biodiversity • Bacteria biomass is an important indicator of soil health and can indicate whether a compost is stable. • Active bacteria are those that are metabolizing oxygen.

6 Nitrification and decomposition rates can also be used to measure activity levels, but this is less common.

BIOLOGICAL SOIL PROPERTIES	RELATIONSHIP TO SOIL HEALTH
Fungi—active and total	• Indicator of soil biodiversity • Fungal biomass are important for soil health. • Active fungi are those that are metabolizing oxygen.
Fungi-to-bacteria ratio	• Indicator of soil biodiversity • Ideal ratios depend on planting type. • Annual and some perennial crops prefer ratios near 1:1, while landscape with more woody vegetation prefer ratios between 5:1 and 1000:1.
Fungi hyphal diameter	• Indicator of soil biodiversity • Beneficial fungi tend to have a larger hyphal diameter.
Mycorrhizal colonization	• Indicator of good soil health • Some plants will only form associations with specific types of mycorrhizae.
Nitrogen cycling potential	• Indicator of potential soil fertility • Correlated from the amounts of protozoa and nematodes
Diversity of beneficial organisms (nematodes, protozoa, flagellates, amoebae)	• Indicator of soil biodiversity • High diversity is desired.
Presence and quantity of harmful organisms (*E. coli*, ciliates, root feeding nematodes)	• Indicator of poor soil health and potential contamination

Table 8. Common Soil Problems and Parameters Used to Troubleshoot Problems

SOIL PROBLEMS	POSSIBLE REASON	SOIL PARAMETERS TO ASSESS IN THE FIELD OR LAB
Compaction	• Excess tillage • Excess vehicular or pedestrian traffic • Low organic matter • Modification of wet soil • Poor soil structure	*Physical* • Bulk density • Penetration resistance • Porosity • Rooting depth • Particle size distribution and texture *Biological* • Anaerobic biology • Hydraulic conductivity (K) and infiltration rate Non-soil parameters: behavior mapping, construction observation
Poor plant health	• Compaction • Low organic matter • Low soil biodiversity • Nutrient or pH problems • Presence of toxins, such as salts or pollutants • Soil pathogens • Soil too wet or too dry	Full soil chemical, physical, and biological testing Non-soil parameters: plant pest and disease, horticultural cultural practices

SOIL PROBLEMS	POSSIBLE REASON	SOIL PARAMETERS TO ASSESS IN THE FIELD OR LAB
Poor drainage or poor infiltration	• Compaction • Excess salt • Extreme drought followed by intense rain or irrigation • High water table • Overwatering • Poor soil structure • Surface crusting	*Physical* • Hydraulic conductivity and infiltration rate • Particle size distribution and texture • Porosity • Rooting depth • See Compaction parameters • Soil infiltration rate • Soil moisture (with irrigation data, if available) • Bulk density *Chemical* • Electrical conductivity *Biological* • Soil organic matter Non-soil parameters: horticultural cultural practices
High salinity	• Excessive de-icing salts • Excessive evaporation • High saline soil amendments • Over fertilization • Poor drainage • Saline irrigation water • Salt water intrusion	*Physical* • See drainage parameters *Chemical* • Electrical conductivity Non-soil parameters: poor horticultural practices, evapotranspiration rates

SOIL PROBLEMS	POSSIBLE REASON	SOIL PARAMETERS TO ASSESS IN THE FIELD OR LAB
Erosion and sedimentation	• Compaction • Lack of plant cover • Low organic matter • Poor plant health • Poor soil structure	*Physical* • Particle size distribution and texture • See Compaction parameters • Soil depth *Biological* • Soil organic matter Non-soil parameters: poor horticultural practices, plant pests, and disease
Changes in or problems with pH	• Excessive or inappropriate fertilizers • Poor drainage	*Physical* • See drainage parameters *Chemical* • pH Non-soil parameters: poor horticultural practices, plant pests and disease
Low available water holding capacity	• Compaction • Low organic matter • Excessive drainage • Low biological activity	*Physical* • Infiltration rate • Particle size distribution and texture • See compaction parameters • Soil moisture *Chemical* • Cation exchange capacity and base saturation • Electrical conductivity *Biological* • Soil organic matter Non-soil parameters: poor horticultural practices

Adapted from USDA NRCS Soil Quality Institute (2001), Doran et al. (1996), Larson and Pierce (1994), Seybold et al. (1997)

METHODS FOR ASSESSMENT AND PEPRFORMANCE BENEFIT CONSIDERATIONS

LAB TESTING

Soil testing is relatively low cost, particularly given the benefits of a high-quality soil and the level of investment that is made on a landscape architecture project. Testing ideally occurs during the site assessment, construction, and post-occupancy phases of a project. For construction testing, specifications will establish the amount of testing required, but typically tests are required from the manufacturer and regular batch testing on-site is required during construction.

Post-occupancy testing may be desirable to test the properties of a soil once each season (four times a year) until there is consistency in the results. These tests can also be useful in guiding management practices of the soil during a warranty period or during permanent maintenance. For projects where de-icing salts are used and plant health is a concern, soil testing during post-occupancy is ideally conducted at the end of the growing season (before de-icing salts are used), again at the beginning of the growing season (once the use of salts are no longer required), and mid-way through the summer.

PHYSICAL AND CHEMICAL

The physical and chemical properties of a soil sample are best analyzed by a reputable, accredited lab that uses methods that are widely accepted and is fully transparent with those methods. Typically, your local extension agency or university may offer low-cost soil tests using industry-accepted testing standards. It is best to use a reputable agency close to your site since they may use specific methods and test for unique parameters of a soil that are specific to the constraints of the local soils. For example, metal testing may be a standard testing parameter in areas dominated with clay soils, where heavy metal toxicity is a concern due to the typical low pH. Local soil testing agencies can also offer diagnostic testing that may help in troubleshooting any issues related to poor plant health, offering remedies to overcome the cause of the problem. Additionally, some agencies may offer specific testing for different landscape types, such as testing green roof media or compost before it is added to a specified soil.

Labs typically provide testing for plant nutrients; organic matter; gradation of gravel, sand, silt, and clay content; cation exchange capacity; sodium absorption ratio; saturated conductivity; bulk density; total porosity; electrical conductivity; pH; and mineral content. They usually have detailed instructions for how to take a soil sample and the forms you will need to send with the soil samples. The way you collect your soil sample and the method you use for collecting representative samples is just as important as the soil sample itself. Soil samples are collected with a soil probe or a simple hand shovel and mailed in a container approved by the testing agency. Generally, labs ask that you collect and mix about 15–20 borings from a representative area for one sample. This can be done randomly, in pre-determined areas, or on a predetermined grid. For the goals of a landscape architect, you should collect samples from each representative landscape type or soil type throughout your project site, such as perennial beds, turf, bioretention, etc. The amount of soil samples and the types of landscape areas you take samples from will vary based upon your goals and budget.

SOIL BIOLOGY

There are three ways one can assess soil biological health: direct counts of organisms and biomass; measuring biological activities of organisms, such as respiration, as an indicator of biomass or quantifying diversity through indirect methods. Unfortunately, there are few labs that perform qualitative and quantitative analyses of soil biology and the tests are often expensive. However, everyday there are more labs beginning to offer this service. Typically, labs associated with experts in soil biology are reputable and reliable.

Soil biology tests are defined as qualitative or quantitative. Qualitative tests give you a sense of relative levels of preferred and harmful organisms, while quantitative tests provide actual counts of biomass in the soil and their relative ratios of fungi to bacteria. Direct qualitative analysis can also be performed with minimal training and a low-cost microscope. Training is relatively inexpensive and can be completed within a short timeframe.

Quantitative tests also provide analyses of active and total soil biology. The term “active” is used to indicate live and breathing metabolizing organisms. Total counts include dormant organisms, so results are comparable regardless of season or available food at the time. In the laboratory, the sample is incubated in favorable conditions and the active organisms will appear first, no matter what time of year, making sample comparisons more accurate. Total numbers are provided as a comprehensive measurement of everything in the sample. Note that some methods of measuring activity levels of soil biology, such as respiration rates, will give you an idea of total biological activity, but will not differentiate between beneficial and harmful organisms (Ingham, Moldenke, and Edwards, 2000).

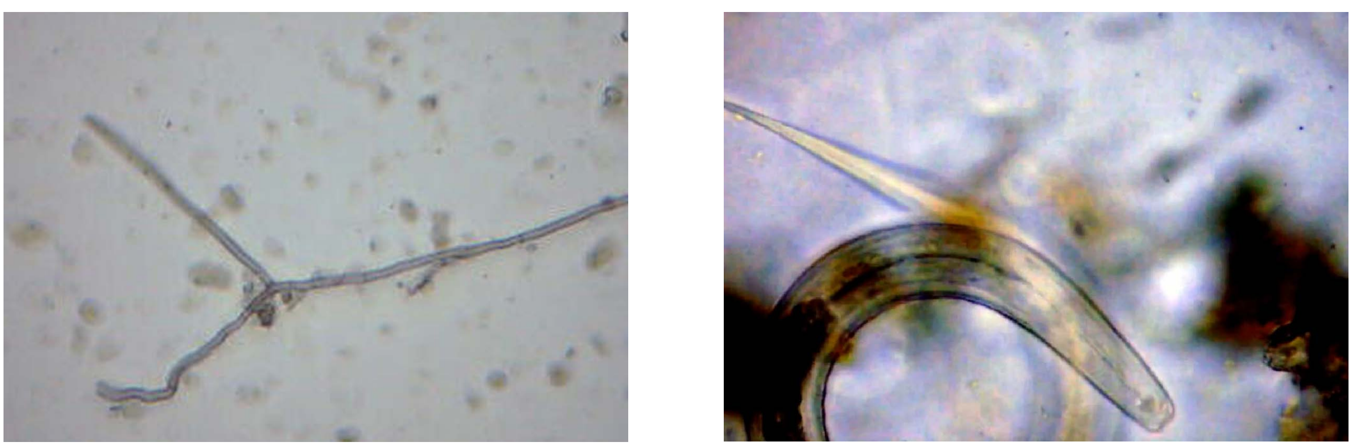

Figure 6. Soil Biology Microscope Photograph of Fungi (left) and a Nematode (right) (Credit: Emily McCoy)

FIELD TESTING

SOIL CHEMISTRY AND BIOLOGY

Although not as accurate as laboratory testing, there are a handful of low-cost, quick methods for determining soil chemistry and biology in the field; these are mostly focused on providing quick assessments of soil fertility for plant growth. These methods include using commercially available, low-cost sensors to test either the soil in situ or to test water extracted from the soil in the field. These sensors include colorimetric, electrical and electromagnetic, optical and radiometric, mechanical, acoustic and pneumatic, and electrochemical sensors that have the ability to test soil texture, organic matter, moisture, salinity, compaction, pH, and macronutrients (Adamchuk et al., 2004).

Colorimetric tests are the most common and require taking soil samples, adding an extractant to the sample, and comparing the color of the sample to a color card. A study conducted by Faber et al. (2007) found that the Rapitest and La Motte Soil test kits were 92 percent and 94 percent accurate when compared to lab tests. Other tests, such as chlorophyll meters, can also be used to determine nitrogen needs of a plant and are now commonly used with smart phone apps to help analyze the results.

Another quick and easy field test for soil chemistry includes pouring distilled water in a soil sample and using a low-cost sensor or "pen" to measure the water from the sample. These tests are commonly used in the horticulture industry. The best methods for use in the field or at the home or office are the saturated media extract and the 1:2 method. The University of Massachusetts at Amherst has helpful technical fact sheets for using pens to assess the pH and electrical conductivity of soil and soilless media.[7]

Soil biology field testing is an emerging market and there is currently only one product available that measures soil biology in the field, the MicroBiometer. This product measures overall soil biomass and does not differentiate between different types of organisms, but it can be great for assessing relative soil biology health.

COMPACTION

Soil compaction is an important consideration in landscape design and management, particularly on sites with high foot traffic or on sites with extensive building construction. Compacted soil can reduce plant health and a soil's ability to manage stormwater. Soil becomes compacted by heavy use and heavy weights, and this is exacerbated in soils with characteristically small pore spaces, such as clay and silt; soils with low organic matter; and in wet conditions. Compaction generally affects the top 24 inches of the soil and can prohibit root penetration; limit water infiltration; contribute to erosion, sedimentation, and loss of nutrients; and degrade overall ecological health (USDA NRCS Soil Quality Institute, 2003). Good soil design and specifications consider potential compaction causes

7 University of Massachusetts at Amherst. "How to Use pH and EC "Pens" to Monitor Greenhouse Crop Nutrition." https://ag.umass.edu/fact-sheets/how-to-use-ph-ec-pens-to-monitor-greenhouse-crop-nutrition)

and propose strategies to resist compaction over time, whether with the soil design itself or with a proposed management strategy that evaluates compaction on a regular basis, including proposed mitigation strategies when compaction is reaching a set threshold.

There are two commonly used methods for determining soil compaction: bulk density and penetration resistance. Bulk density can be measured with a core method using kits, such as the Soil Quality Kit Guide (NRCS Soil Quality Institute, 2001), used to assess compaction in the field. A quick, non-intrusive, easy and low-cost method for measuring compaction is using a cone penetrometer to measure penetration resistance. This tool is pushed into the ground to measure compaction. Setting up sampling points on a grid in regular intervals over your site is a good way to assess the general compaction over an entire site. Usually the readings are in pounds per square inch (psi); 300 psi is typically the level of compaction at which roots resist penetration, and is thus an indicator of compaction.

Penetrometers come with two different types of cones that can be used in different soil types. Readings should be taken when the soil is neither too dry nor too wet. Different penetrometers have different methods for recoding penetration, so it is best to refer to the product's instruction manual for the best method of measurement.

In turf areas, turf thatch—the root mass of a lawn—can limit the penetration of a soil penetrometer. If you also want to understand the compaction of the soil below the turf thatch, you will need to remove it to measure soil compaction. A thick turf thatch can be an indicator that the turf is growing quicker than plant material is being decomposed and that the soil biology is unhealthy. This condition also limits water infiltration into the soil, and thus causes drought stress in the turf or inefficient irrigation regimes. A cone penetrometer can be used to identify turf issues related to a thick thatch, in addition to identifying compacted soil, and help to troubleshoot issues related to vegetation health or irrigation concerns.

Figure 7. Soil Penetrometer Field Demonstration (Credit: Andropogon Associates)

SOIL INFILTRATION AND HYDRAULIC CONDUCTIVITY

Soil infiltration and saturated hydraulic conductivity represent the downward movement of water into soil. The infiltration rate is the velocity with which water moves through a particular medium or soil. Infiltration rates are important for stormwater management, irrigation programs, and overall plant health. The simplest way for landscape architects to quickly and economically test infiltration in the field is with a double-ring infiltrometer. ASTM International has a recommended method for using a double-ring infiltrometer (ASTM D 3385-Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer).

A double-ring infiltrometer is a simple tool, usually between 12–24 inches wide, with two metal rings. The infiltrometer is pressed into the ground (about 2 inches deep) and filled with water. The soil in the rings is moistened before testing, then water is poured into both rings, filled to the top. The rate with which water moves through the inner ring is the infiltration rate. For some tools, you will need to also use a ruler and stopwatch to track the infiltration rate, while others have those embedded in the tool. Refer to the infiltrometer's manual for the specific protocol. Some companies provide data sheets and other helpful monitoring tools on their websites. Taking note of soil compaction with a cone penetrometer is also good practice to potentially correlate compaction with infiltration.

Figure 8. Double-ring Infiltrometer Field Demonstration (Credit: Emily McCoy)

Another device for measuring soil infiltration and hydraulic conductivity is a constant head permeameter. This device can be more accurate than a double ring infiltromenter. It is, however, a more costly alternative, and slightly more difficult to transport and operate. This device applies a constant amount of water to a sample auger hole in order to calculate an infiltration rate and hydraulic conductivity.

SOIL MOISTURE

Soil moisture is particularly important in understanding the full water cycle of a project, specifically for the post-occupancy evaluation of a project with an irrigation system, a green roof project, or a project with green infrastructure best management practices. It can also be useful in troubleshooting issues with stormwater systems and plant or soil health.

Continuous monitoring can be conducted with an irrigation system, which also uses soil moisture sensors to trigger the irrigation system to turn on. These irrigation systems have controllers that log the moisture levels over time (usually in terms of volumetric water ranging from 0 to 57 percent, with saturated soils between 40 and 50 percent, depending on the soil type), and the data can be downloaded. Since the triggers are set at specific moisture levels, you can usually assume the soil never gets drier than the thresholds set in the irrigation timer.

Other methods for continuous monitoring include soil moisture sensors connected to data loggers. Ideally, soil moisture sensors are placed at multiple depths to understand soil moisture characteristics in a soil. They are typically placed in the root zone (the trigger to turn an irrigation system on) and just below the root zone (the trigger to turn an irrigation system off). Although continuous monitoring gives you the most accurate insight into the moisture characteristics of a soil, it is also the most expensive.

Soil moisture can also be measured with simple soil moisture meters, such as tensiometers, that are placed into the ground with measurements read manually. The disadvantage of these meters is that they only take readings as often as you record the data. However, these meters can give you relative moisture readings, and the cost is significantly lower than the continuous methods.

Tensiometers measure soil moisture tension in centibars (cb). Different soil types have varying ideal ranges that indicate whether the soil is saturated or dry. Below is a table showing some typical readings of different soil types.

Table 9. Irrigation Guidelines Based on Tensiometer Readings in Centibars

TENSIOMETER READING (CENTIBARS)	INTERPRETATION
0–10 cb	Saturated soil
10–20 cb	Most soils are at field capacity
30–40 cb	Typical range of irrigation in many coarse soils
40–60 cb	Typical range of irrigation in many medium soils
70–90 cb	Typical range of irrigation in heavy clay soils
> 100 cb	Crop water stress in most soils

Adapted from Watermark Soil Moisture Sensors, The Irrometer Company, Riverside, CA. (Morris and Energy, 2006)

SLOPE STABILIZATION

Soil erosion is a significant issue in many communities in the world. A simple device to measure soil erosion is an erosion pin. Erosion pins are metal spikes that are driven into the ground and are often laid out in a grid pattern over a large landscape. Each pin typically has depth measurements that are recorded over time. The changes in soil depth are multiplied by the area to calculate total erosion volumes. This method could be useful for comparing different erosion control techniques to one another, such as different seed mixes or structural controls.

Water

WHY MEASURE?

Less than one percent of the earth's water is available for human use. Agriculture and irrigation use up to 70 percent of this small amount of available water (Oregon State University, 2008). Water resource management has been cited as one of the most critical issues urban communities will face in the 21st century (Dalhammar and Mehlmann, 1996), and urban stormwater runoff has been identified as one of the major causes of water pollution (U.S. Environmental Protection Agency, 1996).

In the U.S. Environmental Protection Agency's (EPA) 2002 ***National Water Quality Inventory: Report to Congress***, urban runoff and storm sewer discharges were identified as one of the leading sources of water quality impairment in surface waters, among other sources such as industrial discharges and agriculture. In 1999, approximately 5,000 square miles of estuaries, 1.4 million acres of lakes, and 30,000 miles of rivers were impaired due to urban runoff (U.S. Environmental Protection Agency, 2000). This translates to poor drinking water, eroded waterways, loss of aquatic and riparian habitat, aesthetically displeasing water bodies, repeated and more intense water restrictions, and loss of aquatic-based recreation. It is estimated by the EPA (1998) that almost 20 percent of the population that uses publicly supplied water is using water from a source that has had health violations.

In addition to water quality concerns, urban areas are also increasingly suffering from water shortages. Water managers in 40 states expect shortages in some portion of their

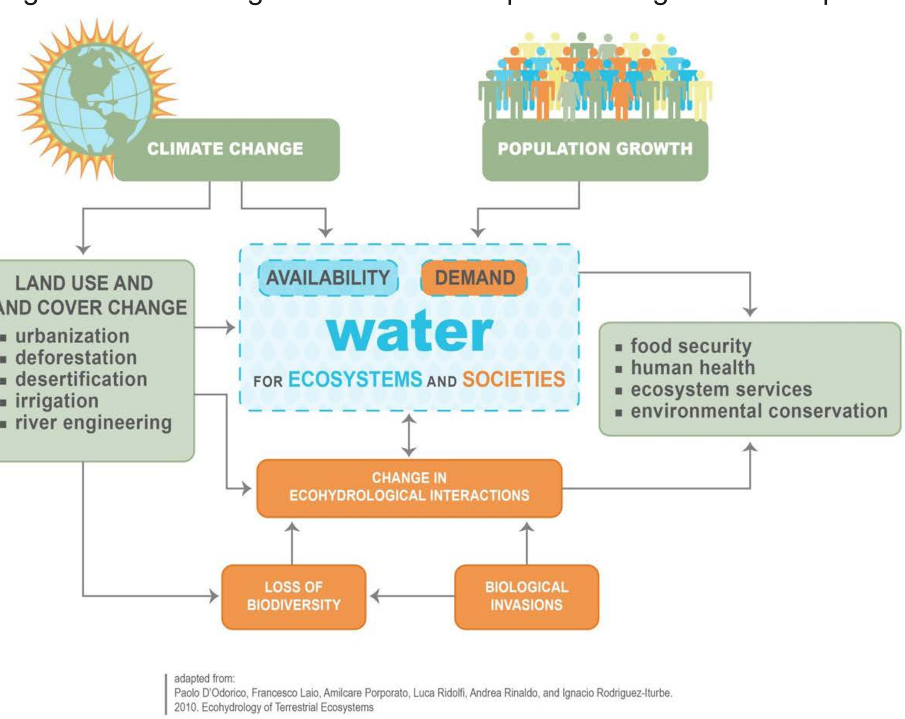

Figure 9. Current Water Issues (Credit: Andropogon Associates)

state under average conditions in the next 10 years (U.S. General Accounting Office, 2014).

The passage of the Clean Water Act in 1972 reformed government policies to not only recognize water pollution but implement standards to reduce it, and today the Clean Water Act is of the most stringent regulations of the built environment. Concerns about the impact of climate change on water availability and water quality are compounding the need for serious sustainable water management with measurable results. Due to the magnitude and complexity of water resource issues presented in our communities, it has become imperative that landscape architects help make sustainable water decisions, helping to alleviate water issues in our communities.

Although there have been great accomplishments in sustainable water management, with a focus on green infrastructure and low impact development best practices in the United States over the last 20 years, there are still gaps in site-level knowledge of the measurable performance of water systems in the built environment and how landscape management influences water management. For example, currently there is a lack of research devoted to how plant selection and soil enhancement can be maximized to support stormwater management goals (Bartens et al., 2009; MacDonagh, 2015; Bush et al., 2008; Whitlow and Bassuk, 1988), particularly in response to seasonal variations (Peters, Hiller, and McFadden, 2011).

Moreover, the current engineering models commonly used in development projects do not always accurately depict the nuanced performance a landscape may be capable of achieving. For example, the older, more commonly used engineering models treat plant species within groups (trees, shrubs, herbaceous perennials) equally in their ability to manage water and do not accurately depict water movement in engineered soils with multiple layers (MacDonagh, 2015; Christianson, Brown, Barfield, & Hayes, 2012), therefore not giving performance credit to more complex designs. This concern has been echoed by experts in the industry who see opportunities for better use of high-performing soils and vegetation in green infrastructure projects.

In water-limited communities, especially in the western United States, irrigation, increased impervious areas, and man-made structures are reducing or altering water flows to natural waterways and aquifers. For example, in Los Angeles almost 50 percent of the precipitation that falls in the region is conveyed through grey infrastructure directly to the sea, whereas in the 1920s only 5 percent of precipitation flowed directly to the sea and 95 percent of was infiltrated into the aquifer system (Green, 2007). These dramatic changes in water flows over relatively short periods of time are creating contentious relationships between communities regarding water rights while taking water away from important species, such as freshwater mussels (Green, 2015). Green infrastructure and informed landscape management may be considered as tools to mitigate these issues. It is estimated by the EPA that in Los Angeles, increased use of green infrastructure practices could enhance groundwater replenishment and supply by about $310 million worth of water a year (U.S. Environmental Protection Agency, 2010).

It is important for land owners, designers, and landscape managers to promote, design, and adaptively manage sustainable water systems in the built environment. Landscapes should be designed and managed to:

- Eliminate or reduce the use of potable water for use in the landscape and buildings;

- Manage and reuse stormwater and wastewater onsite and replicate natural hydrologic conditions;

- Improve water quality; and

- Create aesthetically pleasing stormwater facilities that are multifunctional (treat and conserve water, provide habitat, reduce flooding, mitigate the urban heat island effect, improve air quality, increase groundwater recharge, reduce landscape maintenance costs, etc.).

The only way to promote sustainable management of water systems is to use the best available science to design stormwater systems and to track their performance in the field over time in order to make adjustments when necessary. There are methods that landscape architects and landscape managers can employ to discover how design and management decisions affect performance and to ensure water systems are operating as designed. The more landscape architects are aware of how to monitor the stormwater parameters of a site, the more equipped they are to work with civil engineers to propose monitoring devices during the design process so that the design team, land owner, land managers, and researchers can gain new insights into sustainable water management throughout the life of a project.

Figure 10. Green Infrastructure Overview (Credit: Andropogon Associates)

PERFORMANCE BENEFITS

Clean water is critical for all life. Landscape types can play a critical role in protecting this resource, whether it be through actively improving its quality, or by using it in a responsible manner. Sustainable landscapes treat all water as a resource rather than a waste product. The performance benefits associated with water include:

- Improved stormwater quality management
- Improved stormwater quantity management
- Irrigation reduction and increased efficiency
- Increased air conditioning condensate, greywater, and blackwater reuse
- Enhanced human comfort
- Enhance human well-being
- Urban heat island mitigation
- Enriched aesthetic amenities and beauty
- Improved habitat and biodiversity
- Presence of biomass and primary productivity
- Healthy vegetation
- Ecological, flooding, landslide and drought resilience
- Social and environmental justice
- Revenue generation or cost savings

METHODS OF ASSESSMENT

The civil engineering community has robust methods for measuring water quantity and quality. The EPA's Urban Stormwater BMP Performance Monitoring manual (Strecker et al., 2002) is a great resource regarding in-depth stormwater monitoring methods that are commonly used by civil engineers and researchers. Some municipal and state agencies have developed monitoring protocols specific to the stormwater issues of their communities. The methods outlined in this section borrow from these resources and illustrate cost-effective and low-tech methods that are easy to install on a site during or after construction. In addition, the methods outlined here focus on water systems as they relate to active systems, such as irrigation systems and green infrastructure best management practices

(BMPs). The methods outlined in this section do not discuss stormwater modeling and calculators, or robust methods for tracking quantity and quality in structural BMPs. For more information about models, calculators, and monitoring structural BMPs, see the EPA's Urban Stormwater BMP Performance Monitoring Manual (Strecker et al., 2002) and other resources cited in the references section.

Before pursuing irrigation or stormwater performance monitoring of a project, you should first establish the performance goals for the project and the amount of time and resources you are capable of dedicating to the effort. Also, determine how you are going to use the information in order to determine important monitoring factors such as the number of storm events to monitor or the time period over which to record data in order for it to be statistically significant. This level of rigor may not be necessary if the information is only used for adaptive management of the landscape. However, if the data are going to be shared through databases such as the International Stormwater BMP Database, consider using the EPA's Urban Stormwater BMP Performance Monitoring manual (Strecker et al., 2002) for guidance in determining how many storm events should be monitored and the number of samples necessary for statistical significance, which is most critical for measuring water quality.

STORMWATER QUANTITY

For simple investigations measuring the effectiveness of a stormwater management or irrigation system over time, the main components measured should be water input and water output. In closed systems, such as green roofs or lined bioretention facilities, this is relatively easy to measure. However, in open systems, systems that rely on infiltration (e.g., the tracking of water flow) these measurements can be fairly challenging. With some forethought during the design phase of a project rather than in post-construction, project monitoring can be easier and cost effective, whether it is an open or closed system.

DATA MANAGEMENT: DATA LOGGERS

Data loggers store data from a wide variety of sensors, whether they are integrated in the sensors themselves or are isolated instruments that can be connected to various sensors. Some manufacturers offer packages of weather stations with open ports that can support a wide variety of sensors. When considering data loggers for multiple sensors, make sure the data logger is housed in a waterproof structure that can also be secured onsite. Some data loggers connect online, which makes downloading data very convenient. Also, some data loggers need external power, while others operate on battery power.

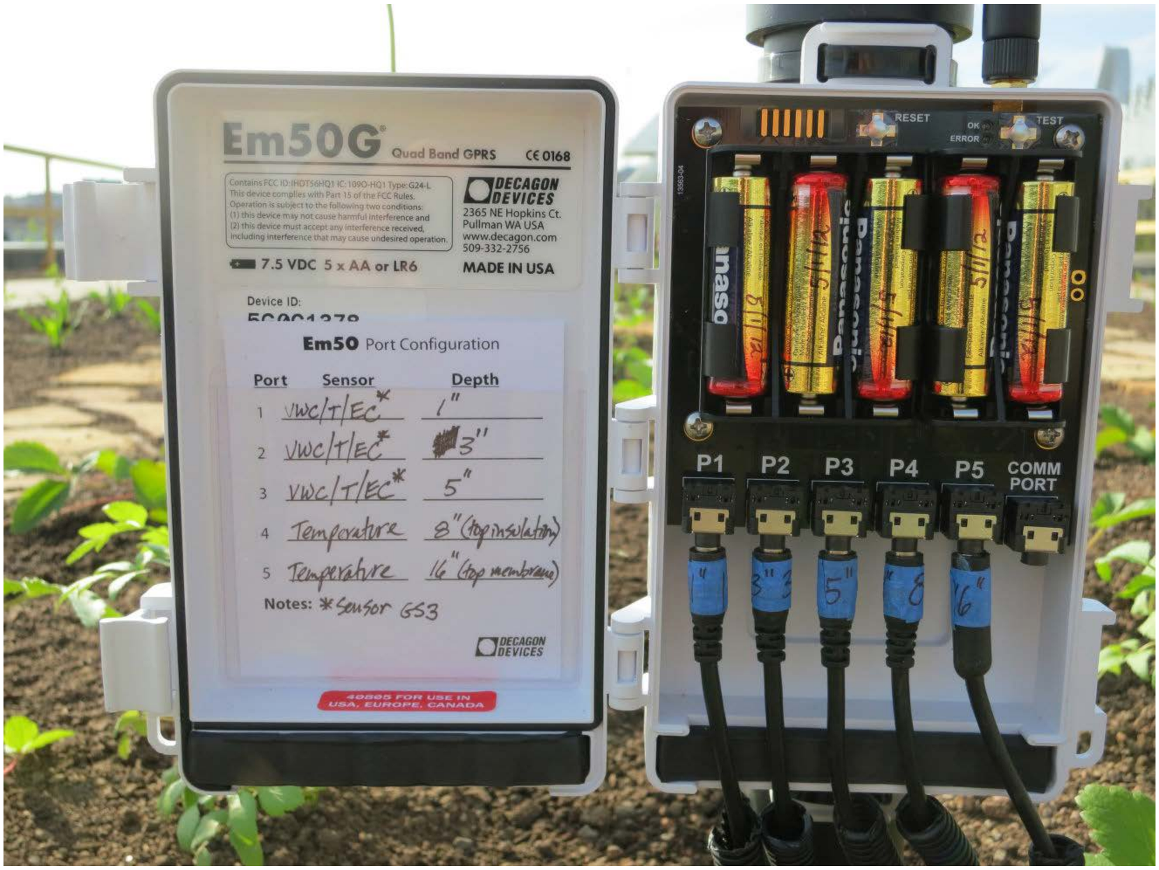

Figure 11. Data Logger (Credit: John Buck, CPSS Civil & Environmental Consultants, Inc., Pittsburgh, PA)

WATER INPUTS: RAINFALL

As noted in the climate section, rainfall data is best collected onsite. Although data collected on websites such as NOAA and Weather Underground are free and simple to download, large variability can exist between local weather stations and your site. For ease of use, a weather station with a tipping bucket rain gauge and data logger is more effective compared to less expensive rain gauges that require manual reading and resetting. Rainfall data is critical for measuring the effectiveness of stormwater and irrigation systems. Hourly data is ideal.

WATER INPUTS: IRRIGATION

Most commercial irrigation controllers track irrigation usage and demand from water sources, whether they be potable or recycled from stormwater and air conditioning condensate. Adding meters to irrigation water sources and connecting the meter to the irrigation controller will give you a full picture of irrigation efficiency when reviewed in conjunction with rainfall data. This should be specified during the design of the irrigation system.

Figure 12. Irrigation Controller (Credit: Emily McCoy)

WATER OUTLETS: WATER FLOW IN WEIRS AND FLUMES

The use of open channels, such as weirs and flumes, to measure flow is common in smaller applications or on green roofs. These structures are placed to intercept water in strategic locations and sensors are used in the structure to monitor flow and volume; these may include float gauges, ultrasonic sensors, and bubbler sensors. For larger landscapes and public landscapes, this method is usually not ideal.

WATER OUTLETS: WATER FLOW IN STRUCTURES WITH PRESSURE TRANSDUCERS

Pressure transducers are cost effective tools for monitoring water flow in closed pipes or observation wells in comparison to flow meters for large pipes. Pressure transducers hang from a stainless steel cable to the bottom of a structure, such as an overflow structure, function box, observation well, or any other isolated structure where water flows. Pressure transducers take continuous measurements of water levels above the sensor and log data at set intervals. At a minimum, place pressure transducers in the last structure before stormwater flows to the final outlet point of the project site or in a monitoring well at the lowest point(s) of a site.

Pressure transducers need the input of barometric pressure in order to calculate water levels. Some pressure transducers are supplemented with sensors that measure barometric pressure and others are not. For those that are not, a reading from a nearby weather station will have to be used to determine barometric pressure. To get the most accurate results, it is recommended to install the transducers that measure barometric pressure or purchase an additional sensor that measures barometric pressure, placed in the same location as the transducer. Inaccurate barometric readings can make your data unusable; however, you can mitigate the impact of inaccurate barometric pressure readings by calibrating the transducer in the field or in the lab with a known water level. Additionally, before you purchase a transducer, you will need to know what the maximum water level will be in order to select the most accurate transducer.

If a pressure transducer is located in a structure with a sump, the pressure transducer should hang almost to the bottom of the sump in the junction box without touching the bottom. When the data is downloaded from the transducer, the sump depth in relation to the outlet pipe's invert should be included in the water level calculation. In other words, when the water level readings are larger than the sump depth, you have water moving though the junction box.

The advantage of placing transducers in stormwater structures is that they can be installed post-construction. The disadvantages are that in order to remove the transducer to download data or perform maintenance on the transducer, heavy manhole covers often need to be removed; the person removing the transducer may also need to have confined space training according to Occupational Safety and Health Administration (OSHA) standards. Removal of manhole covers and removal of transducers in confined spaces requires coordination with landscape managers and property owners, an importnat consideration in a monitoring plan. Some transducers are now equipped with Bluetooth technology that limits the amount of times one needs to physically remove the transducer to download the data. Check with the manufacturer to confirm that the Bluetooth signals can penetrate the cover of the structure.

Monitoring wells can also be used to track stormwater flow in pipes or in open systems that infiltrate water to the ground below. Transducers are easier to remove from monitoring wells because they are usually smaller than standard stormwater structures and have easily removable lids.

An observation well composed of a perforated pipe covered with a screen tracks water level changes when measuring infiltration with a pressure transducer. Observation wells usually have to be planned for prior to construction, but are very easy to access for removal of the transducer.

If you want to know more than whether water is overflowing from a certain structure, you can use flow equations for a given structure to determine the flow rates. Manning's Equation, the Chezy Equation, volume-based calculations, and velocity-based methods can be used to determine flow rates. Refer to the EPA's Urban Stormwater BMP Performance Monitoring manual (Strecker et al., 2002) for more information.

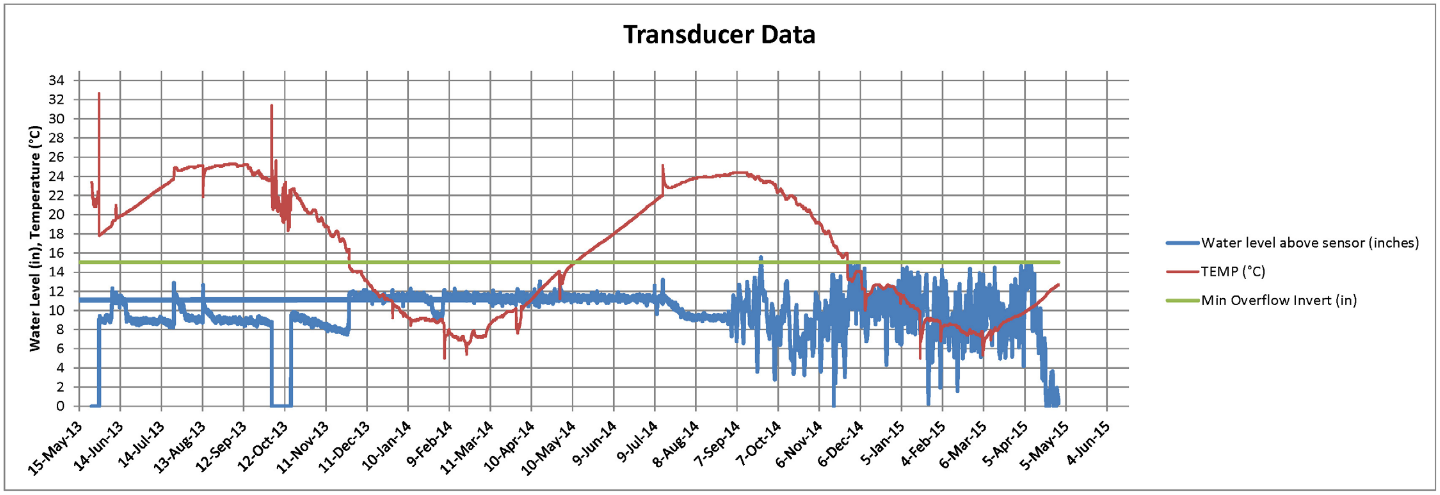

Figure 13. Typical Pressure Transducer Data (Credit: Andropogon Associates)

WATER OUTLETS: WATER FLOW IN PERMEABLE PAVEMENTS

Monitoring infiltration rates in permeable pavements is especially important during construction to ensure the system was installed correctly, and over time to indicate when such systems are in need of maintenance.

Two methods for measuring infiltration rates of interlocking permeable pavements are (1) a modified double-ring infiltration method (DRIT) and (2) rainfall simulation infiltrometer (RSIT) (Nichols, Lucke, and Dierkes, 2014). The DRIT method is the most practical for quick infiltration testing of permeable pavements and is referred to as ASTM Test Method C1701. This method utilizes a standard double-ring infiltrometer, but requires a temporary seal on the bottom of the infiltrometer with a material such as plumbers putty. The City of Philadelphia's water department recommends testing at least three locations for large areas (up to 25,000 square feet), and one additional test for every additional 10,000 square feet (City of Philadelphia, 2014).

WATER OUTLETS: EVAPOTRANSPIRATION

Evapotranspiration (ET) in the landscape is the combination of evaporation of water from a surface and transpiration of water from groundwater to the atmosphere by plants (USGS, 2017). Measuring ET can be expensive and time consuming, and, in most cases, is not a task for the quick field measurements that are the focus of this paper.

Soil evaporation can be measured by the use of weighing lysimeters, a device used to measure soil moisture, or through the use of water vapor transfer calculations (Farahani et al., 2007). Weighing lysimeters use differences in weight to determine soil evaporation quantities, but are expensive. Tensiometers measure soil moisture depletion and are much more cost effective for measuring soil evaporation.

Transpiration in plants can be calculated by measuring both stomatal conductance with a leaf porometer and the leaf area index with a device such as a ceptometer, or using sap

Figure 14. DIY Water Depth Gauge (Credit: Emily McCoy)

flow meters. All techniques for measuring transpiration are costly and require technical training, and are therefore not categorized as quick field methods.

ET can also be measured at larger scales with remote sensing, but the scale is typically too coarse for site-scale projects.

WATER HOLDING: PONDING

Water ponding, such as ponding depths in rain gardens, can also be monitored using pressure transducers, sometimes referred to as water level loggers, which log water level readings over time. Another low-tech, do-it-yourself method is mimicking a typical crest gage commonly used to measure stream crest heights. This device can be made with a clear plastic tube and shredded cork. The plastic tube should have a screen on its bottom and top and be marked with heights above the surface elevations. Shredded cork should be placed inside the tube. When the water level rises then falls in the tube, the cork will stick to the side of the tube, and manual readings of the water height can be logged.

WATER HOLDING: SOIL MOISTURE

As mentioned in the soil section, soil moisture can be easily monitored with soil moisture sensors. These sensors include:

- Those integrated in an irrigation system,
- Stand-alone sensors that can be connected to a data logger for continuous data collection, and
- Manual instruments that can be inserted in the soil for manual readings.

Refer to the soil section for more information.

STORMWATER QUALITY

Water quality parameters can be obtained by manual or automatic samples or sensors. There are a variety of water quality sensors coupled with data loggers that can be used for monitoring wells or surface waters in a manner similar to pressure transducers. Some of the testing parameters currently available include: temperature, dissolved oxygen and other gases, specific conductance, salinity, total dissolved solids, pH, resistivity, nitrate, chloride, turbidity, and ammonia/ammonium. Sensors are moderately expensive and do not require lab analysis, which can be costly if sampling is to be implemented over a long period of time.

Water samples can also be collected by hand or by use of an automatic sampler. Generally, it is best to, at minimum, collect samples during the "first flush" since the initial runoff during a storm has the highest concentration of pollutants. Samples can be collected at single points in the system, known as grab samples, or can be collected at several points and combined, known as composite samples.

Automatic samplers can take samples automatically based on inputs from rain sensors, flow meters, or timers and are useful for collecting samples from multiple points and multiple time periods during rain events, such as collecting first flush samples. Manual samples can be collected with single grab sample bottles that must be approved by the EPA in order to avoid contamination of the sample. If pollutants are a concern, and in order to avoid cross contamination, gloves are recommended to collect grab samples. Samples have a shelf life and generally need to be sent to the lab for analysis within 48 hours. Refer to the Urban Stormwater BMP Performance Monitoring manual and the website[8] for the number of samples required to be statistically significant for your project and for each type of pollutant's shelf life.

Figure 15. Automatic Sampler (Credit: Emily McCoy)

8 U.S. Geological Survey. 2000. "Urban Stormwater BMP Performance Monitoring Manual." https://ag.umass.edu/fact-sheets/how-to-use-ph-ec-pens-to-monitor-greenhouse-crop-nutrition

Many state extension agencies offer this service and provide test kits and instructions for how to collect the sample. These tests are generally low cost.

Typical pollutants that you may want to test for are:

- Total suspended solids (TSS) – Stormwater pollutants that move in association with or attached to particles. Overall chemographs of TSS demonstrate general water quality fluctuations. Maximum holding time is 7 days.

- pH – A general water quality parameter. Maximum holding time is 14 days.

- Temperature – A general water quality parameter. Best to test in the field.

- Chloride – A common elemental base in most commercial deicing treatments. Maximum holding time is 28 days.

- *E.coli* – A common bacterium found in animal fecal matter, fluctuations of *E.coli* are also an indicator measure for other possible bacteria problems.

- Total phosphorus – A natural byproduct of organic decomposition, phosphorus can be difficult for plants to uptake and regularly leaches into the soil. Maximum holding time is 28 days.

- Nitrate and nitrite – The conversion of nitrogen in the soil to usable forms by plant material is a key component in photosynthesis. A byproduct of fossil fuel combustion, atmospheric nitrogen is converted to nitrate and nitrite in the soil. If not absorbed, leaching regularly occurs. Maximum holding time is 28 days.

Vegetation

OVERALL PLANT HEALTH—PLANT VITALS: WHY MEASURE?

Plants contribute to and provide a wealth of ecosystem services—pollination, climate regulation, air and water cleansing, stormwater management, erosion and sediment control, habitat for all animals, human health and well-being, and food and non-food products. Specific to the urban environment, the quality of an urban tree canopy, along with soil pH and soil organic matter, are some of the most important indicators of a city's overall ecological health (Dobbs et al., 2011). Each of the ecosystem services that vegetation provides can be the basis of a performance evaluation or can serve as a comparative measure between projects. Measurable plant attributes also help inform maintenance practices to ensure that landscapes remain or become high-performing overtime.

PERFORMANCE BENEFITS

Among the services that plants provide, there are a few easily measured performance goals that most high-performing landscapes deliver; these include:

- General Environmental Health
    - Mitigating factors of poor acoustic quality
    - Contributing to improved air quality
- Water Management
    - Reducing stormwater runoff through evapotranspiration and supporting infiltration
    - Improving water quality through uptake of nutrients, such as nitrogen and phosphorous, and supporting microbial decomposition
    - Acting as an indicator of inefficient irrigation programs by showing signs of declining health or by the presence of pests and disease
- Carbon Sequestration
    - Directly acting as a carbon sink
    - Indirectly reducing carbon emissions by having fewer maintenance requirements and thus reducing emissions

- Urban Heat Island
    - Reducing surface and air temperatures
    - Reducing building energy consumption

- Soil
    - Reducing erosion and sedimentation
    - Improving soil health through nitrogen fixation, supporting nutrient cycling or pollution reduction

- Ecological resilience, biodiversity, and habitat
    - Providing habitat, food, and shelter for non-human animals
    - Surviving, thriving, or recovering from unforeseen circumstances, such as extreme temperatures, fire and storm events, and still maintaining ecological integrity

- Society and Culture
    - Providing beauty and inspiration through the seasons
    - Supporting mental well-being
    - Providing comfort through shade
    - Promoting sense of place
    - Contributing towards perceived safety, such as allowing for unobstructed views or keeping a neat and kempt appearance with minimal maintenance

- Economics and Asset Management
    - Producing food and non-food goods for humans
    - Low maintenance requirements and needing few inputs, such as irrigation, fertilizer or pesticides

METHODS OF ASSESSMENT

Plants cannot perform ecosystem services if they are not healthy and thriving. There are simple parameters to track over time in order to assess the general health of a plant. These parameters can also serve as indicators alerting designers and managers that there may be negative factors affecting the plant's health and thus its performance. Additionally, many calculations regarding the ecosystem services plants provide require measurement of plant vitals (indicators of a plant's health) in order to quantify their benefits.

Plant vitals include:

- Overall survivability, bloom time and management needs
- Growth rate
- Rooting depth
- Nutrient levels (tissue)
- Presence of disease and pests

OVERALL VIGOR, SURVIVABILITY, BLOOM TIME, AND MANAGEMENT NEEDS

Monitoring plant survivability, overall health, bloom time, and management needs of individual species over time are important, because every site condition and location are unique, especially in urban conditions, and are difficult to predict. This information can inform your practice about how certain species and varieties perform in specific conditions, helping to avoid repeated mistakes in plant selection. Data collection sheets or digital collection methods can be created to conduct site investigations and to interview maintenance staff. This information can then be compiled and disseminated to others, whether it be within your company or to a greater audience.

A scale used by the Snohomish County Surface Water Management Vegetation Monitoring Program (2003) below is an example of a vigor scale that can be used.

1= Thrive. Evidence of vigorous growth includes: new green leaders, flowers, developing fruits, sign of last year's fruits, etc.

2= Alive. No evidence of thriving, but plant is green and has no apparent signs of damage or stress.

3= Stressed. Poor plant color, withering leaves, desiccated leaders.

4= Dead. No sign of life. Scratch bark to check for green cambium layer.

GROWTH

Growth is a relatively easy parameter to measure in the landscape. Growth can be assessed over time and compared to typical growth rates for a species. Common tools to measure tree growth are:

- Diameter tape and calipers to measure diameter at breast height (4.5 feet) for trees or diameter of all stems at 4 inches height for shrubs (you may also record the thickest stem for shrubs and take a stem count).
- Clinometer or smartphone app to measure tree height.

For trees and shrubs, height and width are common parameters to measure with the use of a standard measuring stick or tape measurer.

ROOTING DEPTH

Rooting depth is difficult to measure without destroying vegetation. An expensive, but non-destructive tool is ground penetrating radar, which uses electromagnetic radiation to detect tree roots. Ground penetrating radar requires technical training.

For turf, rooting depth and thatch depth are two important indicators of turf health. A thick thatch (greater than one inch) can create problems for turf health, such as creating reduced access to water, creating ideal environments for pest and disease problems, and holding excess water during wet periods. A thick thatch can also be an indicator of poor soil biology, acidic or compacted soils, and excess fertilizer and pesticide use (Penn State, 2015).

Rooting depth is also important to track in turfgrasses. Reductions in root depth can indicate over or underwatering, lack of oxygen in the soil or root pathogens. Deep turf roots are usually desirable as they tend to not need as much water and are more tolerant of drought. Deep roots also help infiltrate water into the soil below.

One easy tool for measuring root depth and thatch depth of turf grass is a turf profiler. A turf profiler is forced into the ground and cuts a cross section of turf blades, roots, and soil. The turf section can then be easily placed back into the ground. The disadvantage of using a turf profiler is that they are typically are only 7–12 inches deep, which is not as deep as some turf grass roots. A long, narrow shovel (garden or nursery spade) can also be used to examine root depths longer than 12 inches deep.

Table 10. Typical Turf Rooting Depths (modified from Lin, 1985)

SHALLOW (1–8”)	MEDIUM (8–18”)	DEEP (18–60”)
Annual meadow grass/bluegrass	Kentucky bluegrass	Zoysia grass
Creeping bentgrass	Fred fescue	Bermuda grass
Colonial bentgrass	Ryegrass	Tall fescue
	St. Augustine grass	

NUTRIENT LEVELS IN TISSUE

Nutrient soil tests can be good indicators of overall plant health; tissue analysis, however, can give a more holistic view of nutrient levels, and can also be more accurate in pinpointing specific nutrient deficiencies. Many state extension agencies perform tissue sampling and offer plant tissue test kits.

Chlorophyll meters can also be used to estimate nitrogen levels in a plant. These meters are commonly used for agricultural crops and new low-cost meters are now commercially available that can be paired with a smartphone for easy data collection.

PRESENCE OF PESTS AND DISEASE

Integrated Pest Management (IPM) is an “ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment” (University of California Integrated Management Program, 2015).

An IPM program is essential for any sustainable, high-performance site. Misuse of pesticides can be harmful to people and other non-target species. IPM is a holistic tool used to avoid this misuse and offer best practices in pest and disease management. Soil, vegetation, water, and people (landscape users and mangers) should play important roles in an IPM approach to site management.

Although it is not usually the responsibility of a landscape architect to manage pests and disease, it is advantageous for landscape architects to borrow from IPM best practices and to be aware of the signs of pests and disease when monitoring a site or when choosing or inspecting plants. Tracking beneficial organisms is also an important indicator of landscape health.

Standard tools for monitoring beneficial organisms, pests, and disease (also known as scouting) are:

- A hand lens for getting a closer look at pests and disease (10x or higher, consider lenses with embedded lights),
- Sticky traps for surveying pests if you suspect a pest infestation (blue and yellow for different pest species),
- An aspirator for collecting samples without killing the organism,
- Place insects in an approved container with 75 percent alcohol solution for submitting pest samples to your local extension agency, and
- A reference manual for pest and disease identification, which can include useful smartphone apps such as IPMPro.

Signs to look for in the landscape for pest and disease damage are:

- Physical damage to leaves,
- Presence of pests on the top or bottom of leaves (remember, not all creatures are harmful to plants and could actually be predators of pests),
- Spotting or other discoloration on the top or bottom of leaves, and
- Presence of nuisance and aggressive plants.

Common insect pests in the landscape are:

- Aphids
- Mealy bugs
- Leaf miners
- Scale insects
- Spider mites
- White flies
- Thrips
- Beetles (Japanese, Viburnum, etc.)
- Weevils
- Sawfly larvae
- Asian ambrosia beetles
- Leafhoppers
- Emerald ash borer

Common diseases in the landscapes include:

- Powdery mildew
- Root rot (Pythium, Phytophthora, etc.)
- Leaf rusts
- Fungal and bacterial leaf spots
- Botrytis
- Galls
- Virus

If you suspect that there are harmful quantities of pests or disease in the landscape, it is best to alert a landscape manager first to help with the diagnosis if you are not trained in IPM or entomology. Most local state extension agencies have a division that accepts plant and insect samples.

ABOVE-GROUND PLANT BIOMASS AND LEAF AREA INDEX:

WHY MEASURE?

Biomass represents the amount of living material or previously living material on a site by weight. The amount of plant biomass reflects a site's relative productivity and ability to support ecosystem services, such as water management, carbon sequestration, nutrient cycling and pollination (SITES, 2015). The measurement of biomass on a site therefore can be a key component in assessment of environmental performance. Above-ground biomass measurements can be compared over time to determine the increase of ecosystem services and can be an indicator of the health of the vegetation in terms of growth and disease. Since it is difficult to measure the biomass of an entire site, sampling or indices can be used to estimate biomass of a site.

METHODS OF ASSESSMENT

There are several methods that, through both field-testing and remote sensing, can aid landscape architects in measuring biomass changes over time, compare sites to one another, and assess vegetation health and growth at the site scale and beyond. Most direct field methods for measuring biomass require removal of plant material or whole plants. Since this is not feasible in most situations, the methods highlighted here focus on indirect methods that are nondestructive.

BIOMASS DENSITY INDEX

The Sustainable Sites Initiative (SITES) provides calculations for biomass density index (BDI), which are derived from a plant's documented leaf area index (LAI), which is the area of leaves per unit area of ground. The LAI of a plant or given landscape can help report the performance to which leaves are exchanging heat, moisture, CO_2, and trace gases with the atmosphere (Baldocchi, 2012) and, as in this case, used to determine relative biomass.

To prepare biomass calculations for SITES, the pre- and post- site design BDI are calculated and compared based on biome-sensitive empirical estimates of leaf area index (LAI) for each vegetative cover. With the percent coverage of every vegetative type and corresponding biomass density value provided by SITES, a BDI can be estimated (Calkins, 2011). The approach provided by SITES is a good estimate that allows for GIS analysis of a site without any field measurements, but is limited by the accuracy of historical aerial images of a site and empirical data found for similar landscapes used to find BDI (Mattson, 2013). GIS analysis of biomass includes using aerial photography to estimate the vegetative cover or includes using near-infrared band aerial photos to directly calculate biomass. The empirical data is provided in reference tables by SITES based on the given terrestrial biome, determined from the World Wildlife Fund (WWF) Wildfinder (SITES, 2015).

NORMALIZED DIFFERENCE VEGETATION INDEX

The Normalized Difference Vegetation Index (NDVI) image analysis tool in GIS allows for the complete calculation of biomass in large areas. Calculations from several aerial photos taken at different time periods can easily be compared. Using chlorophyll pigment absorptions in the red band and the near-infrared (NIR) band of aerial photos, relative biomass can be estimated through a raster analysis on a scale of -1.0 to 1.0 (Lanorte et al., 2014). In this approach, the user divides areas by vegetative cover or common NDVI values to calculate biomass from the corresponding area. This approach is limited in that spectral vegetation indices, (SVIs) remote-sensing data like NDVI are commonly affected by canopy closure, understory vegetation, and soil background reflectance, but calculations can give relative readings and serve as indicators of changes of vegetation health over large areas.

FIELD MEASUREMENTS

Commonly practiced in forestry, non-destructive above ground biomass (AGB) calculations are assessed through allometric equations relating plant measurements, such as tree diameter and leaf area index (LAI), to established empirical estimates of density and biomass. LAI can be measured with a ceptometer, but the method may be too costly for most applications. A ceptometer takes readings of photosynthetically active radiation (PAR), the wavelength that plants use for photosynthesis. LAI can also be estimated based on available research. Common sources include the Oak Ridge National Laboratory[9], NASA, and peer review journal articles.

9 See Scurlock, Asner, and Gower, 2001.

Estimating biomass based on plant measurements and allometric equations requires users to measure all plants in the landscape or by performing vegetative sampling for representative areas in the landscape, where the assumptions gathered from these sampling areas can be applied to the entire landscape.

This type of sampling includes defining plots or areas representative of a forest or landscape using GPS equipment and recording measurements to calculate either vegetation volumes for herbaceous plants or diameter at breast height of woody plants:

- Crown volume (3-dimensional volume of a plant)
    - Height measured with a clinometer or measurement tape
    - Area or tree crown area (diameter of the crown)
- Tree diameters at breast height (1.3 meters, or 4.5 feet) with calipers or diameter tape.

This method is limited by the accuracy of allometric equations. One allometric equation for forests that may be utilized was developed by Chave et al. (2015) and uses wood specific gravity, trunk diameter, and tree height to estimate biomass. Although it was developed for use in tropical forests, it may also be useful beyond the tropics. Additionally, programs such as i-Tree can be used to calculate tree biomass based on the measurements taken in the field.

Alternative field methods have emerged through mobile applications like the PocketLAI (Orlando, 2015) or Easy Leaf Area (Easlon, 2014), in addition to using remote sensing tools such as LiDAR.

Table 11. LAI Typical Values (modified from Asner et al.,2003)

FUNCTIONAL TYPE	MEAN LAI	STANDARD DEVIATION
Polar desert and alpine tundra	3.85	2.37
Moist tundra	0.82	0.84
Boreal forest woodland	3.11	2.28
Temperate savanna	1.37	0.83
Temperate evergreen broadleaved forest	5.40	2.32
Temperate mixed forest	5.26	2.88
Temperate confer forest	6.91	5.85
Temperate deciduous forest	5.30	1.96
Temperate wetland	6.66	2.41
Cropland temperate	4.36	3.71
Plantation temperate	9.19	4.51
Tall medium grassland	2.03	5.79
Short grassland	2.53	0.32
Arid shrubland	1.88	0.74
Mediterranean shrubland	1.71	0.76
Tropical wetland	4.95	0.28
Tropical savanna	1.81	1.81

ECOLOGICAL RESILIENCE, BIODIVERSITY AND HABITAT VALUE

WHY MEASURE?

In 1998, Leslie Sauer Jones wrote *The Once and Future Forest: A Guide to Forest Restoration Strategies*. Embedded within Ian McHarg's forward of the book was a plea, "We must participate," in order to attempt to reverse environmental degradation, and we can no longer expect our actions to be reversed with inaction. He elaborated his plea with a suggestion, that we must embrace "important havens, such as the interstices of cities," as critical canvasses for habitat enhancement and expansion for our native plants and animals. Jones goes on to say in her closing thoughts that acts of restoration "must be founded in good science." She notes, however, that lack of interest in monitoring remains one of the largest "hurdles."

Today, the hurdles are much the same as they were in 1998. Dialogues about novel ecosystems and native vs. non-native plant use in designed landscapes tend to be heated, yet we still have little information about the potential capacity of our urban environments to perform the ecosystem services we so desperately need them to perform for all life. Although our discourse within design professions has evolved to conversations about performance and metrics, the data are relatively scarce pertaining to the exact challenges of designing landscapes in the built environment.

However, a restoration model, or habitat analogue approach (Richardson, Lundholm, and Larson, 2010; Lundholm and Richardson, 2010) to improving our suburban and urban landscapes is increasingly being recognized as meaningful and relevant. This approach seeks to use natural reference sites as models not to be simply reproduced for their parts, but as aspirations for performance as a system, particularly in their ability to provide habitats for non-humans. This approach concedes that urban landscapes, whether with native or non-native plants, "can contribute, even in small patches" (Lovell and Johnston, 2009) to the ecological health of a city.

Urban, and in some cases suburban, environments may not always be the appropriate place to attempt to bring back some sensitive species, but ecologists have long recognized a small subset of species that can exploit highly altered, anthropogenic habitats in urban (McKinney, 2002) and industrial settings (Johnson, Putwain and Holiday, 1978; Margules and Usher, 1981). Additionally, it is recognized that these environments dominated by humans can provide meaningful contributions to overall biodiversity (Alvey, 2006) and promote ecological resilience of cities in the face of drought, extreme heat, fire, flooding, and landslides.

Almost all landscapes have the potential to provide habitat, such as supporting pollinators and pollinator pathways (Matteson, Ascher, and Langellotto, 2008), and become possible stepping stones for species like migratory birds (Lynch and Whigham, 1984). "Even tiny patches of woods in urban areas seem to provide adequate food and protection for some species of migrating birds as they fly between wintering and breeding grounds" (Oregon State University, 2010; Matthews and Rodewald, 2010).

Creating and enhancing habitat for all creatures, in addition to humans, is just one of the goals we can strive for in our designs as landscape architects. But how do you design for diversity and also calculate the overall value of a habitat for multiple organisms? What data do you need to understand the existing habitat value of a place before a design intervention or for the purposes of selecting conservation areas? Over time, how do you know if you have succeeded in improving and enhancing habitat? Below are some thoughts about how to design for and measure ecological resilience, biodiversity, and habitat value.

METHODS OF ASSESSMENT

BIODIVERSITY

Species diversity or biodiversity accounts for the number of species (richness) and the distribution of individuals among species (known as evenness) (Brower, Zar, and con Ende, 1998). Calculating biodiversity can be useful in the planning or pre-design phase to pinpoint areas for protection or restoration, to compare sites to one another, or to assess the success of a landscape design or restoration after construction.

Traditional methods for assessing habitat value at the site scale are based on measuring plant species biodiversity by use of the Margalef index, Shannon diversity, Shannon evenness, and Simpson dominance indices (Broudaghs, 2004). These indices take into account not only the number of species, but also their evenness and richness. Vegetation sampling is required to calculate the indices and is accomplished by using methods such as quadrat or line-intercept and transect sampling if you have a large site and are not able to quantify all the species on a site.

These indices are relatively simple to measure once you have the data and are most useful when used to compare two sites. For example, the Shannon diversity index formula is as follows:

Formula: H = -SUM [(pi) * ln(pi)]

Where:

SUM = Summation

ln = natural log

pi = Number of individuals of species or total number of samples

There are now several calculators online, software programs, and Excel templates that can be used to easily measure biodiversity. There is also an ESRI ArcToolbox tool that can calculate species diversity for polygons.

Measurements of biodiversity in this manner do not capture other attributes of diversity, such as functional roles and structural diversity (Savard et al., 2000; Jeanneret, Schüpbach and Luka, 2003). Furthermore, not all species may be desirable species, which these indices do not initially take into account. Conversations about how we design for and evaluate a site's ability to support biodiversity can extend beyond these traditional methods of evaluation to considersation of specific groups of species in need of support in any given area, such as pollinators or migratory birds, and about design for climate change, climate adaption, and overall ecological resilience.

DESIGN FOR CLIMATE CHANGE, ADAPTATION, AND BIODIVERSITY

Due to the effects of global climate change and the UHI effect, planting in urban environments to maximize ecological, aesthetic, and economic considerations is challenging and sometimes unpredictable. MaryCarol Hunter's paper, "Using Ecological Theory to Guide Urban Planting Design: An adaption strategy for climate change" (2011), offers a great framework for not only designing resilient landscapes in the face of uncertainty, but for providing insight into a landscape's success or failures, and offers a theoretical framework to compare sites.

Hunter (2011) proposes three characteristics that successful urban planting designs should consider: plasticity, resilience, and structural diversity. Plasticity is the ability of a plant to thrive in a wide variety of conditions. Ecological resilience is an ecosystem's ability to maintain function in response to disturbances, whether they be a hurricane, severe drought, pest infestation, or the like. Ecological resilience relies on biodiversity to provide enough different species that can perform similar functional roles under a wide variety of conditions. Structural diversity and stratification characterize the variety in the physical form (trees, shrubs, herbaceous perennials, and annuals) of an overall landscape.

Using Hunter's methodology, you can code an existing plant palette based on a range of attributes for each species as it relates to plasticity, ecological resilience (functional redundancy and response diversity), and structural diversity. This information can be gathered from sources such as the USDA's PLANTS database.[10] This assessment can be used to fine-tune a plant palette during design, compare sites to one another, or analyze an existing site.

MOTHS AND BUTTERFLIES AS INDICATORS

The population size that an environment can support without degrading is its carrying capacity. It has been demonstrated that certain native genera of woody and herbaceous plants are capable of supporting more native wildlife than others, therefore increasing their value to wildlife or habitat value (Munyenyembe et al., 1989; Sears and Anderson, 1991; Crisp et al., 1998; Terman, 1997).

Doug Tallamy, an entomologist at the University of Delaware, reports that insects, more specifically lepidopterans (moths and butterflies), are good indicators of habitat value and

10 Natural Resources Conservation Service. 2018. "Plants Database." http://plants.usda.gov/java/

overall biodiversity. Insects are one of the most important "machines" for harvesting and transferring plants energy to the ecosystem. Also, lepidopterans were chosen as specific indicators of habitat value because of the amount of data available on this order of insects, and because they are "disproportionately valuable sources of food for many terrestrial birds, particularly warblers and neotropical migrants of conservation concern" (Tallamy, 2009).

Tallamy and his colleagues have documented hundreds of genera in terms of their abilities to support lepidopterans. These measurements can be used to assess existing landscapes, compare sites to one another, inform design decisions, and assess a project overtime.

FLORISTIC QUALITY AND COEFFICIENTS OF CONSERVATISM INDICATORS

The Floristic Quality Assessment Index (FQAI) Index, developed in the Midwest by Floyd Swink and Gerould Wilhelm (1979), is a method for evaluating the integrity of natural plant communities. The index weighs species based on the specialty of their ecological niche using a factor called the Coefficient of Conservatism (CC), giving a higher score to species that are specialists and lower scores to those that are generalists (can live in a wider range of habitats). The CCs are defined by botanists and are specific to a geographic region. FQAI is calculated by multiplying the mean CC by the square root of species richness for an observational unit (Bourdaghs and Johnston, 2006). This index can be used to monitor changes in the landscape over time, assess the ecological integrity of a landscape, and compare landscapes or areas to one another.

An evolution of the FQAI is the Plant Stewardship Index (PSI), which provides a methodology that uses FQAI to provide a numerical index that indicates the quality of the plants in a given area. Simply, the higher the overall score, the higher quality of plant species. CCs are different in each state, so it's important to refer to your state's FQAI for accurate CCs in the PSI calculation. It is common to calculate both the average of all the CCs found on the site and the actual index, which is the average CC multiplied by the square root of the total number of plant species.[11] In states such as Louisiana they have modified the calculation to take into account biomass or percent coverage of each species to weight the CC numbers.[12]

For Pennsylvania and New Jersey residents, the Bowman Hill Wildflower Preserve has an online calculator that makes calculating PSI very easy. Researchers such as Mary Myers at Temple University (2013) have used this tool to assess landscape performance at several sites to compare them to one another and track them over time. PSI indices of high-performance landscapes can also be goals for built landscapes in similar conditions during the design process.

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11 http://conservationtools.org/guides/33-plant-stewardship-index

12 U.S. Geological Survey. "Louisiana Floristic Quality Index." 2011. Available at http://pubs.usgs.gov/fs/2011/3044/pdf/FS11-3044.pdf

SEED BANK ANALYSIS

A seed bank analysis can be beneficial in analyzing the potential of a soil to recover from disturbance, in understanding past plant communities, or in helping to identify potential noxious weeds that may be present. A few labs offer this for a relatively inexpensive cost, such as the Oregon State University Seed Lab.

Society and Culture

> *"Both the public and private sectors are recognizing that investing in high-quality design is good for business and the community."* – Urban Design and the Bottom Line, 2008

WHY MEASURE?

In all regions of the world, the urban population is growing faster than the rural populations, and it is projected that by 2030, 80 percent of the population in North America, Latin America, and the Caribbean will live in urban areas (U.N., 2015). Recent urbanization trends offer the opportunity for cities to be designed and re-designed so economic development can meet basic human needs while enhancing cultures and natural environments, for present and future generations; this is known to many as sustainable development. There is also a great need to ensure that cities are designed to alleviate poverty, promote social equality, and create strong social relationships, while practicing sound environmental management (World Bank, 2005). Landscape architecture is a significant arena in which to address these needs. Those responsible for conserving, planning, and designing public spaces have a professional and social responsibility to ensure that our public lands are multifunctional, equitable, economical, ecologically healthy, culturally relevant, and artfully inspiring.

As designers and planners begin to unravel the complex task of molding places spatially and programmatically in the face of these new challenges, it is becoming evident that enacting strategies to improve urban life can no longer be encapsulated by one discipline's goals, one realm of implementation, or viewed at one scale. To facilitate sustainable development within the urban form, design, and planning strategies must address socio-cultural, environmental, economic, and aesthetic considerations in unison with gathered expertise from a wide array of seemingly unrelated disciplines, such as environmental psychology, public health, community building, and public safety. Particularly, in the realm of social performance, discovering how collaboration among different disciplines can benefit one another, including a critical evaluation of these relationships, will become increasingly imperative. In addition to collaboration, this paradigm shift in the design process also commands that a disciplined scientific rigor, along with a multidimensional creative process, be applied in evaluating, monitoring, and analyzing design projects of the past in order to inform projects of the future and address the myriad of social needs that exist.

This design imperative is echoed by L. Susan Everett of the Landscape Architecture Foundation in Mark Francis's *Urban Open Space* (2003):

> In order to solve these increasingly complex challenges, professionals and their clients need timely information on emerging issues and on innovative projects that show how and why certain approaches and schemes have been successful, as well as offer helpful criticism about their more problematic aspects. Information of this type is vital to the goals of protecting natural resources and landscapes, reclaiming disturbed lands, and creating sustainable communities that foster health and safety.

In addition to participation in a collaborative design process and critical evaluation of precedent studies, Mark Francis, a leader in the study of public space issues in landscape architecture, states that a “prerequisite” for effective design, particularly in the public realm, is accommodating user needs (Francis, 2003). Beyond needs, Francis emphasizes that accessibility to all and “meaning” in the larger context are also essential ingredients (Francis, 2003). Therefore, it is critical when assessing projects regarding their fulfillment of social performance to view this aspect of sustainable design through the lenses of Francis’ ingredients for successful design of social spaces: “needs, rights, and meanings” (Francis, 2003).

However, this almost formulaic way of thinking about the design process in the public realm has spawned much debate in the world of landscape architecture, especially since aesthetics are regularly omitted from the conversation. The extremes of the debate range from claims that disregard of the public’s needs and wants is neglect; and on the other side of the continuum, design solely based on public input is sterile. This arguably false conflict between “high-fashion” design of public spaces and support for a user’s actual wants and needs should be equally considered in any social performance assessment of a project. Since social performance is the most subjective performance category, it is the responsibility of the reviewer to recognize their own biases and perspectives when assessing how well a project carefully balances beauty, inspiration, and functionality.

PERFORMANCE BENEFITS

Landscape architecture is a discipline dedicated to protecting the health, safety, and welfare of all people. As such, designing for social performance and assessing a site for its ability to support social performance criteria is one of the most important considerations in landscape architecture. Social performance criteria include:

- Comfort
- Preference
- Accessibility
- Physical activity and health
- Well-being
- Education and cognitive development
- Safety and perceptions of safety
- Community building
- Beauty, inspiration, and visual quality

- Social and environmental justice
- Spiritual enrichment
- Sense of place
- Cultural heritage, relevance, and history
- Freedom, choice, and democratic space
- Stakeholder needs, and programmatic needs
- Education
- Cultural resiliency
    - Multi-functionality
    - Social capital, and social diversity

METHODOLOGIES FOR ASSESSING SOCIAL PERFORMANCE

INITIAL OBSERVATIONS

Effective research topics and questions are often derived from personal observations and experiences and from a passion for a particular topic. A literature review is a great way to further explore a topic of interest, determine if a topic is worth pursuing, and help refine a research topic (Creswell, 2009). Before embarking on a social performance investigation, it may be worthwhile to observe a space without preparation to let your intuition and gut guide your observations. This type of informal observation along with a subsequent review of the literature will help you establish "initial propositions of study" (Yin, 2003) to help craft your goals and methods.

Helpful Questions for Initial Observations and Analysis of a Space Before or After Construction

How did the place come about?

What are its most important qualities?

Who uses the place?

What activities take place there?

How do people feel about the place?

Is it a successful people place?

How was it designed?

Is the design successful?

Is it managed successfully?

How would you redesign the place to make it more successful?

(Francis, 2001)

Who is (actor),

doing what (act),

with whom?

In what relationship, (relationships: aural, visual, tactile, olfactory, symbolic)

in what context, (socio-cultural context: situation, culture)

and where? (physical setting: props, spatial relations)

(Zeisel, 1984)

THEORETICAL FRAMEWORKS

As with all the performance categories, it is important to review the literature before embarking on a social performance investigation in order to identify theoretical frameworks that can serve as a guiding light during the investigation. Several landscape architecture theorists and professionals have written about what makes open spaces, particularly public spaces, successful, and these contributions can be the evaluation criteria for a post-occupancy evaluation. Some are more concerned with human use, while others have expanded their criteria for social success to sustainability goals such as ecological health, aesthetic appeal, functional forms, cultural importance, and economic growth (Hargreaves, Czerniak, and Beardsley, 2007). Following is a brief summary of a few theoretical frameworks that identify the attributes of successful open space that may be helpful when conducting a post-occupancy evaluation.

THEORETICAL FRAMEWORKS FOR SOCIAL PERFORMANCE AT THE INDIVIDUAL LEVEL

Mental Health and Well-Being

People have innate positive responses to natural landscapes (in this case, landscapes with flora and fauna) (Kellert and Wilson, 1993). Frederick Law Olmsted, "the father of landscape architecture," recognized this in the 19th century (Todd, 1982). This biophilia ("innate tendency to focus on life and life-like processes to the degree that we come to understand other organisms, where we will place greater value on them and on ourselves") (Wilson, 1993) is explained today as a genetic basis for human survival as a species. With this being recognized, it is no surprise that urban spaces with the presence of vegetation have been shown to ameliorate an individual's mental health and functioning (Cimprich and Ronis, 2003; Hartig, Mang and Evans 1991; Kaplan, 1995; Kuo and Sullivan, 2001).

Not only is it known that inferior habitats result in poor mental and physical health (Stilgoe, 2001), but also "greener" spaces have the opposite effect on human health (Kuo, Sullivan, Coley and Brunson, 1998). Even within the hospital environment, it has been found that recovering patients that have views of vegetated areas from their rooms show a significant decrease in the amount of pain medication needed, shorter recovery times, and less negative nurses' notes (Ulrich, 1984). These findings suggest that not only can natural features within the urban environment support mental well-being, but that this contact with other living entities may be a "requirement" for mental health (Roszak, 1995).

Several studies have also concluded that "greener" neighborhoods lead to several measurable benefits within a community when compared to more desolate neighborhoods. These benefits include:

- Stronger social networks (Kuo et al., 1998)
- More pronounced feelings of belonging among residents
- Increased amounts of social activities (Coley, Kuo, and Sullivan 1997; Sullivan et al., 2004)
- Residents familiar with more neighbors (Coley et al., 1996; Sullivan, Kuo and DePooter, 2004)
- Increased feeling that neighbors were concerned with helping and supporting one another (Kuo et al., 1998)
- Decrease in crime within the neighborhood (Kuo et al., 1998)
- Improved self-discipline among inner city girls (Taylor, Kuo, and Sullivan, 2002)

- Decreased mortality among senior citizens (Takano, Nakamura, and Watanabe 2002)

- Increased "emotional, cognitive and values-related development" in children (Kellert, 2002)

- More capability in dealing with challenges (Kuo, 2001)

Kaplan and Kaplan (2003) have also found that one's environment directly affects mental and physical health. They explain this phenomenon in their Reasonable Person Model (RPM), which is a "conceptual framework that links environmental factors with human behavior. "This model suggests that if one's environment can provide an individual with their "informational needs," then this in turn can benefit one's well-being. The people within this ideal environment are thus "more reasonable, cooperative, helpful, and constructive." There are three informational needs an environment must supply if it is to positively influence one's health: (1) exploration and understanding (providing information that can be received, processed, comprehensible, educational, and promote discovery), (2) recovery from mental fatigue (inability to focus, irritability, and impulsiveness), and (3) meaningful action, where participation in one's community negates feelings of helplessness and promotes competence, feelings of usefulness, and the ability to gain respect from others. Their findings directly link the design of a community with one's physical and mental well-being, and cite such problems as crime, lack of community, and dependence on motorized transportation as being causes of poor health.

Furthermore, Kaplan and Kaplan identify community-based activities that revolve around nature and can promote physical and mental well-being. These types of nature-based activities within the community can be tree-planting or gardening; activities can even include organizations that have stormwater management enhancement goals, like installing rain gardens or planting for stream restoration. Researchers have found a series of benefits that a community-based nature activity can provide for individuals and communities:

- Increased sense of pride in one's community (Austin and Kaplan, 2003)

- Greater amounts of time spent with neighbors

- More knowledge about events within the community (von Hassell, 2005)

- Sense of personal identity and connectedness to community (Lynch and Brusi, 2005)

- Increased self-esteem, trust and hope (Stuart, 2005)

Design Considerations for User Health and Well-being

Below is a brief collection of elements and considerations important when designing and assessing for maximum social performance.

Urban Open Space: Designing for User Needs (Francis, 2003)

- Comfort: a place to sit, shelter, food, drink, sun exposure, and shade
- Relaxation
- Passive engagement: people watching, reading, sitting, and sleeping
- Active engagement: walking, sports, gardening, and exercise
- Discovery: public art, landforms, and learning
- Fun

*How to turn a place around: A Handbook for Creating Successful Public Spaces (*Project for Public Spaces, 2000)

- Accessibility
- Activities
- Comfort
- Sociability
- Triangulation
- Indicators (e.g., people in groups, women, age groups, many activities, affection, other people)

With People in Mind (Kaplan, Kaplan, and Ryan, 2008)

- Understanding
    - Coherence
    - Legibility
    - Visual access
    - Human cues

- Restful and Enjoyable
    - Fascination
    - Distraction-free
    - Comfortable
- Meaningful Participation
    - Start early, include many
    - Clear information
    - Alternatives
    - Feedback
- Exploration
    - Complexity
    - Mystery
    - Depth
    - Openings

SEED Network Principles for the Design Process and Project Outcomes (Abendroth and Bell, 2015)

- Advocate with those who have a limited voice in public life.
- Build structures for inclusion that engage stakeholders and allow communities to make decisions.
- Promote social equality through discourse that reflects a range of values and social identities.
- Generate ideas that grow from place and build local capacity.
- Design to help conserve resources and minimize waste

Emotional Attachment, Human-Place Bonding, and *Sense of Place* (Jorgensen and Stedman, 2001; Low and Altman, 1992; Farnum, et al 2005; Kyle, Mowen, and Tarrant, 2004)

- Affect: stimulating emotional responses or activity in the sympathetic nervous system
- Place cognition and place identity: promoting a collection of memories, interpretations, ideas, and related feelings about the physical environment
- Behavioral intention, place dependence, and social bonding: reports of behavioral intentions and behavioral commitments, but not actual behavior

Recreation Experience Preference (REP) Scale to Assess the Motivations for Leisure (Manfredo et al., 1996)

- Achievement and stimulation
- Autonomy and leadership
- Risk taking
- Equipment
- Family togetherness
- Similar people
- New people
- Learning
- Enjoy nature
- Introspection
- Creativity
- Nostalgia
- Physical fitness
- Physical rest
- Escape personal and social pressures
- Escape physical pressure
- Social security
- Teaching and leading others
- Risk reduction

THEORETICAL FRAMEWORKS FOR SOCIAL PERFORMANCE AT THE COMMUNITY LEVEL

Cultural Relevance

The cultural relevance of any particular landscape is difficult to define. However, how a landscape relates to a culture and engages a community instead of ignoring or denying it is an important measure of social performance. Design that is socially responsive is not only focused on form and objects or artifacts, it is also focused on the process of design itself and inspiring collective action—particularly for social, cultural, and aesthetic goals. Economic and environmental sustainability success are relatively easy to measure and assess; aesthetic, cultural, and social successes are much more difficult to measure, but equally important.

Social Capital

Social capital is also another measure of social performance at the community scale. The assets or capital that communities possess can be physical (infrastructure, real estate, etc.), human (job training, education, etc.), social (relationships of trust embedded in social networks), financial, cultural (cultural knowledge that can be used to the owner's socioeconomic advantage), and natural (ecosystem services, natural resources, etc.) (Light, 2004; Costanza and Daly, 1992). Social capital has been identified in the community-building discipline as one of the most important capitals for maintaining and strengthening communities.

The community-building movement places weighted emphasis on community revitalization that focuses on fostering social capital. This focus is based on the belief that communities that are distressed have seen an "erosion of social capital" and are in need of "social cohesion, civic trust and collective efficacy" to improve their quality of life (Vidal, 2004; Hutchinson, 2004). A central idea in this approach is that social capital has profound potential energy that can create a "chain of metamorphosis," where social capital can molt into other forms of capital (social to human, human to financial) and is more readily available to impoverished communities than the other forms of capital.

Community-building approaches have proven to be successful modes of revitalization, particularly in communities that are burdened with unemployment, crime, poor education facilities, and eroding public infrastructure (Kingsley, McNeely, and Gibson, 1997). Much of their success is attributed to its principles of supporting self-sufficiency and connecting people with resources that may have otherwise been out of reach or hidden (Fraser and Kick, 2005). The driving force of this process is to capture the capacities, skills, and assets of communities (individuals, organizations, and institutions) in a manner that promotes economic and social enhancement and links these capacities with others.

Rohe (2004) has established a method for measuring social capital. He points out that measuring social capital is not merely tracing relationships and the outcomes of the interaction, but tracking how the interaction leads to trust and then collective action. It is important to realize that civic engagement does not always lead to trust. In Rohe's ideal social capital model, effective establishment of social capital is a process that goes from civic engagement, to establishment of social networks, to interpersonal trust, to effective collective action, and then creates individual and social benefits.

Other indicators that can be used as measures of social capital include (Mackinko and Starfield, 2001):

- Interpersonal trust
- Participation in social networks
- Sense of collective efficacy
- Trust in institutions
- Use of neighborhood facilities
- Collaborative problem solving
- Attendance in voluntary organizations
- Level of civic engagement
- Voting rates
- Visibility of neighborhood within the larger context

Measuring social capital can inform the effectiveness of a past community design project that strived for improved social networks or help collect baseline data before a community design project is implemented. Institutions such as the World Bank and individuals like Robert Putnam, have developed protocols or tools to measure social capital that may prove useful for a larger scale landscape performance investigation. These tools include the Comprehensive Social Capital Index (Grootaert and Bastelar, 2002), Capital Assessment Tool (SOCAT), and the Social Capital Integrated Questionnaire (SOCAP IQ).

CASE STUDIES AND POST-OCCUPANCY EVALUATIONS

Post-occupancy evaluations and case studies are among the most utilized social research methods in landscape architecture. Francis (2003) explains that case study research in landscape architecture is an endeavor that describes or evaluates a landscape architecture project or process with the purpose of informing future practice, policy, theory, and education. While case studies are qualitative, holistic, and narrative based investigations, post-occupancy evaluations explore specific parameters after a project is built with quantitative research methods. Individually, they are capable of telling a piece of the project's story. Together they offer the most comprehensive evaluation of a project or process.

There are several different methods for executing a case study that range from quantifying measurable dimensions of a project (stormwater management, carbon sequestration, reduction of the heat island effect) to more qualitative methods, such as evaluating people's views and opinions about a place. Qualitative case study methodologies for all research-oriented professions generally use one of the three different case study types (Yin, 2003; Stake, 1995):

- **Intrinsic**: project specific; used to simply understand the case, not to understand a construct or phenomenon or build theory

- **Instrumental**: issue based; one project evaluation to understand an issue or refine theory

- **Collective or multiple case studies**: research of a general condition, over several projects; used to explore differences and similarities between cases

A post-occupancy evaluation is the "study of the effectiveness for human users of occupied designed environments after an environment has been designed, completed, and occupied with the purpose of understanding how a space is used, how it could be better or developing design guidelines" (Marcus, 2012). The need for post-occupancy evaluations arose in the 1950s and 1960s when revolutionaries such as Jane Jacobs, William "Holly" Whyte, and Randy Hester observed many inequities manifested in the design of public spaces. For example, in 1952 while writing for the *Architectural Forum*, Jane Jacobs increasingly became concerned with the current state of urban planning and policies in New York and beyond. From this outrage, Jacobs ventured into Greenwich Village in New York City, and observed people and places to understand why public spaces in the city were successful or not. Based on these observations, Jacobs authored, *The Death and Life of Great American Cities*, one of the most influential books of our time about urban design and planning.

Post-occupancy evaluations are generally defined according to their level of investigation (Marcus, 2006):

- **Indicative**: quick evaluations (interviews, audit tools, walk-through)

- **Investigative**: more in-depth, evaluation criteria defined

- **Diagnostic**: most intensive, requires multiple methods (observation, analysis, interviews), goal is to create guidelines

The typical methods for conducting post-occupancy evaluations are (Marcus, 2006):

- Behavioral observation (traces, mapping),
- Surveys,
- Interview (designers, staff, users),
- Focus groups, and
- Experimental methods.

METHODS OF ASSESSMENT

Recognizing that the evaluation of social performance is a subject worthy of its own publication, the goal of this paper is to review a range of tools that can be used to assess the various aspects of social performance in a post-occupancy evaluation. There is significant overlap with the other categories of landscape performance, and many of the same tools and metrics can also be used to assess social performance. The most common methods and tools for collecting quantitative and qualitative information about social performance are some combination or derivative of questionnaires, surveys, interviews, focus groups and behavior mapping. Below is a list of some social performance criteria and potential methods of assessment, although it is not exhaustive.

Table 12. Typical Social Performance Methods

SOCIAL PERFORMANCE CRITERIA	METHODS OF ASSESSMENT
Stakeholder Needs/ Programmatic Needs	• Interviews • Surveys • Behavior mapping • Participatory mapping
Cultural and Historic Relevance	• Interviews • Surveys • Archival research • Participatory mapping
Inspiration and Beauty	• Interviews • Surveys • Behavior mapping • Participatory mapping

SOCIAL PERFORMANCE CRITERIA	METHODS OF ASSESSMENT
Mental Health and Well-being	• Health impact assessment • Interviews and surveys • Behavior mapping • Participatory mapping • Emotional attachment tools (recreation experience preference [REP], place attachment inventory [PAI], etc.)
Safety and Perceptions of Safety	• Interviews • Surveys • Behavior mapping • CPTED framework • Environmental tools • Participatory mapping
Human Comfort and Physical Health	• Interviews • Surveys • Behavior mapping • CBE Thermal Comfort Tool for ASHRAE55 • Environmental tools • Participatory mapping • Parks and Trails Health Impact Assessment Toolkit [13] • Active living tools (SPACES, Analytic Audit Tool, Irvine-Minnesota Inventory, University of Maryland Urban Design Tool, PEDS, Measurement Instrument for Urban Design Quantities, WABSA, WRATS, SOPLAY, SOPARC, SOPARNA, PARA, etc.) [14]

13 Centers for Disease Control and Prevention. 2015. "Parks and Trails Health Impact Asssment Toolkit." http://www.cdc.gov/healthyplaces/parks_trails/default.htm

14 Active Living Research. 2018. "Active living tools and measures." http://activelivingresearch.org/toolsandresources/toolsandmeasures

SOCIAL PERFORMANCE CRITERIA	METHODS OF ASSESSMENT
ADA Requirements	• Interviews • Surveys • Behavior mapping • Environmental tools • Participatory mapping
Effective Communication and Education	• Interviews • Surveys • Environmental tools
Environmental Justice	• Interviews • Questionnaires • Environmental tools

INTERVIEWS AND SURVEYS

Interviews and surveys are effective tools for gathering data from people that cannot be gathered through observation. They can illuminate people's attitudes and opinions that cannot be gathered any other way. Effective surveys must be carefully crafted to address the research topic in a non-biased way. Open ended questions can also be used to get information that may not have been considered in the creation of a survey, however open-ended answers will need to be summarized or categorized by the researcher if they are to be analyzed with statistics.

Creswell (2009), in his book, *Research Design*, offers helpful rules of thumb in creating an effective survey and best practices for an objective study as outlined below.

The Survey Design

1. Introduce the purpose of the survey research.

2. Decide whether the survey will be cross-sectional, with the data collected at one point in time, or whether it will be longitudinal, with data collected over time.

3. Determine the form of data collection: self-administered questionnaires, interviews, structured record reviews to collect information (financial, medical, etc.), or structured observations.

4. Keep it clear and concise.

5. Ask for help and feedback before distributing surveys or conducting interviews. Consider conducting a pilot test to discover ways to improve the investigation.

6. Do not use jargon or technical language.

The Population and Sample

1. Specify the characteristics of the population and the sampling procedure.

2. Identify the population in the study. Determine the appropriate sample size based on the population. A simple sample size calculator, such as one provided by Survey Monkey, may be helpful.[15]

3. Identify whether the sampling design for this population are individual or groups of individuals. Groups may be used when a large sample size is necessary.

4. Identify the selection process for individuals. Will it be opportunistic or convenient, strategically orchestrated to sample specific groups or random?

5. Identify whether the study will involve stratification (making sure you have a mix of many different types of people) of the population before selecting the sample.

6. Discuss the procedures for selecting the sample.

7. Indicate the number of people in the sample and the procedures used to complete the number.

Instrumentation

1. Name the survey instrument used to collect data (paper, Survey Monkey, etc.)

2. Describe the validity and reliability of the instrument.

3. Consider using awards or other incentives for returning surveys if distributed for individuals to fill out on their own time in order to increase the response rate.

15 Survey Monkey. 2018. "Survey Monkey Sample Size Calculator." https://www.surveymonkey.com/mp/sample-size-calculator/

Questions

1. Use a logical sequence of topics.

2. Start with interesting, non-challenging issues.

3. Don't place important items at the end of a long survey.

4. Use short sentences.

5. Avoid making two queries in a single question.

6. Avoid framing questions in the negative (not, never).

7. Avoid using ambiguous wording.

8. Employ non-threatening language.

Data Analysis and Interpretation

1. Report the number of respondents.

2. Discuss any response biases. Who are your nonrespondents? How might they have changed your data?

3. Discuss how you will analyze the data.

4. Identify the statistics and statistics program you will use.

Data Collection and Analysis Sources

• Survey Monkey

• Google Forms

• Market Research Wiki[16]

• Data Cracker[17]

• Stat Crunch[18]

16 http://mktresearch.org/wiki/Main_Page
17 https://www.datacracker.com/
18 https://www.datacracker.com/

Ethics

- State provisions for keeping individual responses confidential.

- If in an academic setting, you must seek approval from the institution's internal review board before implementing study.

- Consider keeping personal questions optional (gender, income, race, etc.).

Statistics for Surveys and Questionnaires

There are two types of statistics used in analyzing survey data, descriptive and inferential. Both should be used to describe the results of any quantitative research data and to understand whether or not the data are meaningful (most likely that any patterns in the data are not by chance and are related to the tested variable). There are several programs to help with statistical analysis. For the purposes of simple, quick investigations, programs like Microsoft Excel are all you need for basic statistics.

Below are statistics that are commonly used in landscape performance research that can be easily calculated in programs such as Microsoft Excel.

- **Descriptive**: used to describe samples, not to test hypotheses
    - Mean (average): the sum of all samples divided by the number of values
    - Standard deviation: measure of how widely values are dispersed from the average value (the mean)
    - Median: the middle value
    - Mode: the most frequently occurring value
    - Range: the maximum value minus the minimum value
    - Count: the number of values
- **Inferential**: to draw conclusions about an entire population based on measurement of a smaller, observed sample, to test hypotheses
    - Chi-square: to assess whether or not two variables are dependent or independent
    - T-test: to assess whether two groups are statistically different from one another
    - Analysis of variance or covariance: to assess whether three or more groups are statistically different from one another

BEHAVIOR MAPPING

Behavior mapping is a systematic observational method to assess human behavior in a space. Behavior mapping relates certain spatial and environmental attributes and characteristics to how people use them; it is useful because it is objective and unobtrusive (Cosco, Moore, and Islam 2010; Moore and Cosco 2010).

Behavior mapping is typically executed with two observers in the field who record data in rounds. The data typically includes the activity being observed and the characteristics of the person conducting the activity. In addition to rounds, the observers typically first gather data and compare it to one another to assess the reliability of their observational data as a quality assurance test.

Data is either recorded on a physical map of the site or with a digital device such as a tablet or smart phone that is also capable of recording data geographically. Activities and characteristics of people are usually coded with abbreviations so recording of data is efficient. In some instances, the site may be divided into predetermined smaller areas if the site is large or if the site has a high use. Other geographically based tools, such as ArcGIS, can also be used to illustrate and analyze the data, such as the density and distribution of behavior.

A number of protocols have been developed for behavior mapping that are specific to certain investigations. For instance, the Systematic Observation of Play and Recreation in Communities (SOPARC) protocol was developed for behavior mapping in parks (McKenzie, et al., 2006); it also has an accompanying tablet application that makes recording and analyzing spatial data more efficient.

Examples of Observational Systems for Observing Children's Behavior include (Cosco, Moore, and Islam, 2010):

- Child Activity Rating Scale (CARS)
- System for Observing Play and Leisure Activity in Youth (SOPLAY)
- Observational System for Recording Physical Activity in Children – Preschool Version (OSRAC-P)
- Environment and Policy Assessment Observation (EPAO)

There are new tools that can automate behavior mapping with the use of cameras, GPS devices, and specific software. There are also companies that can track behavior, such as Placemeter and Space Syntax. Participatory photomapping (PPM) is another approach to gathering information about human behavior that has been used to understand the health implications of place (Dennis, et al., 2009). This method includes utilizing digital tools, such as smartphone cameras, and interviews to capture qualitative and quantitative information about how people use space.

Economics

Why measure?

The economic performance of a site can offer some of the most useful and convincing knowledge in advancing and making the case for high-quality landscape architecture. Lessons in economic performance can help clients and owners make decisions about balancing short- and long-term goals with other environmental and social performance measures, building the case for more durable, permanent, and effective design. Economic performance data can also help designers avoid costly and inefficient design decisions that could otherwise be detrimental to their reputation or to the discipline.

Performance Benefits

Economic performance can be divided into two categories; economic catalyst, the ability of a project to provide economic gain through revenue generation, and economic savings, the ability of a project to save money or avoid cost through targeted decision making in the design, construction, or post-construction phases.

Economic Catalyst

WHY MEASURE AND METHODS OF ASSESSMENT

The 1997 opening of Frank Gehry's Guggenheim Museum in Bilbao, Spain set the stage for cultural destinations and architecture to be considered true catalysts of economic development around the world. This would come to be known as the Bilbao Effect. More recently, landscape architecture's contribution to large public parks have been recognized as having the same potential, such as New York's High Line and Chicago's Millennium Park. Much of this data is hard to ignore or debate; $2 billion in private investment has been made in the area surrounding the High Line, and in Chicago, the value of commercial properties has more than doubled in the business district adjacent to Millennium Park. However, to truly understand and communicate the economic benefits of these public amenities, there are many factors that should be considered and pitfalls to avoid before describing these benefits.

Analyzing the full economic impact of a built project requires investigating a range of information, including direct economic gains to the immediate areas surrounding the space, secondary economic benefits to the community, as well as other indicators of a thriving economy. The first category is the easiest to assess and measure using pre- and post-construction data with tools such as county data on economics, GIS data collection, and surveys of businesses and users of the public amenity. The specific indices include tax revenue, land value, assessed property values, revenue streams, sales, and sales tax revenue. The secondary economic benefits may take longer to have effect and are more difficult to draw direct connections to, such as job creation, new businesses, and impact fees (both residential and municipal), as well as neighborhood reinvestment. The final category involves studies of crime levels, accident rates, and rates of vacant properties. Although research has been done in the areas, these are complex issues, and therefore require many variables to be taken into account. There are real challenges in being able to isolate the direct causes of a newly thriving economy.

ECONOMIC CATALYST CASE STUDIES

Indianapolis Cultural Trail

(Indiana University Public Policy Institute, 2015; Mendenhall, 2015)

The Indianapolis Cultural Trail: A Legacy of Gene and Marilyn Glick is a less well-known nationally, but has had a big impact in the state of Indiana. This eight-mile bicycle and pedestrian trail weaves through downtown Indianapolis, connecting the city's cultural assets with its people, neighborhoods, and businesses across the city and beyond, through Indiana's extensive greenway system. It was funded through private-public partnerships and opened to the public in 2013. The Indiana University Public Policy Institute (IUPPI) completed an impact assessment of the trail shortly after it opened to the public. This study provides baseline data for future evaluations and the first draft of measurable economic impact immediately after the trail was complete (Burow and Majors, 2015).

In order to gain a complete picture of the economic impact of this trail on the city of Indianapolis, the IUPPI took a multi-pronged approach. The strategies they employed included individual trail user counts, surveys of trail users and surrounding businesses, and analysis of GIS data. The goal of this data collection was to evaluate perceptions of the trail and measure the impact of new business investment and growth in property value assessments. The final step was to use this data to quantify consumer spending that can likely be attributed to the trail. Through the use of GIS software, the research team concluded that the property values within 500 feet of the eight-mile trail increased by a total of more than $1 billion between 2008 and 2014. These included both commercial and residential properties, encompassing some of the largest developments in downtown Indianapolis. Surveys were effective in understanding how much money users of the trail planned to spend on activities such as shopping, cultural events, dining out, or staying at a hotel. Of the 558 surveys collected, 32 percent of respondents indicated that they would be engaging in at least one of the activities in the questionnaire, and 10 percent said they would be participating in more than one activity. The average expected annual spending per person was $53, which means this trail may be responsible for generating between $963,000 and $3.2 million in economic activity for the city of Indianapolis per a year (Burow and Majors, 2015).

Cherry Creek North

Fillmore Plaza, situated within the Cherry Creek North Business Improvement District (BID), is now a highly activated outdoor retail space in Denver, Colorado, complete with large works of public art, lush planting, event spaces, and bold lighting. However, this was not always the case. Before Design Workshop intervened in 2010, this was an underperforming shopping area that was deteriorating both functionally and aesthetically. Design Workshop collected just a small amount of key data to demonstrate how much this revitalized plaza contributed environmentally, socially, and economically. With the assistance of a Landscape Architecture Foundation grant, a research team was able to compile a compelling case study (Yang, 2012; Mendenhall, 2015).

A four-step measurement method was used by the research team to compare the before and after sales tax revenue. First, the team compared the annual sales tax receipts from the year prior to construction to the year after completion of the project. Annual comparisons for Cherry Creek North BID saw a $1,025,970 increase from 2009 to 2010. Second, the team calculated the sales tax increase as a percentage. To do this, they took the difference between the two years ($1,025,970) and divided it by the baseline year, 2009 ($6,363,315), illustrating a 16 percent increase. The third step considers the sales tax percentage increases in the same period for the surrounding area. In this case, they looked at the state of Colorado, the Denver metro area, and the city of Denver. While all of these comparison areas also experienced a growth in sales, the sales tax increase was only between 6.5 and 7.1 percent. This means that the area immediately surrounding Fillmore Plaza increased the sales tax receipts more than twice as much as the rest of Denver, the metro area, and the state (Yang, 2012).

DISCUSSION

There are limitations to a landscape architect's ability to correctly identify and pinpoint the exact inputs that contributed to a district's overall economic growth. Both causality and intercorrelation need to be considered. Other larger economic trends may be contributing to an increase in sales tax and should be recognized. The Indianapolis Cultural Trail is an example of a more thorough look at a range of economic issues. The IUPPI was able to verify that city-level data acquired from GIS was directly related to the trail by circulating surveys. When time and resources do not allow for this level of information gathering, following the lead of the Fillmore Plaza example can take the abstract notion that improvements to a public plaza, streetscape, or trail may lead to economic gains for a district, city, or municipality in the future and make the value concrete and compelling. As landscape architects, we are not necessarily trained to speak in a language that is relatable to a client's bottom line. It is important that we become better able to quantify the economic benefits of our work to expand our role in shaping today's public spaces in both large urban cores and our country's smallest towns.

ECONOMIC SAVINGS

WHY MEASURE AND METHODS OF ASSESSMENT

Beyond landscapes as a financial catalyst, there are other very important considerations when looking at the economics of landscape construction in a larger context. Money can be saved when landscapes are designed for efficiency and low maintenance. For example, converting a lawn to a meadow of drought tolerant plants means less water will be required for irrigation and less fuel will be needed for mowing. The economics of life cycle analysis for all landscape materials, from pre-construction to post-construction, should consider the cost of transporting the material, shipping waste material out, material durability and life span, and how much ongoing maintenance is required. These are all factors that should be evaluated from the onset of a project. This section will outline the basics of Life Cycle Cost Analysis and use a case study from Philadelphia, Pennsylvania, to illustrate how cost savings and reducing the overall carbon footprint of a project can go hand in hand.

Life Cycle Cost Analysis

Budget plays a major role in the decision-making process of almost every landscape architecture project. As landscape architects, we are often forced to focus heavily on the initial up-front cost, while spending little time educating ourselves or our clients on the long-term costs associated with materials and systems. Life Cycle Cost Analysis (LCCA) is a relatively simple tool that allows practitioners to make comparisons among design and construction options. The goal of using this tool is to evaluate economic performance of a construction project over its entire lifetime, achieving a balance between initial construction costs and long-term maintenance so that the most cost-effective design can be proposed. This system also has sustainability implications; materials that require less maintenance and replacement mean less energy and resources go into them after initial installation (Thompson, 2000).

There are five components of cost that must be taken into account for LCCA calculations. These components are capital, maintenance, fuel, replacement and salvage. The following formula can be used to estimate total life cycle cost of a project:

$$LCCA = C + M + F + R - S$$

Capital includes the materials, construction, design, and engineering services. This is typically the only cost considered in conventional bidding. Maintenance consists of all the estimated annual operating expenses, including minor yearly replacement of smaller components. Fuel, while it is directly related to maintenance, is important to document separately as the cost fluctuates dramatically. Additionally, if energy analysis will be part of the study now or in the future it is crucial to understand fuel consumption in isolation. Replacement is limited to repairs and new components that are not regularly scheduled annually. Salvage refers to the reuse of materials, and is therefore subtracted from other costs.

Stanford University has drafted Life Cycle Cost Analysis Guidelines to ensure that these concepts are embedded in all of their new construction. Too often, university budgets fall short of what is needed to adequately maintain and operate their facilities. The document works in conjunction with their campus planning and design documents as well as both the sustainability and facilities guidelines. It outlines LCCA goals for each phase of the design and construction process, including setting a benchmark budget, having operations and maintenance costs included in any cost estimate, developing a LCCA decision matrix, determining which LCCA studies to perform, discussing testing requirements with contractors, and planning for follow-up studies to test outcomes and assumptions (Davis, 2005).

Other inputs into LCCA can include the following:

- Regulatory credits
- Food production

ECONOMIC SAVINGS CASE STUDY

Salvation Army Kroc Community Center, Philadelphia, Pennsylvania

Introduction

Salvation Army Kroc Community Center (SAKCC) is an 87,000-square foot, highly diversified community center offering recreational facilities, job training, and educational and spiritual programs for the Germantown and Nicetown neighborhoods of northwest Philadelphia. The project location, a 13-acre contaminated brownfield, was an industrial site and parking lot. After a site analysis and contamination review, the designers developed a comprehensive landscape approach to accommodate the new site and facilities. The project includes an urban farm, synthetic turf field, playground, and a network of rain gardens and cisterns. In a 2013 article, “Multivalent Landscape: The Salvation Army Kroc Community Center Case Study,” Mary Myers categorizes the many ecosystem service benefits of this project into four valences: construction waste mitigation, stormwater mitigation, carbon sequestration, and plant stewardship. In this section, we will focus on the construction waste mitigation portion of this project.

The team for SAKCC set a goal at the beginning of the project to reduce the carbon footprint of this intervention as much as possible. With this is mind, the designers explored opportunities to reuse construction debris from the existing site. After some initial site investigation, they determined that by salvaging existing pavement, crushing it on site, and reusing it as base courses underneath the proposed parking lot, sidewalks, and building, they could prevent nearly 100 percent of the waste material from leaving the site. Landscape architects, engineers, and contractors worked together to calculate volumes of existing pavement and determined where it would be most appropriate to use it. This prevented 2,692 cubic yards of asphalt, 375 cubic yards of rail ballast, 7,022 cubic yards of aggregate stone, and 2,406 cubic yards of concrete, totaling 12,500 cubic yards, or 17,500 tons of material, from entering landfills. On top of the resource and energy savings benefits from this effort, it also saved the client $575,000 in disposal fees. These costs included transportation to a recycling center and the fee for disposing of material. It did not include the price of crushing and relocating the material on-site. (Myers, 2013)

Conclusions

Life Cycle Cost Analysis is a straightforward and effective tool in understanding the lifetime costs of designed landscapes. This section serves to introduce practitioners to the basic concepts. For more information on this process, consult "Sustainable Landscape Construction: A Guide to Green Building Outdoors," by J. William Thompson and Kim Sorvig (2000). Another more in-depth resource is "Life Cycle Costing for Facilities," by Alphonse Dell'Isola and Stephen J. Kirk (2003). Salvation Army Kroc Community Center illustrates the how practitioners can play a key role in collecting information through the course of a project. While more in-depth research was done by Mary Myers of Temple University after the project was complete, it was the practitioners who had the foresight to document the amount of materials salvaged and the associated costs while the project was being designed and constructed. This information could have easily been lost, and would have been very difficult to verify post-construction. It illustrates the importance of landscape architects learning to think in metrics, whether the project priorities are in saving money or carbon output. In this case, further study is needed to determine whether energy savings occurred by crushing material on-site versus hauling material off site. The project was successful in sparking a meaningful dialogue between professional practice and academic research. It is this synergy that will propel the profession of landscape architecture into a leadership role in shaping the design, management, and planning of the built environment in the 21st century.

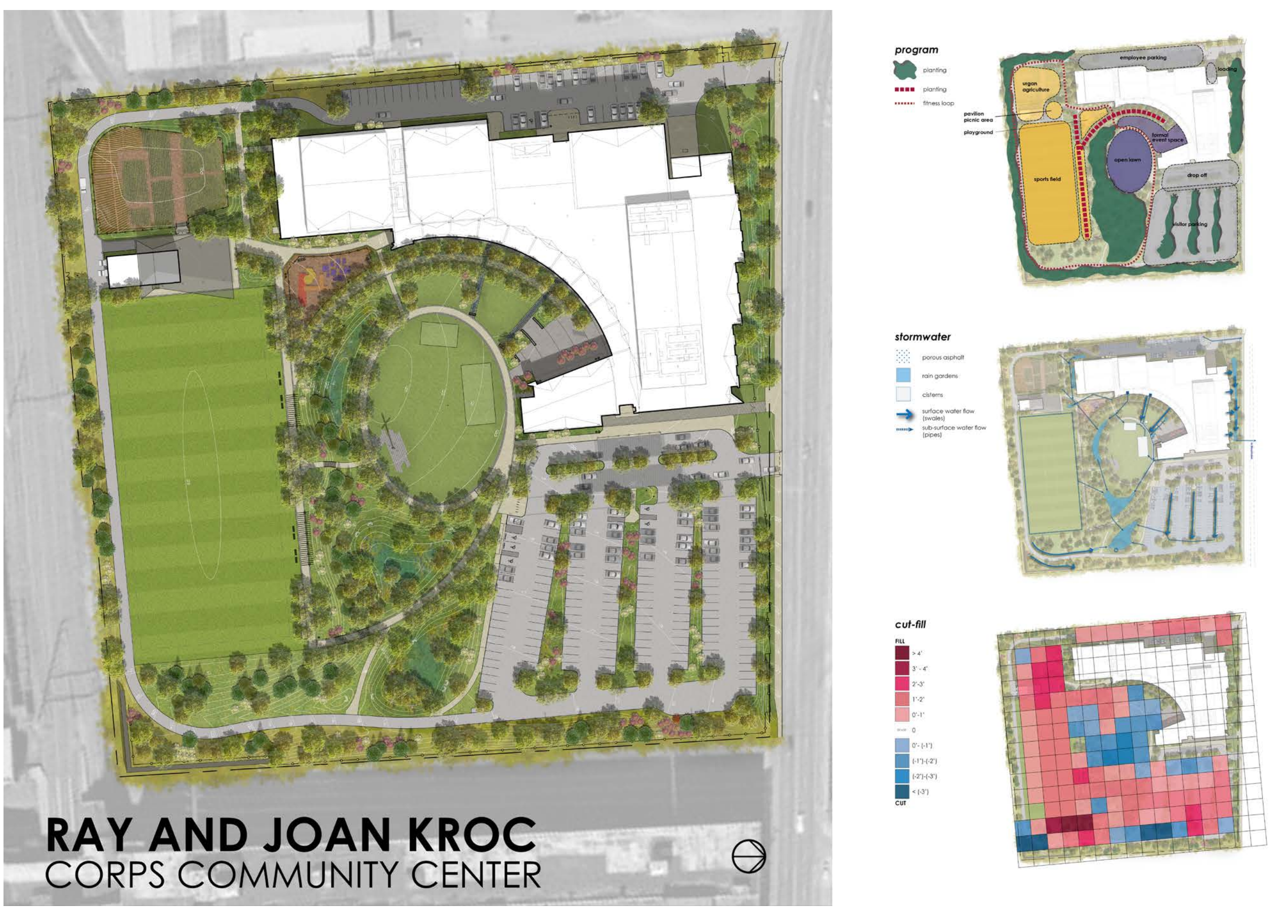


Figure 16. Salvation Army (Credit: Andropogon Associates)

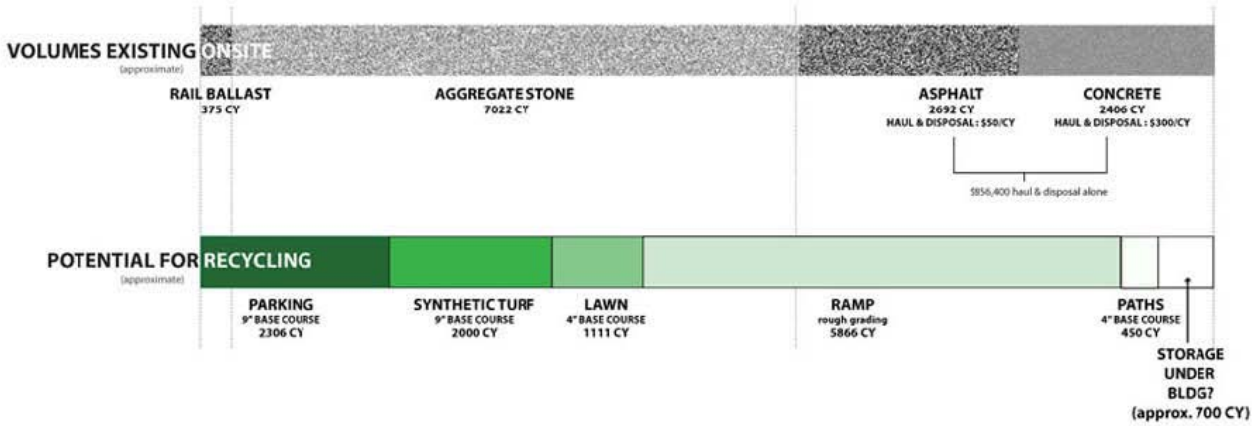


Figure 17. Salvation Army (Credit: Andropogon Associates)

Figure 18. Salvation Army (Credit: Andropogon Associates)

Case Study: Shoemaker Green, University of Pennsylvania, Philadelphia, Pennsylvania

Figure 20. Shoemaker Green Overview (Credit: Barrett Doughtery)

Figure 19. Shoemaker Green Site Plan (Credit: Andropogon Associates)

Figure 21. Shoemaker Green Rain Garden (Credit: Andropogon Associates)

Introduction

Landscape architects experience pressure from municipalities and within the profession to design high-performance landscapes that provide multiple functions, particularly in urban areas where space is scarce. Performance data on individual green stormwater infrastructure (GSI) components has become more readily available, but little performance data exists on (1) the integration of multiple GSI elements within a site over time or (2) the impact of an adaptive management on landscape performance. Most engineering models and current regulatory requirements do not consider the capacity of GSI to meet performance requirements within different contexts, and they typically use a one-size-fits-all approach. Landscape architects need field-verified information to understand how GSI projects perform over time and how to best manage the infrastructure to achieve maximum performance. This information can help landscape architects inform new engineering models, advocate for new GSI policies and regulations, and advance sustainable landscape design and management.

To understand the performance of a treatment train approach of interconnected GSI elements under an adaptive management program, a joint designer-academic research team deployed a three-year investigation of a 2.75-acre urban park located within an urban university's campus. The project was designed to offer landscape monitoring curriculum opportunities and contribute field-collected GSI performance data to the greater community of professionals and regulators. By building partnerships with academic, government, and design professionals, this site-level investigation has provided temporal data that helps the research team better understand performance-based landscape architecture and to establish adaptive management loops to inform landscape management practices that maintain or improve performance of these systems.

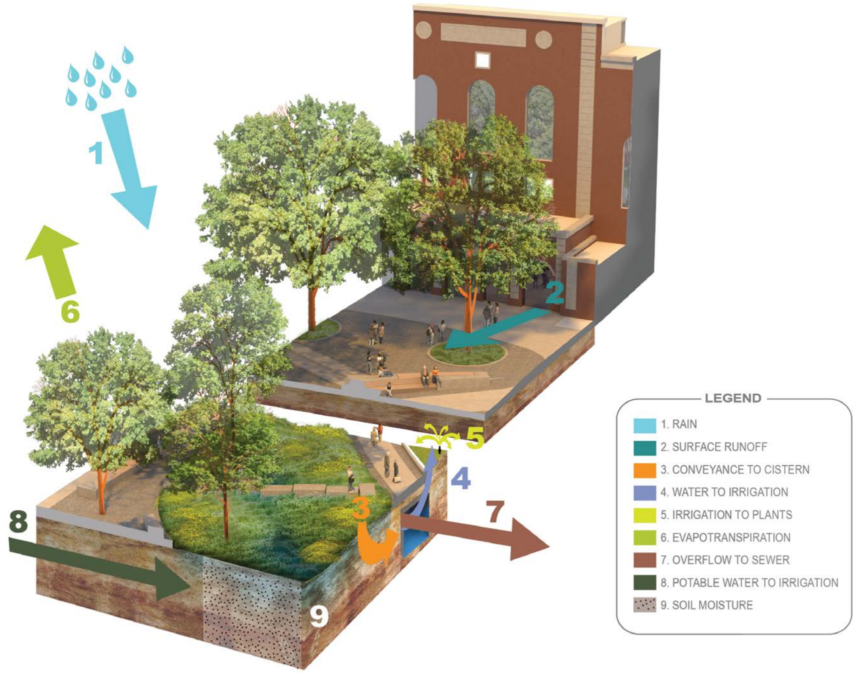


Figure 22. Shoemaker Green GSI Treatment Train (Credit: Andropogon Associates)

Why this site?

The non-infiltrating park leant itself to GSI monitoring.

- Academic Setting: The client is a university, dedicated to extending the classroom to the landscape and exhibiting robust, sustainable practices on campus.

- Limited Outlet Points: Most of the park required a sub-grade liner, like a green roof, and the runoff overflow dispensed solely through two combined sewer outlet points.

- Integrated GSI Design: The park design deployed a treatment train approach that linked engineered soils, a carefully selected plant palette, and a stormwater reuse irrigation system. The majority of water that hits the site is routed through GSI systems, including a:

    - Sub-lawn sand storage bed
    - 4,700-square-foot rain garden
    - Irrigation system fueled by a 20,000-gallon cistern
    - Native plant assemblage beds
    - Continuous tree trenches

Figure 23. Sand Storage Bed Below the Lawn (Credit: Andropogon Associates)

- Adaptive Management Program: The university supported an adaptive management program aimed at improving the site's stormwater management over time. The program includes compost tea application, irrigation monitoring, use of alternative de-icing salts, soil and plant monitoring, and soil and turf remediation.

- Regional Context: The park lies within a city with an aging combined sewer, thereby underscoring the need for GSI performance research with comparative analysis to traditional engineering models that undervalue the role of high-performance soils and vegetation.

Landscape Performance Research Goals

The research aimed to evaluate the engineering model assumptions of GSI performance within an urban setting and to provide feedback to the university's facilities managers to improve campus-wide landscape performance. The key research questions that framed the investigation were:

- How much do soil and vegetation really contribute to stormwater management?

- Can a sand-based soil and organic turf management program promote a healthy landscape, including resisting compaction and maximizing evapotranspiration?

- How can an adaptive management program influence performance?

Methods and Tools

The research team monitored stormwater runoff volume, water quality, soil, vegetation, and social use to answer these questions and understand how the site functions as an integrated GSI system. Several methods were used to analyze the park before, during, and after construction, to provide insight into changes in landscape performance, and to inform the management program. Cost effectiveness and accuracy were balanced when selecting both monitoring methods and instrumentation.

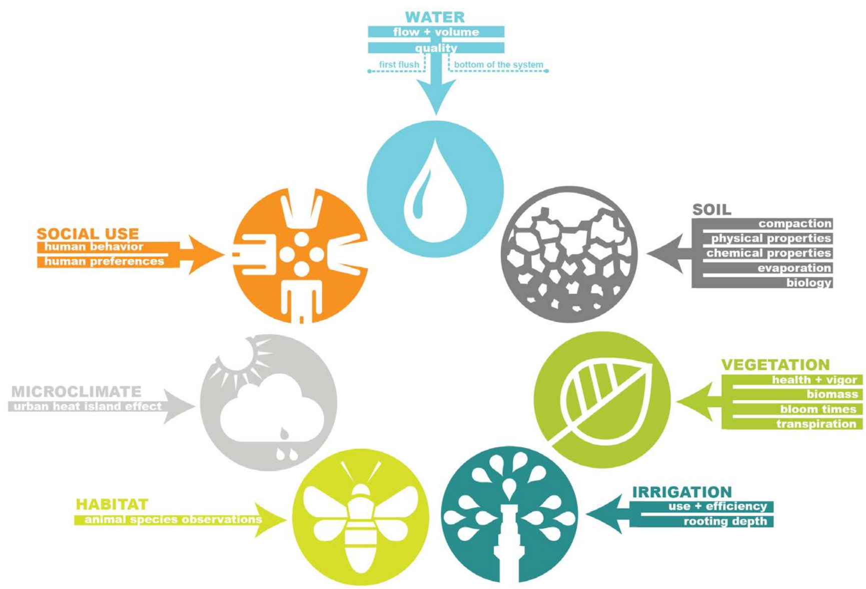


Figure 24. Parameters Measured (Credit: Andropogon Associates)

Water

STORMWATER QUANTITY

- On-site weather station to measure rainfall hourly
- Pressure transducers in junction boxes at the end of each GSI system (AC condensate outfall, lawn sand storage bed, rain garden, cistern overflow, tree trenches, and outlets to city sewer)
- Cork tubes to measure rain garden ponding depths during large events

Figure 25. Installation of the Pressure Transducers at the Overflow of the Cistern (Credit: Emily McCoy)

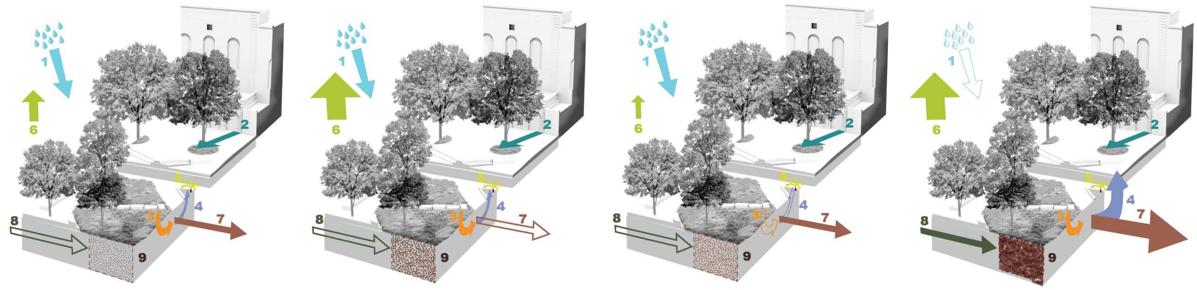
STORMWATER QUALITY

- Automatic sampler in rain garden to capture water before and after it went through the rain garden for the "first flush" of rainfall
- Grab sample bottles to manually collect water samples from the rain garden and later analyzed in the lab with an inductively coupled argon plasma optical emission spectrometer

Figure 26. Installation of the Automatic Sampler Intake at the Bottom of the Rain Garden (Credit: Emily McCoy)

IRRIGATION DATA FROM THE IRRIGATION CONTROL SYSTEM

- Water usage
- Soil moisture
- Water flow to and from cistern



	MODEL SCENARIO	ACTUAL SCENARIO	WINTER SCENARIO	MISMANAGED SCENARIO
RAIN	1”	3.16”	2.94”	0
GALLONS/ MANAGED	53,410	168,776 (cistern, BMP’s, evapotranspiration)	157,026 (BMP’s)	64,500 (mis)managed
OVERFLOW	N/A	0	trace	697
OBSERVATIONS	plants & soil undervalued	plants & soil hardworking	cistern off soil biota & plants semi-dormant soil saturated	oversaturated soil from repeated overwatering
LEGEND	1. RAIN 2. SURFACE RUNOFF 3. CONVEYANCE TO CISTERN 4. WATER TO IRRIGATION 5. IRRIGATION TO PLANTS 6. EVAPOTRANSPIRATION 7. OVERFLOW TO SEWER 8. POTABLE WATER TO IRRIGATION 9. SOIL MOISTURE			

Figure 27. Water Quantity Summary (Credit: Andropogon Associates)

Soil

- Lab analysis of soils three times a year for physical, biological, and chemical properties
- Soil compaction with a cone penetrometer in 10 locations two times a year
- Soil infiltration with a double-ring infiltrometer in four locations two times a year

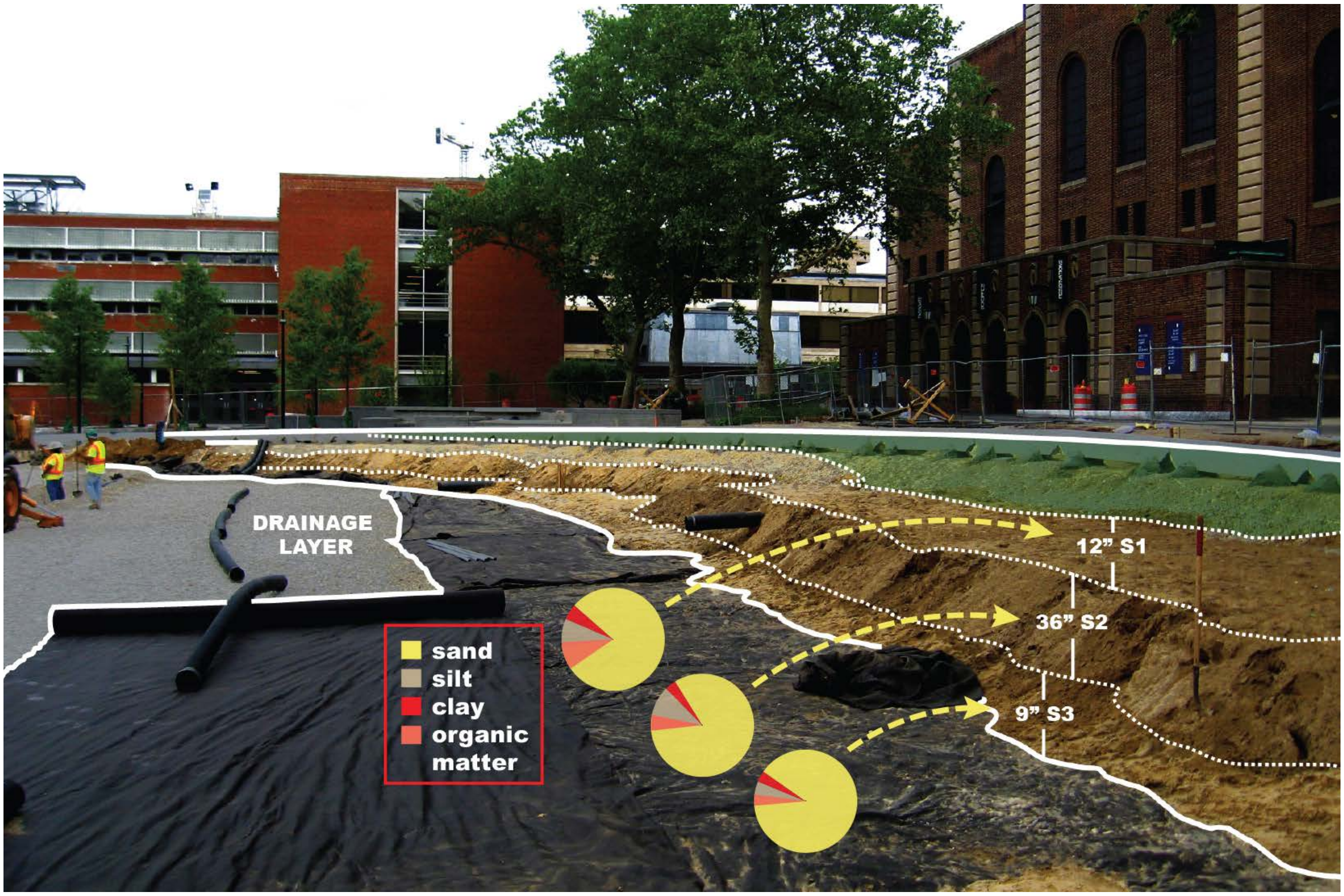


Figure 28. Soil System (Credit: Andropogon Associates)

Vegetation and Wildlife

- Tree height using a smart phone app two times a year
- Tree diameter with a diameter measuring tape two times a year
- Plant vigor using an integrated pest management manual two times a year
- Vegetation transpiration with a leaf porometer (to measure stomatal conductance) and ceptometer (to measure biomass) once a year
- Casual visual observation of wildlife while on-site
- Crowdsourced bird migration data from eBird

Figure 29. Changes in Biomass in Three Years (credit: Andropogon Associates)

GALLONS/DAY/TREE OR GROUNDCOVER AREA

	6/2013	8/2013	9/2014	6/2014	8/2014
QUERCUS PHELLOS - UT permeable pavement	15.47	5.61	4.78	12.26	10.10
QUERCUS PHELLOS - LT street tree trench	13.10		5.62		3.24
QUERCUS PHELLOS - LL lawn	14.95	17.76	4.90	3.51	11.88
TURF (per 10 sq. m.)	1.96	15.40	2.25	.91	1.28
NYSSA SYLVATICA	17.45	25.36	5.49	13.19	27.93
QUERCUS BICOLOR	13.43	25.60	6.91	34.96	15.66
TAXODIUM DISTICHUM	9.32	4.62	5.90	8.92	12.25
LIRODENDRON TULIPFERA	3.00	1.88			2.44
CAREX STRICTA (per 10 sq. m.)	0.76	8.00	2.10	3.25	

HIGHEST
LOWEST

Figure 30. Transpiration Data (Credit: Andropogon Associates)

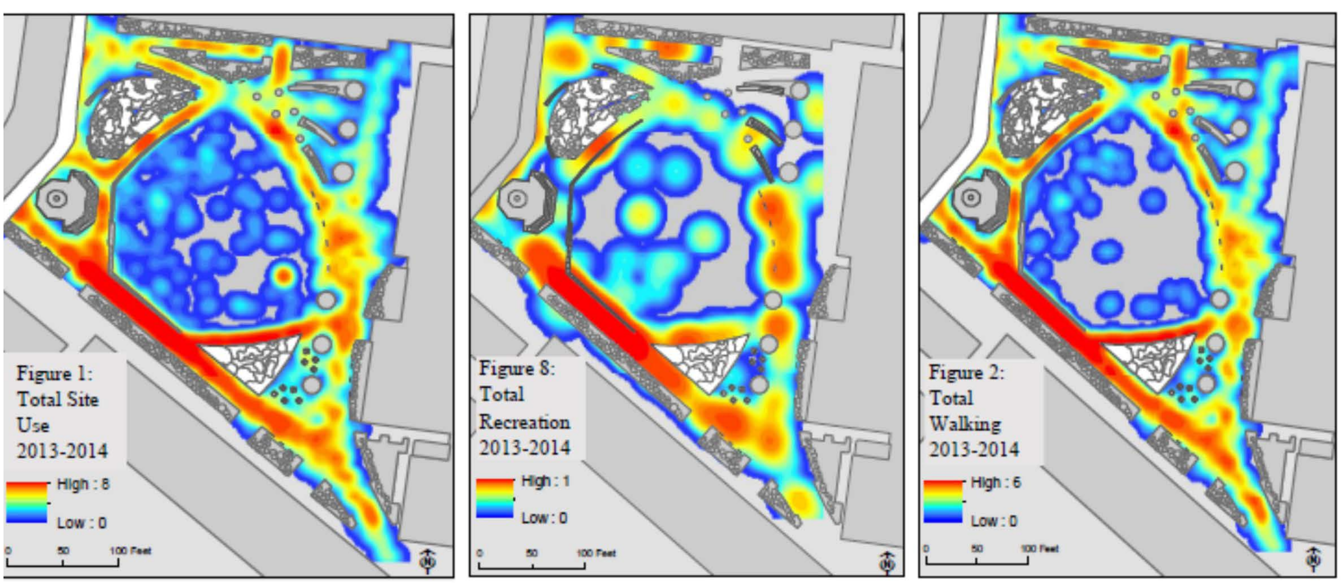


Figure 31. Behavior Mapping Maps (Credit: Alicia Coleman)

Social

- Behavior mapping field observations using GIS four times a year to track and characterize behavior and to cross reference behavior with environmental characteristics, such as shade, ground cover types, proximity to paths, etc.

FINDINGS

Key findings from the three-year landscape performance investigation include:

1. This integrated GSI system can manage at least three times more stormwater runoff than the engineering models predicted.

The engineering models required by local stormwater management regulations did not account for the park's engineered soil, which had a high water storage capacity; its high-performance vegetation, which provided significant water uptake via transpiration; or its stormwater reuse irrigation system, which recycled cistern water for irrigation of the park's plantings. The study period's largest precipitation event occurred on June 7, 2013, when 3.14 inches of rain fell on the site. No stormwater overflowed to the combined sewer during this event, even though the engineering models revealed a maximum of one inch of rainwater capture capacity.

Adaptive Management Lesson

During the study period, the site almost overflowed into the combined storm sewer during seven instances and overflowed once. Six of these overflow close calls occurred during the winter, when the 18,500-gallon cistern was offline for the season (to protect against de-icing salt intrusion). Had the cistern been online during these months, the park would have been able to handle an overflow, even if slightly more water had fallen on the site. The adaptive management response to this scenario is to install devices that monitor the cistern's salt content, so the cistern can remain functional during winter.

2. Irrigation system monitoring is critical in preventing cistern overflows to the storm sewer and for sustainable water management.

The other overflow close call and one actual overflow event occurred during dry-weather. The park's management manual suggests one inch of irrigation per week, but during each of these events, the irrigation system was incorrectly programmed to release four inches of water.

Adaptive Management Lesson

Active monitoring efforts revealed the irrigation problem and consequently provided the landscape managers with proof of overwatering. Unmanaged and mismanaged irrigation systems can lead to significant problems and contribute to unnecessary stormwater overflows to the sewer system.

3. Native floodplain species and uncompacted turf are stormwater workhorses.

Native floodplain species are particularly successful at transpiring water, even within urban settings. Using porometer measurements, the park's young swamp white oak (Quercus bicolor) was found to transpire up to 35 gallons of water per day per tree during the peak growing season. As the trees mature, their water draw is anticipated to increase over time. Uncompacted turf is also hard at work, although transpiration and compaction are inversely proportional. These data were paired with soil evaporation measurements taken from the site's tensiometers in order to understand the amount of water leaving the site through evapotranspiration.

Adaptive Management Lesson

Preliminary data suggest that when designing GSI systems, water should be held in the rhizosphere as long as possible to let soil and vegetation evaporate and transpire as much water as possible without compromising plant health. Irrigation systems that reuse stormwater and air conditioning condensate, continuously cycling water through the vegetated system, can further allow opportunities for water to be transpired and evaporated.

4. The soil management program for the sand-based, engineered soils, including the addition of compost tea to the turf areas, is supporting healthy vegetation, helping mitigate compaction and improving the water holding capacity of the soil with careful monitoring.

The soils to date have held their structure and have not yet become overly compacted. However, compaction readings do indicate that some areas of the lawn (four of the seven sampling points) are slowly approaching the 300 psi threshold, which is the rate when roots begin to resist penetration. Also, organic matter in the soil is increasing to ideal levels when compared to the turf control area, which is not receiving compost tea applications. In the rain garden, soil reports show a balanced fungi to bacteria ratio that is expected in a landscape that supports healthy perennial grasses and understory trees.

Adaptive Management Lesson

The compaction measurements guided the maintenance staff to remediate compacted areas with an aerator before the compaction negatively influenced plant health.

The success of the compost tea program gave the facilities staff confidence to replicate the management regime on other parts of the campus, thus reducing the reliance on synthetic fertilizers.

Case Study Conclusion

This study revealed that engineered soils, appropriate plant selection, irrigation reuse, and adaptive management significantly reduced overflows to the combined sewer system by more than three times than projected by the locally mandated engineering models. Effective advocacy for GSI policy and implementation requires more field-tested research to determine which soils and plants have the potential to manage the most stormwater under a wide variety of conditions. This research helps advocate for more implementation of GSI systems, and for achieving goals such as net-zero water on a site though programs such as SITES and the Living Building Challenge.

Conclusion

Landscape architecture is at a pivotal moment in its history as a discipline, where design practice is becoming more reflective, adaptive, and scholarly. As the need for sustainable design grows, it has become imperative that professionals put their work through an analytical review and set higher standards for their work to perform environmentally, socially, and economically. The field looks more to the integration of research and science in design as a solution to this growing need.

The pressure for landscape architects to produce more resilient and functional designs has increased greatly. A paradigm shift of the discipline, with design decisions increasingly based on facts rather than beliefs, requires that the successful practitioner be an effective designer while thinking like a researcher (Brown and Corry, 2011). With so many designs and strategies that are relatively untested, it is vital that we begin to take a more scientific and analytical look at built work, and learn from successes and failures in the realm of landscape performance. The evaluation of landscape performance is gaining quite a bit of attention within the field, but in many cases professionals do not have the time, resources, or know-how to accomplish these analytical reviews.

This primer scratches the surface of performance monitoring of the landscape, but the hope is that it serves as a catalyst for designers to think more in-depth about landscape performance by getting out into the field and assessing built work, whether it be as an individual, office, or as a multidisciplinary group. Site performance evaluations can be relatively inexpensive and are an investment in the craft and business of landscape architecture. This collective intelligence in our discipline can be used to advocate and communicate the value of our work in protecting the health, safety, and welfare of our communities, and push us all to strive for higher and well-balanced aesthetic, economic, environmental, and social performance goals in the landscape.

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Appendix

APPLICABLE SITES v2 CREDITS

WEATHER, MICROCLIMATE, AIR QUALITY, AND SOUND

Pre-Design

- Pre-Design P2.2: Conduct a pre-design site assessment

Pre-Construction / Baseline Data

- Pre-Design P2.2: Conduct a pre-design site assessment Operations and Maintenance
- O+M P8.1: Plan for sustainable site maintenance

Case Study or Post-occupancy Evaluation

- Soil+Veg C4.9: Reduce urban heat island effects
- Soil+Veg C4.10: Use vegetation to minimize building energy
- HHWB C6.4: Support mental restoration *
- HHWB C6.6: Support social connection *
- Education C9.2: Develop and communicate a case study
- Education C9.3: Plan to monitor and report site performance

SOILS AND AMENDMENTS

Pre-Design

- Pre-Design P2.2: Conduct a pre-design site assessment
- Pre-Design P2.3: Designate and communicate Vegetation and Soil Protection Zones

Pre-Construction / Baseline Data

- Pre-Design P2.2: Conduct a pre-design site assessment

Operations and Maintenance

- Soil+Veg P4.1 Create and communicate a soil management plan
- Soil+Veg P4.2 Control and manage invasive plants
- O+M P8.1: Plan for sustainable site maintenance
- O+M C8.3: Recycle organic matter
- O+M C8.4: Minimize pesticide and fertilizer use

*Eligible Prerequisite or Credit for Performance Monitoring

Case Study or Post-occupancy Evaluation

- Construction P7.3: Restore soils disturbed by construction *
- Construction C7.4: Restore soils disturbed by previous development *
- Education C9.2:Develop and communicate a case study
- Education C9.3: Plan to monitor and report site performance

WATER

Pre-Design

- Pre-Design P2.2: Conduct a pre-design site assessment

Pre-Construction / Baseline Data

- Pre-Design P2.2: Conduct a pre-design site assessment

Construction

- Constructoin P7.2: Control and retain construction pollutants

Operations and Maintenance

- O+M P8.1: Plan for sustainable site maintenance

Case Study and Post-occupancy Evaluation

- Water P3.1: Manage precipitation on site*
- Water P3.2: Reduce water use for landscape irrigation*
- Water C3.3: Manage precipitation beyond the baseline*
- Water C3.4: Reduce outdoor water use*
- Water C3.6: Restore aquatic ecosystems*
- Education C9.2: Develop and communicate a case study
- Education C9.3: Plan to monitor and report site performance

VEGETATION

Pre-Design

- Pre-Design P2.2: Conduct a pre-design site assessment
- Pre-Design P2.3: Designate and communicate Vegetation and Soil Protection Zones

*Eligible Prerequisite or Credit for Performance Monitoring

Pre-Construction / Baseline Data

- Pre-Design P2.2: Conduct a pre-design site assessment
- Soil+Veg C4.4: Conserve healthy soils and appropriate vegetation
- Soil+Veg C4.5: Conserve special status vegetation
- Soil+Veg C4.6: Conserve and use native plants

Operations and Maintenance

- O+M P8.1: Plan for sustainable site maintenance Credit 9.2: Develop and communicate a case study
- O+M C8.4: Minimize pesticide and fertilizer use

Case Study or Post-occupancy Evaluation

- Water C3.6: Restore aquatic ecosystems
- Soil+Veg P4.2: Control and manage invasive plants *
- Soil+Veg P4.3: Use appropriate plants
- Soil+Veg C4.7: Conserve and restore native plant communities *
- Soil+Veg C4.8: Optimize biomass
- Soil+Veg C4.9: Reduce urban heat island effects
- Soil+Veg C4.10: Use vegetation to minimize building energy use
- Education C9.1: Promote sustainability awareness and eduation
- Education C9.2: Develop and communicate a case study
- Education C9.3: Plan to monitor and report site performance

SOCIETY AND CULTURE

Pre-Construction / Baseline Data

- Pre-Design P2.2: Conduct a pre-design site assessment
- Pre-Design C2.4: Engage users and stakeholders

Case Study or Post-occupancy Evaluation

- Water C3.5: Design functional stormwater features as amenities
- HHWB C6.2: Provide optimum site accessibility, safety, and wayfinding *
- HHWB C6.4: Support mental restoration *
- HHWB C6.5: Support physical activity *

*Eligible Prerequisite or Credit for Performance Monitoring

- HHWB C6.6: Support social connection *
- Education C9.1: Promote sustainability awareness and education
- Education C9.2: Develop and communicate a case study
- Education C9.3: Plan to monitor and report site performance

ECONOMICS

Pre-Design

- Pre-Design P2.2: Conduct a pre-design site assessment
- Materials C5.2: Maintain on-site structures and paving
- Materials C5.4: Reuse salvaged materials and plants
- Materials C5.5: Use recycled content materials
- Materials C5.6: Use regional materials

Construction

- Construction C7.5: Divert construction and demolition materials from disposal
- Construction C7.6: Divert reusable vegetation, rocks, and soil from disposal

Operations and Maintenance

- O+M P8.1: Plan for sustainable site maintenance
- O+M C8.5: Reduce outdoor energy consumption

Case Study or Post-occupancy Evaluation

- Education C9.2:Develop and communicate a case study

*Eligible Prerequisite or Credit for Performance Monitoring