Chapter 3

Metrics in Master Planning Low Impact Development for Grand Rapids Michigan

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Additional information is available at the end of the chapter

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Abstract

Planners, designers, citizens, and governmental agencies are interested in measuring and assessing urban design treatments that are environmentally sensitive across numerous environmental design issues such as stormwater, adapting to climate change, wildlife suitability, visual quality, and maintaining soil productivity. This chapter examines a case study in the Grand Rapids Michigan, exploring design ideas for the extension of a medical campus and adjoining areas. The results of the case study present newly derived equations to assess soil productivity. The results of the soil equation development indicate that the soil productivity of an area has two primary dimensions, forming an annual plant preference cluster, a woody plant preference cluster, and a wetland plant preference cluster, where each soil setting requires a different soil profile. The equations explain between 90 and 97% of the variance and are definitive (p-value<.001). The environmental variables examined in the study, including the soil productivity, indicate that the developed master plan for the site is significantly better than traditional approaches and the existing site characteristics (p-value < 0.05).

Keywords: stormwater management, climate change, soil productivity, walkability, microclimate management, biodiversity, urban design, urban campus, landscape urbanism, landscape engineering

1. Introduction

This chapter presents the results of an entry into the 2015 Environmental Protection Agency (EPA) Campus RainWorks Challenge, Masterplan Category, employing the new Michigan Sate University (MSU) Medical Campus in Grand Rapids, Michigan as a case study. The plan employs metrics to demonstrate the effects that the low-impact development can have upon urban sustainability issues. The metrics include the following: reduction in stormwater volume, increase in stormwater quality, increase in songbird habitat suitability, increase in vegetation biodiversity, reduction in water requirements by woody vegetation, increase in latent soil productivity, increase in vegetation adaptation to climate change, increase in visual quality, improvement in microclimate diversity, reduction in landscape maintenance and energy inputs, and walkability.

The plan blends green infrastructure, healthy urban environments, neighborhood entertainment opportunities, and sustainability together addressing fundamental issues. In the development of the project several best management practices (BMPs), tools are presented to improve water quality and the challenges brought by global climate changes. Some of the tools that are employed in the design include green roof, rain tanks and cisterns, permeable pavement, bioretention or rain gardens, dry and wet swale, and constructed wetlands. The project involved students, faculty, and administrators who influenced and directed the final product. The title for this project is "Vault of Heaven," an ancient Hebrew term for the sky, where the rainwater lands on the earth.

2. Pertinent literature

Concepts concerning sustainability and ideas addressing low impact development (LID) in planning and design have been in existence since ages [1]. The Greeks employed a concept now termed *Genuis Loci*, where sites were developed with minimum environmental disturbance and construction [2]. In addition, Roman engineers developed roads at the bottom of hillsides on suitable sandy and gravelly substrate, well above the wetland valleys and below extensive undulating topography, thereby minimizing the need for numerous bridges and extensive site excavation [3]. Burley and Machemer present other examples from history by Chinese and American designers [3]. Wang et al. states "low impact develop is not new, but was not widely known beyond the profession of landscape architecture, natural resource planners, and to some civil engineers ([4], p. 2). However, recently low impact development has been more widely adopted and incorporated into the planning and design of environments." They also indicate that the LID in the United States often means the management of stormwater; in the United Kingdom, the term encompasses a broader range of environmental measures.

A variety of stormwater best management practices (BMPs) can be incorporated into the LID projects, such as rain gardens, green roof, bioretention features, and pervious pavements [5]. The current literatures of the LID impact are mostly relative to the qualitative case study [4–7]. Strauch conducted one of the early studies on statistical comparison of the effects of various treatments; the study compared energy use, wildlife habitat, and stormwater runoff of a site in Montana [8]. A similar study was presented by Wang et al. for a proposed ski resort in Michigan, examining habitat suitability, visual quality, and vegetation diversity [9]. In other words, a variety of variables (visual, wildlife, stormwater, and energy use) can be examined together to evaluate the effectiveness of a design treatment. LID as a best management practice may have significant meaning and influence when addressing the site design. The emergence of this technology and deeper exploration of this green infrastructure approach has expanded rapidly in recent years, and further broader study is encouraged. However, there are relatively few case studies illustrating and statistically comparing LID with other traditional approaches. Planners, designers, citizens, and governmental agencies are interested in understanding more concerning sustainable LID projects. This chapter illustrates one such case study.

3. Study area and methods

3.1. Study area

The agreement supports establishing a new 4-year medical school in Grand Rapids, Michigan. Connecting with a medical school was a critical link for establishing the Grand Rapids as a leading health care and research location City of Grand Rapids [10]. In addition, MSU needed a strategic partner with a research institute and major health-care providers to expand the medical school's teaching and research mission, thereby helping in addressing the State of Michigan's projected physician shortage. The partnership also includes the Spectrum Health and Stain Mary's Health Care.

The Secchia Center opened in the fall of 2010 to serve as the headquarters for the MSU College of Human Medicine (CHM). CHM reached its expansion goal of 800 students and 15 principal investigators with their teams fully occupying the available laboratory space in Grand Rapids in 3 years. As a result, the Board of Trustees authorized planning for a second research facility across the Ionia Avenue. These two facilities, anchoring the intersection of Michigan Street and Ionia Avenue, comprise the MSU Grand Rapids Medical Campus, establishing a gateway to the Central Business District, the Medical Mile, and the North Monroe business district that lies along the Grand River.

The Medical Campus's design addresses urban sustainability in both community- and site-specific context. From a community perspective, the facilities respect their adjacency to the Grand River and the regional stormwater management plan, strategically infill the urban fabric in accordance with the city's master plan, and facilitate the use of the existing mass transit opportunities including the new bus rapid transit system along the Michigan Avenue. At the site-specific scale, the facilities' design incorporates the best management stormwater features that function as a subset of the regional system and leverages urban regeneration principles through redevelopment of the abandoned Grand Rapids Press building. In its totality, the MSU Grand Rapids Medical Campus provides for the needed programmatic facilities identified by the University's College of Human Medicine and supports the City of Grand Rapids' sustainability goals at environmental, social, and economic levels.

The Grand Rapids Research Center (GRRC) is located at the intersection of Michigan Street and Monroe Avenue in Grand Rapids, Michigan (**Figure 1**). The site and MSU College of Human Medicine's (CHM's) Secchia Center, interrupted by highway ramp, are woven into

Figure 1. An aerial view of the study area in Grand Rapids, Michigan.

Grand Rapid's unique urban fabric. MSU CHM Sacchia center is situated in the circle of Grand Rapids Medical Mile, where many public and private health-care facilities cluster. The new research center extends to Monroe Avenue NW and is referred as the gateway to the North Monroe business district.

The study area comprises a 98.5-acre site which includes some of Grand Rapids Medical Mile and partially the North Monroe business district to enhance the linkage between our campus and Grand Rapids downtown areas. The design aims to develop a holistic community that fosters sustainability, economic prosperity, verdant opportunity, walkability, and livability; and reflects a broader investigation of a rather comprehensive perspective, addressing how to adapt and mitigate climate change and other environmental issues.

The city of Grand Rapids is removing the dams, restoring its rapids, and reinforcing the riverfront and water entertainment areas. In addition, the Grand River area is associated with the missions to create a diverse-populated downtown, expand job opportunities, ensure vitality of the local economy, reinvest in public space, culture, and inclusive programming, retain and attract families, talent, and job providers with high-quality public schools. This study includes the above goals and focus on promoting the educational, social, aesthetic, environmental, and economic quality of our campus and its communities. This project also involves college students, advisors, and administrators from different professions. The study team collected the advice and suggestions from different disciplines to address the challenges faced during this project. Therefore, the program for the site included the following:

- Grand River, the longest river in Michigan, is bordered by very busy and prewar historic downtown areas. The Federal Emergency Management Agency (FEMA) recalculates the floodplain for a 100-year 24-h storm event, and it adds 3 feet more to the existing flooding walls.
- The 100-feet elevation change along Michigan Street NE.

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- The incomplete network between Hillside District, North Monroe District, Belknap District, and City Center.
- Lack of crossings.
- Narrow sidewalks.
- Lack of street trees and shade.
- Highway ramps cutting the connections between the business and residential districts.
- Stormwater runoff overloading storm sewers and introducing sediment, pollutants, and contaminants into streams and rivers.
- Climate change effects:
- Warm and wet winter and spring, but dry summer.
- Average temperature and precipitation will increase by 1.1°C and 2.6%, respectively, by 2022, and further increase by 2.2°C and 8.5%, respectively, by 2042.
- Increasing frequency of extreme storm events.
- Facing the above challenges, the design provides a master plan that employs natural process to infiltrate and harvest water, converts landscape to green infrastructure, and improves microclimate for climate resilience. The proposed design will enhance the campus environmentally, socially, and economically.

  To achieve these goals, the team collected data and information from various resources:

  - Site visit.
  - Interviewing with campus stakeholders.
  - Geographic information system data layers and other supporting information.

    Climate change future scenarios for Grand Rapids summarized in Grand Rapids Climate Resiliency Report.
  - Interviewing with transportation engineers at the Michigan State University, the directors of Planning Department and Office of Energy and Sustainability in Grand Rapids, landscape architect work for Grand Rapids Research Center (GRRC) and Green Grand Rapids. During each interview, the team presented design and then obtained the feedbacks from the advisors and administrators.

Phase I is GRRC that intersects Monroe Avenue and Michigan Street, due to its unique gateway position. The Michigan Department of Environmental Quality announced a $1 million grant of disposal of contaminated soil as well as building demolition for MSU (**Figure 2**). Now, MSU is raising $30M for the research center for university funds and debt.

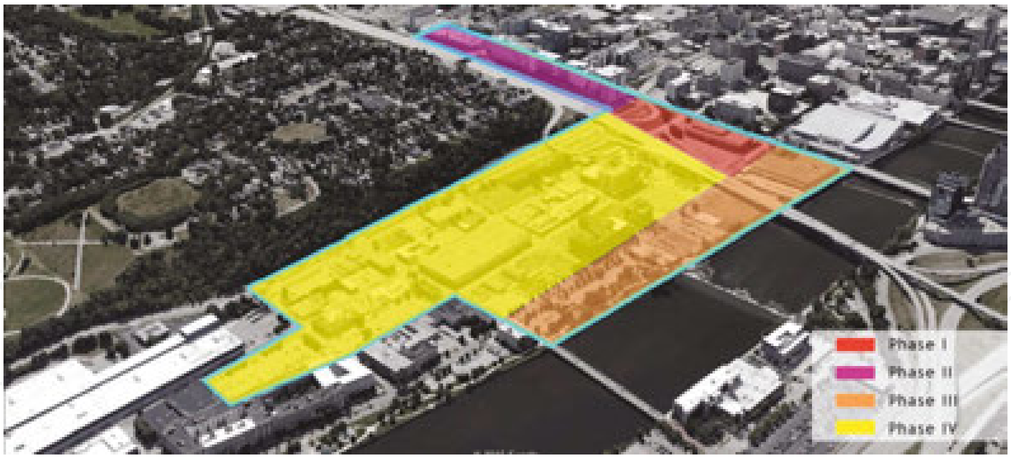

Figure 2. The various phases for site development.

Phase II is Medical Mile along Michigan Street, where the Secchia Center is located. It raised $50M for development and MDOT is awarding TEDF grant of $6,171,966 for addressing traffic flow issues along Medical Mile.

Phase III is along the Grand River. Grand Rapids identifies potential $1.5M funding source together for Grand River dam removal and restoration of rapids from the National Fish and Wildlife Foundation [11]. In addition, Grand Rapids seeks $10 million from state grant to purchase about 4 acres at the riverfront of the Grand River on the west side of Monroe Avenue NW, north of I-196 [11].

Phase IV accommodates many local business stakeholders and is beside the Business routes of U.S. Route 131. The vacant lots and concrete ground-level parking present opportunities for implementing and imbedding green infrastructure within the site. The private ownership might lead the long-term land requirements, while the removal of impervious pavements generates more costs.

3.2. Methods

Based upon the program for the project, the study began preparing a design for completion on the 18th of December 2015. The competition's critical goal was to improve stormwater management treatments. The team specifically designed a series of LID controls and examined the stormwater quantitate changes by the U.S. Environmental Protection Agency (EPA) National Stormwater Calculator (SWC). Another specific topic for this competition was climate change. Many urban activities and elements influence climate change: the traffic loads, gasoline oil and grease, land use, and others. This study measured the variables relating to trees, shades, and land-use changes to examine the impacts brought by different designs. The methods include the before-and-after area changes and the Simplified Landscape Irrigation Demand Estimation (SLIDE) to calculate the tree water consumption.

From this design, the study team would also investigate the metrics to compare the design treatments. The experimental design includes the comparison of the existing site, a traditional design, and a low-impact design across the variables of interest and analyzed through Friedman's Analysis for Variance and Friedman's Multiple Comparison statistical measures to predict the overall differences in the treatments [12]. In addition, the chapter presents previously unreported soil productivity equation research to construct urban soils, employing principal component analysis and regression analysis to assess the suitability of various proposed soil profiles in the urban environment.

3.2.1. Stormwater

The United States Environmental Protection Agency National Stormwater Calculator (SWC) can be utilized by any user who intends to reduce runoff from their properties, such as site developers, landscape architects, urban planners, and homeowners. Users could access to databases for soil, topography, rainfall, and evaporation information that already installed in the SWC. LID controls employ green infrastructures that mimic natural system of water movements; hence, they help purify water and reduce the burden of storm drains. Other data in SWC that users need to specify are the types of LID controls they use, and there are seven green infrastructure practices: disconnection, rain harvesting, rain gardens, green roofs, street planters, infiltration basins, and porous pavement.

When users consider how runoff varies under different scenarios, the SWC estimates the results based on information of soil type, size of green infrastructure, landscape and land-use information, and historical weather or future weather indication [13]. The procedure of SWC is to (1) locate the site's location, (2) identify the site's soil type, (3) specify how quickly the site's soil drains, (4) characterize the site's surface topography, (5) select a nearby rain gage to supply hourly rainfall data, (6) select a nearby weather station to supply evaporation rates, (7) select a climate change scenario to apply, (8) specify the site's land cover for the scenario being analyzed, (9) select a set of LID control options, along with their design features, to deploy within the site, and (10) run a long-term hydrologic analysis and display the results [14].

The team employed the SWC to compute the stormwater for 25-year 24-h storm events and to compute the volumes of annual runoff (lower is better) under different scenarios: existing, traditional design, and design employing LID controls. The calculator also computes the number of days with runoff from a site (lower is better) and the percentage of water infiltration into the site (higher is better). The design developed used many LID controls for stormwater management. The result shown from the SWC indicated that the postdevelopment design with LID treatments decreased the predevelopment's volume of runoff from 53 to 15%.

3.2.2. Tree water consumption

The team had a goal to increase the area covered by trees from 4.73 to 8.26%, with an increase in trees from 590 to 1030, which exceeds the government's goal of 7% tree cover for the city center in Grand Rapids. With a change in tree species, the goal was to eliminate invasive tree species and to actually utilize less water per tree.

The team roughly observed the tree species and the quantities from the site and Google Earth street-view photos and calculated the water demand using the SLIDE method. The SLIDE approach estimates the water demand for water-conserving irrigation plans and irrigations, based on researches of "landscape plant water requirements" and "plant water-use physiology" [15, 16]. It is even applicable for non-irrigated landscaping plans when it can estimate whether the anticipated precipitation is sufficient for any landscape or not [16].

There are four SLIDE rules to frame SLIDE:

SLIDE Rule #1.*Reference evapotranspiration (ETo) accurately estimates water demand of lawns and other uniform turf areas, but it marginally represents water demand of non-turf, non-uniform, physically and biologically diverse landscapes.*

SLIDE Rule #2*. Plant Factors (PFs) alone accurately adjust ETo to estimate landscape water demand, and they are assigned by general plant type categories, not by individual species (see* **Table 1***).*

SLIDE Rule #3*. A landscape area or zone controlled by one irrigation valve (hydrozone) is the smallest water management unit in a landscape; when plant types are mixed in a hydrozone, the water demand is governed by the plant type with the highest PF.*

SLIDE Rule #4*. Water demand of dense plant cover (canopy covers ≥80% of the ground surface) comprised of mixed plant types is that of a single 'big leaf' governed by the plant type category in the mix with the highest PF; demand of sparse plant cover (canopy covers <80% of the ground surface) is that of individual plants and is governed by their leaf area and the PF of their plant type category [16].*

Variables	Existing	Traditional	Low impact development
Percent of forest	1.34	6.68	11.47
Percent of meadow	0.00	4.39	7.77
Percent of lawn	14.34	7.50	10.31
Percent of pervious	0.00	0.00	21.54
Percent of impervious	84.32	81.43	48.91
Total area (acres)	98.50	98.50	107.04

Table 1. National Stormwater Calculator (SWC) parameters.

Eq. (1) is as follows:

$$\text{Landscape water demand (gal.)} = \text{ETo} \times \text{PF} \times \text{LA} \times 0.623 \tag{1}$$

where ETo is the historical average or real-time evapotranspiration for the period, measured in inches; PF is the Plant Factor; LA is the landscape area, in square feet; 0.623 is the factor to convert inches of water to gallons; omit this factor if the estimated water demand is desired in inches.

Eq. (1) is the basic SLIDE equation. If complex water requirement and irrigation demand within a larger landscape are required, sequential sub-equations can be applied Eqs(Eq. (2) and Eq. (3)):

$$\text{Landscape water demand (gal.)} = \sum\{(\text{ETo}\times\text{PF})\times\text{LA}\}1 - x \times 0.623 \tag{2}$$

where ETo is the historical average or real-time evapotranspiration data in inches for the period of interest; PF is the Plant Factor from **Table 1** for the plant category represented in a hydrozone or a landscape area, 1 through x; when plant categories are mixed in a landscape or a hydrozone it is the highest PF among the plant categories represented; LA is the landscape area or hydrozone planted with the respective PF, in square feet; 0.623 is the factor to convert depth of water to volume (gal./[in.×sq. ft.]); omit this factor if the estimated water demand is desired in inches.

$$\text{Irrigation demand (gal.)} = \sum\{([\text{ETo}\times\text{PF}]\text{-P})\text{J-D}\times\text{LA}\times(1\,/\text{DU})\}1 - \text{x}\times 0.623 \tag{3}$$

where ETo is the historic or real-time annual or monthly average evapotranspiration data in inches for months January through December, or other period of interest; PF is the Plant Factor from **Table 1** for the plant category represented in a hydrozone or occupying a portion of landscape area, 1 through x; when plant categories are mixed in a landscape or a hydrozone; it is the highest PF among the plant categories represented; P is optional; it is the historical average or real-time effective precipitation in inches for months January–December, or other period of interest; usually 50% or similar percentage of P is considered effective and is the amount used in the equation; LA is the landscape area or hydrozone, in square feet, devoted to the respective PF; 0.623 is the factor to convert depth of water to volume (gal./[in. × sq. ft.]); omit this factor if the estimated water demand is desired in inches; DU is the distribution uniformity of irrigation in the landscape area or hydrozone 1 through x (often mandated to be ≥0.7).

In our case, we used Eq. (1) because it is a simple, scientifically logical theory to provide accurate plant factors and effective water conservation suggestions that can be applied nationally. Otherwise, it does not require a large database of plant factors.

3.2.3. Change in land cover and reduction in heat island effect

To utilize the six best management practices (BMPs) tools, green roof, constructed wetland, cisterns for water harvesting, permeable pavement, bioretention or rain gardens, and dry and wet bioswales to mimic natural system treating the runoff, the surface cover for the site was modified. In such a design, the runoff does not just flow into a single treatment, but a series of BMP elements for larger efficiencies. More permeable pavements, green spaces, and green roofs in the design should result in a more effective solution to climate change resilience. The decrease of impervious pavement and increase of green areas, including where employ LID controls can promote climate change resilience for a site.

Under the impact of climate change, the heat island effect becomes one of the influential issues in urban environments. The increasing portions of buildings, infrastructures, impervious land covers, and decreasing green areas put the urban environments for human living under a huge crisis.

To minimize the heat island effect in the urban environment of Grand Rapids, the intent is to balance the ratio of the shaded portion of the site with the amount directly exposed to the sun. The design focuses on increasing green areas that do not only reduce runoff, but also promote the urban environment adapting to climate change resilience. The expanding green areas and a long skywalk, which connects the incomplete urban fabric in Grand Rapids, provide shadow to decreasing temperature on ground; thus, these contribute to reducing the urban heat island effect and saving energy costs for cooling [17, 18].

Trees are important in the urban environment and vital to climate change resilience. Urban forests generate environmental, health, and social benefits. The shaded surface can be cooler (25–45°F) than the peak temperatures of the unshaded surfaces [19]. Trees combined with LID controls can reduce stormwater infrastructure costs and improve the quality of runoff entering natural waterways, improve the walkability of the communities, and provide habitat for biodiversity. Tree canopy can mitigate the increasing extreme hot weather that causes the degradation of air quality, which triggers the exacerbation of chronic health conditions such as asthma and diabetes [17]. The leaves absorb carbon and dust from the air and generate oxygen.

3.2.4. Habitat suitability—field sparrow and fox squirrel

Field Sparrow (*Sciurus niger* L. 1758) inhabits old fields with scattered woody vegetation and forages perches, such as shrubs. Seeds and vegetative materials account for their diets: 80–90% of fall or winter diets and 45–49% of spring or summer diets. Breeding habitats are a mixture of shrubs and herbaceous plants with a few large trees. They usually require trees with a maximum diameter at breast height (dbh) of 2.5 cm (1 in.) and height range of 2–8 m (6.6–26.2 ft) for nesting and small stems with diameter stem density ranging from 350 to 700 stems/ha (142–283 stems/acre) [20, 21].

Fox squirrel (*Spizella pusilla* (Wilson) 1810) inhabits open forest setting and would be better interspersed with understory vegetation and agricultural lands, so does its breeding habitats. Their living options are leaf nests and tree cavities. They require 2–121.4 ha (5–300 acres) farm woodlots [20, 22].

Habitat suitability index (HSI) model assumes that reproductive habitat needs are met and uses the reproductive habitat that needs to determine the overall habitat quality. Each cover type within the site can provide the habitats of field sparrow and fox squirrel, and nearby shrub, grassland, or wooded areas may add to the habitat suitability [20, 21, 22].

3.2.5. Visual quality

Visual quality evaluation has made great advancements in the last 50 years. Burley and Ylimaz recently reviewed the state-of-the-art published results explaining 98.5% of the variation [23]. An early formative equation developed in 1997 by this group was employed in this study [23]. Scores in the 100s indicate environments with extremely poor visual quality and often industrial sites. Scores in the 70s and 80s are typical of many urban environments, while scores in the 50s and 60s are environments containing abundant vegetation such as parks, agricultural land, forests, and well-vegetated suburban areas. Low scores around 30 have the best visual quality, containing views of mountains, abundant flowers, and wildlife.

3.2.6. Soil productivity

Predicting soil productivity has been studied extensively and predicted by Burley for areas in North America, with the most recent equation published concerning reconstructing soils for Chippewa, Wisconsin [24]. The team followed the methods described by Chang et al., for Houghton County, Michigan to develop an equation that could be used to computer soil productivity in the general region [16]. The crops and wood plants studied to produce the equation include oats (*Avena sativa* L.), potato (*Solanum tuberosum* L.), corn (*Zea mays* subsp. *mays* L.), strawberries (*Fragaria* x *ananssa* Duchesne), alfalfa (*Medicago sativa* L.), brome grass (*Bromus* sp. Scop.)/alfalfa (*Medicago sativa* L.), pasture, sugar maple (*Acer saccharum* Marshall), red maple (*Acer rubrum* L.), bigtooth aspen (*Populus grandidentata* Michaux), red pine (*Pinus resinoa* (Sol ex Aiton), jack pine (*Pinus banksiana* Lamb.), and black spruce (*Picea mariana* (Mill.) Britton, Sterns, & Poggenburg). In past studies, 10 main effect variables, squared terms, and first-order interaction terms are examined. In this study, an 11th variable, high water table was also included as a variable and electrical conductivity which does not change across the soils was dropped as a potential regressor.

Based upon the design, the study team calculated the metrics for the following items: soil infiltration, days per year with runoff, number of trees average water use/gallon/year, green space (acres), impervious surface (acres), green roof (acres), phosphorus removal, field sparrow habitat suitability index, fox squirrel habitat suitability index, average visual quality score, and average soil productivity.

4. Results

4.1. Site design

Figures 3–6 present the basic configuration the site design as completed by the team. **Figure 3** is a general site plan for the study area, while **Figure 4** illustrates the layers of features, surfaces comprising the site plan. **Figure 5** illustrates the location of stormwater surfaces for the site. Finally, **Figure 6** presents four elevations of site details related to stormwater.

Figure 3. The resulting plan for the study area.

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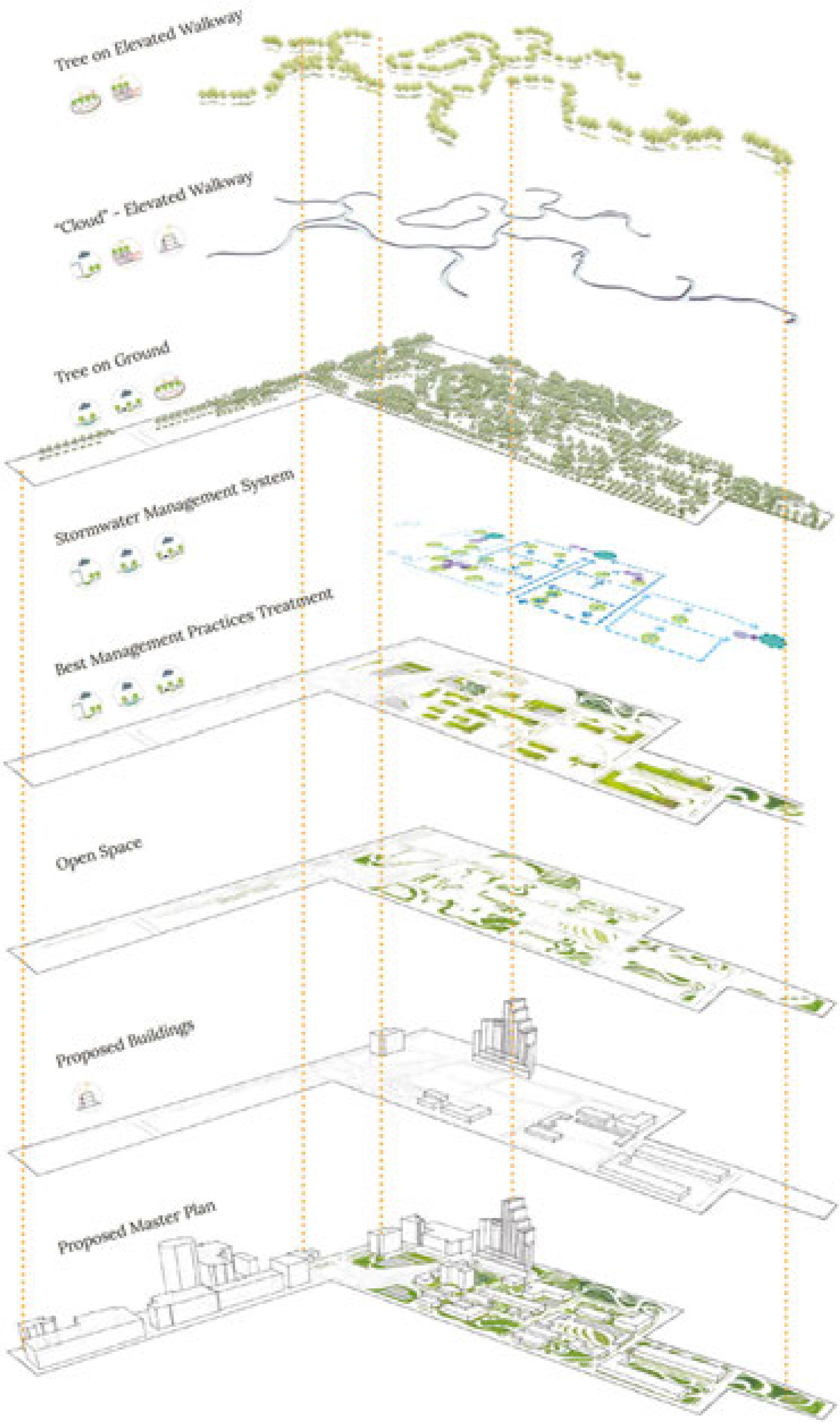

Figure 4. Various layers of the design.

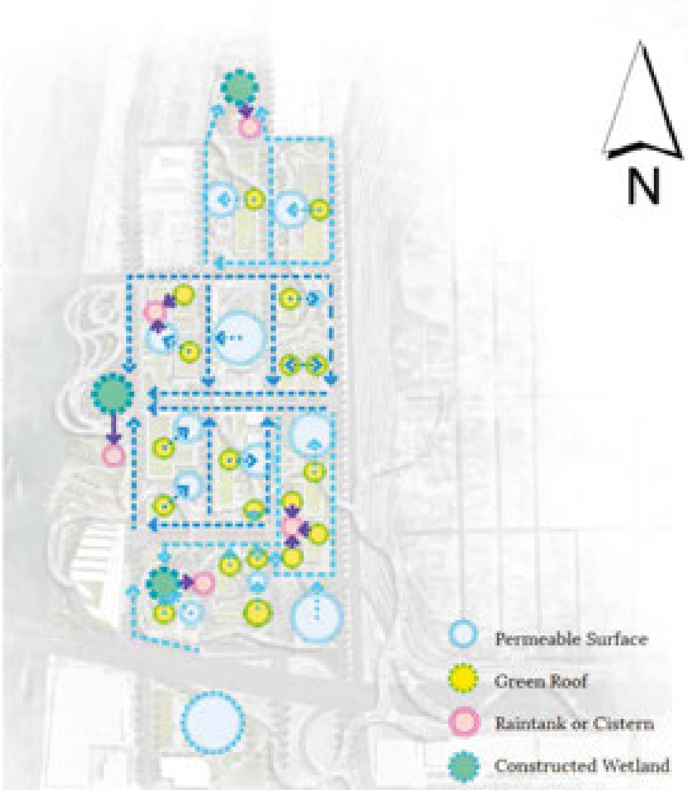

Figure 5. Stormwater surfaces of the proposed design.

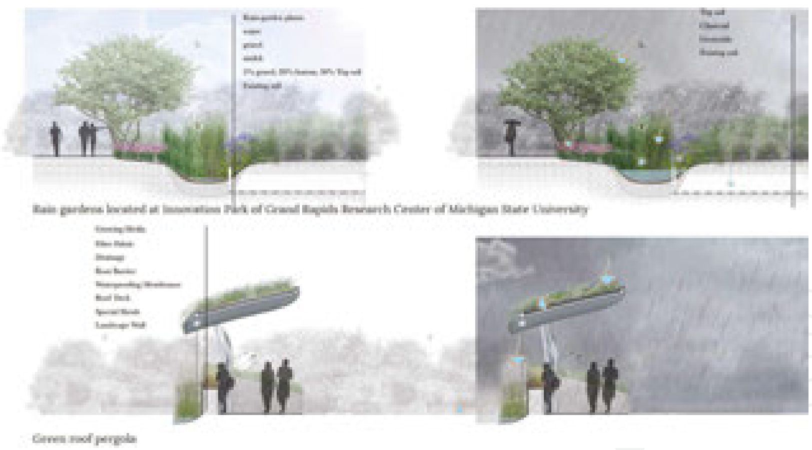

Figure 6. Elevations for the proposed design.

4.2. Site metrics

4.2.1. Stormwater

The study computes the stormwater for 25-year 24-h storm events by comparing predevelopment land use to postdevelopment without LID and with LID treatments. The SWC results indicate that the LID controls in the study improve stormwater management efficiency. When predevelopment scenario and postdevelopment scenario generate 53 and 43% runoff, respectively; the design with LID treatments decreases runoff to 15% (**Figure 7**).

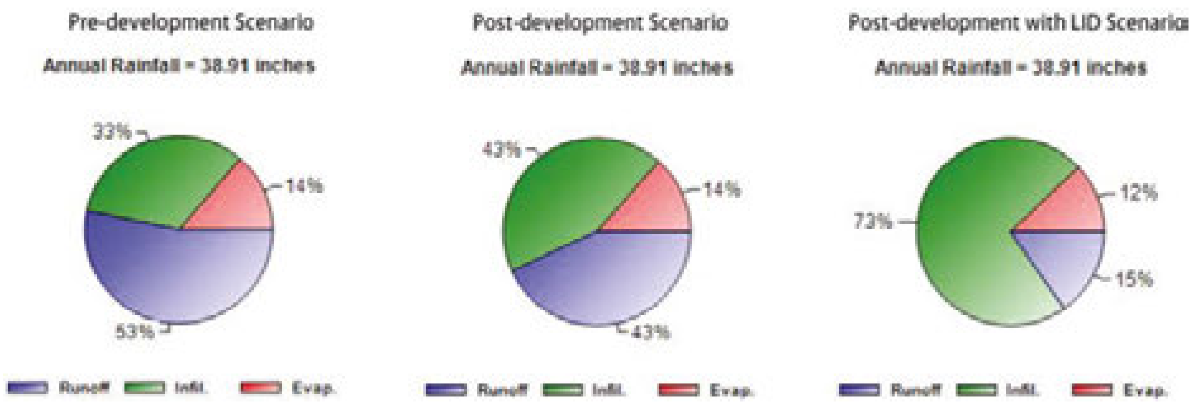

Figure 7. SWC scenario differences.

The study site is 98.5 acres, with B Hydrologic Soil Group (HSG) derived from the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) SSURGO database, which represents moderately low soil type. The hydraulic conductivity of the site is 0.3 inch/h. The general surface slope is approximately 5%. The precipitation and evaporation data are from Grand Rapids Gerald R. Ford International Airport weather station. Wet day threshold is 0.1 in. The climate change scenario is warm and wet and is of long term.

Variable	Predevelopment	Postdevelopment	With LID
Average annual rainfall (in.)	38.91	38.91	38.91
Average annual runoff (in.)	20.80	16.84	5.43
Days/year with rainfall	75.11	75.11	75.11
Days/year with runoff	46.93	39.29	12.03
Percent of wet days retained	37.52	47.68	83.98
Smallest rainfall with runoff (in.)	0.15	0.15	0.15
Largest rainfall without runoff (in.)	0.30	0.39	1.06
Maximum rainfall retained (in.)	1.13	1.41	2.71

Table 2. SWC statistic analysis.

There is neither a meadow area nor a pervious pavement within the current boundary, although the city of Grand Rapids is proposing and promoting the use of permeable pavements for the city center renovation. The LID treatments used in the postdevelopment area are substituted by normal grasses and shrubs in the traditional design. The team added a skywalk area covered with trees, LID treatments, and pervious pavement to predict the scenario which employs the LID controls, ending up with a total site area of 107.04 acres. **Table 1** shows other different parameters that the team used in the SWC tool.

According to **Table 2**, the number of days with runoff of the existing condition, traditional design, and the design employing LID controls are 46.93, 39.29, and 12.03 days, respectively. The percentage of water infiltration into the site is 47.42, 47.68, and 83.98%, respectively. The greatest rainfall without runoff increases by the design deploying LID treatments from 0.3 in. of predevelopment to 0.94 in. The SWC model indicates that the LID treatments can retain much more water on site and reduce the burden of stormwater infrastructure and their costs.

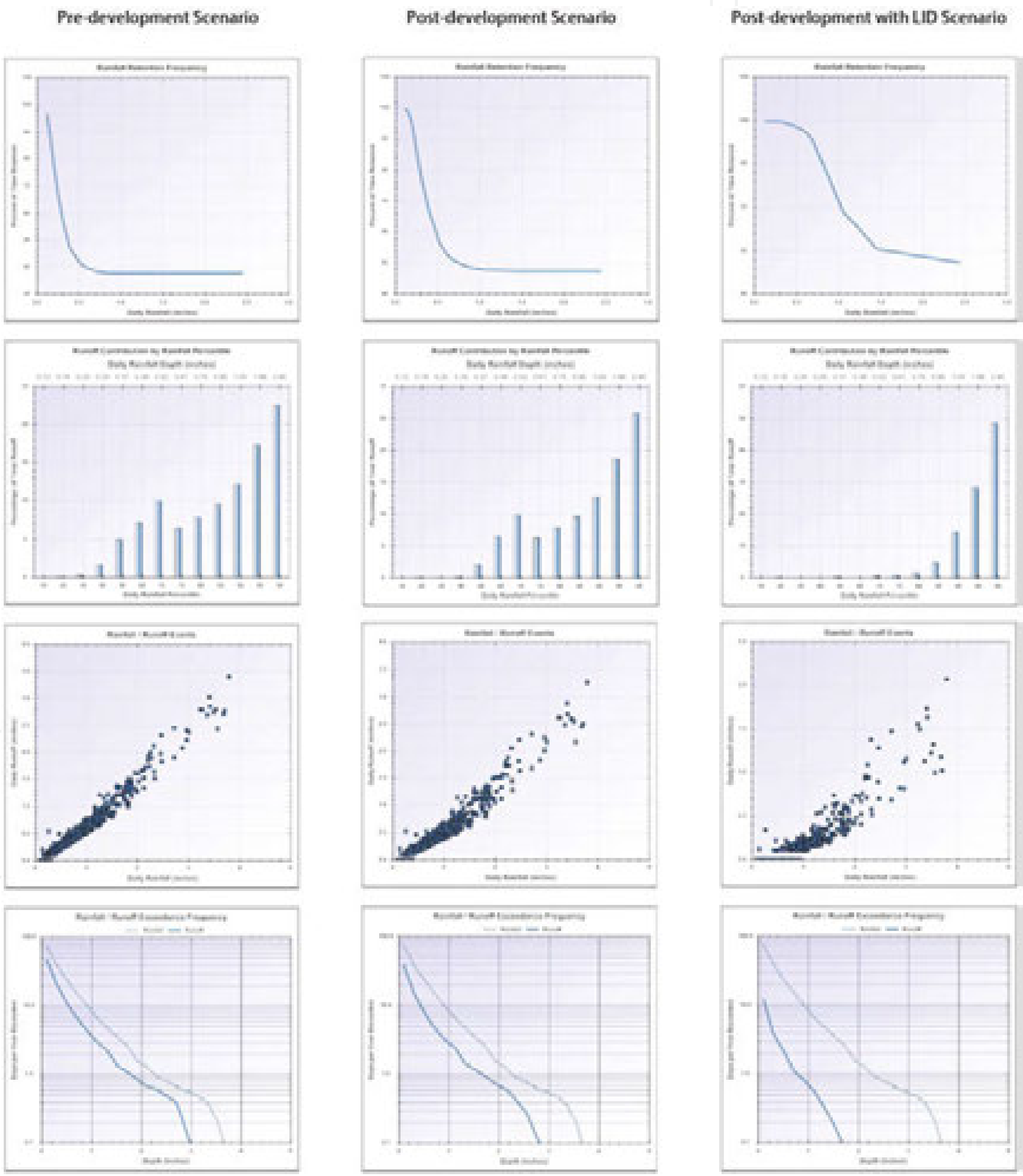

Figure 8. SWC analysis results.

Figure 8 shows how effective the design with LID controls contributes to reduce the runoff intensities and the frequency of large-volume rainfall/runoff treatment. The rainfall retention frequency of the scenario with LID controls does not decrease dramatically like the existing condition and the traditional design solution. It is able to retain the water for larger rain events.

The runoff contribution by rainfall of pre-design and traditional design scenarios have a peak at 0.52 in., while the design employing LID controls eliminates the peak and increases visually at 0.8 in. of the daily rainfall depth. LID treatments can also calm rainfall/runoff events and reduce rainfall or runoff exceedance frequency, compared to predevelopment and traditional development scenarios.

4.2.2. Tree water consumption

Based on the GVSU tree canopy analysis, the average tree area for each tree is 360 sq. ft [18]. We estimate evapotranspiration in Grand Rapids is 31.48 inch per year, based on the real-time and historical evapotranspiration data collected in Sparta, MI [25]. The study also estimated other water-conserving tree species' plant factor as 0.4. The selected tree species are Serviceberry, Alternate leaved dogwood, Juneberry, American hophornbeam, Allegheny serviceberry, White oak, Bur oak, Kentucky coffeetree, Red oak, Northen hackberry, Blackcherry, Basswood, Shagbark hickory, Pignut hickory, Black spruce, Eastern red cedar, and Eastern white pine. Based on the suggestions given by *SLIDE: Simplified Landscape Irrigation Demand Estimation* [16], Black spruce and Basswood tree species used 0.5 as the plant factor, while the remains used 0.4. As a result, the average landscape water demand for each tree on site is 2442.41 gal./year, decreased 53.89 gal./year from 2496.3 gal./year, the current average tree demand water.

4.2.3. Change in land cover and reduction in heat island effect

The pervious surface area includes green roof the team designed for the buildings on the site. The shadow area was added by building shadows and tree shadows. The postdevelopment site only added 0.17-acre building shadow, but increased 3.63-acre and 8.34-acre tree shadows for postdevelopment and postdevelopment with LID controls, respectively. The more shade the site provides, the more heat **Table 3**.

Variables	Existing	Traditional	Low impact development
Impervious surface area (acres)	83.06 (84.32%)	80.21 (81.43%)	52.35 (48.91%)
Green space area (acres)	15.44 (15.68%)	18.29 (18.57%)	31.63 (29.55%)
Pervious surface area (acres)	0.00 (0.00%)	0.00 (0.00%)	23.06 (21.55%)
Shadow area (acres)	9.62 (9.77%)	13.44 (13.64%)	26.69 (24.93%)
Total area (acres)	98.50	98.50	107.04

Table 3. Land use change.

4.2.4. Habit suitability: field sparrow and fox squirrel

4.2.4.1. Field sparrow

The variables that influence field sparrow are V1 – percent shrub crown cover, V2 – percent of total shrubs of height less than 1.5 m, V3 – percent canopy cover of grasses, and V4 – average height of herbaceous canopy. The cover types field sparrow needs for breeding are (1) evergreen shrub land, (2) deciduous shrub land, (3) evergreen shrub savanna, (4) deciduous shrub savanna, (5) grassland, and (6) forbland.

$$\text{Habit sustainability index} = [\text{Min.}(V1,V2) \times \text{Min.}(V3,V4)] \tag{4}$$

The study used Eq. (4) to calculate field sparrow HSI for different scenarios: predevelopment, postdevelopment, and postdevelopment employing LID controls. The results are shown in **Table 4**.

Variable	Existing	Traditional	Low impact development
V1	0.00	0.26	0.49
V2	0.20	1.00	1.00
V3	0.29	0.15	0.21
V4	0.00	0.80	0.80
HSI	0.00	0.04	0.12

Table 4. Habit sustainability index (HSI) of field sparrow.

4.2.4.2. Fox squirrel

The variables that influence field sparrow are V1 – percent canopy closure of trees that produce hard mast, V2 – distance to available grain, V3 – average dbh of overstory trees (height≥80% of trees), V4 – percent tree canopy closure, and V5 – percent shrub crown cover. The cover types field sparrow needs for breeding are (1) deciduous forest, (2) deciduous tree savanna, and (3) deciduous forested wetland.

$$\text{Winter food} = \frac{3V1+V2}{3} \tag{5}$$

$$\text{Habitat cover or breeding} = (V3 \times V4 \times V5)^{(1/3)} \tag{6}$$

The study used Eqs. (5) and (6) to calculate field sparrow HSI for different scenarios: predevelopment, postdevelopment, and postdevelopment employing LID controls. The results are shown in **Table 5**.

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Variable	Existing	Traditional	Low impact development
V1	0.08	0.12	0.17
V2	0.10	0.10	0.10
V3	1.00	1.00	1.00
V4	0.25	0.43	0.66
V5	1.00	1.00	1.00
HIS of winter food	0.11	0.15	0.20
HIS of habitat cover of breeding	0.63	0.75	0.87

Table 5. Habit sustainability indexes (HSI) of fox squirrel.

The scores of indexes of both field sparrow and fox squirrel are the highest for LID scenario, which reveals that the postdevelopment with LID controls provides the best habitats for them.

4.2.5. Visual quality

The measurement of visual quality for the non-LID treatments revealed scores typical of urban environments for the existing and traditional conditions (mid to low 70s). The LID design contained more green spaces and vegetation, generating scores usually in the 50s. Selected areas within the LID proposal possessing numerous flowers and abundant wildlife scores even better (mid 40s) and portions of the LID proposal with less vegetation within the view scored higher (mid 60s).

Regressor	Coefficient
Intercept	−94.33616
FR (% Rock Fragments)	−1.60108
HC (Hydraulic Conductivity)	4.31294
PH (Soil Reaction pH)	30.87176
OM (% Organic Matr)	15.26411
HW (High Water Table)	−2.01359
FR2 (% Rock Fragments squared)	−0.00838
CL2 (% Clay squared)	0.00817
HC2 (Hydraulic Conductivity squared)	−0.01604
PH2 (Soil Reaction pH squared)	−2.37381
OM2 (% Organic Matter squared)	0.12101
HW2 (High Water Table squared)	0.22692
TPFR (Topographic Position * % Rock Fragments)	−0.04701
TPCL (Topographic Position * % Clay)	0.0419

Regressor	Coefficient
TP (Topographic Position * % Organic Matter)	−0.51303
SLCL (% Slope * % Clay)	−0.00565
SLBD (% Slope * Bulk Density)	0.11043
FRBD (% Rock Fragments * Bulk Density)	2.0781
FRHC (% Rock Fragments * Hydraulic Conductivity)	0.0303
FRPH (% Rock Fragments * Soil Reaction pH)	−0.262
CLHC (% Clay * Hydraulic Conductivity)	−0.06456
CLPH (% Clay * Soil Reaction pH)	−0.06796
CLOM (% Clay * % Organic Matter)	0.05429
BDHC (Bulk Density * Hydraulic Conductivity)	−2.73812
HCAW (Hydraulic Conductivity * Available Water Holding Capacity)	1.33765
HCOM (Hydraulic Conductivity * % Organic Matter)	−0.03302
AWOM (Available Water Holding Capacity * % Organic Matter)	−13.63024
PHOM (Soil Reaction pH * % Organic Matter)	−2.52367
HWSL (High Water Table * % Slope)	−0.02655
HWCL (High Water Table * % Clay)	−0.04633
HWAW (High Water Table * Available Water Holding Capacity)	9.67109
HWOM (High Water Table * % Organic Matter)	0.49451

Table 6. The significant regressors and coefficients forming an equation of the first dimension.

4.2.6. Soil productivity

Most of the metrics in the study were developed by others and simply applied by the study team, with the exception of the soil productivity equation. Therefore, the results of the soil productivity equation are presented first, before presenting the comparison results. The results of the soil equation development indicate that there are two primary dimensions to soil productivity for the area, forming an annual plant/ woody plant preference cluster forming (**Table 6**), where the preferences for annuals and woody plants negatively covary along the same dimension and wetland plants negatively covary. The second equation represents an annual plant (positive)/wood plant (negative) preference cluster forming (**Table 7**). In other words, the vegetation studied in the investigation did not covary across all types of vegetation and separated themselves into three groups, similar to results discovered in Florida by Burley and Bauer in 1993, where they discovered two groups, a wetland ground and an upland group. Each of the regressors is where each soil setting required a different soil profile [26]. The equations explain between 90 and 97% of the variance and are definitive (p-value < .001) and all of the regressors are significant ($p \leq 0.05$), with no significant multi-collinearity. Depending upon whether the planting area is intended for woody plants, annual plants, or wetland plants, the soil preferences are different (**Figure 9**).

Regressor	Coefficient
Intercept	−25.60295
TPS	7.63063
SL (% Slope)	−2.55098
BD (Bulk Density)	23.57679
BD2 (Bulk Density squared)	−3.76982
TPBD (Topographic Position * Bulk Density)	−4.52653
TPOM (Topographic Position * % Organic Matter)	−0.35556
SLFR (% Slope * % Rock Fragments)	0.00537
SLCL (% Slope * % Clay)	0.00514
SLBD (% Slope * Bulk Density)	1.46534
SLHC (% Slope * Hydraulic Conductivity)	0.02762
FRCL (% Rock Fragments * % Clay)	−0.04181
FRHC (% Rock Fragments * Hydraulic Conductivity)	0.00606
FRAW (% Rock Fragments * Available Water Holding Capacity)	1.6382
CLHC (% Clay * Hydraulic Conductivity)	0.02662
HCAW (Hydraulic Conductivity * Available Water Holding Capacity)	−0.69977
HCPH (Hydraulic Conductivity * Soil Reaction pH)	−0.04902
HWTP (High Water Table * Topographic Position)	−0.15515
HWCL (High Water Table * % Clay)	−0.00759
HWBD (High Water Table * Bulk Density)	−0.21784
HWAW (High Water Table * Available Water Holding Capacity)	6.97171
HWOM (High Water Table * % Organic Matter)	0.43754

Table 7. The significant regressors and coefficients forming an equation of the second dimension.

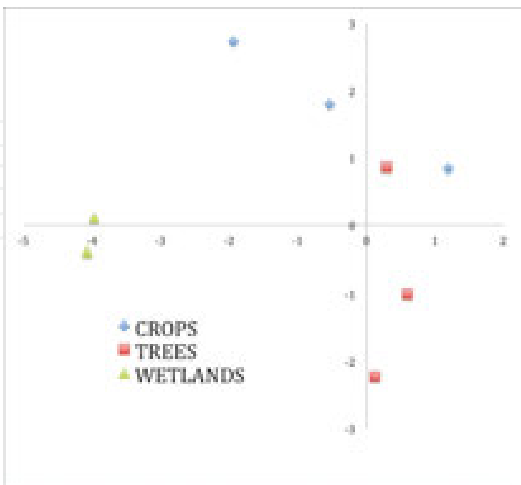

Figure 9. A plot of areas for soil preference for various plant clusters.

The results of the soil equation development indicate that there are two primary dimensions to soil productivity for the area, forming an annual plant preference cluster, a woody plant preference cluster, and a wetland plant preference cluster, where each soil setting required a different soil profile. The equations explain between 90 and 97% of the variance and are definitive (p-value < .001).

When the Friedman's analysis of variance is applied to the ranks of **Table 8**, at least one of the treatments is significantly different that at least one of the other treatments at a p-value of <0.005, where 22.54 is greater than a Chi-square distribution of 10.597. When the Friedman's multiple comparison test is applied, the low impact development treatment is significantly different from the other two treatments at a p-value of 0.05. The existing and traditional treatments are also significantly different (p-value 0.05).

Variables	Existing	Traditional	Low impact development
Runoff (liters)	2.43 billon	2 billion	0.59 billion
Soil Infiltration	35%	40%	76%
Days per year with runoff	46.93	39.29	12.03
Number of trees	590	700	1030
Average water use/gallon/year	2496.3	2600	2442.41
Green space (acres)	15.44	18.29	31.63
Impervious surface (acres)	83.06	80.21	43.26
Greenroof (acres)	0.14	0	7.64
Phosphorus removal	0	0	89%
Field sparrow suitability index	0	0.04	0.12
Fox squirrel suitability index (winter food)	0.11	0.15	0.20
Average visual quality score	74.5	72	52
Average soil productivity	−0.05	1	2.25

Table 8. Numerical results.

5. Discussion and conclusion

The Medical Mile including MSU College of Human Medicine is an established significant landmark for the city of Grand Rapids to revitalize the campus visionary aesthetics, exceptional functionality, and adjacent communities. The 98.5-acre design contains both campus area and abutting district employing a variety of green infrastructure and microclimate treatments. The design considers a master plan that utilizes innovative stormwater management system, creates a variety of use areas, focuses on reviving local business, and provides an elevated walkway network to tie different districts within our boundary.

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It is apparent that the LID treatment has environmental benefits and that in the planning and design phases, it is possible to generate solutions that are more sensitive. But the costs associated with these benefits such as providing more land for green space and stormwater management are not evident. In addition, the design is just one idea concerning the spatial arrangement of the site. It is not necessarily an optimum design. The design is simply the ideas of the team. In the planning and design process, numerous other scenarios and ideas could be explored to refine the design. However, this case study illustrates how to evaluate a series of variables of environmental interest collectively and statistically. As an environmental impact assessment methodology, this process may be of interest to planners, designers, concerned citizens, and governmental agencies.

This case study addressed only a few of the variables that are possible to examine. The list of environmental variables could potentially be much larger and extensive, leading to different results. However, interest in environmental variables in urban design is increasing. This case study illustrates how these variables are measured and examined in the urban context.

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