A Tool for Sustainable Residential Water Management

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ABSTRACT

Water problems due to scarcity or climate change urge changes regarding how professionals design buildings to sustainably manage water. In the near future, it is expected that water scarcity and general environmental awareness will increase the demand for sustainable water management (SWM) practices in the US residential sector. However, research on SWM design practice has been oriented to specific design professionals, problems, and technologies. These approaches lack a holistic perspective on SWM, especially at the single-site, residential scale. Even though tools have been developed for SWM, there is a dearth of tools oriented to designers in the residential sector.

This dissertation's main objective was to investigate the needed components and initiate development of a tool oriented to SWM design for the residential sector. The development of such a tool began with a literature review, an ethnographic study, and a national survey that helped to develop the SWM design process model and the tool's requirements. Using the information gathered and insights obtained, a prototype SWM design tool for residential applications was developed that integrates the required functionalities and allows for further development recommendations.

This dissertation contributes to increase the knowledge about the SWM design process in the residential sector providing a better understanding of the early phases of the SWM design process for SWM. The literature review enabled identification of the gaps in the knowledge base regarding the description of the SWM design process and the tools available for the residential sector. The ethnographic analysis of the SWM process based on a real case study in Pittsburgh, PA, and the national SWM survey provided critical information about components of an SWM design process model and the requirements of the tool. From the literature review, and the previous studies evaluated, a model of the SWM design process was developed and implemented in a prototype.

The tested prototype tool builds upon the principles of SWM design and integrates the functionalities required by professionals for SWM design in the residential sector:

- The prototype provides a holistic approach to SWM design. It integrates indoor and outdoor water needs and allows SWM components to be included its management. Through a water balance table, the prototype incorporates different water supply sources

(including reuse of grey and blackwater) and deploys them according to the quality needs of water uses.

- The prototype integrates costs and environmental performance in the early phases and supports multicriteria decision-making in SWM design. In addition to the water balance estimation, the prototype performs hydrological and water quality estimations and cost estimations that serve as the basis for comparison of alternative designs through the use of Multi-Criteria Decision Making (MCDM) techniques. The user gains from this approach a better understanding of the range of possible designs and the tradeoffs involved in choosing from among them.
- The prototype incorporates methods of appropriate technical complexity for the early phases of design adapted to non-expert SWM designers. Widely-used procedures are employed, and regulations, assumptions, and suitability criteria for SWM components are made explicit to the user.
- The prototype provides a user-oriented environment that allows modification and testing of alternatives or partial solutions with fast feedback to test design for sustainable residential water management.

The functionalities tested in the prototype can be used as a specification for software. This will foster the integration of SWM strategies early into the design process with an approach that responds to designers' needs while adopting computational tools barrier-free.

This research provides a better understanding of the early phases of the architectural design process for SWM at the residential scale. It allows the development of future tools for residential water-system design rooted in the reality of architectural and SWM design practice.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

3D: three-dimensional

AC Sheets: Asbestos Cement Sheets

AEC: Architecture, Engineering and Construction

AIA: American Institute of Architects

ANSI: American National Standards Institute

ArcGIS: geographic information system by the Environmental Systems Research Institute

ASABE: American Society of Agricultural and Biological Engineers

ASCE: American Society of Civil Engineers

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASLA: American Society of Landscape Architects

ASOS: Automated Surface Observing Systems

AWWA: American Water Works Association

BPM: Best Management Practice

CAD: Computer-aided design

CaGBC: Cascadia Region Green Building Council

CE: Cost-Effectiveness

CEA: Cost-effectiveness analysis

CN: NRCS Curve Number

CNT: Center for Neighborhood Technology

CSO: combined sewer overflow

CWAA: Clean Water America Alliance

EC: Environmental Center

EMC: Event Mean Concentration

EPDM: ethylene propylene diene monomer

ETOs: Evapotranspiration

EWRI: Environmental & Water Resources Institute

GBS: Green Building Studio

GHCN: Global Historical Climatology Network

GIS: geographic information system

GVC: National Green Values Calculator

GWDD: Greywater Diversion Device

GWTS: Greywater Treatment System

HSPF: Hydrological Simulation Program

i-DSTss: Site-Scale Integrated Decision Support Tool

IC: Irreducible Concentration

ICE: Institution of Civil Engineers

IDEF: Integrated DEFinition Methods

IDF: Intensity Duration Frequency

IDP: Integrated Design Process

IE: Irrigation efficiency

IES-VE: Integrated Environmental Solutions - Virtual Environment

IES: Integrated Environmental Solutions

ILFI: International Living Future Institute

IP: information processing

IRB: institutional review board

JIT: Just-in-time

L-THIA-LID: Long-Term Hydrologic Impact Assessment-Low Impact Development

Latis-LIDIA: Low-Impact Development Implementation Assessment tool

LBC: Living Building Challenge

LCC: Life Cycle Cost

LCCA: Life cycle cost analysis

LEED: Leadership in Energy and Environmental Design

LID: Low Impact Development

LIDRA: Low Impact Development Rapid Assessment

MCDM: Multi-Criteria Decision Making

MDE: Maryland Department of the Environment

ME: Microsoft Excel

NCEI: National Centers for Environmental Information

NJGRM: New Jersey Groundwater Recharge Method

NOAA: National Oceanic and Atmospheric Administration

NPV: Net Present Value

NRCS: Natural Resources Conservation Services

NREL: National Renewable Energy Laboratory

NSC: National Stormwater Calculator

NSRDB: National Solar Radiation Database

O&M: Operation and Maintenance

PA DEP: Pennsylvania State Department of Environmental Protection

PNNL: Pacific Northwest National Laboratory

PVC: Polyvinyl chloride

RM: Rational Method

RSWMM-Cost: Stormwater Management Model V5 with Optimization in R and Cost Module

RWH: rainwater harvesting

SDSS: Spatial Decision Support System

SISS: Superintendencia de Servicios Sanitarios

SSHM: Small Storm Hydrology Method

SSRS: Stratified simple random sampling

SUSTAIN: System for Urban Stormwater Treatment and Analysis Integration Model

SWM: Sustainable Water Management

SWMM5: Storm Water Management Model 5

TC: Time of Concentration

TN: Total Nitrogen

TP: Total Phosphorus

TSS: Total suspended solids

TWDB: Texas Water Development Board

UI: User Interface

USEPA: US Environmental Protection Agency

USGBC: US Green Building Council

WB: Water Balance

WERF: Water Environment Research Foundation

WinSLAMM: Source Loading and Management Model for Windows

WUCOLS: Water Use Classification of Landscape Species

SYMBOLS

%: percentage

$: dollar

$/sq. m: dollar por square meter

ac: acres

cft /s: cubic feet per second

cft: cubic feet

csm/in: cubic feet of discharge per second per square mile of watershed per inch of runoff

cu m: cubic meters

ft: foot

ft/ft: foor per foot

gal: gallons

gal/flush: gallons per flush

gal/month: gallons per month

gal/person/day: gallons per person per day

gal/year: gallons per year

GPD: gallons per day

GPM: gallons per month

hr: hour

in: inches

in/h: inches per hour

kg: Kilogram

kg/year: Kilogram per year

L: liters

mg: miligrams

mg/L: milligrams per liter

ml: milliliter

mm: millimiters

MPN/100mL: most probable number per 100 millilitres

sq. m: square meter

sq.ft: square feet

sq.mi: square miles

ug/L: micrograms per liter

USD: US dollar

1. INTRODUCTION

1.1. Sustainable Water Management and Design

Sustainable Water Management (SWM) aims to protect and conserve water resources while making wise use of them. To achieve these goals, the design and implementation of SWM need a holistic approach (Reed 2009; O'Connor, Rodrigo, and Cannan 2010; ILFI 2019). The principles of an integrated approach to managing water are:

1. Minimize water consumption
2. Use all types of water as supply (i.e. rainwater, groundwater, greywater, blackwater)
3. Match the water need to a supply with the appropriate water quality
4. Reuse water
5. Manage and infiltrate all water on the site
6. Treat water without chemicals (e.g., chlorine)

Of the five green certification programs in the US, the most rigorous in water management is the Living Building Challenge (LBC) standard. The LBC standard has a holistic approach for managing water that is translated into two requisites: 1) to satisfy the project's water needs only from rainwater or recycled wastewater; and 2) to manage 100% of rainwater and wastewater on-site. The fundamental aim of the LBC is to advance building design to equate the natural flow of water over the site without polluting it. The LBC standard urges projects to evolve and cause restorative effects within the environment (CaGBC 2008).

However, this new approach to designing for SWM requires a change in the traditional process followed by design professionals (Novotny, Ahern, and Brown 2010). When designing for SWM, professionals are challenged by regulatory barriers, demand for quantitative information to support recommendations of unexplored and unproven solutions, the need for a more collaborative design approach early in the process, and the lack of appropriate tools.

The Cascadia Green Building Council (CaGBC) (2008) reports that the main barrier to the implementation of SWM solutions in Oregon is the current building codes. CWAA (2011) reports that the span of federal to local regulations "can be lacking, conflicting, or restrictive" to the implementation of SWM components (p.3). Additionally, the lack of institutional capacity and legislative mandates are identified as impediments for professional designers to pursue SWM solutions (Roy et al. 2008; CWAA 2011). Backhaus, Dam, and Jensen (2012) point out that designers expressed concerns about dealing with the legal aspects of private property boundaries. Farrelly and Brown (2011) expose the need for a more flexible regulatory framework to allow experimentation.

Another issue with the traditional process involves the need for quantitative information to support SWM design recommendations. CWAA (2011) points out the need for pilot projects that provide performance data and learning experiences to help designers become more accustomed to implementing SWM components. Furthermore, designers state that the two leading detractors to the support of professional recommendations of SWM components are: 1) the lack of information about the SWM components' environmental benefits and costs, and 2) insufficient availability of standards and guidelines (Roy et al. 2008). Moreover, Backhaus, Dam, and Jensen (2012) report designers' concerns when sizing systems, understanding water movement, understanding the ecology of the final design, and performing cost estimations when the SWM approach is new.

Guidance for high-quality decision-making for various stakeholders is fundamental (Barbosa, Fernandes, and David 2012). SWM design requires considering environmental impacts early in the process and a collaborative approach (Reed 2009; ASHRAE Press 2006). The introduction of environmental requirements in a project's early phases provides the opportunity to understand the relationships between the project's different systems (i.e., energy, water) and to achieve innovative and cost-effective solutions (Ramani et al. 2010; Reed 2009). As water management is a highly technical and regulated sector, it requires a coordinated approach between technical, scientific, and social issues, leading to the need for communication among a large group of stakeholders and high-quality information for the decision-making process (Ramani et al. 2010).

Finally, designers affirm that they have limited knowledge about and time to find the best tools to use. Furthermore, the tools are either too generic or too complicated. They require extensive data and resources that are unavailable or inaccessible and lack legitimacy, reliability, and transparency. Designers require tools that support "more decentralized, integrated, context-specific solutions" for SWM (Makropoulos et al. 2008).

1.2. Motivation

There has been little research targeted to SWM design in the residential sector. Most literature focuses on green infrastructure, large-scale urban projects, and watershed levels, targeting predominantly rainwater management. Publications of the International Living Future Institute (ILFI) present case studies on residential projects (CaGBC 2011a; CaGBC 2011b; ILFI 2014a, ILFI 2014b), most of which have partially implemented SWM components or are located outside the US. Besides, rating systems guidelines are not comprehensive, and new movements such as regenerative architecture are too new. Thus far, the literature has focused on large-scale SWM issues rather than on small projects and teams implementing SWM components for residential projects.

The impact of residential projects on water resources is significant. Residential land use in cities accounts for about 65 to 75% of total urban land in the US (Rodrigue 2013), and trends show that urban land use is increasing in the US (Vesterby et al. 2006). 80% of residential sites hold a one-unit house and are distributed throughout watersheds. Thus, residential land use directly contributes to non-point source pollution of local water bodies, affecting water supply sources, groundwater quality, and downstream rivers and lakes. The introduction of environmental practices on a small scale in the residential sector could significantly contribute to the protection and conservation of water resources. Small and relatively easy changes in environmental behavior could generate awareness and support for regulations regarding SMW.

Fortunately, the demand for the design and implementation of SWM components in the residential sector is rising. The ILFI reported from 2006 to 2013 the completion of only two certified residential projects. The ILFI reports 50 single-family and ten multifamily projects are pursuing the LBC certification (information provided in an email message to Caroline VanHarmelen on December 05, 2013, Living Building Challenge Coordinator). Thus, support for residential project design for SWM will be needed. Finally, the implication for residential design practices is not limited to architects. Builders and real estate companies also design and make decisions in the residential sector. Thus, a tool targeted at residential projects has a scalability opportunity, as it can reach a large sector with a large number of clients.

Design in the residential sector presents challenges when introducing new practices. Residential projects are usually of small scale, limited in budget, and managed by small teams of professionals, such as an architect occasionally with the assistance of an engineer and a landscape architect. Professionals in the residential sector prefer proven practices and do not typically have the resources for innovation. In such a resource-limited and risk averse domain, new practices and tools are difficult to introduce. Therefore, tools targeted at small teams must be easy to use, quick to learn, and inexpensive.

1.3. Objectives, Research Structure, and Scope

General Objective

This dissertation's main objective is to investigate the issues related to the development of a tool oriented to the SWM design for the residential sector, i.e., on small projects with small design teams.

The development of a tool that responds to the needs and motivations of designers about SWM in the residential context involves the identification of the tool's requirements from the practice perspective. Five tasks have been defined to carry out this research. The first three tasks, a literature review, an ethnographic study, and a national survey, have been performed to outline the tool's requirements. Then, from the results of these studies, a proposed process model for the SWM design - Task 4 - and the tool's requirements have been developed. Finally, Task 5 includes a proposed tool and develop a prototype that integrates the required functionalities. Task 5 also includes recommendations for further development of the tool to respond to the needs of SWM design in the residential sector.

The scope of this research is developing, testing, and making recommendations for the redesign of a prototype. The intention is to build a software prototype that will serve as a proof of concept and not necessarily a commercially viable system. This prototype will allow studying the issues on integrating the necessary functionalities with a basic user interface and storage capabilities (see Figure 1.1).

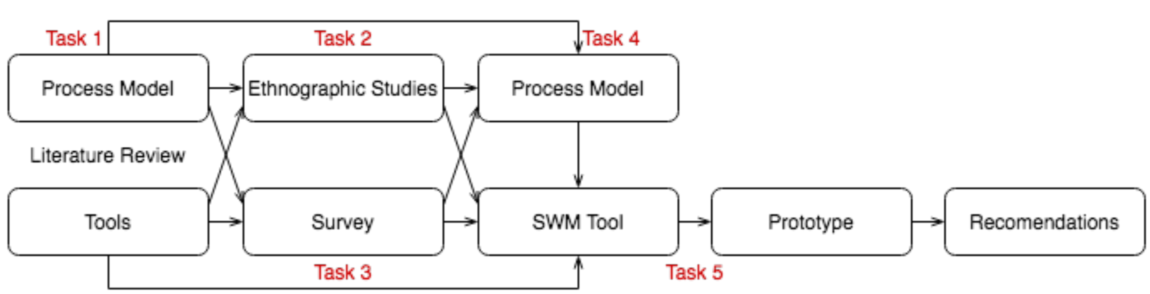


Figure 1.1. Research Structure

1.4. Overview

This dissertation is structured as follow:

Chapter 2 presents the literature review regarding the design process and tools for SWM design, which provides the background knowledge to build the process model of the SWM and the requirements of a tool.

Chapter 3 presents the studies designed to define better a model of the SWM design process and the requirements of a tool for that process.

Chapter 4 presents the SWM design process model proposed. The section contains a summary of the literature review and studies and a description of the process model.

Chapter 5 presents the proposed tool, its features, and the implementation and testing of the prototype.

Chapter 6 presents the summary, contributions, and the recommendations for future work.

2. SUSTAINABLE WATER MANAGEMENT DESIGN: PROCESS MODEL AND TOOLS

The purpose of this literature review is twofold: to present a review of past work on the design process for SWM, and to present a review of recommendations for the development of available tools for SWM design. Both sections emphasize the early phases of design and present work with a focus on the US context.

2.1. SWM Design Process Model

2.1.1. Design Process Model

This section presents a review of descriptive design process models and SWM design process models to inform the development of a process model and identify the requirements of a tool for SWM.

The design process aims to provide a set of design documents (i.e., specifications, construction drawings) that fulfill given requirements (i.e., functions, needs, and goals) within a defined budget, schedule, and quality standard and to obtain permits to build, operate, and monitor a building. The design process is divided into several phases that help efficiently and effectively communicate the design work to a diverse group of stakeholders (Akin 1986). The design process involves several different activities, such as the construction and manipulation of abstract representations of the site/building, the keeping of records of goals and regulations, and the coordination of different human resources to deliver the design to the client (Akin 1986). However, the complexity of building design has increased over the years. New technology, higher standards on safety, construction methods, resource management, user comfort, and the 'green' design approach--specifically about SWM goals—have created new possibilities and constraints for building design solutions.

SWM design is embedded in a general project life cycle. The Institute of Civil Engineers (ICE) provides a complete vision and description of the life cycle of a project as guidance for a successful delivery and operation (ICE Publishing 2009). Howard, Culley and Dekoninck (2008) based on their study of 23 Engineering Design Process Models defined six universal stages of the design phase. Figure 2.1 presents both staged processes in parallel, the ICE Publishing (2009) model at the left side and Howard, Culley and Dekoninck (2008) model at the right side. As SWM design is embedded in the general building design process ICE (2009) and Howard, Culley and Dekoninck (2008) design process model will be used as a framework for SWM's proposed process model.

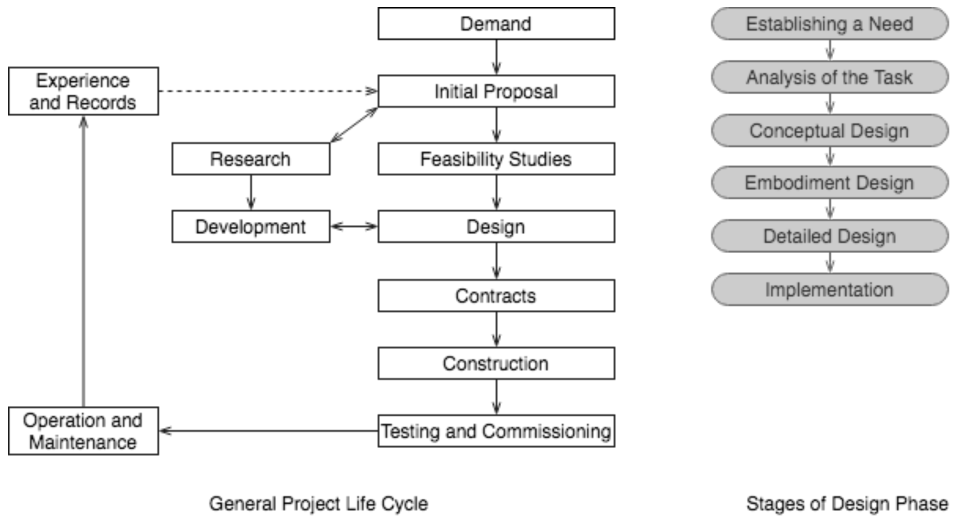


Figure 2.1. Project Life Cycle and Design Process. Left: Phases in a project cycle (Adapted from ICE Publishing 2009). Right: Universal design stages (Adapted from Howard, Culley and Dekoninck 2008)

The cognitive description of the design process, based on empirical studies, presents a closer illustration of designer activities, behavior, knowledge, and representations used during design. Cognitive definition and characterization of the design process have evolved since the early 1980s. A relevant base for several studies in this domain has been the analysis of the information processing (IP) model (Simon 1969) and its application to design (Dorst 2006; Visser 2009). Critics of the IP model have proposed new frameworks to study design. That is the case in Schon (1983), Dorst and van Overveld's (2009) (based on Schon's work), and Visser (2006). The following paragraphs present the current state of the cognitive description of the design process.

The design process is a "co-evolution" between the definition of requirements, the generation of solutions, and their evaluation (Maher, Poon, and Boulanger 1996; Dorst and Cross 2001). The IP approach considered the design process a two-step process between problem-structuring (i.e., requirements' definition) and problem-solving (solution search). Empirical research has demonstrated that designers do not methodically perform those steps; rather, they constantly redefine the requirements, introducing new goals or constraints (Cross 1984; Lloyd and Scott 1994; Akin 2001; Dorst 2006; Reymen, Dorst, and Smulders 2007; Akin 2009; Gero, Kannengiesser and Poumohamadi 2012). Designers start from any aspect of the design, adjusting, changing, and improving design solutions and the evaluation criteria (Akin 2009; Visser 2009).

The design process can take multiple paths that lead to various design solutions. Design problems lack clear goals, incomplete design briefs, and do not suggest procedures to the designer as “business as usual” type of problem-solving case (Reitman 1964; Eastman 1970; Simon 1973; Rittel and Webber 1973; Mayer 1989; Ball and Christensen 2019). Designers adopting different approaches, levels of expertise, constraints, goals, and having different pieces of information will arrive at different acceptable final designs (Eastman 1970; Akin 2001). Moreover, designers must deal with stakeholders' socio-cultural factors such as values, beliefs, roles, language, and education (Akin 1986; Le Dantec and Do 2009; Luck 2009; Visser 2006). To make the design process manageable in such open-ended conditions, designers idiosyncratically decompose the design problem and refine it until it satisfies the requirements (Akin 2001; Simon 1975; Akin 2009).

Early phases of the design process are key for the entire design process. Designers have to deal with a large body of criteria and information (i.e., a client's requirements, technical, legal, aesthetics, and formal features), making the problem conceptualization and possible design solutions critical to subsequent phases. In the early stages, designers prioritize the goals and constraints, generate initial solutions, evaluate them, and create a framework that directs further design phases (Akin 1994; Visser 2009). Designers do not dedicate much time defining the problem and do not set it completely. They are eager to explore design solutions that help them understand better the design problem (Ball and Christensen 2019).

Designers generate a relatively small number of alternative solutions before committing to a detailed study of the best options (Akin 1986; Akin 2008; Ball et al. 2001; Eastman 1969; Kazakçi et al. 2014). After evaluating those alternative solution ideas, designers commit to one of them early in the process (Gero, Kannengiesser, and Pourmohamadi 2012; Ball and Christensen 2019). Alternative solution generation rarely occurs in later phases of design (Akin 2009), as designers prefer to revise initial solution ideas rather than searching for new solutions (Ullman, Dietterich, and Stauffer 1988).

Decisions in the design process are highly interrelated (Dorst and van Overveld 2009). As an illustration, "Also within a single design project, there is a large variation of issues. For instance, decisions relating to the mechanical structure of a household implement relate to its manufacturing, which relates to the cost price, which relates to the intended market, which relates to the advertisement strategy." (Dorst and van Overveld 2009 p. 455). To manage such complexity, designers decompose the problem (Visser 2009) and work iteratively to implement integrate partial solutions into a comprehensive design (Akin 2001; Akin 2009). Designers usually implement a top-down, breadth-first strategy to ensure a holistic approach to the development of the solution advancing the design in a balanced manner (Ball and Christensen 2019). Designers use the depth-first strategy opportunistically to solve a part of the design problem when they feel in doubt (Visser 2006). When integrating partial solutions, multi-criteria evaluation plays an essential role in the decision-making process to ensure a balanced design solution (Ball and Christensen 2019).

Designers need a strategy for restructuring the problem as the design process proceeds. (Akin 1994). Design tasks often have poorly defined initial design goals; thus, and part of the design process is generating or refining those goals and their evaluation criteria (Bonnardel 1991; Visser 2006). Restructuring occurs mainly during the early part of the design process. (Gero, Kannengiesser, and Poumohamadi 2012). Restructuring, which is necessitated by the rejection of partial solutions (Akin 2009), is influenced by the designer's expertise, the technical objectives, and negotiation between the team and the client (D'Astous et al. 2004; Martin, Détienne, and Lavigne 2007; Luck 2009; McDonnell and Lloyd 2014).

Case-based design, analogical reasoning, and mental simulations are widely used strategies implemented by designers. They use it "in a variety of ways" (Akin 1986; Akin 2002 p 423-424; Clark and Pause 2012). Designers retrieve case information from several sources and apply it to their current design problem in the following ways: (1) informing pre-design activities (e.g., defining goals); (2) establishing a database of prototypes and templates to be used in the development of the design; (3) illustration of procedures to solve a new design; and (4) providing evaluation criteria (Eilouti 2009; Akin 2002).

Analogical reasoning, defined as transferring knowledge from one discipline or case to another, provides designers (1) possible solutions, (2) ways of identifying problems in the solution under development, (3) identification of new functions of a design, and (4) resources to explain a new concept to the team members (Ball and Christensen 2009). Mental simulations, defined as running a sequence of events to define its consequences over the design or the impact of a design decision, help designers evaluate solutions quickly and qualitatively without manipulating the design (Ball and Christensen 2009).

Designers use “a rich set of representations” during the whole design process (Akin 2009). Representations evolve from abstract to more concrete descriptions during the design process (Visser 2006; Goel 1992). Representations are used (1) to record ideas, (2) as a source of stimulation, (3) to foresee consequences of design decisions, (4) to evaluate scenarios, and (5) to communicate the design to stakeholders (Visser 2006). The representations are both symbolic and analog, though the latter are most prevalent in the design process (Hwang and Ullman 1990; Akin 2001). Designers use symbolic representations to evaluate the performance of design' solutions (i.e., water savings in buildings) (Akin 2009, Parthenios 2005).

There are two main approaches for organizing team efforts in the design process: distributed design and integrated. In both methods, cognitive activities usually observed in individual design sessions have been found in collaborative design activities (Visser 2006). The main difference between the two approaches is the structure of the design team and the decision-making process. The distributed-design path follows a hierarchical structure where each professional pursues goals specific to his/her expertise, contributing to the overall final design (Visser 2006). Decision-making occurs individually, in small groups or full team meetings. A global coordinator of the design organizes the work. The integrated approach is explained in the following section in depth as this is a best practice in sustainable design and the focus of this research.

2.1.2. Green Building and SWM Design process

The Integrated Design Process (IDP) evolved from the Canadian C-2000 program. This program demonstrated that stakeholders' early involvement and a holistic approach to design played an important role in achieving high building performance levels with a marginal increase in cost (Larsson 2009). Reed (2009) gave the IDP its name to underscore that the process should be thought of as a cycle that requires an on-going effort.

The IDP is an approach “to achieve environmentally effective and cost-effective green buildings” (Reed 2009). To accomplish this, the IDP organizes the stakeholders' participation through a cycle of individual work and workshops. The integrated approach follows a horizontal structure, where the team develops the solution together, with each member contributing their specific expertise. Outside specialists are usually invited to participate for short periods. Decision-making usually occurs in workshops (Visser 2006). The IDP allocates more time to the early phases of the process with two benefits: It does not extend the total time for design, and fewer delays occur because of the better coordination of the team early on. Drawings are started later in the process but undergo fewer iterations (Reed 2009). Figure 2.2 shows how the organization of individual work and workshop activities under the IDP fall into the distributed design process.

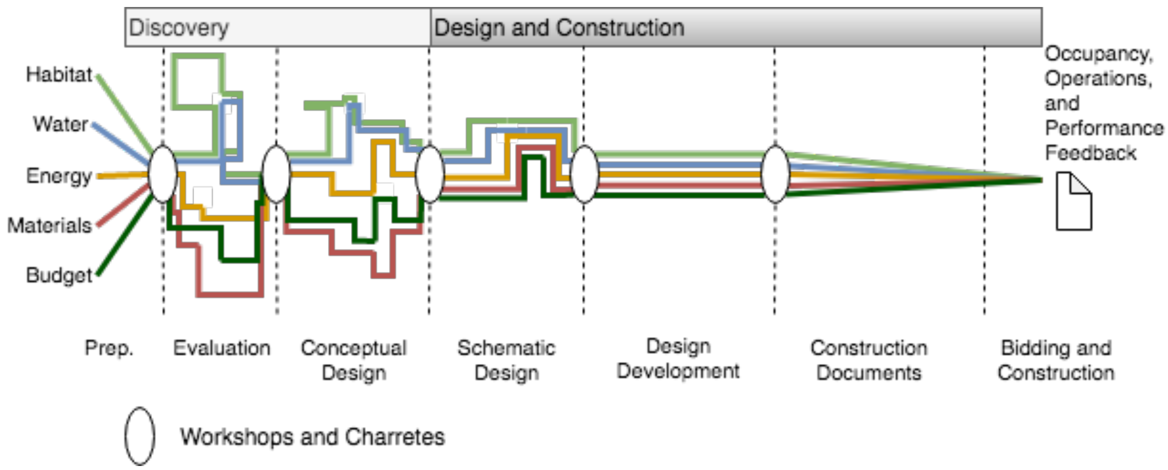


Figure 2.2. The integrative design process over the distributed design process. This figure shows the ideal progression of the design process in the IDP. Reed (2009) points out that iterations of the design are encouraged throughout all phases of the process. Image adapted from Reed (2009)

Green buildings and SWM components should be evaluated in terms of cost-effectiveness, using life-cycle costs (LCC) and considering the entire project (Reed 2009). Green features are usually more costly than traditional systems. However, green features such as bioretention cells or constructed wetlands reduce the size of or eliminate the need for other systems (e.g., piping, pumping, curbs), which may reduce the overall project cost. Likewise, green features usually minimize maintenance and operation costs that offset higher construction costs of the SWM components. Reed (2009) recommends using Net Present Value (NPV) calculations for the building's life cycle.

Regarding information needed and activities for SWM design, Reed (2009) recommends that before the start of workshops the team should: 1) investigate and collect data on the site characteristics, water flow, and water quality (e.g., existing conservation methods, topography, geohydrology, soils, adjacent bodies of water); 2) perform a pre-development water balance study; 3) gather information about water sources and infrastructure available at the site (e.g., annual and monthly rainfall, groundwater, location, type of treatment and leakages of wastewater treatment plants, the carbon footprint of drinking and wastewater treatment plants, cost of potable water supply and wastewater treatment); and 4) select performance criteria (e.g., LBC standard). Then, during the first workshop, stakeholders are expected to determine:

1. the performance targets (e.g., reduction of municipal water use);
2. the tools to account for those performance targets (e.g., water balancing analysis);
3. the potential SWM components to implement (e.g., rainwater harvesting);
4. order-of-magnitude LCC estimates of SWM components; and
5. whether more information is needed and how to obtain it.

Afterward, the design team should identify possible combinations of SWM components and assess their performance for water quantity and quality.

Regarding tools and methods in SWM design, Reed (2009) recommends performing potential rainfall catchment analysis, water balancing, and modeling. Potential rainfall catchment calculations estimate the amount of rainwater used as a water supply for a site and building. These analyses are usually performed in spreadsheets and help determine the size of rainfall storage and life cycle costs of different SWM components. Water balancing accounts for all types of water sources that feed and leave a building and its site such as rainwater, greywater, blackwater, potable water, and groundwater. Water balancing (WB) is performed in different design stages, using spreadsheets and system diagrams. WB helps to organize, re-assign, and track the design progress or possible conflicts of design changes in achieving the water performance targets. Specific information needed for water balancing is the number of users and water demand per capita, roof area and roofing material, type of building, landscape area and its water demand, total paved area, its topography and surfaces, and possible rainfall amount for periods of drought or excess of rainfall to build scenarios of analysis. Modeling includes input and output flows for each type of supply (e.g., greywater, rainwater).

2.1.3. Other SWM Design Process Models

Normative procedures and guidelines for SWM design are available to designers. However, these are developed for obtaining rating system credits or permits. Rating systems provide guidelines and calculation methods for SWM design without targeting a holistic SWM. For example, the Leadership in Energy and Environmental Design Certification Program (LEED) asks designers to compare the project's water performance against a baseline model based only on potable water usage (Kubba 2012). Guidance for obtaining permits is focused on rainwater control, reduction of potable water consumption, or on-site wastewater treatment (see USEPA 2014a; USEPA 2014b; USEPA 2013; USEPA 2014d).

Another set of procedures is provided by the Pennsylvania Best Management Practices (BMPs) Manual (PA DEP 2006) includes a step-by-step procedure, checklists, and calculation methods for comprehensive rainwater management. It presents a site design procedure which prescribes starting with a pre-submission meeting with authorities, followed by the design process in three steps: (1) the site analysis, (2) the incorporation of Non-Structural BMPs, to minimize runoff, and (3) the incorporation of Structural BMPs to manage the remaining runoff peak flow and volume. Some design iteration must occur between the incorporation of Non-Structural and Structural BMPs to achieve an optimal design for runoff reduction. The manual includes 15 BMPs. Early involvement of authorities and similar design process steps are common recommendations in other manuals (See the list at USEPA 2014a).

2.1.4. Findings of the literature review that informs the SWM design process model

Based on the literature review, an SWM design process model should include:

- The stages of a design process
- The three main design activities: Definition of Requirements, Generation of Alternatives, and Evaluation and the feedback loops between them that cause the iteration of the design
- The use of IDP as the organization of the teamwork
- The main representations used: diagrams and water balances, implemented in spreadsheets
- The knowledge and knowhow that stakeholders bring to the process
- The definition of requirements activity should include the following actions: Gather Information and Site analysis, Initial Water Balancing (Reed 2009), and the Definition of SWM Goals and Evaluation criteria. Reed (2009) and the PA DEP (2006) manual provide a list of information to gather for SWM design that serves as a starting point for the model. PA DEP (2006) manual also provides soil testing and site infiltration protocols. As a set of requirements, Reed 2009 recommends using the LBC standard or LEED
- The Generation of Alternatives activity should include the following actions: select SWM components, create combinations of SWM components, and estimate the water balance of them. Reed (2009) and the PA DEP (2006) manual provide a list of SWM components for outdoor and indoor that can be initially used. The selection process should start with non-structural SWM components and follow with the structural SWM components.

- The water balancing activity should include water quantity and water quality for combinations of SWM components, using water balances, rainwater runoff modeling, and potential rainfall catchment (Reed 2009)
- The evaluation activity should include a multi-criteria evaluation, including economic and environmental criteria. Economic evaluation should be performed using LCC and NPV

2.1.5. What is Missing from this Literature Review?

Reed's IDP process and the other models are prescriptive, but some specifics of how designers conduct the process of SWM design are not revealed. For a complete description, the following information is required:

- Which professional of the team develops the design of which SWM component?
- Who are the key stakeholders for SWM design?
- What information is not available during the design process, and what are the sources consulted by the team for obtaining it?
- Who coordinates water balances, and who performs them?
- What are key issues, problems, barriers found during the design of SWM that directed design decisions? How many of them are related to regulations?
- How are costs and environmental benefits taken into account during the design process?
- Until what stage of the SWM design the changes occur?
- Is LCC used in the early phases? Or are just construction costs included in decision-making?
- What information is shared, and in what format (representation) among the designers?

For residential projects, it is also relevant to know the following:

- Which are the trends and needs in green design practices
- The most widely known SWM concepts among the professionals and the implementation of rating systems in residential projects
- Which are the most implemented SWM components in residential projects
- Which tools are used and which tools are needed for residential SWM design in the US

2.2. Tools for SWM Design

This section presents general recommendations for tools that assist in sustainable design, the current tools for SWM design, and decision-making. This section ends by exploring the limitations of the current tools in SWM design for the residential context.

2.2.1. Recommendation for Tools for Green Design (design)

After analyzing 60 case studies of the Practical Evaluation Tools for Urban Sustainability project, Jensen and Elle (2007) observed the following common features about the use of green tools: 1) Tools are customized to fit the stakeholders' needs, higher standards, or local contexts, 2) multiple tools are used, 3) local procedures and tools addressing local regulations are widely used, and 4) tools are used only a few times because they do not fit the purpose or are managed by an expert. In summary, tools for sustainable design have the following requirements (Jensen and Elle 2007):

- they should be able to be adaptable to the end user's needs
- they should incorporate local issues such as regulations
- they should guide the user (i.e., help)
- they should contain references, baselines and benchmark information
- they should be targeted to the user's level of expertise

2.2.2. Recommendation for Tools for Rainwater Control

Based on a literature review and survey of design professionals with a focus on rainwater management, Moore (2010) suggests that a tool for water management design should consider:

- Site-scale design
- Best Management Practices and/or Low Impact Development strategies (BMPs/LIDs) runoff quality performance
- Cost comparison between traditional versus BMPs/LIDs solutions to inform decision making
- Provide "quick and effective" results of pre- and post-development hydrology and water quality analysis to inform decision-making about BMPs/LIDs implementation
- Easy to use forms and applications such as spreadsheets

A tool for rainwater management design should be a spreadsheet since it can perform the most accepted hydrologic procedures (e.g., NRCS Curve Number or Rational Method). Microsoft worksheets are easy to use and widely adopted by water sector professionals (Moore 2010).

2.2.3. Computational Tools for SWM

Available tools for SWM design have been developed by governmental, academic, and commercial organizations. The tools presented here are divided into two areas of focus: rainwater control/green infrastructure and water management in buildings. All of them perform analyses for small sites for most locations in the United States and contain economic and environmental information for assessing designs. Tools for obtaining municipal permits are not included in this section. No specific tools exist for the residential sector.

2.2.3.1. Tools for Rainwater Control / BMPs

Available decision support systems for rainwater control / green infrastructure have been developed over the years with the support of organizations such as the Environmental Protection Agency (USEPA 2012b) and the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture. This section presents representative tools, classified as complex, intermediate, and simple, according to the level of expertise needed to use the tools appropriately.

2.2.3.1.1. Complex Tools

System for Urban Stormwater Treatment and Analysis Integration Model – SUSTAIN

SUSTAIN is a Spatial Decision Support System (SDSS) that facilitates the selection and placement of combinations of 12 BMPs at various watershed scales targeted to stormwater management professionals. The selection and optimization of the solutions are based on performance assessment of water quantity, water quality (i.e., total suspended solids - TSS), and construction costs. The main methods used by SUSTAIN to simulate runoff and pollutant loads are the EPA Storm Water Management Model 5 (SWMM5) and Hydrological Simulation Program – FORTRAN (HSPF). The cost estimation is based on a cost database expressed in terms of unit costs of individual construction components of the BMPs. The optimization is implemented using a scatter search and a genetic algorithm. Finally, a post-processor helps analyze and interpret simulation outputs for several scenarios (Shoemaker et al. 2009). SUSTAIN is the most complete SDSS available for free to assess a combination of BMPs on a site. SUSTAIN's UI interface guides on managing data, performing simulation activities, and analyzing the results. However, SUSTAIN installation and use requires proprietary software, ArcGIS (USEPA 2014c).

Two other complex tools available are the Source Loading and Management Model for Windows - *WinSLAMM* (Pitt and Voorhees 2002) and the RSWMM-Cost (Alamdari and Sample 2019). The WinSLAMM is a software planning tool targeted to watershed decision-makers to comprehend the source of urban runoff contamination for different rainfall depths and to evaluate stormwater management programs at the watershed level (Pitt and Voorhees 2002).

Runoff volume calculations are based on the Small Storm Hydrology Method (SSHM) (Pitt 1987). The method is based on actual field measurements. It allows accurately predicting at site and watershed level the runoff volume of different urban cover areas, especially for storms between 0.5 to 1.5 inches depth that involves the 75% of runoff pollutants discharge (Pitt 1999). WinSLAMM has been coupled with SWMM to abroad its use and evaluates the impact on receiving waters and ArcGIS to facilitate the study of large urban watersheds. The RSWMM-Cost is a Decision Support tool targeted to stormwater professionals and planners for evaluating BMPs/LIDs for urban watershed restoration efforts (Alamdari and Sample 2019). The RSWMM-Cost integrates the SWMM 5.0 model (Rossman 2010) with a calibration, sensitivity analysis, and cost-optimization process developed in R to optimize the selection and sizing of BMPs/LIDs. Selection and sizing are based on water quantity, quality, and cost-effectiveness for medium-sized watersheds (500 and 1000 ac) (Alamdari and Sample 2019). The RSWMM-Cost is expected to assist in evaluating TDML plans, evaluating permit compliance of BMPs/LIDs solutions, or defining cost-effective BMPs/LIDs implementation designs for sewer overflows avoidance (Alamdari and Sample 2019).

2.2.3.1.2. Intermediate Tools

The Long-Term Hydrologic Impact Assessment-Low Impact Development 2.1 (L-THIA-LID 2.1)

The L-THIA-LID 2.1 model is an SDSS, easy to use screening tool, targeted to planners and decision-makers for assessing the benefits of BMPs' implementation at the watershed or site scale (Liu, Bralts and Engel 2015). The L-THIA-LID 2.1 is an enhanced version of the L-THIA-LID 2.0 (Liu et al. 2015), the L-THIA-LID web-based stand-alone spreadsheet and model (Ahiablame, Engel, and Chaubey 2012), and the L-THIA model (Engel and Hunter 2009). The current 2.1 version, in addition to the estimate of the effectiveness on hydrology and water quality of BMPs/LIDs, has the following features: 1) twelve BMPs available for water and cost analysis, 2) an improved method for estimating runoff for BMPs/LIDs using the Curve Number Method (NRCS 1986) and the percentage of runoff volume reduction method, 3) calculation of reduction of pollutant concentration by BMPs/LIDs incorporating data from the International Stormwater Best Management Practices, 4) perform runoff and water quality simulations for BMPs arranged in series, and 5) cost-effectiveness estimation of the different of BPMs/LIDs arrangement scenarios at watershed level (Liu et al. 2015; Liu, Bralts and Engel 2015). The L-THIA-LID 2.1 model, calibrated and validated for annual runoff volume, has been successfully tested on several lands uses - low and high-density residential areas, industrial, and commercial sectors – at the Crooked Creek watershed, Indiana, US. (Liu, Bralts and Engel 2015).

Other intermediate tools available in the US are the BMP-Checker (Johnson and Sample 2017), the Latis-LIDIA (Southeastern US) (Wilkerson et al. 2010), and the LIDRA model (Montalto 2007; Yu et al. 2010). These are a tool for planning stages of design targeted to stormwater practitioners in consulting firms or municipalities. All of them allow set models at site scale to calculate runoff water for estimations at urban watershed scales. The hydrology models implemented are simple such as the NRCS curve number or water balance. They include a wide range of BMPs to account for their performance in reducing runoff volume and pollutants (except the Lidra tool that does not have pollutants reductions). The software environment of these tools is Microsoft Excel (ME) with Visual Basic code and linked to map visualization applications (i.e., ArcGIS) and databases or uses excel spreadsheets and ArcGIS files as inputs (i.e., BMP-Checkers developed in Python).

2.2.3.1.3. Simple Tools

The National Green Values Calculator

The National Green Values Calculator (GVC) is a website application targeted to municipal planners and engineers to assess rainwater management. The tool compares water performance, costs, and benefits of BMPs against conventional rainwater practices for initial planning phases (CNT 2013; USEPA 2012b). The National GVC estimates runoff volume reduction for single sites. Two types of results are shown: 1) progress on project water quantity reductions, and 2) a comparison of three scenarios (pre-development, conventional, and green) in terms of total changes in runoff volume, land use, and lifecycle cost-benefit analysis. Runoff estimations are based on the Curve Number Method (NRCS 1986). The Net Present Value of Costs includes capital costs, operation, and maintenance costs, and lifespan data obtained from several US sources. Benefits are monetized to be included in the life cycle cost analysis. Because the National GVC combines a wide range of information from several sources, the calculator works only as a general screening tool (CNT 2013). Costs and benefits are fixed values that cannot be modified by the user to reflect local information.

Other simple tools, targeted to a wide range of users, from practitioners to homeowners, for rainwater management are the WERF SELECT (Reynolds et al. 2012), the National Stormwater Calculator (NSC) (Schifman et al. 2018), and the Site-Scale Integrated Decision Support Tool (i-

DSTss) for Stormwater Management (Shojaeizadeh et al. 2019). These tools simplify the user interface while improving and adapting complex hydrological estimations methods. The i-DSTss (Shojaeizadeh et al. 2019) is an example of this adaptation. The i-DSTss is a multi-criteria optimization tool targeted to designers, regulators, and municipalities. It has been developed for assisting planning stages in selecting and sizing rainwater BMPs. The tool can be adapted to be used across the United States. The i-DSTss is built on Microsoft Excel Visual Basic for Applications and has four main independent modules that help estimate the site's hydrology, the BMP selection and sizing, and the Life Cycle Cost of the design. The tool includes three categories of BMPs: green roof systems, infiltration-based, and storage-based. The hydrology module's relevant feature is the translation and implementation in spreadsheets of the event and continuous simulation procedures to estimate runoff depth. The module implements the NRCS curve number and the Green-Amp method with a mass-balance approach that includes precipitation intensity, evapotranspiration rate, and infiltration rate (Shojaeizadeh et al., 2019).

Kuller et al. (2017), Jefferson et al. (2017), and Eckart, McPhee, and Bolisetti (2017) work present abroad reviews of tools for modeling and assessment of BMPs with a focus on urban watersheds.

2.2.3.2. Tools for SWM in Buildings

Tools supporting SWM for buildings are commercial systems targeted to designers provided by companies such as the Integrated Environmental Solutions (IES) and Autodesk. The following paragraphs provide brief descriptions of the tools.

2.2.3.2.1. Integrated Environmental Solutions - Virtual Environment (IES-VE)

IES provides an application entitled VE-Gaia that works for the IES-VE for engineers and architects, separately. The VE-Gaia application guides users in managing the model's data to perform sustainable building analysis for the early stages of design. VE-Gaia contains several climatic and natural resource analyses, of which three cover SWM matters. The IES VE-Gaia can estimate possible rainwater collection and storage, potential water appliance use and reduction, and greywater and blackwater generation and reuse within the building. Designers can also analyze building water use under several rating systems. To perform these analyses, IESVE requires an initial building geometry, an occupancy load, and a regulatory framework to work (IES 2014).

2.2.3.2.2. Autodesk - Green Building Studio

The Autodesk Green Building Studio (GBS) application is a cloud-based software package targeted to the architecture, engineering and construction (AEC) professional to perform sustainable building analysis in the early stages of design. The design is imported into the app using gbXML format to analyze the energy use, water consumption, carbon footprint, and rating system compliance of the building. Water analysis only includes potable water usage and its costs (Autodesk 2020). Indoor water analysis considers building occupation estimates, fixtures, and equipment counts. Outdoor water analysis includes irrigation needs, irrigation system schedules and efficiency, vegetation, presence of water equipment, and the use of greywater for irrigation purposes. Data and regulatory frameworks used within the software are obtained from several sources, such as the National Climatic Data Center, the 2000 Uniform Plumbing Code of the IAPMO, or the American Water Works Association (AWWA) Research Foundation. The application estimates the reduction of drinking water use and sewer charges from a utility, considering: 1) reduction of potable water use by efficient fixture, 2) use of harvested rainwater, 3) greywater use, and 4) other sources of a potable water (i.e., wells and streams) (Autodesk 2020).

2.2.3.2.3. Rainwater+

Rainwater+ is a free software package targeted to architects and landscape architects to assist them during early phases of design to analyze a site, estimate runoff volume, and select and size LID practices for rainwater control and management sites less than 1 square kilometer. Rainwater+ is built on the proprietary three-dimensional (3D) digital computer-aided design application Rhinoceros and Grasshopper with a nascent user community in the architecture field. Rainwater + has four main modules (Chen, Samuelson and Tong 2016): 1) a database with rainfall information from the Precipitation Frequency Data Server at the National Oceanic and Atmospheric Administration (NOAA), 2) a terrain module that uses the 3D model information to represent the hydrology flow of the site, 3) a database of LID practices such as includes rainwater collection systems, green roofs, rain gardens, and bioswales, subsurface infiltration systems and porous pavements, and a 4) runoff volume calculator based on the NRCS curve number method (NRCS 1986). The tool also provides a range of cost estimates of the LIDs used in the design based on the intervention's surface area (Chen and Samuelson 2016). According to Chen, Samuelson, and Tong (2016), the tool provides instant feedback about water management as changes are made to the design.

A similar tool, as an add-on for Rhinoceros and Grasshopper, has been developed by Han and Reinhart (2018). The Urban stormwater manager using the NCRS Curve Number Method (NCRS 1986) estimates the runoff volume for pre- and post-development surfaces for neighborhood-scale runoff volume from site type of interventions. The tool includes the following LID for stormwater management: green roofs, bioretention systems, infiltration systems, porous pavement, and rainwater collection systems. More details of this tool can be found in Han and Reinhart (2018).

2.2.4. Recommendations for a tool for SWM design

Based on the review of literature and tools, a tool for SWM design should provide a holistic approach, where the design solutions are a composite of indoor and outdoor SWM components. Moreover, the tools should be designed for the SWM design practice.

- Based on the co-evolution and restructuring trait of design, the tool should: 1) support the iterations between the definition of requirements, alternative generation, and evaluation, 2) support starting a design at any at any stage in the process, 3) allow redefining the requirements without starting from scratch, 4) allow on-going testing after any of those restructuring events, and 5) when recording a solution, allow attaching the criteria used to the evaluated solution
- Based on the open-ended conditions of design, a tool should accommodate a diversity of problems and solutions and adapt to different work practices
- Based on the different levels of knowledge about SWM that designers have, the tool should inform and guide the different factors that affect the design of SWM solutions such as state and local regulations or technical restrictions of systems. They should explicitly present the system capabilities, assumptions, and calculation methods (Jensen and Elle 2007)
- Based on the needs of water sector professionals a tool for SWM should be targeted to site-scale level and be developed in a designer's known application such as spreadsheets
- Based on the alternative solution generation activities of designers, a tool should 1) support the development of alternative design solutions in early phases,2) help to organize the different alternatives (Parthenios 2005), and 3) allow the evaluation of those alternatives and in-depth development of a subset of them
- Based on designers' strategies to manage complexity in design, a tool should: 1) allow the development of parallel partial solutions (i.e., decomposition), 2) allow for the merging of

alternatives (i.e., pairwise integration), and 3) provide single and multi-criteria testing for quicker and more coherent judgment (Parthenios 2005). It should not provide best solutions since partial solutions will also be evaluated against the entire design requirements

- Based on the wide use of case-based design among designers, a tool should provide access to cases' information and reuse previous design solutions (Ozkaya and Akin 2006)
- Based on the information needed and activities in SWM design, a tool should allow storage and help process the data for site analyses, the definition of requirements, the performance of calculations, evaluations, and comparisons of SWM solutions
- Based on the multi-criteria nature of decision making in green design, a tool for SWM should: 1) support economic assessment by performing LCC, NPV and cost-effectiveness calculations, and 2) support the assessment for water quantity and quality, using water balancing, and modeling of solutions. 3) For the estimation of rainwater runoff volume and peak in urban and site scale the tool should use the Runoff Curve Number Method and Small Storm Hydrology Method (PA DEP 2006)
- Based on the designer's use of representations and the collaborative nature of SWM design, a tool should have the ability to 1) produce and record the evolution from abstract to concrete developing of water balances and water system diagrams, and 2) share the information produced with the stakeholders.

2.2.5. Problems of Current Tools for SWM Design

The computational tools described in the previous section perform SWM analysis for decision-making and design. However, none of the tools presented provides a holistic approach to SWM for building/site projects. These tools were developed to consider only one realm of water use, outdoor or indoor. None of the tools allow implementing a case-based design or recording the design's evolution within the tool. Only three tools allow making comparisons of solutions. The only tool that integrates basic stormwater modeling with building and site design is Rainwater+. However, it covers only runoff volume management with LIDs without considering pollutant removal or rainwater harvesting as supply.

Among the tools for outdoor analyses, sophisticated tools such as SUSTAIN do not adequately support SWM in the residential sector (or designers who are not water management experts). SUSTAIN can analyze small sites, perform an economic and environmental assessment for local conditions, and help users manage data. However, SUSTAIN requires 1) a knowledgeable user in water resource engineering to set models and input large volumes of data, and 2) a well-defined design.

Table 2.1. Comparative table analysis of current SWM analysis design support tools

	Tools													
Criteria	SUSTAIN	WinSLAMM	RSWMM-Cost	L-THIA-LID 2.1	BMP-Checker	Latis-LIDIA	LIDRA	National GVC	WERF SELECT	NSC	i-DSTss	VE - Gaia	Green Building	Rainwater+
Support combination of SWM components for a holistic approach (indoor-outdoor)														
Adaptable to the design process											x	x	x	x
Adaptable to the designers (lack) expertise in SWM								x		x		x	x	x
Customize to local conditions, costs, and constraints	x	x	x	x	x		x		x	x	x	x	x	x
Multi-criteria testing. Economic and water quantity assessments	x		x	x		x	x	x	x	x	x			
- LLC and/or NPV	x			x		x	x	x	x		x			
- potential rainwater catchment, water balancing and/or modeling	x	x	x	x	x	x	x	x	x	x	x			x
- Water quality	x	x		x	x			x	x		x			
Comparisons of alternatives solutions	x[1]		x						x					
Allow different types of representations. Diagram, water balances, and modeling	x													

[1]compares cost-effectiveness of the alternatives created during the optimization processes

Simple tools available for outdoor SWM components can help assess designs in early phases; however, they do not provide ways to customize the model's cost and benefit parameters. Tools for indoor water analysis are commercial software focused only on the reduction of potable water consumption. Table 2.1 presents a comparative analysis of the tools described in this section. The comparison was based on the requirements discovered in this literature review (more details of the comparison criteria are found in Chapter 5).

3. ETHNOGRAPHIC STUDIES AND NATIONAL SURVEY OF SWM PRACTICES

The development of a process model and the definition of the tool's requirements that respond to the needs and motivations of design professionals pursuing SWM in the residential context have been performed utilizing an ethnographic study and a national online survey.

3.1. Ethnographic study: The Debriefing Session and the Recording of Design Meetings

Two complementary ethnographic studies on architectural design were implemented to explore the decision-making process of the design team to achieve SWM. These studies collected information from the interactions between designers and stakeholders in order to obtain a complete idea of all elements involved in the process. The research questions were: 1) what are key issues/problems/conditions that inform design decisions for SWM? 2) What information is needed, and how does the team obtain it when designing for SWM? 3) What are the methods and tools used in the project for SWM design?

The first study consisted of the analysis of the weekly meetings of the design team for over four months. This period covered only a couple of SWM design decisions because the project had already advanced to the construction documentation phase. Each meeting was recorded, transcribed, and analyzed with a focus on SWM decisions to supplement information for the second ethnographic study, the debriefing session, which covered the SWM design process from the beginning until the documentation phase. Details on the research design and study protocol for the two ethnographic studies can be found in the Appendix A.

A debriefing is a semi-structured oral discussion in which a facilitator and the participants engage in a progressive question-answer session. The session is designed to guide participants to recall events in which they have participated, but that have not been recorded (Schoepfle and Werner 1999; Lederman 1992).

Ethnographic studies such as debriefing sessions and the study of meetings provide essential details of the process being performed (Ericsson and Simon 1984). In the case of the recording of the meetings study, the method allows the capture of what information is relevant to participants when making decisions about the design (Ericsson and Simon 1984). In the case of the debriefing session, the method provides a means to create a chronology of the actions taken by the designers, the strategies used, the information retrieved during the discussion, and the decisions made with the information at the moment (Ericsson and Simon 1984). Ericsson and Simon (1984) recommend recording the session to obtain detailed outcomes and better analyze the data.

Among the debriefing methods, the ones applicable to this research are the process-based methods, which aim to gather lessons from the process followed by teams, projects, or events (Schindler and Eppler 2003). Process-based methods include Ethnographic Debriefings, After-Action Reviews, the Critical Incident Technique, Post-Mortem Reviews, and Post-Project Reviews. After a comparison of these methods based on the criteria below, Ethnographic Debriefing was selected as the method to be applied in this study (see Table 3.1). The criteria for selecting a debriefing method were the following: 1) it is usually applied to teams; 2) it can be applied during the project or at the end; 3) the data is collected from the group discussion; 4) it is usually performed in a one-time session; 5) it can be applied to design projects; 6) it can reduce participants' memory bias and inability to reflect, and 7) it can unveil tacitness due to the diversity of the group.

The main focus of the debriefing session was to recall important decisions and events related to achieving the SWM of the LBC standard during the initial phases of the design (i.e., conceptual, schematic, and detailed design). The study was structured in two phases: a debriefing session, and follow-up interviews.

The debriefing session was a one-time meeting with all of the professionals related to the SWM design of the project. The session was a group retrospective interview directed by me, where I acted as the facilitator. The facilitator asked questions that helped the participants to recall issues and decisions made during the design process. The session was recorded and transcribed. Eight (8) professionals participated in the debriefing session, including the architect, landscape architect, stormwater consulting engineer, civil engineer, project management firm, sustainability consultant, and client.

The follow-up interviews aimed to trigger the recall of details about specific methods or tools used during the design and decision-making process of the project not mentioned during the debriefing session. The interviewees were strategically selected, to maximize the amount of information recalled to fill the gaps and to reduce the number of interviews to a minimum. Two interviews were performed, one with the architect and the other with the project manager of the client. In addition to the interviews, project documents were reviewed to fill information gaps that occurred in the debriefing session and interviews.

Table 3.1. Comparative table of debriefing process-based methods

	Method				
Criteria	Ethnographic Debriefing	After Action Review	Critical Incident Technique	Post-Mortem Review	Post-Project Review
For teams	1	1	0	1	1
Flexible time of execution (During and/or at the end)	1	1	0	0	1
Group interaction mode	1	1	1	1	1
Less time consuming	1	1	0	1	0
Applicable to design process	1	0	0	0	0
Reduce memory bias/inability to reflect	1	1	1	1	0
Can unveil tacitness	1	0	0	0	1
Total	7	5	2	4	4

3.1.1. Case Study Selection

The selection of a case study to perform the ethnographic research was made according to the criteria below. The project that complies with most of the criteria was selected.

Criteria:

- located in the US
- Residential type (only residential or mixed-use)
- Small to medium size (from one to 15 residential units per project)
- Considers comprehensive SWM (from supply to discharge), ideally pursuing LBC standard
- In the design stage (schematic to construction documents) or recently completed the design process
- Designed by a professional team that includes architects, landscape architects, civil or stormwater engineers
- Design team accessible to the researcher

Due to a lack of residential projects in the design phase available at the time of the research, a non-residential project was included. The reasoning behind the inclusion of a non-residential case was that the design process, permit approvals, and the experience gained by the design team about SWM design can be transferred to other types of projects such as residential. Table 3.2 presents the characteristics of all of the cases analyzed, both residential and non-residential.

Only one case study was analyzed since debriefing sessions consume time and money, and the number of cases does not limit the validity, quality, and usefulness of the data gathered.

According to Ericsson and Simon (1984), one case study is satisfactory since the information gathered from it is very detailed, and the cognitive processes of teams are consistent over time. Even though it can be argued that different teams have different approaches, the cognitive processes and strategies used in design remain similar. These characteristics of design processes allow generalizations at a high level.

Table 3.2. Comparative analysis table of cases studies

	Selection Criteria							
Cases	**U.S. Location**	**Only Residential**	**Small to Medium Size project**	**Comprehensive water management**	**In the design process**	**Designed by a Professional Team**	**Team accesible**	**Data/Literature Available**
EVA-LAXMEER Housing	No	No	No	Yes	No	Yes	No	Yes
Sustainable Home Brisbane	No	No	Yes	No	No	Yes	No	Yes
Dockside Green	No	No	No	Yes	No	Yes	No	Yes
Rocky Bay	Yes	Yes	Yes	No	No	Yes	No	No
zHome	No	Yes	Yes	No	No	Yes	No	Yes
Common Ground	Yes	No	Yes	No	No	Yes	No	Yes
Di Diego + Ferris Residence	Yes	Yes	Yes	No	No	Yes	No	Yes
Eco-sense Residence	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Desert Rain House	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Environmental Center (EC)	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Source of cases: ILFI 2011a, except EC

3.1.2. Environmental Center Case Study

The case study selected was the Environmental Center (EC), called in this way to protect the identity of the participants. The EC Project was a joint effort between a non-profit organization and the city where it is located. The project was built in the same location as an old center. The new building hosts educational programs and provides space for volunteer activities and community outreach programs. The owner had a strong wish for a project that demonstrates comprehensive and sustainable management of water. For that purpose, the design followed the LBC standard, which is the more advanced green design standard in practice for built and landscape environments (Barbosa, Fernandes, and David 2012).

3.1.3. Results and Answer to Questions

This section presents the results from then ethnographic studies with a focus on identifying information to develop the SWM design process model and the requirements for a tool that assists in SWM design. The main research questions were the following:

1) What information is needed, and how does the team obtain the unavailable information when designing for SWM?

2) What are key issues/problems/conditions that inform design decisions for SWM?

3) What are the methods and tools used in the project for SWM design?

The subsequent paragraphs present the main findings about these three inquiries divided into five topics.

3.1.3.1. Information needed in early design phases

There is a need for utilizing site and regulatory information to assess the feasibility of the SWM solution early in the design process. Information such as soil infiltration rate, soil depth, and local regulations, if provided later, can create delays and changes in the design process. For example, the EC design team made an informed guess of the soil depth to design an underground drip disposal system for wastewater treatment; however, after soil testing, which was performed during the detailed design phase, the soil depth required by state regulations was found in a remote area of the site and not where the team expected it. This fact required the team to revisit other alternatives, delaying the project's development, and even put in doubt the client's implementation of a SWM approach at all. The SWM design process model should show how critical information such as regulatory requirements or site soil characteristics constrain the selection of SWM components. The model should also present testing needs (e.g., soil depth, infiltration rate). A tool for SWM should alert designers to the limitations that local regulations impose on SWM goals and SWM components, and recommend the collection of crucial information related to the SWM components under consideration (e.g., depth to the water table, soil testing, building distances).

3.1.3.2. Decision-making Based on Economic and Environmental Factors

Cost and environmental factors were considered together in the decision-making process. The client was demanding about the environmental impacts of the SWM components and their construction methods, but always willing to research and listen to experts for making decisions. The first construction method selected to build the drip disposal system was questioned by the client due to the risks of damaging the roots of surrounding trees. The team took the time to research the impact on roots and performed cost estimates of different construction method alternatives. Although the final drip disposal construction method selected was more expensive than the initial one, the overall cost of the black water treatment system was not considered to be costly in proportion to the overall budget and compared to the environmental benefits from pollutant removal, recharge of groundwater, and avoiding the use of a centralized wastewater treatment. The general approach was to achieve the cost-effectiveness of the systems implemented.

Cost estimates of the SWM solution were performed in conjunction with all other costs of the project; the project's budget was considered as a sum lump value. The type of cost estimates used were Order of Magnitude, and detailed estimates were based on the unit cost method. For decision-making, maintenance and operation costs were considered when selecting SWM components, but not included in the cost analysis. Estimates of the environmental benefits of SWM solutions were based on water managed using Water Balances (WB) and stormwater modeling. Regulations set pollutant removal requirements, and rain and blackwater treatment systems were designed to comply with them.

The SWM design process model should inform the assessment and comparison of SWM solutions based on economic and environmental criteria using cost-effectiveness, Life Cycle Cost (LCC), and quantification of water managed by performing WBs and stormwater modeling. A tool supporting SWM design should support LCC analysis and water quantity assessments. The user should be able to update cost information and share it for complete design cost assessment. It should also support cost-effectiveness analysis regarding the amount of water treated. The case study did not clearly indicate the importance for estimating the environmental benefits of water pollution removal.

3.1.3.3. Water Balance

The design team checked WB estimations throughout the design process. Two WBs were initially used to estimate potential water availability, and later, three more were performed to check compliance with SWM goals and to confirm the rainwater cistern size. During the occupancy phase, the building's manager will closely monitor water consumption and will compare it with earlier WB estimates. Engineers used proprietary software to perform simulation of rainwater runoff and wetlands retention capacity. The architect, client, landscape architect, and sustainability consultants collaboratively estimated the indoor water demand using spreadsheets. The architect then integrated the information for indoor and outdoor water availability and provided a unified WB in a single spreadsheet, which was manually updated. This practice entailed two challenges: 1) manual transference of information that might create errors, and 2) since the same spreadsheet was updated, no records were kept of previous estimates and assumptions were not readily available for the team. A SWM design process model should include the occupancy phase of the building and the following stakeholders: architects, client, civil, stormwater engineers, and landscape architects. A tool supporting SWM design should allow managing the collection, update, and recording of WBs' results. Based on the small number of WB updates and the use during the several stages of design, the tool should visibly present assumptions and information used in early WB versions. The case study confirms the need for the sharing of WB information among stakeholders.

3.1.3.4. Collection of information for design

Information needed during the design process is gathered in several ways by the design team, including pre-design general knowledge and the just-in-time (JIT) information strategy. During the initial phases, the design team relied on "at-hand" general information, the design team professionals' knowledge and knowhow, and on conversations with permitting authorities. As the design process evolved, the team gathered more detailed information in a "just-in-time" (JIT) manner. JIT information is the information needed by users at an exact time and in a particular manner that allows them to make a decision (Guerra and Cianchette 2006). In the case study, the preferred way of gathering JIT information was through phone calls or face-to-face meetings with outside experts, green design consultants, and providers. The team also researched and visited similar projects where the SWM goals or components in question were implemented. A SWM design process model should include JIT information gathering as a method, professionals' knowledge and knowhow as input for design, and outside experts, green design consultants, and providers as stakeholders. A tool supporting SWM design should support the collection of information in a just-in-time manner and allow recording and sharing of professionals' knowledge and knowhow that emerges in the design process.

3.1.3.5. Organization of the work

The design team used an approach to SWM design which was hybrid of a distributed and IDP approach. Three characteristics of the IDP approach were observed in the case study (AIA 2012). First, stormwater engineers and permit authorities were invited early into the design process. Stormwater engineers were part of the two initial design workshops. Permit authorities from the PA Department of Environmental Protection (PA DEP) and the County Health Department were invited to team meetings beginning in the conceptual design phase. Second, water balances were built collaboratively during the design process. Third, later, the design team used workshops to solve problems encountered with SWM components during the design process. For example, after the permit authorities rejected the selected blackwater treatment, the team used a workshop to quickly review previous systems considered, propose new options, and settle on blackwater treatments to be further researched. A SWM design process model should include IDP features such as workshops and the participation in the definition of requirements and the incorporation of authorities and specialists among the stakeholders. The findings confirm that a tool should allow sharing information between stakeholders.

Key finding of this section are included in the model and requisites of the prototype tool developed. The finding included in the model and prototype are stated in Chapter 4 and Chapter 5.

3.2. National Survey of SWM Practices

A national survey entitled "Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design" was administered to identify trends and needs in green design practices, SWM components implementation, and tools in meeting SWM in the US. The survey also served as a methodological triangulation (Mathison 2004) to validate the findings from the ethnographic studies.

An online survey was selected because it allows us to easily access a large number of participants distributed over a vast geographical region at a reduced cost. Online surveys also provide privacy and time-flexibility for participants and increase timeliness. Some of the disadvantages of online surveys are low response rates and possible measurement errors due to participants' misunderstanding of questions without the opportunity for the researcher to clarify them (Groves et al. 2009).

3.2.1. Survey Design

The survey was a qualitative/quantitative cross-sectional study. The population target was architects, landscape architects, and engineers with a green design background. The sampling frame, a full list from where the sample is extracted, was obtained from public contact information lists of LEED, and Green Globes certified professionals. The list of landscape architects was obtained through the American Society of Landscape Architects (ASLA). The sampling technique used was a stratified simple random sampling (SRS) without replacement. This technique divides up the population into a small number of groups and then takes a separate SRS in each group. The estimated sample size was 505 participants (adjusted) for a margin of error equal to 0.05. Eight groups were created: architects, LEED Homes architects, landscape architects, engineers (civil, mechanical, plumbing, and environmental), and Green Globes professionals. Data collection was performed via email invitation to an online questionnaire. The questionnaire had 45 questions that took 20 to 25 minutes to answer. The questions were a mix of multiple-choice, matrix of choices, rating scale, and open-ended type. Random selection was only possible on three of the groups because of the limited number of the emails collected in the other groups. The three main groups are architects (29% of all participants), landscape architects (39% of all participants), and civil engineers (10% of all participants), which in total represent 78% of participants. A pairwise comparison-adjusted with Bonferroni correction (Gelman, Hill and Yajima 2012) among these three groups was performed. The response rate of accepted invitations was 12%, and the number of valid responses analyzed was 529 of 777 participants.3.2.2. Survey Results

The following section presents the results from the survey with a focus on informing the development of a process model and a tool that supports SWM design in residential projects. Differences between architects, landscape architects, and civil engineers are highlighted where they are significant. All other results represent all participants.

3.2.2. Survey Results

The results from the survey are presented with a focus on informing the development of a process model and a tool that supports SWM design in residential projects. Differences between architects, landscape architects, and civil engineers are highlighted where they are significant. All other results represent all participants.

3.2.2.1. When should SWM components be introduced in the design process?

The survey results suggest that SWM components are considered in the initial phases of design. Responses to the question, "In what phase of the residential project's life cycle do you include SWM components?" show that the majority of professionals plan for SWM in early phases (see Figure 3.1). When comparing the answers between civil engineers, architects, and landscape architects, the latter two groups showed significant differences with civil engineers on including

BMPs and LIDs in the schematic design phase. In all other stages, there were no differences between the different groups. Responses to the open-ended question, "Thinking on the design process of SWM in residential projects, what would you avoid doing in the future?" 14% of participants stated that they would avoid introducing SWM components late into the design process. Responses presented below illustrate the opinions on the late inclusion of SWM components in the design process:

> "It is best to get the conversation started early in order to get the owner and the entire team thinking about a truly integrated approach. Waiting to talk always makes implementation more costly and more time-consuming."

> "All strategies are good to discuss at the beginning. It is better to narrow down the list sooner so you can move on in the design process."

Figure 3.1 shows that SWM components are also added later in the design process although less frequently than at earlier stages. This may be because specific components are conventionally decided in later stages (e.g., fixtures and fittings) and can be integrated without producing changes in the design (e.g., rain barrels). A model and a tool for SWM design should be targeted to initial phases of design, though without being limited to them.

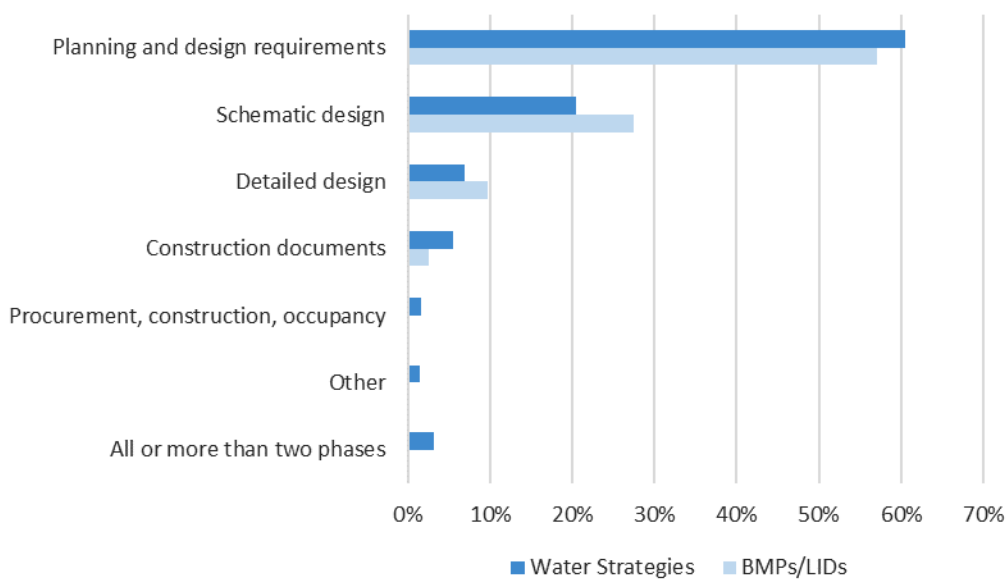


Figure 3.1. Answers to questions "In what phase of the residential project's life cycle do you include the SWM components?" show that SWM components are included early

3.2.2.2. Which SWM components to consider in a tool?

The survey results suggest that a broad range of SWM components are known and have been implemented in residential projects. SWM components included in the survey were divided into two groups: water components from rating standards and Best Management Practices (BMPs). The results show that all SWM components listed in the survey were familiar to the majority of professionals and were implemented in at least one project. Figures 3.2 and 3.3 demonstrate both familiarity and implementation of water components of rating systems and BMPs, respectively. The most-implemented water components of rating standards/BMPs were the simpler ones: 1) water-efficient landscaping, 2) minimum site disturbance, 3) rainwater harvesting for non-potable use, 4) vegetated swales, 5) porous pavement, and 6) bioretention. The least-implemented water components/BMPs were more complex systems. A model and a tool for SWM should consider a set of SWM components that include the most frequently implemented ones. The list of SWM components to include in the tool will be limited, though, by the capability of current modeling methods to represent them.

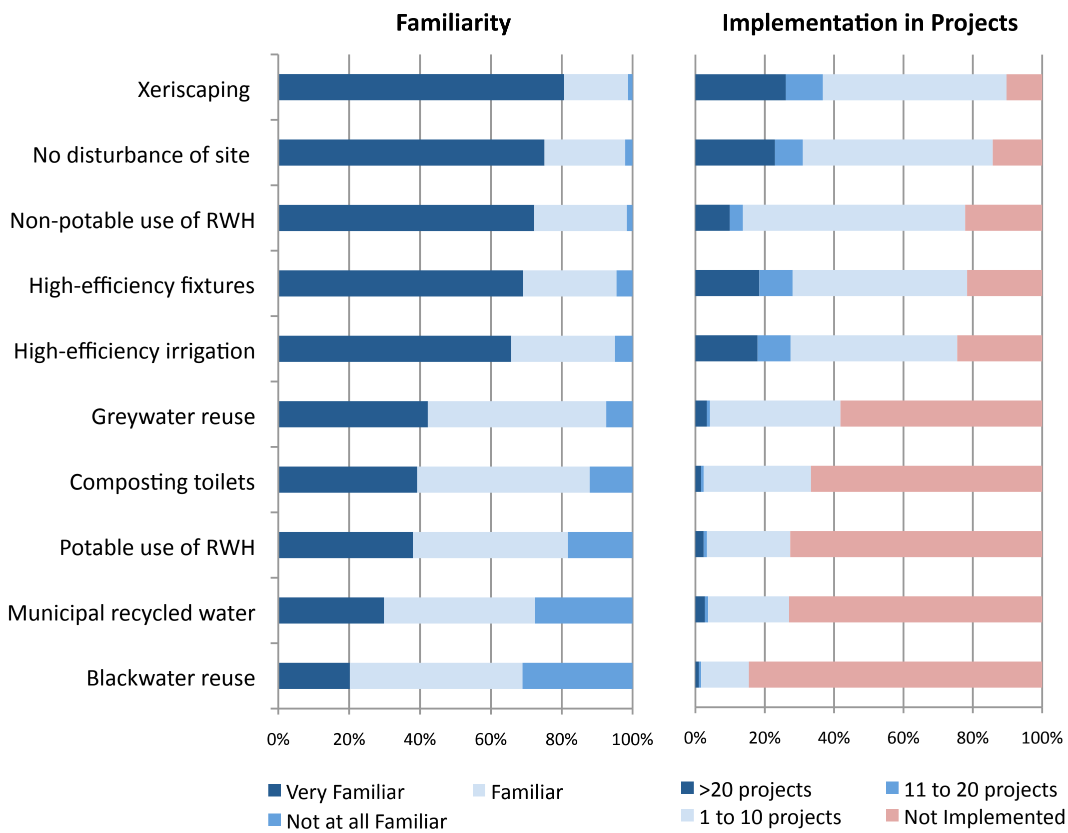


Figure 3.2. The graph shows both the familiarity and implementation of water components in residential projects.

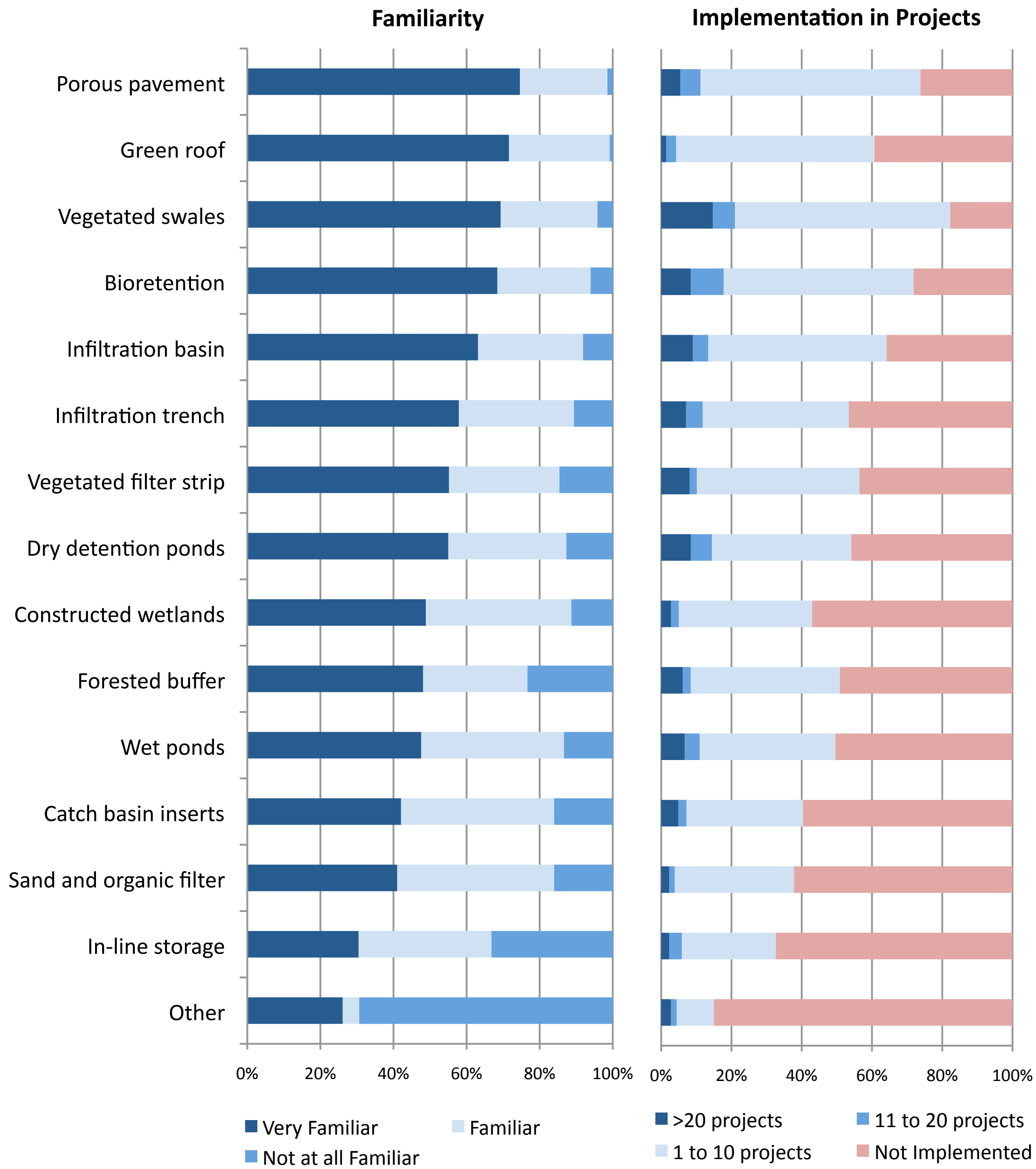


Figure 3.3. The graph shows both familiarity and implementation of BMP's in residential projects

3.2.2.3. Which SWM measurements to consider in a tool?

To assess which types of measure should be included in the tool to evaluate an SWM component, professionals were asked to rate the importance of five measurements during the design process: construction costs, O&M costs, pre- and post-development WBs, a combination of components, and pollutant removal calculations. Figure 3.4 shows that the majority of professionals rated it "extremely" and "very important" to know the initial and maintenance costs of SWM. Even though participants rated environmental measurements lower in importance during the design process, WB calculations and estimation of the quantity of water managed are still considered “extremely” and “very important” by more than 55% of participants. The pollutant removal calculation is lowest rated lowest in importance, with 48% of participants stating that the measure is “extremely” and “very important.” Differences among the three groups were found. Landscape architects ranked higher the importance of the ability to combine strategies compared to architects. Civil Engineers ranked higher the importance of estimating pollutant removal compared to architects and landscape architects. Overall, the economic assessment is a relevant type of evaluation for SWM; information about life cycle cost provides designers with strong evidence to select SWM components during their decision-making process (Moore 2010). Furthermore, environmental performance assessment is a plus when designing for SWM. A model and a tool for SWM should include LLC assessment, water quantity modeling, and estimation of water quality benefits of SWM components.

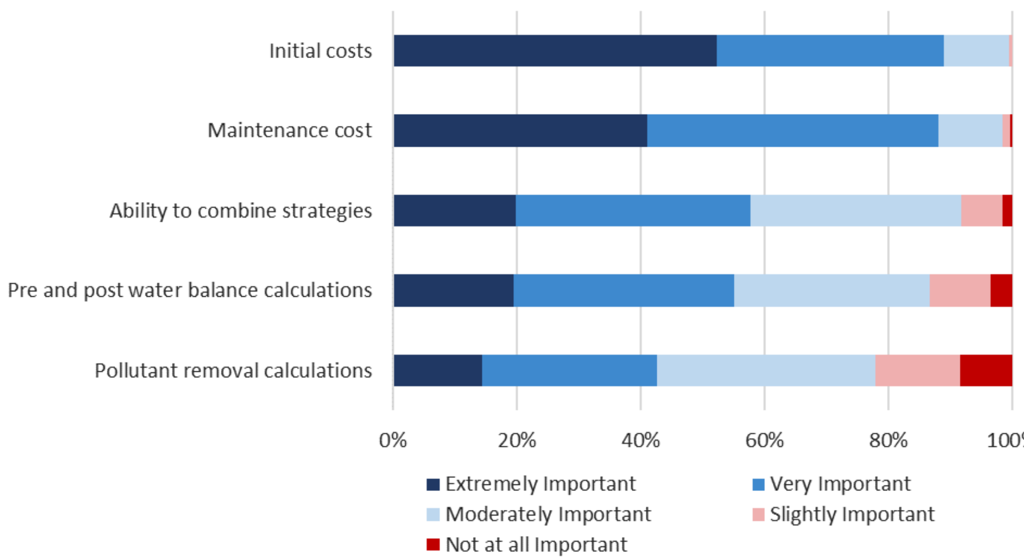


Figure 3.4. The graph shows the importance of 5 measurements during the design process: initial costs (i.e., construction costs), O&M costs, pre- or post-development WBs, combine components, and pollutant removal calculations

3.2.2.4. Evaluation of SWM solutions based on economic and environmental factors

Participants evaluated cost-effectiveness (see Figure 3.5) as an extremely important factor to consider in the design process. Similarly, the initial and O&M costs of components were also of high priority. These results are related to the drivers and barriers to the implementation of

SWM. While the main drivers to SWM implementation come from the personal commitment of designers and clients to green design, the barriers to implementation are high cost or client rejection (see Figure 3.6). Therefore, a tool is needed for the comparison of SWM solutions based on high environmental performance at a lower cost to justify environmental choices with economic feasibility. Such a tool can provide support for a professional's recommendations to a client. A model and a tool for SWM should guide in the selection and comparison of SWM solutions based on economic and environmental benefits using cost-effectiveness and LCC analysis.

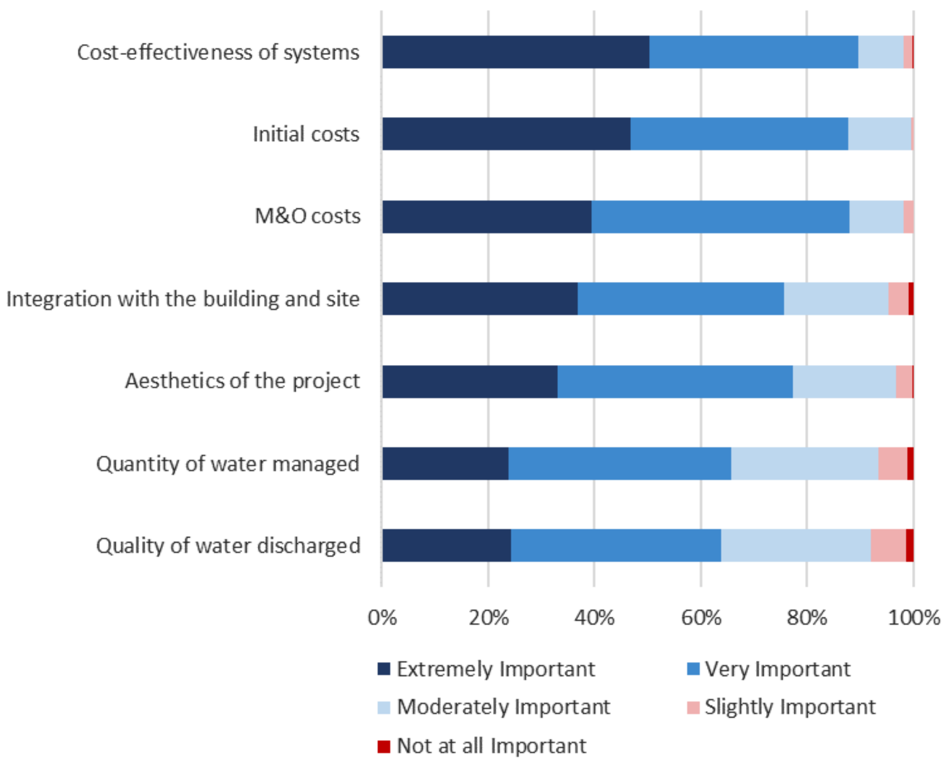


Figure 3.5. This graph shows the importance of evaluating seven aspects of SWM solutions during the design process

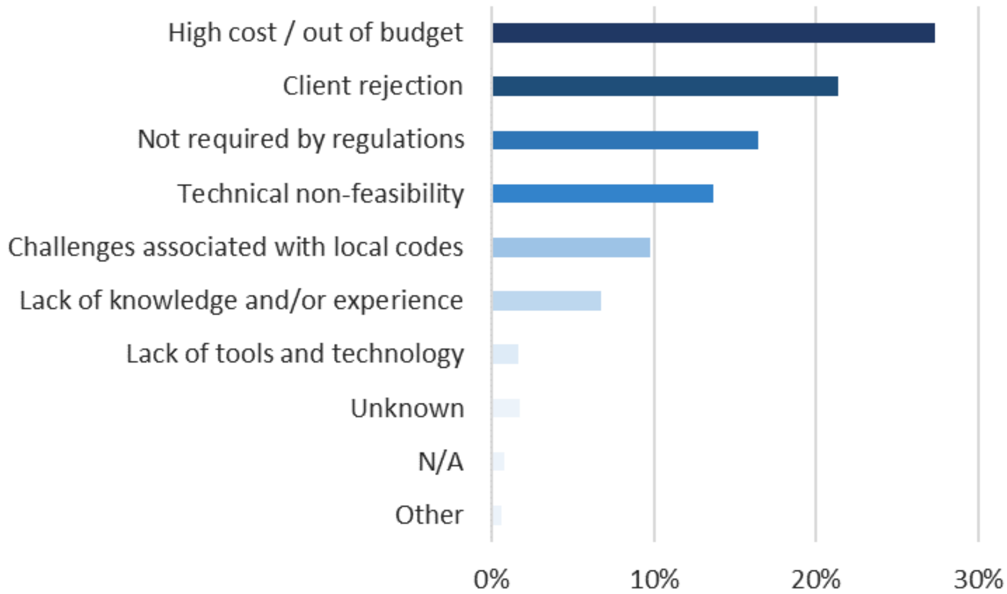


Figure 3.6. This graph shows the main barriers to the SWM implementation: costs, client rejection, and no obligation by regulations, codes or construction standards

3.2.2.5. Standard tools used in SWM design practice and likely of use of a new tool

Results from the survey revealed that computational tools currently used for SWM design in residential projects consist of traditional designers' methodsrather than SWM-oriented tools. The top three tools currently in use are CAD drawings (86.1%), hand sketches (80.1%), and spreadsheets (74.7%). The use of CAD drawings is high among the participants and markedly elevated in civil engineers. Landscape architects use hand sketches more frequently than civil engineers. No significant difference was found among the three groups on the use of spreadsheets. The use of more specialized software is not widespread among participants, and their use is closely tied to their area of expertise: 3D modeling, GIS, and advanced modeling and simulation tools for water management are mentioned by 48%, 20%, and 21% of participants, respectively. Architects use 3D models more frequently than do landscape architects and civil engineers. Civil engineers significantly reported significantly more frequent use of modeling and simulation apps (SUSTAIN, SWMM5, HSPF) compared to architects and landscape architects (see Figure 3.7). No significant difference was found among the three groups in the use of GIS.

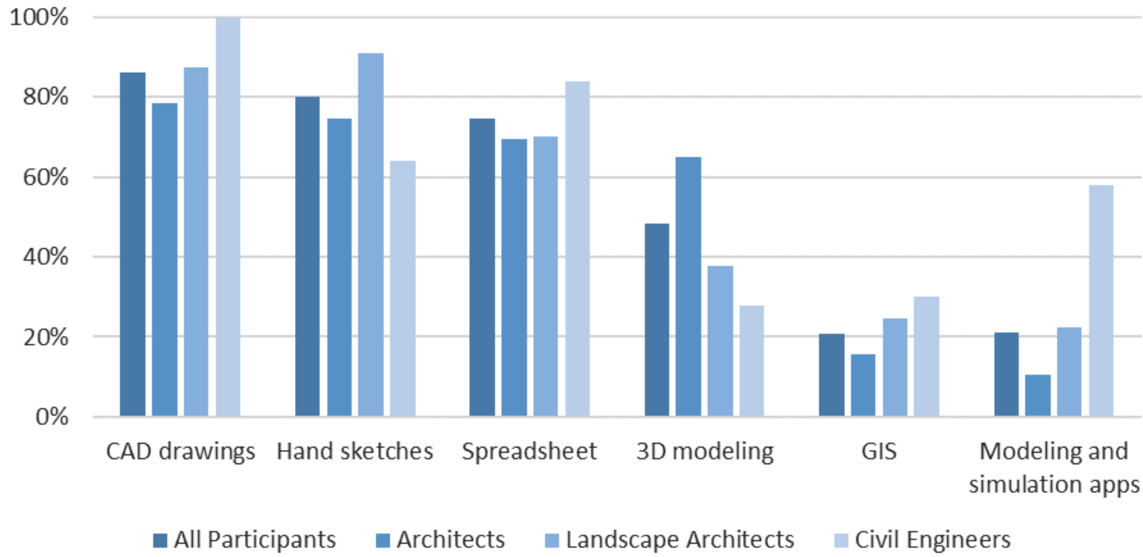


Figure 3.7. Answers to the question, which tools or applications do you currently use when designing for sustainable residential water management? Please select all that apply" show the use of computational tools for SWM design in residential projects for all participants and the three groups analyzed

Professionals will likely use a tool that combines several capabilities for SWM design. 63.2% of professionals stated that they were "extremely" or "very likely" to use a tool that combines initial and maintenance cost computations, pre- and post-construction water balance computations, ability to integrate components, and pollutant removal computation when designing for SWM in a residential project. 24.5% of professionals stated a moderate probability of using such a tool (see Figure 3.8).

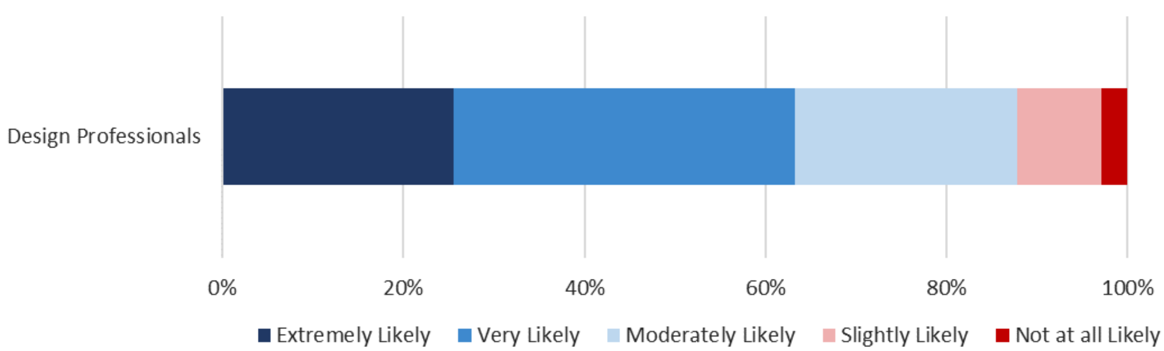


Figure 3.8. Likelihood of using a tool that combines several capabilities for SWM design in a residential project

The preferred type of tool would combine assessments of cost and, water quantity and quality impacts of an SWM solution, and it should be a stand-alone system that that can be coupled with other tools (i.e., CAD, GIS). The second preferred option is an "all in one online tool" (see Figure 3.9). Typically, designers are not willing to spend time learning new tools (Jensen and Elle, 2007). Responses presented below illustrate the leading opinions on the use of tools in SWM design:

"Whatever is easiest and not complex; otherwise, I would not use it."

"a new application should be able to integrate into applications currently and commonly used by the design professionals."

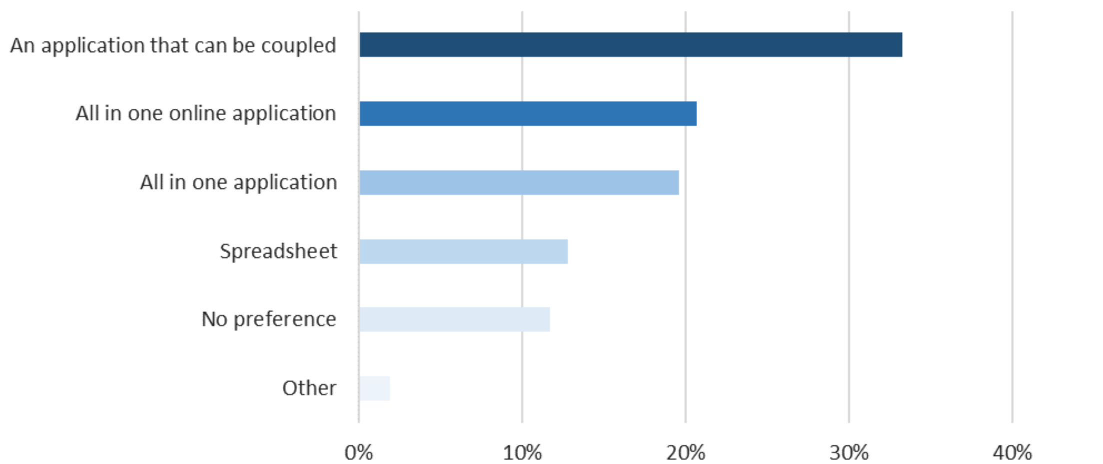


Figure 3.9. Answers to the question, if an application combines cost assessments, water quantity, and quality of an SWM solution, which type of application would you prefer?

An SWM design process model should include the standard tools used for SWM design (i.e., CAD drawings, hand sketches, and spreadsheets) and modeling (i.e., SWMM5, SCS Curve Number). A tool for SWM design should be developed to work with traditional tools or be built on the same platforms (e.g., Excel spreadsheets), be easy to understand and use, and be able to operate with the current tools used by different professionals involved.

Key findings of this section are included in the model and requisites of the prototype tool developed and discussed in Chapters 4 and 5.

4. SWM DESIGN PROCESS MODEL

This section presents an SWM Design Process Model that will support the development of a tool targeted at supporting the design of residential buildings that sustainably manage water.

4.1. Summary of Attributes of SWM Design

From the information and results derived from conducting the literature review, the ethnographic studies, and the survey, I propose a process model that describes the SWM design. Table 4.1 presents a summary of the SWM design attributes taken from the mentioned studies to build the process model and the tool.

Table 4.1. Summary of attributes of SWM design

LR= Literature Review, ES=Ethnographic Studies, and S=Survey

For	The SWM Process Model and the tool should incorporate:	Source		
		LR	ES	S
Design stages	the stages of design plus the occupancy stage (see Figure 2.1)	√	√	
	initial stages of design, though without being limited to them			√
Work organization and stakeholders	a hybrid organization of the design work between the distributed and integrated design approaches	√	√	
	the following list of stakeholders: architect, client, civil engineer, stormwater engineer, landscape architect, construction manager, permit authorities, outside specialists, green design consultants, and providers		√	
Information managing and sharing	JIT information gathering strategy		√	
	professionals' knowledge and know-how as input for design (i.e. cost information of SWM components); the tool also should allow for the recording and sharing of this information between the stakeholders	√	√	√
	the accommodation of a diversity of problems and solutions, and adaptability to different work practices	√		
	the system capabilities, assumptions, calculation methods, and information used	√	√	
	a software environment already known to designers, simple to use (spreadsheets, CAD) and interoperable with the tools used by the stakeholders	√		√
	recording and helping to process climatic and site data, requirements, results of evaluations and comparisons, and the criteria used to evaluate the solutions	√	√	
Specific activities	the iteration of the three main design activities: 1) definition of requirements, 2) generation of alternatives, and 3) evaluation. The tool also should allow users to begin a design at any of the activities mentioned	√		√

Table 4.1. Summary of attributes of SWM design (continued)

LR= Literature Review, ES=Ethnographic Studies, and S=Survey

For	The SWM Process Model and the tool should incorporate:	Source		
		LR	ES	S
Definition of Requirements	the following sub-activities: 1) gathering of information, 2) site analysis, 3) initial water balancing, and 4) defining SWM goals and evaluation criteria	√		
	Reed (2009) and PA DEP's (2006) checklist of information to collect and testing protocols for the gathering of information sub-activity	√		
	the LBC standard for the defining SWM goals and evaluation criteria sub-activity	√	√	
	the redefinition of the requirements without starting from scratch	√		
Codes and constraints	alerts for designers about local regulations and site constraints that affect SWM goals and SWM components, and messages urging them to obtain key information in early phases (e.g. soil type)	√	√	
Generation of Alternatives	the following sub-activities: 1) selection of SWM components, 2) combining of SWM components, and 3) estimation of water performance of a solution	√		
	a large enough set of SWM components to be able to combine indoor and outdoor components			√
	1) the most implemented SWM components from the survey and 2) the PA DEP (2006) manual's list of SWM components for the outdoors	√		√
	the selection process that starts with non-structural SWM components and follows with the structural SWM components (PA DEP 2006)	√		
	the development of alternative solutions and assistance with organizing them	√		
	the development of parallel partial solutions and allowance for the later merging of those alternatives	√		
	collecting, updating, and recording of the evolution of water balances and water system diagrams	√	√	
	water balancing and modeling for rainwater runoff volume and peak rates with common tools used for SWM design (e.g. spreadsheets) and modeling (e.g. SCS Curve Number)	√	√	√
Case-based design	recording and accessing case studies as support for the design (i.e. for informing the definition of requirements and the generation of alternatives)	√		
	the reuse of previous design solutions	√		
Evaluation activity	single and multi-criteria evaluation and comparison of SWM solutions	√	√	√
	economic evaluation using LCC and NPV	√		√
	environmental evaluation using cost-effectiveness based on LCC, water quantity and overall water quality benefits	√		√
	collecting, updating, and recording of SWM component information (e.g. costs, water quality benefits)	√	√	

4.2. Description of the SWM Design Process Model

The SWM design process model is described in this section through IDEF0 diagrams. In IDEF0 diagrams, boxes represent the activities. Inputs to the activities are represented as arrows flowing to the left side of the boxes. Outputs from the activities are represented as arrows flowing out from the right side of the boxes. Constraints are represented as arrows flowing down to the upper sides of the boxes. Mechanisms are represented as arrows flowing up to the bottom side of the boxes. Feedbacks are represented as outputs-inputs segmented lines that flow out from the right side of the boxes to flow towards the left side of the activity boxes (see Figure 4.1).

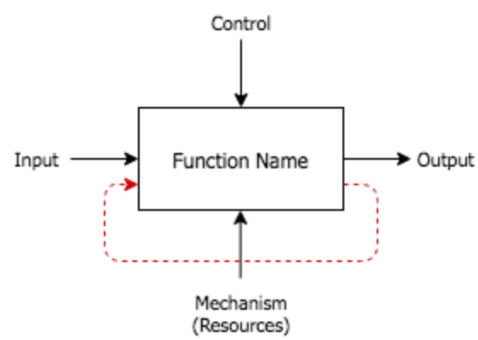


Figure 4.1. IDEF0 diagram

4.2.1. SWM design process: Activities, People, and Organization of the work

The SWM design occurs until the occupancy stages of the life cycle of the building. The model recognizes this and presents how feedback from the occupancy stage and others can generate changes to an SWM solution. The model also presents the hybrid approach for organizing teamwork: distributed, and integrated design. Figure 4.2 shows the overall context where the SWM design happens. Recognizing that the design evolves from the abstract to the concrete, the model integrates conceptual design with detailed design. The output of the design stage is building construction documents.

The design stage (Figure 4.3) is further described as the iteration between the Definition of Requirements, Generation of Alternatives, and Evaluation Activities. Key stakeholders in this stage are architects, clients, civil engineers, stormwater engineers, landscape architects, construction managers, permit authorities, outside specialists, green design consultants, and providers. Tools and practices that support design activities are workshops, meetings, individual work, and JIT information gathering (case-based reasoning). Feedback loops come from within the design activities and from other stages of the design process (segmented line in red in Figure 4.3). In the design stage, inputs include professionals' knowledge and know-how on design, site and project information, regulations, LBC standard, and cases. Constraints on the activity are regulations, LBC standards, budget, and technical restrictions. In the following paragraphs, more details about inputs, constraints, and methods are provided.

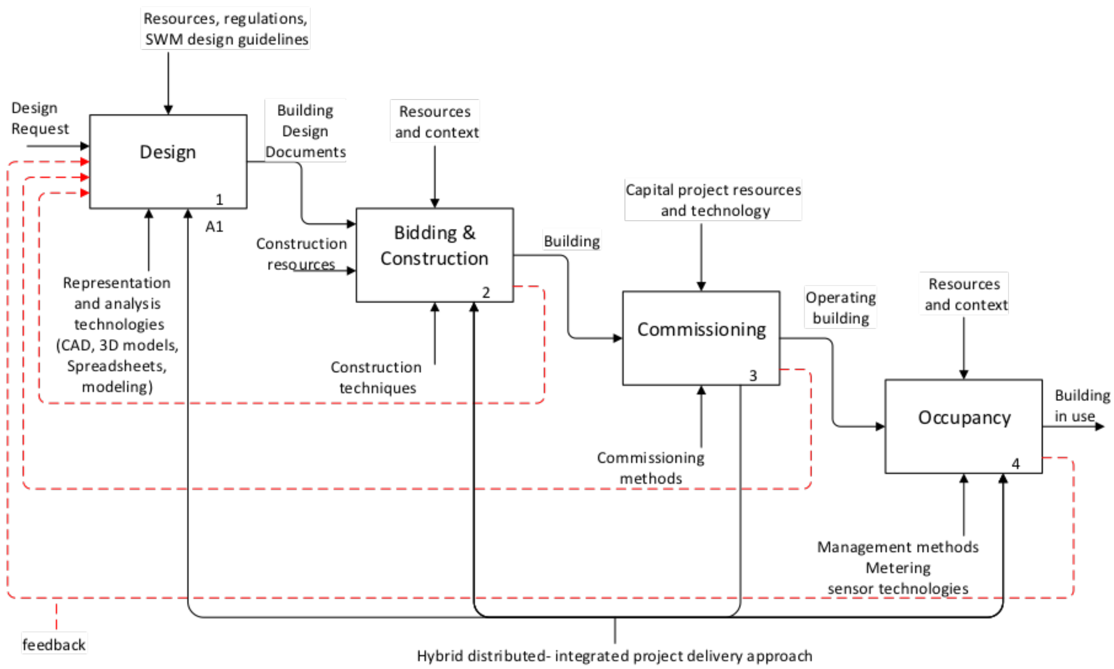


Figure 4.2. Stages of the SWM Design Process Model

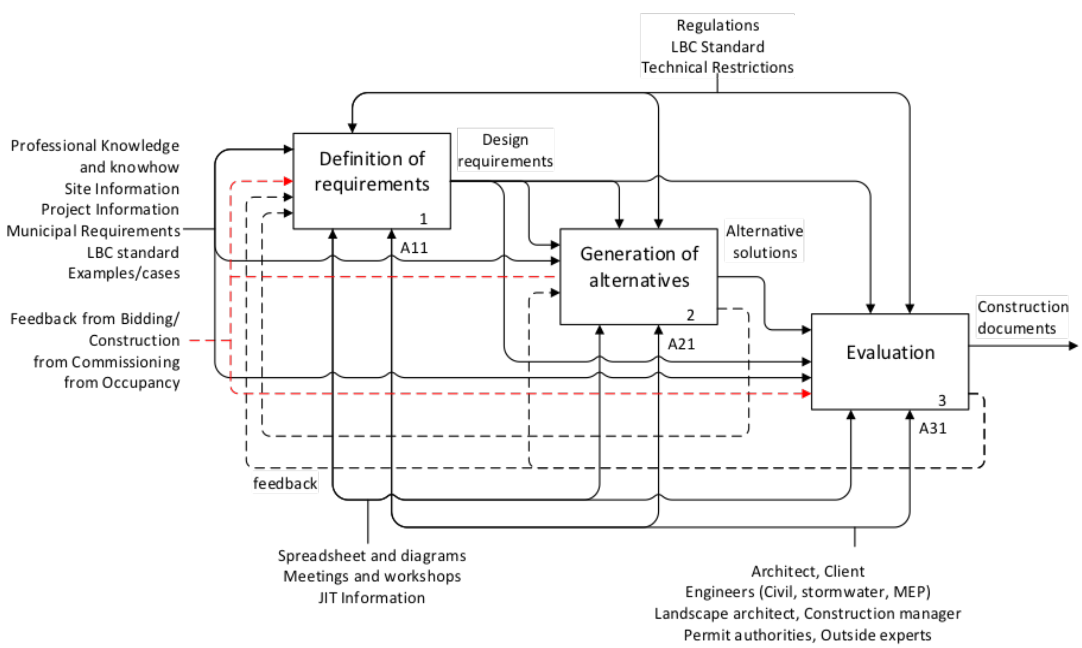


Figure 4.3. Design stage of the SWM Design Process Model

4.2.2. Definition of Requirements and Site Information/Analysis: Inputs and Constraints

The definition of requirements entails five activities: 1) Gather and analyze site information for SWM, 2) Estimate water needs and potential reuse, 3) Estimate water supply, 4) Estimate stormwater to control, and 5) Define SWM goals and evaluation criteria (see Figure 4.4).

Relevant information to the SWM design process is the site information and regulations. They define the scope of the SWM goals in terms of the expected amount of water available for use, reuse, infiltration, and what qualifies as water supply (e.g., rainwater) (see Figure 4.4). Specifically, as represented in Figure 4.5, the information needed for the site analysis is 1) hydrologic description of the site's surroundings such as flooding areas downstream of the site or slide prone areas; 2) site information such as hydrology, topography, soils, vegetation, and existing water infrastructure; 3) examples and cases that refer to how site limitations or opportunities were handled; 4) professional's knowledge and know-how in design practice; and, 5) feedback from other stages of design that trigger the collection of more or new information. For a full checklist on information to gather, see PA DEP (2006) and Reed (2009).

Constraints for an SWM design come from state and municipal restrictions (See Figure 4.5). These restrictions are related to 1) type of water supply allowed, 2) water quality of discharge to streams and water bodies, 3) site grading, landscaping and maintenance requirements, 4) stormwater control, and 5) methodological requirements such as design storm to use or testing protocols. The outputs of the analysis of the site delivers what regulations and requisites applied to 1) the estimations of water needs, supply, and stormwater, 2) the definition of goals and evaluation criteria, and 3) the selection and combination of SWM components (see Figure 4.5).

Initial water balance (blue box in Figure 4.4) comprises three sub-activities: 2) Estimate water needs and potential reuse, 3) Estimate water supply, 4) Estimate stormwater to control (see Figure 4.4). To present the inputs and constraints of the sub-activities, I explain here one of them. Estimating stormwater to control requires as inputs: vegetation cover, soil infiltration rate, and possible rainwater capture. Constraints in estimating stormwater to control are regulations about design storms that may be used in calculations, water quality targets, and limitations to the implementation of SWM components.

In defining the SWM goals and evaluation criteria, relevant inputs are LBC standards and the outputs of the three initial water balance activities. Relevant constraints are site limitations to the implementation of SWM components and particular SWM regulations at the site. For design, both inputs and constraints help to define realistic SWM goals and performance targets for demand/supply, stormwater quantity, and stormwater quality (see Figure 4.4).

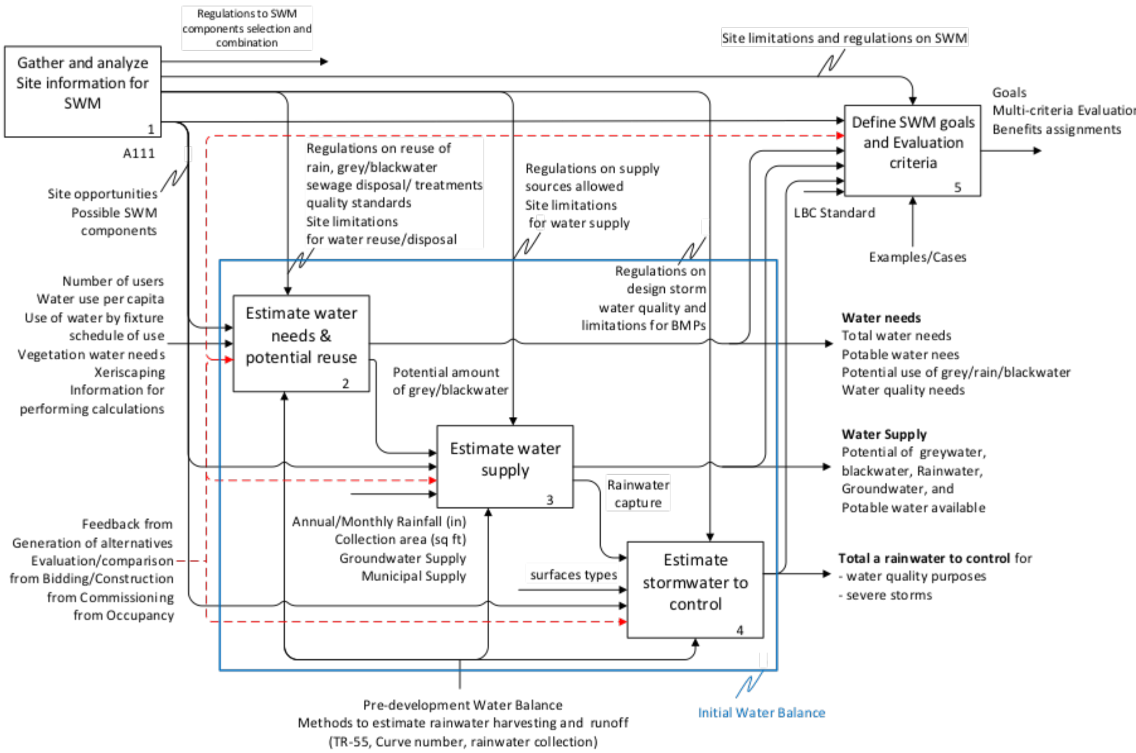


Figure 4.4. Definition of Requirements in the SWM Design Process Model

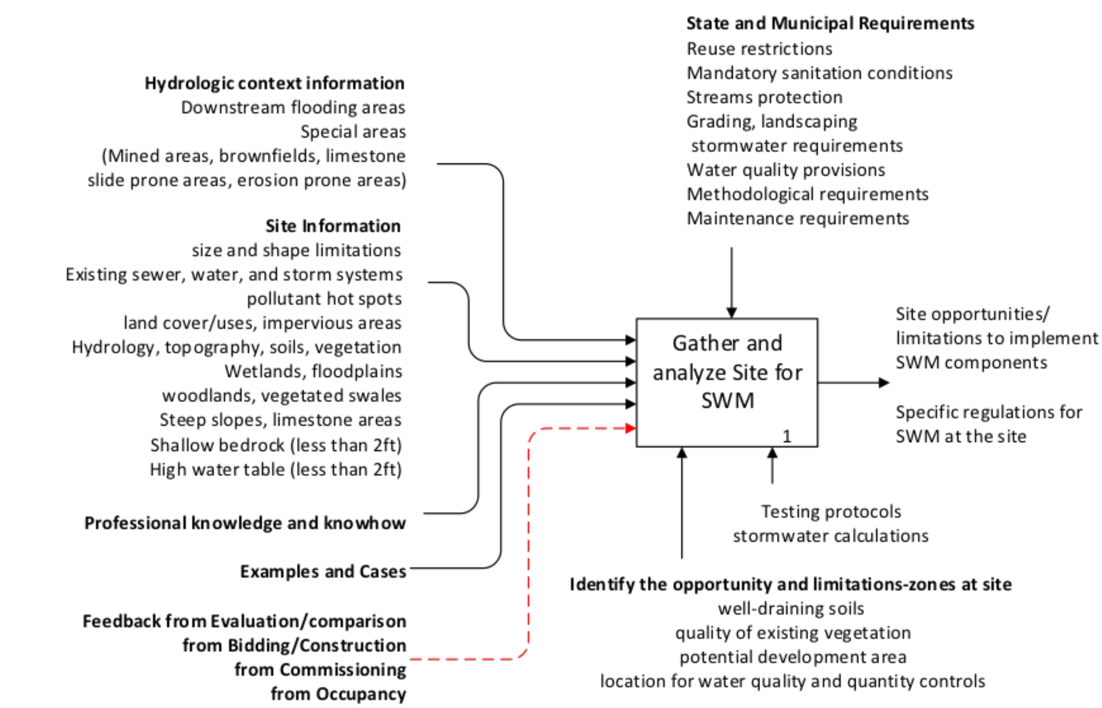


Figure 4.5. Gather and analyze site information for SWM in the SWM Design Process Model

4.2.3. Generation of Alternatives and Evaluation: Mechanisms and Outputs

The Generation of Alternatives activity entails four sub-activities: the selection of SWM components, the combination of SWM components, the estimation of water managed by a solution, and the storage of solutions generated (alternatives) (see Figure 4.6). The use of examples and cases plays an important role in the selection of SWM components as mechanisms or inputs. These provide starting points to generate solutions. For the model, a list of SWM components was created from the survey results and the PA DEP (2006) manual, containing indoor and outdoor components. Relevant constraints in the selection of SWM components are their specific regulations and technical aspects that generally determine the feasibility, suitability, and sizing of the components. The selection process of SWM components follows the "non-structural first, structural-second" method of the PA DEP (2006) manual. The output of the selection of SWM components activity is a set of SWM components prepared for being combined and modeled for performance analysis.

In combining SWM components, system diagrams help to visualize the input and output flows of the different components of a solution (set of SWM components combined). In estimating water managed and cost, the water performance of a solution is calculated using water balance spreadsheets and stormwater modeling methods and tools. The result of the analysis contains the total water managed by the solution, and total water managed on-site, water use and reuse by type, amount of water infiltrated, stormwater performance, and cost of the solution (construction and OO). The output of the Estimated Water Managed and Cost activity can be saved for later use, become the output of the Generation of Alternatives activity, or become feedback for changes in the design.

Finally, SWM design involves decision problems such as selecting water treatment systems, comparing water management or pollutant removal performance of solutions, or deciding based on the cost of systems and the overall construction budget. The decisions in SWM design require a multi-criteria approach, considering diverse and usually contradictory factors (costs versus environmental performance) at the same time that is considered stakeholders' preferences (Ogrodnik 2019). For that reason, the Evaluation activity in this process model considers Multi-criteria decision-making tools. The Evaluation activity is divided into three sub-activities: Evaluation, Storage of evaluated alternatives, and Comparison of solutions (see Figure 4.7). In evaluating a solution, the Life Cycle Cost analysis of a solution is calculated using Net Present Value, water management results are compared to performance targets to assess compliance with the SWM goals. The output of a solution's evaluation is saved for later comparison based on cost-effectiveness or becomes the output of the Evaluation activity. From the evaluation of a solution or comparison of solutions activities, outputs can become feedback for changes or decision making in the design process.

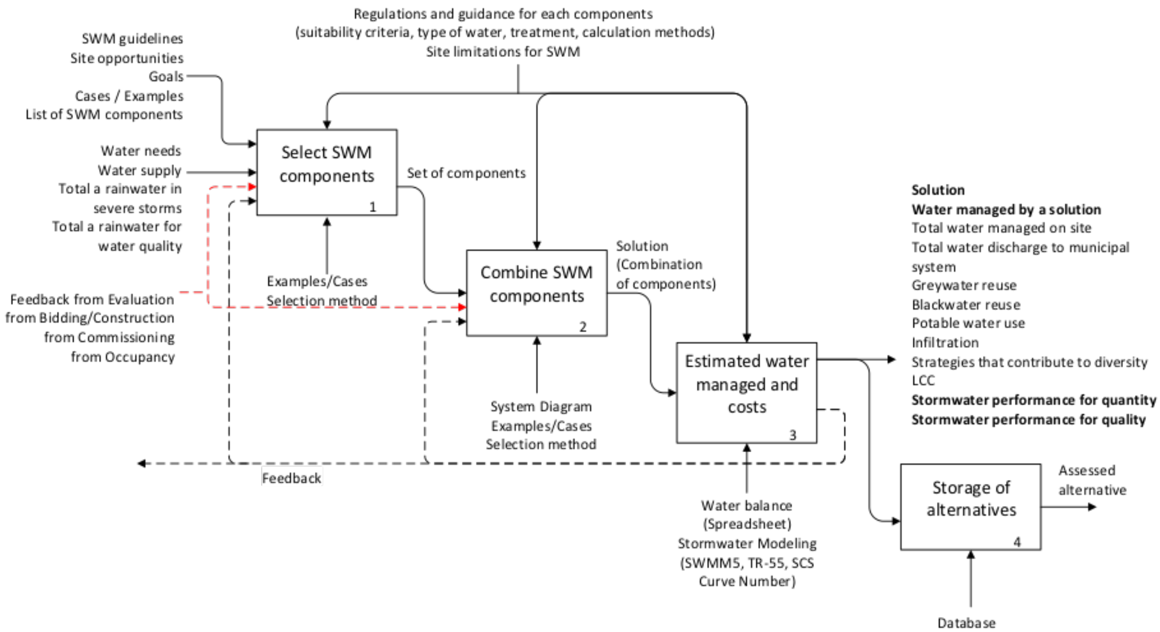


Figure 4.6. Generation of Alternatives activity in the SWM Design Process Model

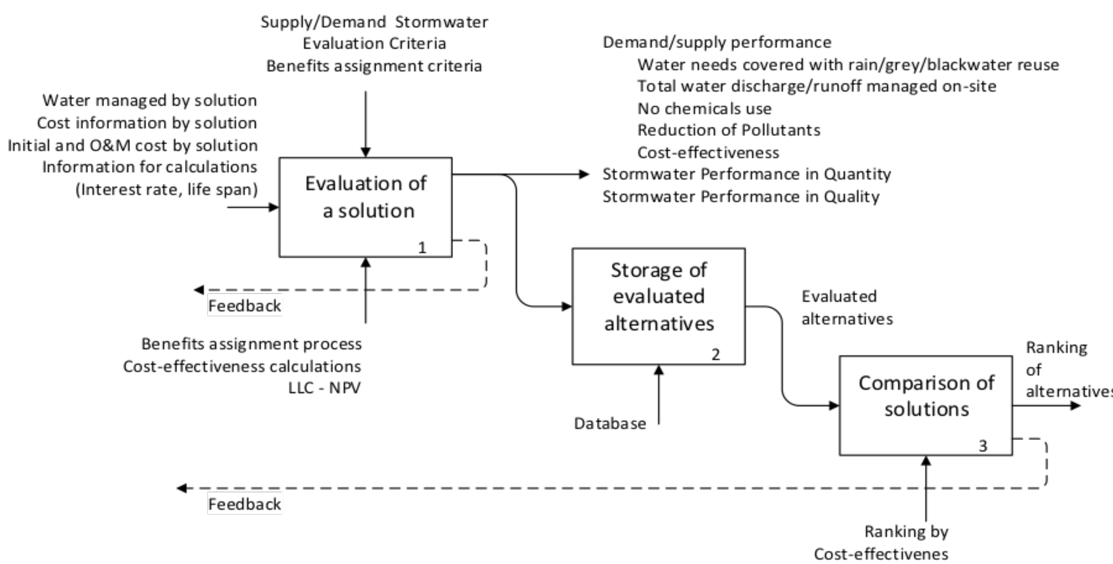


Figure 4.7. Evaluation activity in the SWM Design Process Model

5. A TOOL FOR SWM DESIGN

This section presents the proposed tool for SWM design, its requirements, and a prototype that integrates the required functionalities. The prototype allowed studying the issues on integrating the necessary functionalities with a basic user interface and storage capabilities. The section starts with the identification of the requirements, then describes the use cases and software architecture. The third part of this section presents the prototype's development, scope, components, organization, and testing protocol and results.

5.1. The requirements for a tool for SWM

From the results of the literature review, the ethnographic studies, and the survey, I identified the requirements for a tool that supports SWM design. Table 4.1 presented a summary of the attributes of the SWM design taken from the mentioned studies to identify the tool's requirements. Five requirements for the tool have been defined in this research. These requirements apply to the SWM design process:

1. **Support a holistic approach.** The tool should allow for the definition of goals and their performance criteria to achieve the principles of SWM (Reed 2009; O'Connor, Rodrigo, and Cannan 2010; ILFI 2019). These criteria are:
    1. Minimize water consumption
    2. Use all types of water as supply
    3. Use different water qualities for different needs
    4. Reuse water
    5. Manage all water in the site. Strive for infiltration in the site
    6. Treat water without chemicals (e.g. chlorine)

   To be holistic, the tool should also offer enough SWM components so that all indoor and outdoor strategies are possible and so that the SWM principles are supported. A group of SWM components should include the most frequently implemented ones found in the survey. However, the SWM components list will be limited by the current modeling methods' capabilities to represent them.
2. **Support SWM design in early phases.** The tool should support the following features of early for SWM design:

   1. The tool should support iterations between the definition of SWM goals and evaluation criteria, the generation of SWM solutions, and their evaluation. The designer should be able

to start a design, make changes or update any of these activities at any point of the design. Designers should be able to make changes without starting from zero. The designer should be able to generate partial solutions and combine those partial solutions to form a final one and the tool should help in organizing the alternatives generated.

2. For ease of use, the tool should provide storage of: 1) examples, cases and previous designs, 2) climatic and site data for calculations, 3) design requirements, and 4) the results of evaluations/comparisons and the assumptions applied. Consequently, the tool should also allow managing the collection and update of information, especially for water calculations.

3. The tool should explicitly present the system capabilities, assumptions, calculation methods and information used in the tool.

3. **Support the adoption of local information and regulations and provide guidance on them.** SWM design problems entail resolving technical, regulation, and local water issues (e.g. drought, flooding, combined sewer overflows). The tool should allow the customization of goals and evaluation criteria. Costs or environmental benefits information of SWM components should be able to be updated or added. Local climatic data and site soil information should be able to be entered if not available in the tool. Regulations are one of the main barriers to the implementation of SWM; therefore, a tool should alert designers of limitations that local codes impose on SWM goals and components. The tool should recommend the collection of key information related to the SWM components under consideration (e.g. soil testing, building distances).
4. **Support decision-making about SWM components taking into account economic and environmental factors.** The tool should support the evaluation and comparison of solutions based on multiple economic and environmental criteria. Economic assessment should be based on Life Cycle Cost analysis using Net Present Value. Environmental assessment should be based on water quantity assessments and pollutant loads. The evaluation should include all of the criteria and convey the tradeoff among them.
5. **Support Water Balance estimations for SWM solutions.** The tool should support the quantification of water managed by a combination of SWM components (a solution). Two main methods should be included: Water Balance for demand and supply conditions and stormwater estimations. For estimating water balance, inputs and outputs for annual and monthly volumetric estimations should be included. For estimating stormwater to control, simulation of rainwater runoff volume and peak are required.

Three other requirements for the tool have been defined. These requirements apply to the whole process, not exclusively to SWM design:

1. **JIT Information Gathering Strategy.** The tool should support the collection and recording of information, as it is needed, just-in-time. Relevant information from all sources, such as phone calls, face-to-face meetings, emails with outside experts, green design consultants, and providers, should be able to be saved along with the evolution of the design solution.
2. **Collaborative Work.** The tool should support collaborative work related to the sharing of information and assumptions among the different stakeholders. It should support 1) the recording and sharing of professionals' knowledge and knowhow that emerges during the design process and 2) the sharing SWM components information.
3. **Software environment friendly to users.** The tool should be built on well-known platforms for SWM professionals. In the case of SWM design, spreadsheets are commonly utilized. It should be easy to understand and use, so designers are willing to learn it. A tool should be able to interact with the current applications used by different professionals involved in the design process.

5.2. Implementation in Uniform Modern Language

This section presents the SWM tool's implementation to put into practice the requirements described in Section 5.1. The implementation has two components: the software architecture and the description of the use cases.

5.2.1. Use Cases Identified

A use case is a group of steps that describe the interplay between the user and the system to complete an objective (e.g. to evaluate a solution). To develop the tool's software requirements for the features described, I have identified eleven use cases (Cockburn 2000) which can be also be thought of as the components of the design process. The use cases are:

1. Entering Site Information
2. Guiding the Designer
3. Estimating Initial Water Balance
4. Defining Goals and Evaluation Criteria
5. Defining a scenario (dry, wet, normal weather) (water demand)
6. Building a solution
7. Building a model (scenario + solution)

8. Estimating the water performance and cost of a model
9. Evaluating a model
10. Comparing models
11. Storing information in the database

The first two use cases are oriented to the input of site information. Inputs come from the users' knowledge or are pulled from the database. The designer controls the input of site location, characteristics, limitations, and climatic data. For climatic data, the system can accept designers' inputs or retrieve climatic data and hydrologic data for defined locations from a database.

For regulation information, the system is in charge of retrieving regulations and SWM design guidelines according to the site location, from the database. To provide guidance to the designer, the system revises the regulations and sends alerts about code restrictions that affect SWM goals, evaluation criteria, and SWM components.

The third use case is oriented to the estimation of the Initial Water Balance. The designer is in charge of inputting project information. The system sends the project and site information for estimating demand and supply, performing pre and post-development water balances and to estimate stormwater runoff volume, pollutant loads and peak discharge.

The fourth use case is oriented to defining the goals and the evaluation criteria for the design. The designer is in charge of defining the SWM goals (e.g. 100% of water use will be covered with captured rainwater). The system, according to the goals and code restrictions, will translate the goals to performance targets and scores for evaluating the solution. If preferred, the designer can accept or change the performance targets and scores.

Use cases 5, 6, and 7, are oriented to building the model. Here, a "model" is comprised of a "scenario" and a "solution" or design. The designer builds a scenario, which consists of water demand and climatic data, and a solution that contains a combination of SWM components. The system then combines the scenario and the solution and forms the model for which water performance and costs will be estimated.

Use case 8 is oriented to the estimation of the water performance and cost estimates of the model. The designer only has to initiate the run and the system determines the water balance for the demand and supply conditions, stormwater quantity, quality and peak flow, and life cycle costs of the model. Determining the water quantity and water quality benefits of the SWM design requires modeling of water volume for storm events.

The evaluation and comparison of solutions are covered in use cases 9 and 10. The designer has to request the evaluation of the current model, or the comparison of several models already stored in the system. For the evaluation, the system retrieves the information of the model and compares its water performance results against the performance targets. Then, the system builds a cost-effectiveness curve to compare different solutions.

Finally, storing information in the database is covered in use case 11. The designer can save new data or save a design into the database. The system assists by communicating to the database for saving the relevant information.

Access to the database provides the designer the capability of customizing the design to local conditions such as climatic data, site information (soils), augmenting the SWM components library, and reusing past solutions. These use cases can be found in Appendix C.

5.2.2. Software Architecture

The software architecture employed is based on the Model-View-Controller pattern (Larman 2002) which separates the user interface from database control and manages the coordination and transference of information between the modules with a controller. The separation allows the developer to make changes to any of the components without affecting the others. The architecture is shown in Figure 5.1 and discussed below.

The system's software architecture contains three main sections: User Interface (UI), Process Module, and Database.

5.2.2.1. User Interface

The UI organizes the user's inputs into 5 sections:

1. The Site Information UI receives information about the site for performing water balance calculations, estimation of stormwater to manage, and water quality for pre and post development. User's inputs are location, size, length, width, slope(s), land cover, and associated runoff coefficients, soil hydrologic groups, length of flow and user identified site's constraints.

2. The Initial Water Balance UI receives user's inputs for three topics: users' water needs, landscape's water needs, and roof collection areas for rainwater harvesting—which support the estimation of the initial water balance for the site.

3. The Goal and Evaluation UI allows the user to set SWM goals and evaluation criteria for assessing a design or to compare alternative designs and to command the evaluation and comparisons of solutions.

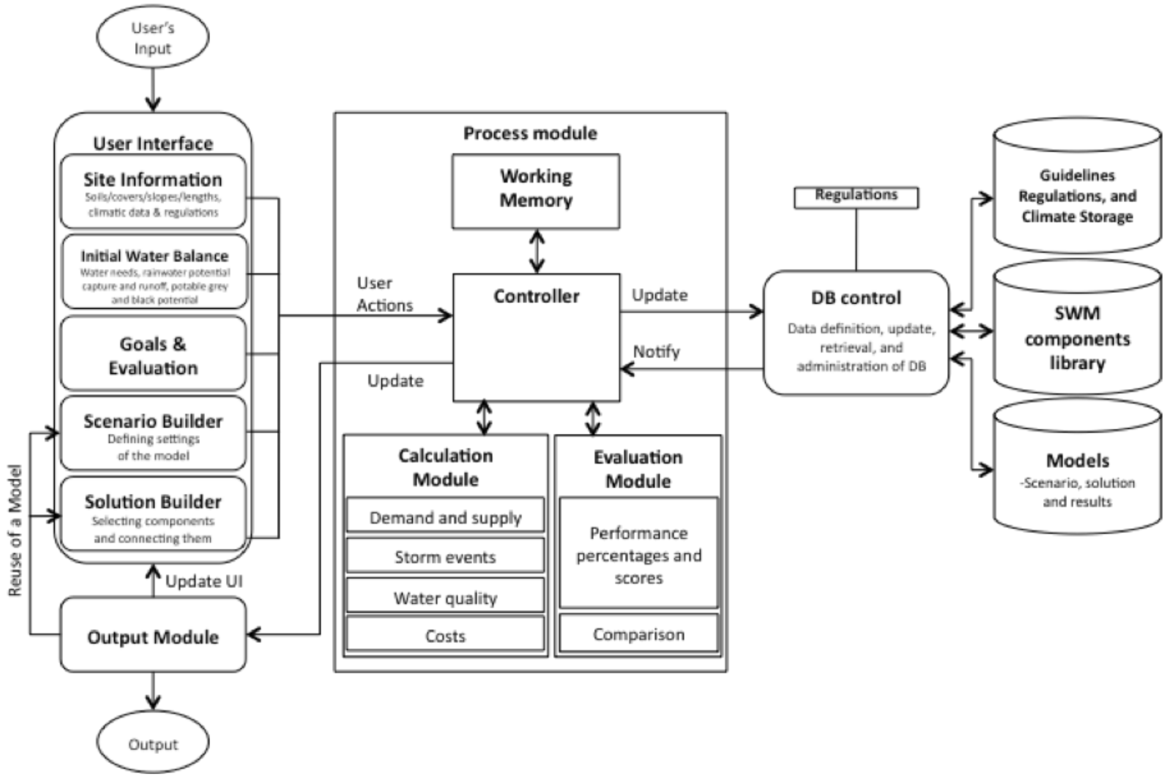


Figure 5.1. Software Architecture

4. The Scenario Builder UI allows the user to define what-if conditions for analysis, changing rainfall or water demand of the project.

5. The Solution Builder UI allows the selection of SWM components from the library (e.g. rain garden, rainwater harvesting cistern systems) and their combination. Water inputs and outputs are defined in the solution builder UI, creating a solution.

5.2.2.2. Process Module

The Process Module contains four components: Controller, Working Memory, Calculation Module and Evaluation Module.

1. The Controller coordinates the information and transfers data between the user interface, the Working Memory, the calculation modules, the database control, and the output module.

2. The Working Memory stores the current input information and the results of the Calculation and Evaluation modules. This is a temporary memory where the different actions of the user in building a solution or solutions are recorded.

3. The Calculation Module performs all the calculations needed in the tool. Here are located the modeling methods and calculation procedures to estimate the performance of a solution. The estimations are: Indoor water needs, other water needs, Landscape water needs, Rainwater harvesting potential supply, Stormwater volume runoff, Stormwater runoff quality, Stormwater runoff peak discharge, Water balance, Life cycle cost, and Goals setting.

4. The Evaluation module contains the methods to compare a solution against the evaluation criteria and with other solutions.

5.2.2.3. Database

The Database Control handles data definition, update, retrieval, and administration of three sections 1) water use, guidelines, regulations, climate, and site data; 2) SWM component library; and, 3) storage of solutions. It also receives and transfers plug in information to the database (i.e., regulations plug-ins).

The Output Module updates the user interface, allows the reuse of stored solutions, and handles additional outputs needed such as new windows with graphs and tables for visualization of results.

Finally, the software environment proposed for this tool is a Microsoft Excel (ME) spreadsheet, with an interface developed in Visual Basic and a database. ME spreadsheets are commonly used and are able to perform the most accepted hydrologic methods (Moore 2010; Ahiablame, Engel, and Chaubey 2012; Liu et al. 2015; Wilkerson et al. 2010).

5.3. Prototype Development

5.3.1. Prototype scope

In software design, a prototype is a concrete piece of software representing a part of a future interactive application. Different types of prototypes can serve different purposes for the creation of an application. Selecting the appropriate level of development of a prototype helps to efficiently gather the data desired by the researcher (McCurdy et al. 2006). The following paragraphs cover five critical factors considered in building and testing the prototype implemented in the dissertation.

5.3.1.1. Throw-away, Iterative and Evolutionary Prototypes

Three types of prototypes regarding life span are identified in the literature: throw-away, iterative and evolutionary. Throw-away prototypes are recommended as the indicated method to test new systems because they are cheap and easy to build and discard, allowing the researcher further iteration and testing of the features under analysis (Beaudouin-Lafon and Mackay 2007). This dissertation aims to establish the basis for an application's future development; therefore, a throw-away prototype is developed to serve as an exploratory tool that can be easily replaced.

5.3.1.2. Breadth versus Depth of Functionality

Four types of prototypes are defined in the literature regarding the breadth or depth of the functionalities represented: horizontal, vertical, task-oriented, and scenario-based prototypes. Horizontal prototypes are representations of the complete application without developing the details of its functionalities (Beaudouin-Lafon and Mackay 2007). On the other hand, vertical prototypes are only a part of an application that represents only one functionality, and they are useful for analyzing feasibility (Beaudouin-Lafon and Mackay 2007). Task-oriented prototypes are a combination of horizontal and vertical prototypes that usually cover several functionalities. They cover several tasks (breadth) and implement in detail the functionalities that support those tasks (depth) (Beaudouin-Lafon and Mackay 2007). Finally, the purpose of scenario-based prototypes is to show how they would be used in a real context and over time (Beaudouin-Lafon and Mackay 2007). For this dissertation, a task-oriented prototype has been selected since it will cover future application requirements. These requirements need to have a representation of the functionalities to be adequately tested.

5.3.1.3. Interface Versus Functionality Focus

Prototypes can be focused on user interaction or the functionality of the future application. Since a task-oriented approach has been selected, the prototype focuses on the tool's functionality to test the requirements. Therefore, there is less emphasis on interface development.

5.3.1.4. Accuracy and Richness of the Data in Use

The accuracy and richness of the data used in the prototype can range from general, modeled, or real data. Depending on the relevance of the data with the task to be performed, McCurdy et al. (2006) recommend deciding on the depth and extent of the data according to how they affect task performance and the purpose of the prototype. For example, McCurdy et al. (2006) developed the SPIFe prototype as a high-end prototype regarding the richness of data because they tested the complexities of the management of a planning tool that contained hundreds of activities. In this case, a simplified version would not represent the real-world challenges under study. For this dissertation, a medium to a high level of accuracy is proposed for the prototype. A medium depth of data regarding regulations will be implemented (i.e., only federal or state level of regulations) and covering only three cities in three different climates. A medium accuracy of cost information will be used as well. For water performance calculations, a high level of data accuracy will be used, so the modeling methods implemented can be compared against other publications using the same procedures.

5.3.1.5. Level of Visual Details

The level of visual details ranges from the high refinement of high quality and fully-designed mock-ups or screenshots to low sophistication in the form of hand-drawn paper prototypes (McCurdy et al. 2006). Minimal visual details are recommended for early design stages because they allow general prototype questioning and foreseeing essential issues at a low cost (McCurdy et al. 2006; Budde et al. 2011). For this dissertation, a low level of visual detail has been selected to develop the prototype to concentrate more on the functionality of the tool than on the aesthetics.

5.3.1.6. Summary of Prototype

The proposed prototype is a medium-fidelity prototype since it will be a partial representation of the complete software. This medium-fidelity prototype will be developed in an Excel spreadsheet where the processor module and the database's functionalities are represented. The prototype was created on my personal computer and is a throw-away object, integrating real calculations supported by the spreadsheet. It depicts in breadth and depth the requirements identified. The prototype has medium to high accuracy and richness of the data to perform calculations and provide good results. Data used in the prototype come from reliable sources. This medium prototype has a low visual detail. This prototype's purpose was to have an object that can be easily modified and tested several times.

5.3.2. Prototype Implementation

This section presents the components and operation of the prototype that put into practice the requirements described in sections 5.1 and 5.2.

5.3.2.1. Estimation and Evaluations Methods

Implementing the requirements of the SWM tool entailed the selection of methods to estimate or evaluate the many elements of a SWM model. Multiple alternative methods have been proposed in the literature for the following modules:

1. Indoor water needs and other water needs
2. Landscape water needs
3. Rainwater harvesting potential supply
4. Stormwater volume runoff
5. Stormwater runoff quality
6. Stormwater runoff peak discharge
7. Groundwater recharge
8. Water balance
9. Life cycle cost
10. Goals setting
11. Evaluation and comparison of solutions

The selection of methods was made according to the criteria below. Each method was evaluated in each parameter assigning a score from one to three, with 1 being low compliance and 3, high compliance. The sum of all scores is the total for each method. The method(s) with the highest total was (were) selected. Table 5.1 presents the methods, the scores assigned and totals. Water balance, Life cycle cost, Goals settings, and Evaluation and comparison of solutions methods are not included in the table.

Selection criteria:

1. **Simplicity:** The method is simple enough to be understood and performed by users without water management knowledge.
2. **Accuracy:** The method uses data from reliable sources
3. **Implementability:** The procedure is described adequately in the literature
4. **Standard:** The procedure is widely accepted

5. **Transferable to a spreadsheet:** The method can be transferred and performed in a spreadsheet.
6. **Data available:** Data is available for using the method with the locations selected (Pittsburgh, Vancouver, and Concepcion)
7. **Uses local/Site data:** The method runs with local data or local data can be added to the computation.
8. **Ease of integration:** Can integrate the procedures and their results with other models used in the prototype.

For Indoor Water Demand, two methods were selected, 'Estimate water demand by each device/activity' and 'Meter readings and water end-use statistics.' The first one is the standard procedure to estimate water consumption. This method allows to divide the water demand into potable and non-potable supply requirements and estimate the potential grey-and blackwater production. The second method was selected because it provides the designer with an alternative estimation procedure that includes a metered water consumption (supplied by the client) for a quick estimation in the absence of detailed information. The 'Meter readings and water end-use statistics' procedure provides a close enough potable and non-potable supply requirements based on DeOreo et al. (2016) and potential grey-and blackwater production.

For Landscape Water Demand, the ANSI/ASABE S623.1. Determining Landscape Plant Water Demands was the preferred method because its applicability in several regions due to the use of local climate data in the procedure. The WUCOLS IV was excluded because it is a method developed for landscapes in California. The PNNL method was excluded because it uses averaged evapotranspiration data for regions, making it less customizable.

For Stormwater volume and runoff quality, the L-THIA-LID 2.1 was preferred since it is widely accepted and uses simple runoff volume calculations. The model includes estimations of volume and quality and is transferable to spreadsheets. In addition, the use of the model was facilitated by Dr. Liu and Dr. Engel (Purdue University), who sent the python code to be used in this dissertation work. The Latis-LIDIA and National GVC methods were excluded for not being customizable to local conditions. The SSHM, the NSC, and the WERF SELECT methods were excluded because of the complexities of transferring the methods to spreadsheets. The LIDRA method was excluded because it only calculates runoff volume.

For Rainwater Harvesting Supply, the Texas Manual procedure on Rainwater Harvesting was selected since it is the professional practice preference.

Table 5.1. Comparative Table of Methods for the Prototype

Scores (1-3) indicate low- to high-compliance

Estimation	Methods	Simplicity	Accuracy	Implementability	Standard	Transferable	Data available	Uses Local Data	Ease of integration	Total	Source
1. Indoor Water Demand	Estimate water demand by each device/activity	3	2	2	3	3	3	3	3	**22**	Cahill et al. 2013
	Meter readings and water end-use statistics	3	1	1	2	3	3	3	3	**19**	DeOreo et al. 2016
	Average use gal/capita/day and water end-use statistics	3	1	1	1	3	3	1	3	**16**	DeOreo et al. 2016
2. Landscape Water Demand	ANSI/ASABE S623.1. Determining Landscape Plant Water Demands	3	2	3	3	3	3	3	3	**23**	ASABE 2017
	Water Use Classification of Landscape Species (WUCOLS IV)	3	1	3	3	3	1	3	3	**20**	Costello and Jones 2014
	Estimating Landscaping Water Use Using the Evapotranspiration Method. (PNNL)	3	1	3	3	3	2	2	2	**19**	McMordie 2010
3. Rainwater Harvesting Supply	The Texas Manual on Rainwater Harvesting	3	2	3	3	3	3	3	3	**23**	Mechell et al. 2009
	NRCS Curve Number Runoff Volume	2	2	3	2	3	3	3	2	**20**	Liu 2015
4. Stormwater Volume	NRCS Curve Number Runoff volume (L-THIA-LID 2.1)	2	2	3	3	3	3	3	2	**21**	NRCS 1986; Liu 2015
	Small Storm Hydrology Model (SSHM)	2	2	3	3	3	1	3	1	**18**	Pitt 1999
	LIDRA	2	2	3	3	2	1	3	1	**17**	Montalto 2007; Yu et al. 2010
	National Stormwater Calculator (NSC)	1	2	3	3	1	2	3	1	**16**	Schifman et al. 2018
	Latis-LIDIA	2	2	3	3	1	1	3	1	**16**	Wilkerson et al. 2010
5. Runoff Quality	Event Mean Concentration and Irreducible Concentration methods (L-THIA-LID 2.1)	2	2	3	3	3	3	3	2	**21**	Liu 2015
	The National Green Values™ Calculator (National GVC)	3	3	3	3	3	1	1	1	**18**	CNT 2013
	WERF BMP SELECT Model (WERF SELECT)	1	2	3	3	1	2	3	1	**16**	Reynolds et al. 2012
6. Stormwater Peak Discharge	Rational Method (RM)	3	1	3	3	3	3	3	3	**22**	McCuen, Johnson, and Ragan 2002
	NRCS Graphical Method Peak Discharge	2	2	3	3	3	3	3	3	**22**	NRCS 1986
7. Groundwater Recharge	New Jersey Groundwater Recharge Method	2	2	3	1	3	1	1	1	**14**	Blick, Kelly, and Skupien 2004
	Estimation of actual evapotranspiration and groundwater recharge	1	1	3	1	2	2	1	2	**13**	Miegel, Bohne, and Wessolek 2013

For Stormwater Peak Discharge estimation, both methods were selected. The NRCS Graphical Method Peak Discharge for US regions and the Rational Method for Chilean cities. More details of its use in Section 5.3.2.1.5.

The prototype did not include groundwater recharge estimation because: 1) the New Jersey Groundwater Recharge Method (NJGRM) has been specifically developed for the municipalities of the state for which parameters such as the climatic factor (ratio of precipitation to potential evapotranspiration), the average annual precipitations, the soil series information and parameters for root zone water capacity have been prepared only for that region. Its implementation outside the New Jersey State requires the development of such information, work that is outside of this dissertation scope. And 2) the Miegel, Bohne, and Wessolek (2003) method has been developed for German soils where capillary ascent rates from the groundwater to the lower limit of the effective root area as a function of soil type (parameters p1 and p2 needed as inputs in the estimation) are not developed for US soils. In an email conversation with Dr. Bohne, he suggested two alternative methods to estimate p1 and p2 values:

a. to choose a texture class (from the ones available for the German soils) according to the clay and silt content of the site's soil. This would yield an approximate estimation of p1 and p2.

b. for a more precise estimation perform the following steps:

> "1. Estimation of the parameters of the vanGenuchten equation either from measured soil water retention data or from a pedotransfer function of your confidence; 2. application of eq. (6) to a range of groundwater depth values; 3. estimation of p1 and p2 by regression." (Bohne, Klaus, 'Program GWR for United States'. Email, 2018).

The two methods suggested by Dr. Bohne presented drawbacks for their implementation in the prototype. The first suggestion uses data that are not site-specific making the results not accurate enough for this research. The second suggestion involves work beyond the scope of this research.

Water balance, Life cycle cost, Goals settings, and Evaluation and comparison of solutions methods are discussed later in this chapter.

Descriptions of the selected methods and their operation in the prototype are found in the following paragraphs.

5.3.2.1.1. Indoor Water Needs and Other Water Needs

Indoor Water Needs estimation provides a monthly water volume needed to cover potable and non-potable requirements and the type of discharge that is generated (grey or blackwater). The disaggregation of water needs by artifacts (or activity) has been set as the primary procedure because it provides the detail required (Cahill et al. 2013). The monthly indoor water volume is estimated from daily consumption of drinking water and use of artifacts. For example, monthly water use for single flush toilets is estimated using Eq. (1):

$$Q_t = \left(\frac{gallons}{flush}\right)\left(\frac{flush}{day \cdot person}\right)\left(\frac{persons}{household}\right)\left[\frac{days}{1\ month}\right] \quad (1)$$

Where:

Q_t = Toilet monthly water use in gallons

Default users' habits were obtained from DeOreo et al. (2016), DeOreo and Mayer (2014), and the Observatorio de Ciudades UC (2009). The flow rate and water volumes for artifacts were obtained from EPA 2020; DeOreo and Mayer 2014; DeOreo et al. 2016, for the US and the Observatorio de Ciudades UC 2009, for Chile. For each water use, equations have been developed and can be found in Table 5.2.

Table 5.2. Equations for each water use

Artifact / Activity	Equation
Drinking Water (d)*	$Q_d = \left(\frac{gallons}{day \cdot person}\right)\left(\frac{persons}{household}\right)\left[\frac{days}{1\ month}\right]$
Bathroom Faucet (b) Kitchen Faucet (k) Showerheads (s) Pre-rinse valve (r)	$Q_{b,k,s,r} = \left(\frac{gallons}{minute}\right)\left(\frac{persons}{household}\right)\left(\frac{number\ of\ uses}{day \cdot person}\right)\left(\frac{minutes}{use}\right)\left[\frac{days}{1\ month}\right]$
Toilets (t)** Urinals (u)	$Q_{t,u} = \left(\frac{gallons}{flush}\right)\left(\frac{flush}{day \cdot person}\right)\left(\frac{persons}{household}\right)\left[\frac{days}{1\ month}\right]$
Bathtub (bt)***	$Q_{bt} = \left(\frac{gallons}{person \cdot day}\right)\left(\frac{persons}{household}\right)\left[\frac{days}{1\ month}\right]$
Dishwasher (ds) Clothes washer (c)	$Q_{ds,c} = \left(\frac{gallons}{cycle}\right)\left(\frac{cycles}{day \cdot person}\right)\left(\frac{persons}{household}\right)\left[\frac{days}{1\ month}\right]$

* Default drinking water volume per person per day (0.8 gal) from Institute of Medicine 2005** Single flush toilets. For dual flush toilets, the prototype allows separate estimation for a full flush and reduced flush (Figure 5.2) *** Default bathtub volume per person per day from DeOreo and Mayer 2014

The database in the prototype provides standard and efficient water use artifacts (in flow rate, flush volume or gal per cycle) according to the US WaterSense program for the following artifacts: bathroom faucets, kitchen faucets, showerheads, toilets (single, dual flushing and waterless systems), urinals, dishwashers, clothes washers, and pre-rinse spray valves.

When no detailed information is available for an initial estimation, the disaggregated method has been coupled with general country water use statistics for an artifact (or activity) and water volume from meter readings. For this option, the user has to input a monthly metered water quantity per household, the number of users, and the country of the site's location. A daily indoor water need per household is estimated by dividing the metered volume by 31 days and then multiplying by the number of days per month to obtain a total volume per month. The monthly water use minus the drinking water needs is then divided among the artifacts and uses (faucets, showerheads, toilets, dishwasher, clothes washer, bathtub, leaks, and others) according to percentage average use. The average water end-use percentages for the US were obtained from DeOreo and Mayer (2014) and DeOreo et al. (2016). For Chile, the percentage of average water end-use percentages were obtained from SISS (2011). More details can be found in Table 5.3. The faucet end-use percentage is then further divided between the bathroom and kitchen faucets: 38% and 62%, respectively (Jordan-Cuebas et al. 2018).

Table 5.3. Percentages of average water end-use statistics for US and Chile

Country	Faucets	Showerheads	Toilets	Dishwasher	Clothes washer	Leaks	Other	Bathtub
US	19%	20%	24%	1%	17%	12%	4%*	3%
Chile	18%	30%	25%	0%	20%	0%**	7%	0%

* The "Other" category includes evaporative cooling, humidification, water softening, and other uncategorized indoor uses ** No information available

Both procedures for estimating monthly indoor water needs are found in the same spreadsheet in the prototype tool. The results of the estimation selected are linked to the Water Balance spreadsheet. Figure 5.2 and 5.3 shows pictures of parts of the Indoor Water Needs spreadsheet built into the prototype. Yellow boxes indicate user inputs in dropdown menus. Grey boxes show the monthly water volume estimated (Link to the prototype: https://bit.ly/3anFO5c).

Drinking Water Needs		Daily Volume (gallons/user/day)				0.8	Number of users			4			
Month	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Annual**	**Daily**
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	1
Gallons	98.3	88.8	98.3	95.1	98.3	95.1	98.3	98.3	95.1	98.3	95.1	98.3	1157.1	3.2

Figure 5.2. Table for Estimating Monthly Drinking Water Needs in the prototype

Toilet (1)	Type	US Low Water Volume Dual Flush 1,2/0,7	Number of users	4	Full Flush Volume (gallons)	1.20	Number of Full Flushes /day		2	Reduced Flush Volume	0.7	Number of Reduced Flushes/day		3
Month	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Annual**	**Daily**
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	1
Gallons	558.0	504.0	558.0	540.0	558.0	540.0	558.0	558.0	540.0	558.0	540.0	558.0	6570.0	18.0

Figure 5.3. Table for Estimating Monthly Toilet Water Use in the prototype

Other Water Needs

Other Water Needs include estimates of monthly water volume for car washing, swimming pools, and other uses defined by the user. For Car Washing, users select the device and frequency per month. The device defines the water volume used. Table 5.4 shows the different devices and water volumes available in the prototype. For Swimming Pools, the user needs to input the pool volume and the month for filling it. For Other needs, the user must input the water volume, the frequency per month, and the uses per month.

Table 5.4. Car washing mode and water volume

Car Washing Mode	**Volume (gal)**	**Source**
Hose without an automatic shutoff nozzle	100*	MDE 2020
Hose with an automatic shut-off nozzle, Average consumption	65**	
Hose with an automatic shut-off nozzle, Low consumption	30	MDE 2020
With a bucket	25	SISS 2011

*Assumes a 15-minute car wash with flow of 10 gallons per minute. **Average value between high and low water use

Other Water Needs estimation is found in an independent spreadsheet in the prototype, and its results are linked to the water balance spreadsheet (described below in the text). Figure 5.4 shows an example of how the estimation is performed in the prototype. Yellow boxes indicate user input required, and grey boxes show the results (Link to the prototype: https://bit.ly/3anFO5c).

Car Washingn Water Needs			
1) Modus	with a bucket		
2) Frequency per month	2	volume/wash (gallons)	25
3) Type of water needed	Non-potable	Monthly volume (gallons)	50
4) Type of water produced	Greywater	Annual volume (gallons)	600

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Washing this month? (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water volume per month (gallons)	50	50	50	50	50	50	50	50	50	50	50	50

Figure 5.4. Estimation of car washing water needs

5.3.2.1.2. Landscape Water Needs

Landscape Water Demand provides a monthly estimate of plants' water needs based on the ANSI/ASABE S623.1 JAN2017 standard. The standard provides a procedure to estimate minimum water plant needs for different species to maintain the whole landscape area's aesthetic quality. The method requires using Evapotranspiration values (ETOs) calculated using the ASCE-EWRI standardized reference evapotranspiration equation (Walter et al. 2005). The ETOs for the prototype locations were calculated using Snyder and Eching (2007) spreadsheet available at Biometeorology Group at UC Davis website. Data for temperatures, wind speed, dew point or relative humidity, and solar radiation for the US cities were obtained from the National Oceanic and Atmospheric Administration (NOAA) and The National Renewable Energy Laboratory (NREL) websites in .csv format. For locations in Chile, solar radiation and wind speed data were retrieved from the Ministry of Energy website in .csv format. Precipitation, temperature and relative humidity data were obtained from the General Direction of Civil Aviation website in .pdf format.

The ANSI/ASABE S623.1 method requires using an effective rainfall value in the calculation. For the early stages of design, estimations are recommended to use 50% of the rainfall on the location as effective rainfall value. Landscape area can be divided by the water requirements of the plant species. Monthly Landscape water needs for each area are estimated using Eq. (2):

$$LWN_i = ([ET \times PF_i] - Re) \times A_i \times 0.6234 \div I.E. \qquad (2)$$

Where:

LWN_i: water needs for each area with a specific plant type (in gal)
PF_i: plant factor for each plant type (Table 5.5)
Re: effective rainfall (in inches) (in)
A_i: area of the plant type (sq. ft.)
0.6234 is a conversion factor to gallons
IE: assumed irrigation efficiency

Table 5.5. presents the plant factors for various plant types. When the canopy cover is less than 80% of the area, the plant factor must be adjusted, multiplying it by the percent of canopy cover. The Adjusted Plant Factor is estimated using Eq. (3):

$$Adjusted\ Plant\ Factor = PF \cdot \frac{plant\ coverage\ area\ (\text{sq.ft})}{total\ managed\ area\ (\text{sq.ft})} \qquad (3)$$

Table 5.5. Recommended Plant Factors for acceptable appearance of landscape plants

Plant Type	Recommended Plant Factor
Turf, cool season	0.8
Turf, warm season	0.6
Annual flowers	0.8
Woody plants and herbaceous perennials, wet*	0.7
Woody plants and herbaceous perennials, dry	0.5
Desert plants	0.3

* Tropical plants: for tropical plants with precipitation in the majority of months, a plant factor of 0.7 applies. Where monsoonal climates are present, 0.7 applies for the wet season, and 0.5 during the dry season (ASABE 2017) (adopted from ASABE 2017)

Irrigation efficiency (IE) depends on design, installation, management of the landscape, and the type of irrigation system (ASABE 2017). For reference, "an appropriately designed, well-maintained, and properly managed sprinkler irrigation system (solid set) has an irrigation efficiency of 75%" according to the Irrigation Association (2011) (As cited in ASABE 2017).

The prototype provides an initial estimation of LWN (pre-project) for high water consumption plants and low water need plants and uses this information for the initial water balance. No user inputs for initial LWN estimations are required in the spreadsheet. The prototype takes the landscape area information from the Site and Project spreadsheet and uses default values (see Table 5.6).

Table 5.6. Default values used in the initial landscape water needs estimations

Parameters	High Water Needs Landscape	Low Water Needs Landscape
Plant Type	Turf, cool season. Cool-season grasses, which do better in the cooler times of the year and thrive in temperatures from 65° to 75°F (18° to 24°C). Examples: bluegrass, tall fescue, perennial ryegrass, and fine fescues.	Desert plants. Plants that can survive a very dry (<10 in. of annual precipitation) environment.
Plant Factor	0.8	0.3
IE	80%	80%
Canopy Cover	> 80%	> 80%

The prototype allows setting three different plant areas for an entire project. For each landscape area with a dominant type of plant, the user must input: 1) the surface area (sq.ft.), 2) IE, 3) the plant type, and 4) the canopy covering. For canopy covering less than 80% of the area, the user must input the cover percentage. If the site is planted with isolated plants, the user must define the diameter of the canopy. The results will sum up the water needs of each area for each month over a year. These results are later used in the water balance estimation spreadsheet.

5.3.2.1.3. Rainwater Harvesting Supply

Rainwater Harvesting Supply provides an estimate of the potential to capture rainwater from the total projected roof areas for potable or non-potable use. The estimation method is based on Mechell et al. (2009). The Monthly Rainwater harvesting Supply (MRWS) is computed in the following Eq. (4):

$$MRWS = PCP \cdot A \cdot Coef_{roof} \cdot S_{factor} \cdot C_{factor} \tag{4}$$

Where:

PCP: Monthly precipitations (in)
A: Catchment area (sq. ft.)
$Coef_{roof}$: Runoff coefficient of roof material
S_{factor}: Safety factor
C_{factor}: Conversion factor for converting to gallons (0.6234)

Rainfall data representing wet, dry and normal precipitation years are available for the calculations in the prototype. Precipitation information used in the prototype was obtained from the Global Historical Climatology Network database for US locations and from the 'Dirección Meteorológica de Chile' website for Concepcion. Catchment area in square feet is a user input. Runoff coefficients of roof material were obtained from Haan, Barfield, and Hayes (1994), Tomaz (2009), Downey (2009), Novak et al. (2014), and USGBC (2019) and shown in Table 5.7. Safety factors available in the prototype are the recommended by Mechell et al. (2009) in the range of 0.65 to 0.95. Figure 5.5 presents the Rainwater Harvesting Supply estimation implemented in the prototype. Yellow boxes indicate user inputs and grey boxes show the results (Link to the prototype: https://bit.ly/3anFO5c).

Rainfall Pattern	Normal year	Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Year	2010	Precipitations - PCP (in)	2,90	3,22	2,19	1,76	5,19	5,13	2,87	1,68	3,28	2,12	5,97	1,57

Roof area (sqft)	3500	Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Roof Material	Roof -Asphalt, Asphalt Shingles	Harvested Water Volume (gallons)	4571,2	5073,6	3454,7	2778,7	8174,8	8087,9	4515,4	2642,2	5166,6	3343,1	9409,1	2468,6
Runoff Coefficient	0,85													
Safety Factor	0,85													
Conversion Factor	0,623													

Figure 5.5. Rainwater harvesting supply estimation in the Prototype

Table 5.7. Runoff Coefficients of Roof Materials

Type and Material of Surface	Value	Type and Material of Surface	Value
Roof - Metal Panel	0.85	Roof - Plastic Panel	0.92
Roof - Corrugated Metal Sheets	0.85	Roof - Membrane Type EPDM, PVC	0.97
Roof - Tar-and-gravel	0.82	Roof - Glass and polycarbonate sheets	0.92
Roof - Asphalt, Asphalt Shingles	0.85	Green roof < 10 cm depth	0.5
Roof - Clay Roof Tiles	0.85	Green roof 10 cm > depth < 20 cm	0.3
Roof - Glazed Roof Tiles	0.92	Green roof 20 cm > depth < 50 cm	0.2
Roof - AC Sheets	0.85	Green roof > 50 cm depth	0.1

Sources: Haan, Barfield, and Hayes (1994), Tomaz (2009), Downey (2009), Novak et al. (2014), and USGBC (2019)

5.3.2.1.4. Stormwater Runoff Volume and Quality

The L-THIA-LID 2.1 model (Liu, Bralts, and Engel 2015) has been adopted for estimating pre and post-development runoff volume and pollutant discharges of a site and buildings in the prototype.

A. Stormwater Runoff Volume Estimation

The L-THIA-LID 2.1 model uses the NRCS Curve Number (CN) method to estimate the development's runoff volume before implementing BMPs/LIDs. The CN value, empirically defined for a different combination of soil covers and hydrologic soil, predicts direct infiltration and runoff from rainfall excess. The runoff volume for each combination of soil cover and hydrologic soil in a site is defined by Eq. (5):

$$Q_v = 0.001 \times Q_h \times A \qquad (5)$$

Where:

Q_v: Stormwater runoff volume (in cubic meters) (cu m)
A: Surface area in square meters (sq. m)
Q_h: Stormwater runoff depth (in millimeters) (mm)

The runoff depth (Q_h) is estimated using Eq. (6):

$$Q_h = \frac{(P-0.2S)^2}{(P+0.8S)}, when\ P > 0.2S \qquad (6)$$

$$Q_h = 0, when\ P \leq 0.2S$$

Where:

Q_h: Stormwater runoff depth (in mm)
P: Daily rainfall depth (in mm)
S: initial abstraction (in mm)

The initial abstraction S is estimated based on Eq. (7) and CN values are obtained from tables in the NRCS 1986 publication.

$$S = \frac{25400}{CN} - 254 \tag{7}$$

For estimating the runoff volume of BMPs/LIDs, the L-THIA-LID 2.1 model uses Adjusted CNs for the following LIDs: green roof, bioretention system, rain barrel, cistern, permeable patio, and porous pavement. The CN values were obtained from Sample et al. (2001) and Ahiablame, Engel, and Chaubey (2012). For BMPs/LIDs without documented CNs values, the L-THIA-LID 2.1 model represents them by applying the percent runoff volume reduction method. This method estimates the runoff volume after implementing BMPs/LIDs as a percentage of the total runoff volume managed by the strategy (Liu 2015). The proportion of runoff for each BMPs/LIDs is calculated by the ratio between the outflow runoff volume and the inflow runoff volume. The default volume ratios used for each BMPs/LIDs in the L-THIA-LID 2.1 (and in this research work) were defined from databases and literature (Strecker et al. 2004; CWP and CSN 2008; GC and WWE 2011). Table 5.8 shows the CN values used for LIDs and Table 5.9 presents the discharge runoff volume/inflow runoff volume Ratios for BMPs/LIDs. Values presented in both tables are used in the Runoff Calculation Method.

Table 5.8. LIDs CN values for Runoff Calculation Method

BMPs/LIDs	**Hydrologic Soil**			
	A	B	C	D
Green Roof	85	85	85	85
Rain Barrel/Cistern	85	85	85	85
Permeable patio	76	85	89	91
Porous Pavement	70	80	85	87
Bioretention	15	20	35	40

Adapted from Liu (2015)

Table 5.9. BMPs/LIDs discharge/inflow runoff volume Ratios (L-THIA-LID 2.1 model)

BMPs/LIDs	**Ratio**	**BMPs/LIDs**	**Ratio**
Biofilter - grass swale	0.58	Permeable patio	1
Biofilter - grass strip	0.66	Green roof	1
Wet Pond (Retention pond)	0.93	Wetland channel	1
Dry Pond (Detention basin)	0.67	Bioretention system	1
Wetland	0.95	Porous pavement	1
Rain barrel/Cistern	1	Green roof with rain barrel/cistern	1

Adapted from Liu (2015)

The drainage area that each LID treats follow the following rules (Liu 2015):

a. Rainwater harvesting (rain barrels and cisterns) and green roof manage runoff only from roofs.
b. Porous pavement manages runoff from the surface of roads, sidewalks, driveways, and parking lots.
c. Permeable patio manages runoff from the surface of its area.
d. Bioretention system manages 15% of the remaining runoff after being treated by other LIDs such as green roof, rain barrel/cistern, porous pavement, and permeable patio.
e. Grassed swale, grass strips, and wetland channel strategies only manage remaining runoff after being treated by LIDs such as green roof, rainwater harvesting (barrel/cistern), porous pavement, permeable patio, and bioretention systems.
f. BMPs manage a portion of the runoff generated by LIDs.

For estimating runoff volume from LIDs sitting in series, the following rules are applied (Liu 2015):

a. The green roof and rainwater harvesting can be implemented in series.
b. Porous pavement and permeable patio are independent runoff areas.
c. The porous pavement in roads, sidewalks, driveways, and parking lot areas are always managed in series.
d. Grassed swale and wetland channels are independent runoff areas.
e. All LID practices can be applied in series with BMPs. But,
f. BMPs are independent runoff areas and considered parallel to each other.

The runoff volume calculation sequence that the L-THIA-LID 2.1 model perform is the following (see Figure 5.6): First, the model estimates the runoff volume before implementing BMPs and LIDs from roofs, patios, roads, driveway, sidewalk, parking area and other areas (e.g., open space, landscape). Second, runoff volume after implementing LIDs from a green roof, rain barrel/cistern, permeable patio, and the porous pavement is estimated. Third, 15% of the remaining runoff volume is considered to be treated by bioretention areas. Fourth, runoff volume is calculated after being treated by grassed swale, grass strips, or wetland channel strategies. Finally, the remaining runoff volume is considered to be treated by one of the following BMPs, wet pond, dry pond, or wetland (Liu 2015).

To estimate pre-development and post-development runoff volume in the prototype, the user must input the following site and project information: Location, city, rainfall pattern (normal, wet or dry), hydrologic soil group, soil cover for each different area (roof, patio, road, sidewalk, driveway, parking lot, landscape, and open areas. The user also must input LIDs types to include and the percentage of the drainage area each manages. For example, for a green roof, the user needs to indicate its use (Selecting Yes or No) and if the green roof will cover 100% of the area or less (an input value between 0 and 100%). The following rules of implementation of LIDs are incorporated in the prototype:

a. The sum of the percentage areas dedicated to a green roof, rainwater harvesting (RWH), or a green roof with RWH must be equal or less to the total roof area of the project
b. Bioretention maximum area is 15% of the site size
c. The sum of the percentage areas dedicated to the grassed swale, grass strip, and wetland channel must be equal or less to the total open areas available (landscape, Area 1 and Area 2)
d. The sum of the percentage areas dedicated to wet pond, dry pond, and wetland must be equal or less to the total open areas available after LIDs placement areas

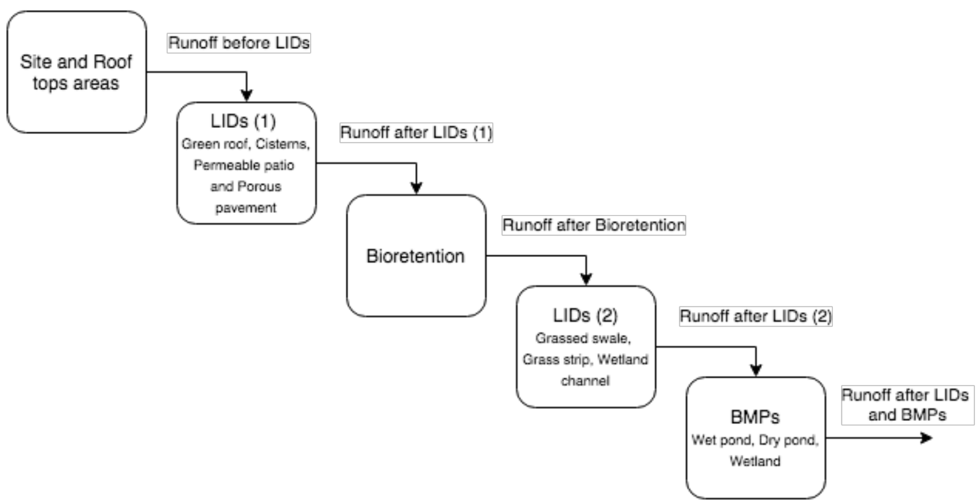


Figure 5.6. L-THIA-LID 2.1 Model's sequence of runoff volume calculation including BMPs/LIDs

For pre-development estimations, the default soil cover is defined as Forest/Woodland according to PA and WA regulations. For post-development estimations, the user has to input soil covers for landscape and open areas. Runoff volumes are calculated on a daily basis. Yearly Runoff volume is determined in cubic meter per year (cu m/year) for the project with and without the implementation of LIDs and indicating the reduction percentage. The calculations in the prototype include the BMPs and LIDs of the L-THIS-LID 2.1. model. However, the three BMPs strategies are not considered for selection because they are recommended for drainage areas greater than 10 to 25 ac, which are not considered in this research work. The result of the analysis pre-and post-development includes annual runoff volume with and without LIDs.

B. Stormwater Runoff Quality Estimation

Runoff water quality is estimated by the L-THIA-LID 2.1 model applying the Event Mean Concentration and Irreducible Concentration methods (Liu 2015, Liu et al. 2015; Liu, Bralts and Engel 2015). To simulate pollutant concentrations in runoff from the site, the model uses Eq. (8):

$$WQ_{m1} = EMC \times Q_v \quad (8)$$

Where:

WQ_{m1}: Pollutant load before implementing BMPs/LID strategies. (Colonies/cu m for Fecal Coliform and Fecal Strep, MPN/cu m for E-coli, and mg/L for all other pollutants in the model)
EMC: Event mean concentration (Colonies/100mL for Fecal Coliform and Fecal Strep, MPN/100mL for E-coli, and mg/L for all other pollutants in the model)
Q_v: Stormwater runoff volume in cubic meters (cu m)

There are 19 pollutants simulated in the L-THIA-LID 2.1 model. The prototype includes the estimation of the most common pollutants required to control by regulations: Total Suspended Solids (TSS), Total Phosphorus (TP), and Total Nitrogen (TN). The default soil cover used in the prototype for estimating original concentration pollutants is Low-Density Residential land use. Table 5.10 presents the values of EMC for different soil covers of the L-THIA-LID 2.1 model.

Table 5.10. Values of Event Mean Concentration in L-THIA-LID 2.1

	Soil Cover							
Compound	**Forest**	**Agricultural**	**Grass**	**LD Residential**	**HD Residential**	**Industrial**	**Commercial**	**Water**
Suspended Solids (mg/L)	0.48	44.58	0.83	30.91	30.91	35.96	33.45	0
Dissolved Solids (mg/L)	2073.37	10366.87	2073.37	1134.01	1134.01	981.68	1565.61	0
Total Phosphorus (mg/L)	0	0.46	0.04	0.29	0.29	0.1	0.1	0
Dissolved Phosphorus (mg/L)	0	0	0	0.57	0.57	0.22	0.09	0
Total Nitrogen (mg/L)	0.5	4.14	0.9	1.96	1.96	1.26	1.41	0
Total Kjeldahl Nitrogen (mg/L as N)	0.74	2.27	0.37	3.88	3.88	1.83	2.22	0
Nitrate+Nitrite (mg/L)	1.1	5.11	2.76	2.31	2.31	1.03	0.83	0
Total Lead (ug/L)	2.2	0.93	5	9	9	15	14.5	0
Total Copper (ug/L)	10.5	1.57	10.5	15.75	15.75	15.75	15.22	0
Total Zinc (ug/L)	6	16	6	80	80	245	180	0
Total Cadmium (ug/L)	0.18	0.8	0.9	0.73	0.73	2	1.23	0
Total Chromium (ug/L)	7.5	10	7.5	2.1	2.1	7	10	0
Total Nickel (ug/L)	0	0	0	3.28	3.28	39.4	19.13	0
Fecal Coliform (colonies/100 ml)	37	0	37	20000	20000	9700	6900	0
Fecal Strep. (colonies/100 ml)	0	0	0	56000	56000	6100	18000	0
E-coli (MPN/100 ml)	188	21813	3750	11466	11466	1281	5373	0
BOD (mg/L)	0.46	3.2	0.53	25.5	25.5	14	18.47	0
COD (mg/L)	0	0	0	35.5	35.5	45.5	53.5	0
Oil and Grease (mg/L)	0	0	0	2.1	2.1	3	4.59	0

Adapted from Liu et al. 2015. Sources of pollutant concentrations: Baird et al. 1996; RRNWWDP 1998; Camp Dresser and McKee Inc. 2004; Collins, Allen and Gill 2004; Selvakumar and Borst, 2004; Maestre and Pitt, 2005; Miller 2005; Ellis and Revitt 2008; McCarthy et al. 2008; Stein, Tiefenthaler and Schiff 2008; Wilson and Weng 2010.

Table 5.11. Default values of Irreducible Concentration (IC) for each BMP/LID strategy

	BMPs/LIDs											
Compound	Grassed swale	Grass strip	Wetland channel	Bioretention system	Porous pavement	Wet Pond	Dry Pond	Wetland basin	Rain cistern	Permeable patio	Green roof	Green roof w/cistern
Suspended Solids (mg/L)	13.6	19.1	14.4	8.29	13.3	13.5	24.2	9.06	1E+08	1E+08	1E+08	1E+08
Dissolved Solids (mg/L)	69.5	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
Total Phosphorus (mg/L)	1.E+08	1E+08	0.143	0.0884	0.0887	0.128	0.22	0.0828	1E+08	1E+08	1E+08	1E+08
Dissolved Phosphorus (mg/L)	1.E+08	1E+08	1E+08	0.135	1E+08	0.0638	1E+08	0.0461	1E+08	1E+08	1E+08	1E+08
Total Nitrogen (mg/L)	0.714	1.13	1.33	0.896	1E+08	1.28	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
Total Kjeldahl Nitrogen (mg/L as N)	0.617	1.09	1.23	0.598	0.804	1.05	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
Nitrate+Nitrite (mg/L)	0.245	0.272	0.189	0.222	1E+08	0.176	0.364	0.0835	1E+08	1E+08	1E+08	1E+08
Total Lead (ug/L)	2.02	1.96	2.49	2.52	1.86	2.75	3.09	1.21	1E+08	1E+08	1E+08	1E+08
Total Copper (ug/L)	6.55	7.3	1E+08	7.67	7.84	4.99	5.65	3.57	1E+08	1E+08	1E+08	1E+08
Total Zinc (ug/L)	22.8	24.3	15.6	18.2	15	21.2	29.8	22	1E+08	1E+08	1E+08	1E+08
Total Cadmium (ug/L)	0.314	0.183	0.487	1E+08	1E+08	0.228	0.311	0.176	1E+08	1E+08	1E+08	1E+08
Total Chromium (ug/L)	2.33	2.73	1.4	1E+08	1E+08	1.36	2.97	1E+08	1E+08	1E+08	1E+08	1E+08
Total Nickel (ug/L)	3.16	2.92	2.18	1E+08	1.71	2.19	3.35	1E+08	1E+08	1E+08	1E+08	1E+08
Fecal Coliform (colonies/100 ml)	1.E+08	24000	1E+08	1E+08	1E+08	706	1030	6170	1E+08	1E+08	1E+08	1E+08
Fecal Strep. (colonies/100 ml)	1.E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
E-coli (MPN/100 ml)	1.E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
BOD (mg/L)	1.E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
COD (mg/L)	1.E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
Oil and Grease (mg/L)	1.E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08

Adapted from Liu et al. 2015

The reduction of pollutant concentration by implementing BMPs/LIDs is estimated by applying the Irreducible Concentration (IC) method. The IC is considered as the lowest discharge concentration reachable after being managed by BMPs/LIDs strategies. Median values of discharge concentrations obtained from the International Stormwater BMP Database (www.bmpdatabase.org) (Liu 2015, Liu et al. 2015) were taken as default irreducible concentration values (see Table 5.11).

Pollutant concentration of runoff after being managed by BMPs/LIDs strategies is estimated based on the irreducible concentration method and following three conditions (Liu 2015):

<u>Condition 1.</u> When the Event Mean Concentration before BMPs/LIDs (EMC’) is less than the Irreducible Concentration (IC): the Event Mean Concentration after BMPs/LIDs (EMC) is equal to EMC’.

1) When $EMC' < IC$:

$$EMC = EMC'$$

<u>Condition 2.</u> If the Event Mean Concentration before BMPs/LIDs (EMC’) is greater or equal to the Irreducible Concentration (IC) and the Event Mean Concentration before BMPs/LIDs (EMC’) multiplied by Ratio_c is less than IC: the Event Mean Concentration after BMPs/LIDs (EMC) is equal to IC.

2) When $EMC' \geq IC\ \ and\ \ \ EMC' \times Ratio_c < IC$:

$$EMC = IC$$

Condition 3. If the Event Mean Concentration before BMPs/LIDs (EMC') multiplied by Ratio_c is greater or equal to IC: the EMC after BMPs/LIDs (EMC) is equal to Event Mean Concentration before BMPs/LIDs (EMC') multiplied by Ratio_c.

3) When $EMC' \times Ratio_c \geq IC$:

$$EMC = EMC' \times Ratio\_c$$

The Ratio_c is the ratio of median discharge pollutant concentration to median inflow pollutant concentration for each BMPs/LIDs (Liu 2015). Default Ratio_c values were estimated based on the International Stormwater BMP Database (www.bmpdatabase.org) (Liu 2015). Table 5.12. presents the default value of the ratio of discharge concentration to inflow concentration (Ratio_c) for each BMPs/LIDs model.

Table 5.12. Default ratio of discharge concentration to inflow concentration for each BMPs/LIDs

	BMPs/LIDs											
Compound	Grassed swale	Grass strip	Wetland channel	Bioretention system	Porous pavement	Wet Pond	Dry Pond	Wetland basin	Rain cistern	Permeable patio	Green roof	Green roof w/cistern
Suspended Solids (mg/L)	0.63	0.44	0.72	0.22	0.20	0.19	0.36	0.45	1	1	1	1
Dissolved Solids (mg/L)	0.90	1	1	1	1	1	1	1	1	1	1	1
Total Phosphorus (mg/L)	1	1	0.93	0.79	0.57	0.43	0.78	0.65	1	1	1	1
Dissolved Phosphorus (mg/L)	1	1	1	0.53	1	0.49	1	0.57	1	1	1	1
Total Nitrogen (mg/L)	0.96	0.84	0.84	0.72	1	0.70	1	1	1	1	1	1
Total Kjeldahl Nitrogen (mg/L as N)	0.86	0.85	0.85	0.64	0.48	0.82	1	1	1	1	1	1
Nitrate+Nitrite (mg/L)	0.82	0.66	0.55	0.85	1	0.41	0.66	0.35	1	1	1	1
Total Lead (ug/L)	0.52	0.22	0.85	0.67	0.43	0.32	0.51	0.60	1	1	1	1
Total Copper (ug/L)	0.60	0.30	1	0.45	0.60	0.52	0.53	0.64	1	1	1	1
Total Zinc (ug/L)	0.63	0.24	0.68	0.25	0.26	0.40	0.42	0.46	1	1	1	1
Total Cadmium (ug/L)	0.63	0.35	0.98	1	1	0.47	0.80	0.56	1	1	1	1
Total Chromium (ug/L)	0.52	0.50	0.81	1	1	0.33	0.59	1	1	1	1	1
Total Nickel (ug/L)	0.34	0.54	0.78	1	0.47	0.49	0.59	1	1	1	1	1
Fecal Coliform (colonies/100 ml)	1	0.73	1	1	1	0.37	0.70	0.47	1	1	1	1
Fecal Strep. (colonies/100 ml)	1	1	1	1	1	1	1	1	1	1	1	1
E-coli (MPN/100 ml)	1	1	1	1	1	1	1	1	1	1	1	1
BOD (mg/L)	1	1	1	1	1	1	1	1	1	1	1	1
COD (mg/L)	1	1	1	1	1	1	1	1	1	1	1	1
Oil and Grease (mg/L)	1	1	1	1	1	1	1	1	1	1	1	1

Adopted from Liu 2015

The water quality for the total site is calculated using Eq. (9) (Ahiablame, Engel and Chaubey 2012):

$$WQ_{m2} = \sum_{i}^{N} Q_{after\ i} \times A_i \times EMC_{after\ i} \quad (9)$$

Where:

WQ_{m2}: Pollutant load after implementing BMPs/LID strategies. (Colonies/100mL for Fecal Coliform and Fecal Strep, MPN/100mL for E-coli, and mg/L for all other pollutants in the model)
N: Quantity of soil cover and BMPs/LIDs in the site
A_i: Area of each soil cover or BMPs/LIDs
$Q_{after\ i}$: Stormwater runoff depth after BMPs/LIDs
$EMC_{after\ i}$: Pollutant concentration after BMPs/LIDs. (Colonies/100mL for Fecal Coliform and Fecal Strep, MPN/100mL for E-coli, and mg/L for all other pollutants in the model)

The prototype includes all 19 pollutants calculations for BMPs and LIDs, but only three (TSS, TP, and TN) are used to evaluate and compare solutions. Pollutant load results are delivered in the prototype in Kilogram per year (kg/year).

To estimate runoff pollutant loads in the prototype, the user must input the following information in addition to the data inputted for runoff volume estimation: Soil cover for Original Pollutant Concentration values (EMC Method). For pre-development, Forest/Wood land use is defined as a soil cover by default according to PA and WA regulations. For post-development, Low-density residential land use is set by default. The user can change the land use of the Original Pollutant Concentration for the EMC method. The L-THIA-LID model and the prototype provide eight different soil covers for original pollutant concentration values (Forest, agricultural, grass, Low-density residential, High-density residential, commercial, industrial, and surface water). Pollutant loads results are calculated on a daily basis for Total Phosphorus (TP), Total Nitrogen (TN), and Total Suspended Solids (TSS). Yearly pollutant loads in kg per year for the project are presented with and without the implementation of LIDs and indicating the reduction percentage. The calculations in the prototype include the BMPs and LIDs of the L-THIS-LID 2.1. model. However, the three BMPs strategies are not included for selection and results. The results of the pollutant loads of the pre-and post-developments include:

- Yearly Pollutant Load with and without LIDs for Total Suspended Solids (TSS)
- Yearly Pollutant Load with and without LIDs for Total Nitrogen (TN)
- Yearly Pollutant Load with and without LIDs for Total Phosphorus (TP),
- reduction in load for each pollutant compared to the base case (It does not include LIDs).

5.3.2.1.5. Stormwater Peak Discharge

This calculation provides an estimation of stormwater peak discharge for pre and post-development. The pre-development peak runoff is used as a reference for the goals setting module. The post-development peak discharge is used for informing the flow with and without the implementation of LIDs.

The NRCS Graphical Method (NRCS 1986) and the Rational Method (McCuen, Johnson, and Ragan 2002) have been selected as the main procedures to estimate stormwater peak discharge. Both methods are widely used in the US (and only the Rational Method is used in Chile), require few parameters that are easy to obtain in early phases of design, and are suitable for small urban areas. Regarding its applicability in small sites, the NRCS Graphical Method has a minimum of 1 acre. The Rational Method has an upper limit of 20 ac. Both methods are in the range of the prototype scope. However, what limits the applicability in small sites of both methods is the computation of the Time of Concentration (TC). Small urban areas usually have low TC values. In the Rational Method, the rainfall intensity is assumed to be constant for a duration equal to the time of concentration. Intensity-Duration-Frequency (IDF) tables in the US include durations as short as 5 minutes. However, IDF tables in Concepcion begin at 10 minutes. Therefore, the Rational Method could not be used for small areas in Chile with TC less than 10 minutes. The NRCS Graphical Method can be applied for sites with TC values between 6 minutes and 10 hours. Clayton and Schuler (1996) recommend using the TR-55 graphical Method (a particular implementation of the NRCS Method) over the Rational Method. They also say that RM can be used if reliable IDF tables or curves for the storm and region are available. Dr. Enrique Muñoz, specialist in Water Resources and Agricultural Engineering, does not recommend using the NRCS Method in Chile because the method has been developed for different rainfall patterns coupled with different mixes of topography and soil types specifically for the US and cannot be assumed to be similar to the Chilean storms, topography and soils (personal communication on Monday, November 18, 2019. Concepcion, Chile). In specific, the CN values that the NRCS method uses were developed from rainfall and runoff data of 307 watersheds or sites located in the east, midwest, and south of the United States (Woodward et al. 2003).

Both methods have been criticized and improved over time. Clayton and Schuler (1996) state that two of the shortcomings of the NRCS method are that: 1) for small storms, the method underestimates the peak discharge, and 2) TC should be greater than 6 minutes for small drainage sites. McCuen and Okunola (2002) indicate that the original TR-55 (NRCS 1986) is not accurate for estimating TC for small sites and developed an extension of the TR-55 model. The extension applies to the estimation of TC, peak discharge, and adjustment for storage. Wang and Wang (2018) propose the Rational Method Prime (RMP) because it "has three merits 1) providing an integrated response of the whole catchment with runoff controls; (2) interpreting runoff control effects by plotting runoff flow rate-rainfall duration curves; (3) connecting the design of runoff controls and storm sewers that are based on different design principles and rainfall statistics" (Page 112). However, the equations are not simple to follow and implement in spreadsheets. Dr. McCuen recommends the best approach is through a Spatio-temporal model which better shows the effects of the location of BMPs/LIDs and the amounts of storage. Then the watershed time of concentration would be appropriate--not the traditional TC concept (McCuen, Richard H., 'comments'. Email, 2019).

For this dissertation's purpose, the NRCS Graphical Method was used for estimation in the US and the Rational Method for sites in Chile. But, future work based on this dissertation work should consider the use of Dr. McCuen's recommendation of spatio-temporal model which seems like a promising line for research.

A. NRCS Graphical Method

The prototype implements the NRCS Graphical Method as is presented in the Technical Release TR-55 Urban Hydrology for Small Watersheds for the locations of Pittsburgh, PA and Vancouver, WA, and estimates pre and post development discharge. The peak discharge is calculated using Eq. (10) (NRCS 1986):

$$q_p = q_u A_m Q F_p \tag{10}$$

Where:

q_p = peak discharge in cubic feet (cft)
q_u = unit peak discharge (csm/in)
A_m = drainage area (sq. mi)
Q = runoff (in)
F_p = pond and swamp adjustment factor

The unit peak discharge is calculated using Eq. (11):

$$log(q_u) = C_0 + C_1 log(T_c) + C_2[log(T_c)]^2 \tag{11}$$

Where:

q_u = unit peak discharge (csm/in)
T_c = Time of concentration in hours (hr) (minimun, 0.1; maximun, 10.0)
C_0, C_1, C_2 = coefficients from Table 5.13 according to the Rainfall Type Distribution of the location

Rainfall Type Distributions are synthetic rainfall patterns developed by the NRCS based on rainfall frequency data that "includes maximum rainfall intensities for the selected design frequency in a sequence that is critical for producing peak runoff." (NRCS 1986, B-1). Four synthetic 24-hour rainfall distributions are for the US (I, IA, II and III) (NRCS 1986). Locations included in the prototype uses Type II (Pittsburgh, PA) and Type IA (Vancouver, WA).

Table 5.13. Coefficients C_0, C_1, C_2 for the Eq. 6

Rainfall Type	Ia/P	C0	C1	C2
I	0.10	2.30550	-0.51429	-0.11750
	0.20	2.23537	-0.50387	-0.08929
	0.25	2.18219	-0.48488	-0.06589
	0.30	2.10624	-0.45695	-0.02835
	0.35	2.00303	-0.40769	0.01983
	0.40	1.87733	-0.32274	0.05754
	0.45	1.76312	-0.15644	0.00453
	0.50	1.67889	-0.06930	0.00
IA	0.10	2.03250	-0.31583	-0.13748
	0.20	1.91978	-0.28215	-0.07020
	0.25	1.83842	-0.25543	-0.02597
	0.30	1.72657	-0.19826	0.02633
	0.50	1.63417	-0.09100	0.00
II	0.10	2.55323	-0.61512	-0.16403
	0.30	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.08820
	0.40	2.36409	-0.59857	-0.05621
	0.45	2.29238	-0.57005	-0.02281
	0.50	2.20282	-0.51599	-0.01259
III	0.10	2.47317	-0.51848	-0.17083
	0.30	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985
	0.40	2.30726	-0.46541	-0.11094
	0.45	2.24876	-0.41314	-0.11508
	0.50	2.17772	-0.36803	-0.09525

Adopted from NRCS 1986

Prior to run the peak discharge estimate, the NRCS Graphical Method requires the following inputs:

1) Drainage area of the site (sq. mi) which is the only user input,
2) The Rainfall Type Distribution
3) the 24-hour rainfall (P) in inches that in the case of the prototype is estimated for the 2, 5, 10, 25, 50 and 100-year frequency. The data was obtained from the NOAA Atlas 14 Volume 2 Version 3 for Pittsburgh and from the NOAA Atlas 2 Volume 9 for Vancouver.
4) the NRCS runoff curve number (CN). According to the project's covers, a weighted CN curve number is automatically estimated based on the NRCS (1986). This CN value is used to find the I_a value in Table 5.14 (NRCS 1986). Then, using Table 5.13 and the I_a/P value, the 'C' coefficients are found for estimating the unit peak discharge.
5) the adjustment factor (F_p) in case of pond and swamp areas and are not considered in the Time of Concentration (T_c) computation, and

Table 5.14. Ia values for runoff curve numbers

CN	Ia (in)	CN	Ia (in)	CN	Ia (in)	CN	Ia (in)	CN	Ia (in)
40	3.000	52	1.846	64	1.125	76	0.632	88	0.273
41	2.878	53	1.774	65	1.077	77	0.597	89	0.247
42	2.762	54	1.704	66	1.030	78	0.564	90	0.222
43	2.651	55	1.636	67	0.985	79	0.532	91	0.198
44	2.545	56	1.571	68	0.941	80	0.500	92	0.174
45	2.444	57	1.509	69	0.899	81	0.469	93	0.151
46	2.348	58	1.448	70	0.857	82	0.439	94	0.128
47	2.255	59	1.390	71	0.817	83	0.410	95	0.105
48	2.167	60	1.333	72	0.778	84	0.381	96	0.083
49	2.082	61	1.279	73	0.740	85	0.353	97	0.062
50	2.000	62	1.226	74	0.703	86	0.326	98	0.041
51	1.922	63	1.175	75	0.667	87	0.299		

Adapted from NRCS 1986

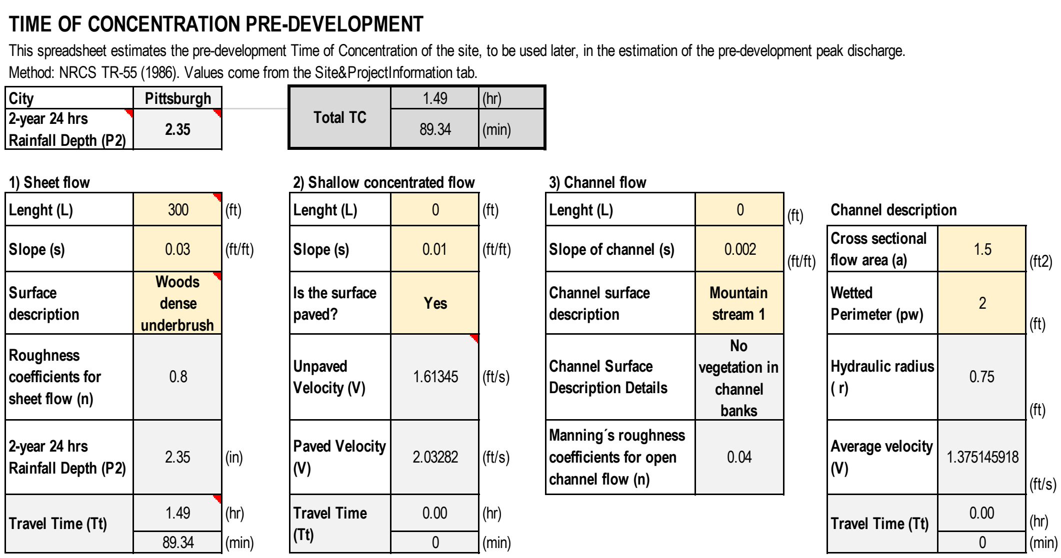
6) Time of Concentration, (T_c) in hours. The procedure used to estimate the T_c is found in the NRCS (1986) and is based on Eq. (12), the sum of travel time (Tt) values for consecutive flow segments.

$$T_c = T_{t1} + T_{t2} + \dots T_{tm} \quad (12)$$

Where:

T_c=time of concentration (hr)
M= number of flow segments

The prototype uses three type of flow segments: sheet, shallow concentrated and open channel flow. For sheet flow estimation, the prototype uses Manning's kinematic equations found in the NRCS (1986). Figure 5.7 shows the spreadsheet for the T_c calculation in the prototype in the case of sheet flow only (Link to the prototype: https://bit.ly/3anFO5c).



TIME OF CONCENTRATION PRE-DEVELOPMENT

This spreadsheet estimates the pre-development Time of Concentration of the site, to be used later, in the estimation of the pre-development peak discharge.
Method: NRCS TR-55 (1986). Values come from the Site&ProjectInformation tab.

City	Pittsburgh
2-year 24 hrs Rainfall Depth (P2)	2.35

Total TC	1.49	(hr)
	89.34	(min)

1) Sheet flow

Lenght (L)	300	(ft)
Slope (s)	0.03	(ft/ft)
Surface description	Woods dense underbrush	
Roughness coefficients for sheet flow (n)	0.8	
2-year 24 hrs Rainfall Depth (P2)	2.35	(in)
Travel Time (Tt)	1.49	(hr)
	89.34	(min)

2) Shallow concentrated flow

Lenght (L)	0	(ft)
Slope (s)	0.01	(ft/ft)
Is the surface paved?	Yes	
Unpaved Velocity (V)	1.61345	(ft/s)
Paved Velocity (V)	2.03282	(ft/s)
Travel Time (Tt)	0.00	(hr)
	0	(min)

3) Channel flow

Lenght (L)	0	(ft)
Slope of channel (s)	0.002	(ft/ft)
Channel surface description	Mountain stream 1	
Channel Surface Description Details	No vegetation in channel banks	
Manning´s roughness coefficients for open channel flow (n)	0.04	

Channel description

Cross sectional flow area (a)	1.5	(ft2)
Wetted Perimeter (pw)	2	(ft)
Hydraulic radius (r)	0.75	(ft)
Average velocity (V)	1.375145918	(ft/s)
Travel Time (Tt)	0.00	(hr)
	0	(min)

Figure 5.7. Pre-development estimation of TC in the prototype

The results of peak discharge calculations in the prototype for pre and post-development conditions are in cubic feet for the 2 to the 100-year rainfall frequency (see Figure 5.8). The post-development estimation includes the LIDs of the L-THIA-LID 2.0 model (Liu 2015). (Link to the prototype: https://bit.ly/3anFO5c).

GRAPHICAL PEAK DISCHARGE METHOD

This spreadsheet estimates the pre-development stormwater peak discharge of the site to be used as a reference for the goals setting module of the prototype. The method implemented is found in the NRCS TR-55 (1986)

City	Pittsburgh

Tc	1.49	(hr)
Drainage area	0.0016	(sq. mi)
Rainfall distribution	II	Type
Hydrological Soil Group	C	
Soil Cover	Forest/Woods	
CN	70	If pond and swamp areas are spread throughout the watershed and are not considered in the
Pond and Swamp adjustment factor	0.0%	Tc computation, an adjustment for pond and swamp areas is also needed.
Fp	1	From Table A

Rainfall Frecuency	**2**	**5**	**10**	**25**	**50**	**100**	yr
Rainfall, P (24-hour)	2.15	2.79	3.24	3.85	4.34	4.85	in
Initial Abstraction, Ia	0.86	0.86	0.86	0.86	0.86	0.86	in
Compute Ia / P	0.40	0.31	0.26	0.22	0.20	0.18	
Rainfall type	II	II	II	II	II	II	
C0	2.37	2.45867	2.48	2.50	2.51	2.52	
C1	-0.60	-0.62	-0.62	-0.62	-0.62	-0.62	
C2	-0.06	-0.11	-0.12	-0.13	-0.14	-0.15	
Unit Peak Discharge, qu	182.12	222.76	234.30	244.44	250.73	256.05	
Runoff Q	0.30	0.60	0.85	1.23	1.56	1.93	in
Fp	1	1	1	1	1	1	
Peak Discharge	**0.09**	**0.22**	**0.32**	**0.49**	**0.63**	**0.80**	cft

Figure 5.8. Pre-development estimation of Stormwater Peak Discharge in the prototype

B. Rational Method

The prototype implements the Rational Method as is presented in the Technical Report Highway Hydrology Hydraulic Design Series Number 2, Second Edition for the locations in Chile to estimate the pre-development discharge. The peak discharge is calculated using Eq. (13) (McCuen, Johnson, and Ragan 2002):

$$Q = C\ i\ A \tag{13}$$

Where:

Q = the peak flow (cft/s)
i = the rainfall intensity for the design storm (in/h)
A = the drainage area in acres (ac)
C = dimensionless runoff coefficient assumed to be a function of the cover of the watershed and often the frequency of the flood being estimated

For Chile, the rational method uses design storms (probabilistic storms) that are defined by each region or city. Soto and Meier (2013) evaluated the design storms that the Chilean Ministry of Public Works recommends and found that the design storms underestimate the run-off peaks. They also propose new coefficients to estimate the design storms for Concepcion, which are available in the prototype. Dr. Meier recommends using the new coefficients because they will respond better to future changes in rainfall characteristics for Concepcion due to climate change (Meier, Claudio, 'Consulta sobre Curvas IDF para Concepción' 'Consultation on IDF Curves for Concepcion'. Email, 2017). Runoff coefficients (C) were obtained from ASCE (1960), Sun et al. (2014), Palla, Gnecco and Lanza (2010), Scharer et al. (2020).

RM peak discharges are calculated in the prototype for pre- and post-development conditions for the 2 to the 100-year rainfall frequency. The post-development estimation includes all the LIDs of the L-THIA-LID 2.0 model (Liu 2015). A weighted Runoff Coefficient (C) value is estimated to perform the stormwater peak flow calculations.

5.3.2.1.6. Water Balance

The water balance estimation provides monthly and annual water needs, supply, and discharge from artifacts or activities. (It does not include stormwater runoff volume or peak discharge estimations.) The water balance is divided into four sections: water needs, water supply, the balance table, and the results. The method used is a hybrid between the
The water needs section gathers the monthly information about indoor water needs, other water needs, and landscape needs. It divides them, in a table, into:

- Artifacts or activities that require potable water (drinking, bathroom faucets, showerheads, bathtub, and kitchen faucets), and
- Artifacts or activities that can use non-potable water (i.e., toilets, urinals, dishwasher, clothes washer, pre-rinse spray valves, landscape, car washing, pool, other uses).

No user inputs are required in this section since all information must have been provided previously (i.e., Site&Project information_, Indoor water needs, Other water needs, and Landscape water needs spreadsheets). Monthly potable, non-potable and total water needs are calculated using the following equations:

$$WN_{pt} = DK + BF + SH + Tub + KF \tag{14}$$

$$WN_{np} = T + U + DW + CW + PR + Land + Car + Pool + OU \tag{15}$$

$$WN_t = WN_{pt} + WN_{np} \tag{16}$$

Where:

WN_{pt} is monthly potable water use (in gal)
WN_{np} is monthly non-potable water use (in gal)
WN_t is total monthly water use

The remaining variables are the monthly water use from the following artifacts and activities: DK: Drinking water, BF: Bathroom faucets, SH: Showerheads, Tub: bathtubs, KF: Kitchen faucets, T: Toilets, U: Urinals, DW: Dishwasher, CW: Clothes Washer, PR: Pre-rinse spray valves, Land: Landscape needs, Car: Car washing, OU: Other uses

The water supply section gathers the monthly information on rainwater harvesting, and potential groundwater, greywater, and blackwater supplies. In addition to the information provided by other spreadsheets in the prototype, some user inputs are required for the final volume estimation of all the supply types. For rainwater harvesting, the user must input a tank capacity (in gal), a supplementary water volume in the tank for the first month (in gal), and define if the harvested water will be for potable and non-potable needs. For groundwater supply, the user must input a monthly extraction capacity (in gal) and indicate if the well water will cover potable and non-potable needs. For greywater and blackwater supply, the user must input a safety factor or keep the default value (0.9) and state if the reused water will cover potable and non-potable needs. A public owner provider system is left to the end, by default, and supplies is not covered by the other sources. The Rainwater supply Spreadsheet provides monthly rainwater supply. Monthly groundwater supply is the monthly extraction capacity defined for each month. Monthly greywater supply is based on Eq. (17):

$$MGS = (BF + SH + Tub + CW) \tag{17}$$

Where:

MGS: Monthly Greywater Supply (in gal)
BF: Monthly bathroom faucets water needs (in gal)
SH: Monthly showerheads water needs (in gal)
Tub: Monthly bathtubs water needs (in gal)
CW: Monthly clothes washer needs (in gal)

Monthly water supply for blackwater is based on Eq. (18):

$$MBS = (KF + T + U + DW + PR) \tag{18}$$

Where:

MBS: Monthly Blackwater Supply (in gal)
KF: Monthly kitchen faucets water needs (in gal)

T: Monthly toilet water needs (in gal)
U: Monthly urinal water needs (in gal)
DW: Monthly dishwasher water needs (in gal)
PR: Monthly Pre-rinse spray valve water needs (in in gal)

It is assumed that all water used by an artifact or activity is collected. However, the safety factor includes an estimate of system losses.

The balance table, the third section of the water balance estimation, is a cascade of monthly calculations where water needs are fulfilled with supply from the different sources. Since the user can set each source to supply potable and/or non-potable water needs, several combinations of groundwater, recycled greywater, recycled blackwater, or harvested rainwater can be considered. However, the order in which needs are met and supplies are used is set up by default. First, potable needs are covered, then non-potable. The sources to fulfill the potable needs are used to exhaustion in this order: rainwater, groundwater, greywater, and public provider. For the non-potable needs, the order is rainwater, groundwater, greywater, blackwater, and public provider. In case one or more of the water supplies is not desired, the balance table moves the needs to be fulfilled to the next supply source. If, after considering all the onsite supplies, there are still needs to be met (potable and non-potable), the amount remaining is provided by a public system.

The balance table starts with rainwater as a supply source. The rainwater supply uses an adaptation of the Texas Water Development Board, Rainwater Harvesting System Size Calculator 2.0 (TWDB 2021). The water available in the rainwater tank includes the rainwater harvested from roofs and a supplementary provision defined by the user for the first month. Rainwater availability is the water remaining from the previous month plus rainwater harvested in the current month. If Rainwater is not used as a supply for potable or non-potable water, the Rainwater available at the beginning of the month is equal to zero. The Rainwater available in the tank is estimated based on Eq. (19):

$$S_{t+1} = S_t + H_t - P_t - NP_t \quad if\ RHS < C \tag{19}$$
$$S_t = C \quad if\ RHS > C$$

The withdrawal for potable and non-potable uses is estimated as follows:

$$P_t = DP_t \qquad if\ S_t + H_t \gg DP_t$$
$$P_t = S_t + H_t \quad if\ S_t + H_t < DP_t \tag{20}$$

$$if\;\; P_t < DP_t \;\; then \;\; NP_t = 0$$

$$if\;\; P_t = DP_t \;\; then$$

$$NP_t = S_t + H_t - P_t \quad if\, S_t + H_t - P_t < DNP_t$$

$$NP_t = DNP_t \qquad if\, S_t + H_t - P_t \gg DNP_t \tag{21}$$

Where:

S_t is the storage in the tank at the beginning of month t
C is the capacity of the tank
H_t is rainwater harvested during t
P_t is withdrawal for potable uses during t
DP_t is the potable need during t
NP_t is the withdrawal for non-potable uses during t
DNP_t is the non-potable need during t
S_0 is the supplementary water in tank the first day of the month

The rainwater available in the tank on the first month of the year based on Eq. (19) is:

$$S_1 = S_0 + H_1 \quad if\, RHS < C$$

$$S_1 = C \quad if\, RHS > C$$

The rainwater available after covering potable needs is estimated:

$$S_{APN\; t+1} = S_t + H_t - P_t \tag{20}$$

Where:

S_{APNt} is the storage in the tank after covering potable needs

Potable water needs after rainwater is estimated:

$$PN_{ARt} = DP_t - P_t \tag{21}$$

$$if\, DP_t < P_t$$

$$then, DP_t = 0$$

Where:

PN_{AR}: Potable water needs after rainwater (in gal)

Non-Potable water needs after rainwater is estimated:

$$NP_{ARt} = DPN_t - S_{APN\; t+1} \tag{22}$$

$$if\, DPN_t < S_{APN\; t+1}$$

$$then, NP_{ARt} = 0$$

If rainwater will not be used as supply for DPN_t,

$$then, NP_{ARt} = DPN_t$$

Where:

NPARt is the non-potable water needs after rainwater (in gal)
DPNt is the non-potable need during t (in gal)
SAPNt is the storage in the tank after covering potable needs (in gal)

Any potable needs not covered by rainwater (DPt) are moved to the next source of supply which is groundwater. Groundwater withdrawn (GW_s) to cover potable needs is estimated using Eq. (23):

$$if\ PN_{ARt} < GMC_t$$

$$GW_{st} = PN_{ARt} \qquad (23)$$

$$if\ not, GW_{st} = GMC_t$$

Where:

GW_{st}: Groundwater withdrawn (in gal)
PN_{ARt}: Potable water needs after rainwater (in gal)
GMC_t: Groundwater monthly withdrawal capacity (in gal), which is a user input. As a guidance the prototype includes regulation provisions that can help to define a pumping capacity.

If the monthly capacity is greater than the needs, groundwater supply will cover the potable needs, leaving water available for non-potable needs. Potable needs after groundwater are:

$$PN_{AGt} = PN_{ARt} - GW_{st} \qquad (24)$$

Where:

PN_{AGt}: potable needs after groundwater (in gal)

Groundwater available after covering potable needs is:

$$GW_{sapt} = GMC_t - GW_{st} \qquad (25)$$

Where:

GW_{sapt}: Groundwater available after potable needs (in gal)

Non-potable water needs after groundwater withdrawals is:

$$if\ NP_{ARt} - GW_{sapt} < 0$$

$$then, NP_{AGt} = 0 \tag{26}$$

$$if\ not, NP_{AGt} = NP_{ARt} - GW_{sapt}$$

Where:

NP_{AGt}: Non-potable water needs after groundwater (in gal)

Groundwater available after covering non-potable needs is estimated using Eq. (27):

$$if\ GW_{sapt} - NP_{ARt} < 0$$

$$then, GW_{anpt} = 0 \tag{27}$$

$$if\ not, GW_{anpt} = GW_{sapt} - NP_{ARt}$$

Where:

GW_{anpt}: Groundwater available after non-potable needs (in gal)

If groundwater will not be used as a supply for potable or non-potable water, the groundwater available for the month is equal to zero, and the needs are moved to the next source, Greywater. If Greywater will not cover potable needs, Greywater supply (Greys) is equal to zero. Greywater supply (Greys) in the balance table is estimated using Eq. (28):

$$Grey_{St} = MGS_t \times SF \tag{28}$$

Where:

$Grey_{st}$: Greywater supply (in gal)
MGS_t: Monthly Greywater Supply (in gal)
SF: Safety Factor (0.9 default value) This safety factor is for accounting for potential systems losses.

Potable needs after the use of greywater are:

$$PN_{AGreyt} = PN_{AGt} - Grey_{st} \tag{29}$$

Where:

PN_{AGreyt}: Potable needs after the use of greywater (in gal)
$Grey_{st}$: Groundwater supply (in gal)
PN_{AGt}: potable needs after groundwater (in gal)

The greywater available after covering potable needs is estimated using Eq. (30):

$$if\ Grey_{st} - PN_{AGt} < 0$$

$$Grey_{apt} = 0 \quad (30)$$

$$if\ not,\ Grey_{apt} = Grey_{st} - PN_{AGt}$$

Where:

$Grey_{apt}$: Greywater available after covering potable needs (in gal)
$Grey_{st}$: Greywater supply (in gal)
PN_{AGt}: potable needs after groundwater (in gal)

If the remaining potable water needs are not entirely covered by greywater, the Public System Supply (PSS) will absorb the remainder, completing the chain supply for potable needs. Potable needs after PSS are always zero. Public System Supply for potable needs (PSSp) is:

$$PSS_{pt} = PN_{AGreyt} \tag{31}$$

Where:

PSS_{pt}: Public System Supply (in gal)
PN_{AGreyt}: Potable needs after the use of greywater (in gal)

If greywater is not used as a supply for non-potable, the needs are moved to the next source, blackwater. In the that case greywater does supply non-potable needs, but not potable needs, the greywater available for covering non-potable needs is:

$$Grey_{npt} = Grey_{st} \tag{32}$$

Where:

$Grey_{npt}$: greywater available for covering non-potable needs (in gal)
$Grey_{st}$: Greywater supply

In the case that greywater supplies are used for both potable and non-potable needs, the greywater available for covering non-potable needs is:

$$Grey_{npt} = Grey_{apt} \tag{33}$$

Where:

$Grey_{npt}$: greywater available for covering non-potable needs (in gal)
$Grey_{apt}$: Greywater available after covering potable needs (in gal)

Non-potable needs after the use of greywater is estimated using Eq. (34):

$$\begin{gathered} if\ NP_{AGt} - Grey_{apt} < 0 \\ then, NP_{agreyt} = 0 \\ ifnot,\ \ NP_{agreyt} = NP_{AGt} - Grey_{apt} \end{gathered} \tag{36}$$

Where:

NP_{agreyt}: Non-potable needs after the use of greywater (in gal)
NP_{AGt}: Non-potable water needs after groundwater (in gal)
$Grey_{apt}$: Greywater available after covering potable needs (in gal)

Greywater remaining after its use for non-potable needs is calculated based on Eq. (37):

$$if\ NP_{AGt} - Grey_{npt} < 0$$
$$then, Grey_R = 0$$
$$if\ not, Grey_{Rt} = Grey_{npt} - NP_{AGt} \quad (37)$$

Where:

$Grey_{Rt}$: greywater remaining (in gal)
NP_{AGt}: non-potable water needs after groundwater (in gal)
$Grey_{npt}$: greywater available for covering non-potable needs (in gal)

If any greywater and blackwater are left in tanks, they are considered discharge at the end of the month. The grey- and blackwater remaining estimation is used as discharge to sewer or on-site treatment system. If blackwater is not used as a supply for non-potable, the blackwater available for the month is equal to zero. Otherwise, Blackwater supply for non-potable needs is calculated using eq. (38):

$$Black_{st} = MBS_t \times SF \quad (38)$$

Where:

$Black_{st}$: Blackwater supply (in gal)
MBS_t: Monthly Blackwater Supply (in gal)
SF: Safety Factor (0.9 default value) This safety factor is for accounting for potential systems losses.

Non-potable needs after the use of blackwater are:

$$if\ NP_{agrey\ t} - Black_{s\ t} < 0$$
$$then, \quad NP_{ablak\ t} = 0$$
$$ifnot, \quad NP_{ablack\ t} = NP_{agrey\ t} - Black_{s\ t} \quad (39)$$

Where:

$NP_{ablack\ t}$: Non-potable needs after the use of blackwater (in gal)
$NP_{agrey\ t}$: Non-potable water needs after greywater (in gal)
$Black_{s\ t}$: Blackwater supply (in gal)

Blackwater remaining after its use for non-potable needs is calculated based on Eq. (40):

$$if\ NP_{agrey\ t} - Black_{s\ t} < 0$$
$$then, Black_{R\ t} = 0$$
$$if\ not, Black_{R\ t} = Black_{s\ t} - NP_{agrey\ t} \quad (40)$$

Where:

$Black_{R\,t}$: blakwater remaining (in gal)
$NP_{agrey\,t}$: non-potable water needs after greywater (in gal)
$Black_{s\,t}$: Blackwater supply (in gal)

Remaining non-potable water needs not covered by blackwater are met by the PSS, completing the chain supply for non-potable needs.

$$PSS_{np\,t} = NP_{ablack\,t} \tag{41}$$

Where:

$PSS_{np\,t}$: Public System Supply for non-potable needs (in gal)
$PN_{ablack\,t}$: Potable needs after the use of blackwater (in gal)

Non-potable needs after PSSnp are always zero.

The last section of the water balance estimation is the results. The result section provides four outcomes that will be used later in the evaluation and comparison of solutions: 1) the Project Annual Water Consumption from the Public Provider, 2) the Reduction of Annual Water Consumption from the Public Provider, 3) the Project Annual Water Discharge to the Public Sewer, and 4) Reduction of Annual Water Discharge to the Public Sewer. The Project Annual Water Consumption from Public Provider is:

$$Project_{AWCPP} = \sum PSS_{p\,t} + \sum PSS_{np\,t} \tag{42}$$

Where:

$Project_{AWCCP}$: Project Annual Water Consumption from Public Provider (in gal)
$PSS_{p\,t}$: Monthly Public System Supply for potable needs (in gal)
$PSS_{np\,t}$: Monthly Public System Supply for non-potable needs (in gal)

The Reduction of Annual Water Consumption from the Public Provider is calculated based on Eq. (43):

$$Reduction_{AWCPP} = \frac{(Base_{AWCPP} - Project_{AWCPP})}{(Base_{AWCPP})} \times 100 \tag{43}$$

Where:

$Reduction_{AWCPP}$: Reduction of Annual Water Consumption from Public Provider (in percentage)
$Base_{AWCPP}$: Base case Annual Water Consumption from Public Provider (in gal)
$Project_{AWCPP}$: Project Annual Water Consumption from Public Provider (in gal)

The Project Annual Water Discharge to a Public Sewer is:

$$Project_{DPS} = \sum Grey_{pt} + \sum Black_{pt} \tag{44}$$

$$Grey_{Dt} = MGSt - \left(Grey_{St} - Grey_{apt}\right) - (Grey_{npt} - Grey_{Rt}) \tag{45}$$

$$Black_{Dt} = MBSt - (Black_{St} - Black_{Rt}) \tag{46}$$

Where:

$Project_{DPS}$: Project Annual Water Discharge to Public Sewer (in gal)
$Grey_{D\,t}$: Monthly Greywater discharge (in gal)
$Black_{D\,t}$: Monthly Blackwater discharge (in gal)

Suppose greywater and blackwater are set to supply for potable or non-potable needs. It is assumed that the system will treat all the grey and blackwater (if it corresponds) remaining at the end of each month and discharge the treated effluent in the site. The estimation from eq. 38 to 46 guide on the sizing of the on-site system. For the purpose of the goal of reducing water discharge to Public Sewer, if blackwater treatment is in place, the $Project_{DPS}$ is equal to zero. The Reduction of Annual Water Discharge to Public Sewer is calculated based on Eq. (47):

$$Reduction_{DPS} = \frac{(Base_{DPS} - Project_{DPS})}{(Base_{DPS})} \times 100 \tag{47}$$

Where:

$Reduction_{DPS}$: Reduction of Annual Discharge to Public Sewer (in percentage)
$Base_{DPS}$: Base case Annual Discharge to Public Sewer (in gal)
$Project_{DPS}$: Project Annual Discharge to Public Sewer (in gal)

The prototype includes two water balance spreadsheets, one for base case estimates (Water Balance_Initial Assessment) and a second one for the water balance of the model (design and scenario) being evaluated (Water Balance_Model). The former spreadsheet provides the Base Case for Annual Consumption from Public Provider and annual Discharge to Public Sewer values and contains the water needs and the water supply values used in the Water Balance-Model calculations.

The initial water balance also provides two initial values of Landscape Water Needs that are used in the goal setting module: 1) for high water consumption plants, and 2) for low water consumption plants. The settings are for 1) Turf, cool season covering over 80% of the landscape area, with a Plant Factor of 0.8 and IE of 0.8. and for 2) Desert plants covering over 80% of the landscape area, with a Plant Factor of 0.3 and IE of 0.8.

The initial water balance also includes data about the roof which are used in determining the Rainwater supply.

5.3.2.1.7. Life Cycle Cost

Life cycle cost analysis (LCCA) has been selected to estimate the overall cost of a model (project) and its design alternatives to later compare them. Conventional water management and SWM systems have long-term service lives where about 80% of the total life-cycle cost occurs in the use phase (Park 2011). LCCA integrates capital, operational, maintenance, and repair expenses allowing decision-making based on a better understanding of total cost over the system's life (Park 2011). LCCA is an essential element of a cost-effectiveness analysis of solutions in the early phases of design (Park 2011). The cost estimation incorporates Net Present Value (NPV) (Park 2011):

$$NPV = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n} \quad (48)$$

Where:

An: Net cash flow at period n
i: interest rate
N: service life of the project

For each SWM system available in the prototype, the NPV includes initial, operation, maintenance, and repair costs (when available). The default Interest rate is 2.5%; this value can be changed by the user in the prototype. N = 20 years since most of the systems have that range of life span.

In addition to the NPV calculation, the cost estimation spreadsheet has two other sections: the assumptions and the cost data. The assumption section allows the user to review or input the details of the systems such as type, size, description, the unit costs and the life span. LIDs drainage areas are retrieved from the model's site and information spreadsheet. Cost information is available in the prototype only for the US. The data source of each system included in the prototype are presented Appendix E.

To fully represent a model in the cost spreadsheet, user inputs are required for artifacts types and water supply systems such as groundwater, greywater, blackwater, disinfection for rainwater and public drinking and sewer systems.

5.3.2.1.8. Goals Settings Module

The goals settings section of the prototype presents to the user nine goals for sustainable water management and provides an initial assessment of feasibility. The goals were extracted from the Living Building Challenge 4.0 Standard (ILFI 2019). Questions are presented at each goal. The prototype performs the estimations to solve the questions running default values and provides the answers. After that, the user has to decide which goals will purse for evaluation of the solution. The goal settings module contains several recommendations and guidance to the user about regulations related to the implementation of SWM.

The nine goals (and 1 exception) presented in the goals settings section aims "to encourage to treat water like a precious resource, minimizing waste and the use of potable water, while avoiding downstream impact and pollution." (ILFI 2019, 38).

The goals are divided into two groups, the first six are the base for defining Sustainable Water Management on the evaluation module. The other group is included as recommendations.

1. <u>Goal 1: Reduce Potable Water Consumption</u>. Two goals are set to achieve goal 1.

   1.1. *Use less potable water than the baseline case.* For new buildings the reduction must be at least 50%, being the goal reducing 100%. The water needs do not includes irrigation. The question included is: Can the project use less potable water than the baseline case thought high-efficiency appliances or use of alternative water supply? The prototype performs two estimations to answer: 1) the percentage of reduction of potable use by implementing high-efficiency artifacts, and 2) the percentage of coverage of water needs with on-site supply (rainwater, groundwater, grey- and blackwater).

   1.2. *Use no potable water for irrigation and non-potable uses.* The project must irrigate with water sources other than public supply and use no potable water for non-potable needs. The questions included are: Can other sources together cover irrigation needs on the warmest month after covering potable needs? Can other sources together cover non-potable needs on the warmest month after covering potable needs? The prototype performs four estimations to answer them, considering high and low water demand landscapes: 1) compares the high and low consumption landscape water needs with the total potential supply of rainwater, groundwater, and greywater, 2) compares the average non-potable demand with the total potential supply of rainwater, groundwater, and greywater, 3) adds the high consumption landscape needs with the average non-potable needs and compares it with the total potential supply of rainwater, groundwater, and greywater, 4) adds the low consumption landscape needs with the average non-potable needs and compares it with the total potential supply of rainwater, groundwater, and greywater.

2. Goal 2: Supply 100% of water needs from site available supply sources. The project should cover water supply with rainwater, on-site groundwater, grey/blackwater, or a closed loop water system. The question included is: Can water needs be covered up to 100% with site available sources? To answer, the prototype estimates the coverage percentage of the monthly on-site supply over the monthly water needs.
3. Goal 3: All greywater and blackwater are treated, reused or infiltrated on-site. The project should treat and infiltrate all greywater and blackwater on-site. The question is: are there areas for infiltration? To answer, the prototype estimates the minimum size of a spray field and the minimum size of the aggregate absorption area (for septic systems) for the project (The estimation procedure was retrieved from the Pennsylvania Code Chapter 73 since the case study is located in Pittsburgh). Then, compares the sizes of the spray field and the absorption area with the project's non-disturbed areas for infiltration.
4. Goal 4: Treat all Stormwater on-site. The project should treat and manage all stormwater on site based on the pre-development hydrology and current conditions.
   The question is: Has the project site for BMPs/LIDs? The prototype, to assist with this goal, presents the pre-development runoff volume and the 10-year peak discharge estimations. And to answer the question, it presents the project's non-disturbed areas available for green infrastructure.
5. Goal 5: Stormwater Pollutant Reduction. The project should treat and manage all stormwater reducing pollutant discharge. The questions are the same as in Goal 4. The prototype presents the pre-development pollutants loads estimations. And to answer the question, it presents the project's non-disturbed areas available for green infrastructure.
6. Goal 6: Green Spaces. The project should dedicate open spaces to natural areas or that favors nature. The question included are: How much of the site will be dedicated to natural areas or that favors nature? Is it more than 50% of the site committed to green spaces? To answer the prototype performs two estimations, 1) adds the landscape areas

and the open areas of the project, and 2) estimates the percentage of green areas over the site's total area.

For each of these six goals, the user has the option to include it in the evaluation of the model. In the Evaluation Module, this option is called 'User's Goals'. Table 5.15. presents the six goals and their influence in the evaluation criteria for the User's Goals option.

Table 5.15. Goals and evaluation criteria for the user's goals option

Goal	Evaluation Criteria
Goal 1: Reduce Potable Water Consumption	Reduction of Public Supply
Goal 2: Supply 100% of water needs from site available supply sources	Reduction of Public Supply
Goal 3: All greywater and blackwater are treated, reused or infiltrated on-site	Reduction of Discharge
Goal 4: Treat all Stormwater on-site.	Managed Runoff
Goal 5: Stormwater Pollutant Reduction	Reduction of TSS, TN, TP
Goal 6: Green Spaces.	Green Spaces

The next three goals and one exception are stated in the prototype as recommendations.

1. Goal 7: All water must be purified without chemical
2. Goal 8: Provide drinking water for regular persons for up to a week through water storage on-site
3. Goal 9: All projects on combined sewer overflow (CSO) or floodplain areas should use stormwater detention and avoid sheet flow off the site
4. Exception 1: Community or municipal connection allowed if water treatment is to terciary levels, reuses or infiltrates all water in balance with the watershed and has a biologically based treatment process without chemicals.

For the implementation of the Evaluation Module, goals 1 through 6 are considered and called the Best Management Practice Option. The Evaluation and comparison of solution procedures are explained below.

5.3.2.1.9. Evaluation and Comparison of Solutions

SWM design decisions require a multi-criteria approach, considering diverse and usually contradictory factors (cost versus environmental performance), to take into account stakeholders' preferences (Ogrodnik 2019). For that reason, the Evaluation Module includes multi-criteria decision-making tools to evaluate a solution and compare it with other alternatives. The Evaluation Module objective is to present the water management performance and cost information in a broad view that allows the user to fully picture the different aspects and trade-offs involved in the SWM design and facilitates the comparisons of solutions.

A. Evaluation of a Model

The criteria for evaluating solutions include Life Cycle Cost and many dimensions of water management performance. Each of the criteria has its own units and scale which can complicate the already challenging task of comparing models and understanding tradeoffs. To ease the comparison, we have expressed each criterion in terms of percent achievement of the optimum for that criterion. The cost criterion is expressed as a percentage between a lower and upper-cost value among the models under comparison (or a default range of $11000 to $200000 USD).

$$CP = 100 - \left(\frac{(Total\ Cost - LowerTotalCost)}{(UpperTotalCost - LowerTotalCost)} \times 100\right) \tag{49}$$

Where:

CP: Cost percentage (%)
Total Cost: Net Present Value (NPV) of a model (in USD)
LowerTotalCost: Lower limit of NPV values between models (or by default) (in USD)
UpperTotalCost: Upper limit of NPV values between models (or by default) (in USD)

The water performance of a model is compared to holistic water management (based on the Living Building Challenge standards and presented in the goals settings module). The water performance of a model includes the reduction of potable water use, the reduction of the most common pollutants TSS, TP, and TN in the stormwater runoff, and the amount of green spaces. The estimation of each criterion is described below.

The overall water management, called, **Water Managed** is estimated as the average of the reduction of potable water supply from the Publicly Owned Provider (%), the reduction of discharge to a public sewer (%), and the managed Runoff Volume (%). Best practice for potable water use and public sewer discharge is 100% reduction compared to the results of a base case conventional design without implementing SWM. The Water Managed is (Eq. 50):

$$WM = \frac{Reduction_{AWCPP} + Reduction_{DPS} + MRoff}{3} \tag{50}$$

Where:

$Reduction_{AWCPP}$: Reduction of Annual Water Consumption from Public Provider (%)
$Reduction_{DPS}$: Reduction of Annual Discharge to Public Sewer (%)
MRoff: Managed Annual Runoff Volume (%)

The **Managed Annual Runoff Volume** is based on the ratio of runoff volume produced by the model to the volume in the Base Case, relative to the pre-development runoff volume. A lower runoff volume yields better performance; 100% corresponds to a runoff volume equal to the pre-development runoff volume. The Managed Annual Runoff Volume (MRoff) criterion is:

$$MRoff = 100 - \left(\frac{YearlyRunoff_{Model} - YearlyRunoff_{Pre-develop}}{YearlyRunoff_{BaseCase} - YearlyRunoff_{Pre-develop}} \times 100\right) \quad (51)$$

Where:

MRoff : Managed Annual Runoff Volume (%)
$YearlyRunoff_{Model}$: Runoff Volume of a model (in cu m)
$YearlyRunoff_{pre\text{-}develop}$: Runoff Volume of the site's pre-development (in cu m)
$YearlyRunoff_{BaseCase}$: Runoff Volume of a Base Case (in cu m)

The **Reduction of Potable Water Use** is expressed as the percentage of reduction of potable water supply from a Publicly Owned Provider compared to the base case. The Reduction of Potable Water Use is:

$$RPS = \frac{BaseCase_{AWCCP} - Project_{AWCCP}}{BaseCase_{AWCCP}} \times 100 \quad (52)$$

Where:

RPS: Reduction of Potable Water Use (%)
$BaseCase_{AWCCP}$: Base Case Annual Water Consumption from Public Provider (in gal)
$Project_{AWCCP}$: Project Annual Water Consumption from Public Provider (in gal)

The **Reduction of TSS, TP, or TN** is expressed as the percentage of reduction of each pollutant due to the implemented LIDs compared to the base case pollutant loads. The Reduction of TSS, TP, or TN is calculated based on Eq. (53):

$$RP_p = \frac{BaseCase_{PLp} - Project_{PLp}}{BaseCase_{PLp}} \times 100 \quad (53)$$

Where:

RP_p: Reduction of Pollutant (p=TSS, TP or TN) (%)
$BaseCase_{PLp}$: Base Case Annual Pollutant Load (in kg)
$Project_{PLp}$: Project Annual Annual Pollutant Load (in kg)

The **Green Spaces** value is the percentage of the site's total area dedicated to open spaces with vegetation.

$$GreenSpaces = \frac{Project_{Green}}{Site\ Size} \times 100 \quad (54)$$

Where:

Green Spaces: Percentage of the total site dedicated to open areas with vegetation (%)
$Project_{Green}$: Size of green areas of the site (sq.ft.). Includes the landscaped areas and open areas without pavement (Area 1 and 2 of the model).
Site Size: Total area of the site (sq.ft.).

The prototype produces a spider graph for the model under evaluation. These graphs show the value of many variables simultaneously, allowing the user to see the values of all of the water performance criteria and the costs. With our definition of criteria as the percentage attainment of best values, being farther out on a radial axis of the spider plot is better, even for criteria, like cost, which otherwise would be minimized. Furthermore, by expressing all criteria as percentages each axis has the same scale. As a result, the spider plot allows for useful visual interpretation, including the comparison of models. The prototype includes a table of values corresponding to the display in the spider graph to help users to understand the results.

As an example, Table 5.16 and Figure 5.9 show the water performance results and the costs of two models, Model 1 and Model 2, and the Base Case. The Base Case is a residential building on a one-acre lot in Pittsburgh without SWM strategies, meaning there is no implementation of efficient artifacts, rainwater harvesting, grey or blackwater reuse or treatment, or LIDs. Model 1 is an attempt to achieve sustainable water management. Model 2 is an improvement of Model 1, aiming for refining water performance in all the criteria at a lower cost. A detailed description of this Case Study is found in section 5.4.1. Details about Model 1 and Model 2 can be found in Appendix F.

Model 1 has higher values in water management and reduction of pollutants. However, the cost criterion of Model 1 is low, meaning that Model 1 has a relatively high cost, which is typical for environmental projects where better environmental performance usually is accompanied by higher costs. Model 2 also has good water management results, but with lower performance in one pollutant reduction, TP, and a higher cost percentage, representing a lower cost. The link to see the full prototype can be found in Appendix G.

Table 5.16. Water performance results and the costs of Model 1, Model 2 and the Base Case

Models	Water Managed	Reduction Public Water Supply	Reduction of TSS	Reduction of TN	Reduction of TP	Green Spaces	Cost	Total Costs
	%	%	%	%	%	%	%	$
Base Case	0	0	0	0	0	87	99	$ 12,008
Model 1	87	98	53	46	51	87	72	$ 63,479
Model 2	90	100	60	50	48	87	76	$ 54,967

Figure 5.9. Spider graphs for Model 1, Model 2 and the Base Case
Link to the prototype: https://bit.ly/3anFO5c

Spider graphs also allow the superposition of a couple of models to compare the solutions in each of the performance criteria. Figure 5.10 presents the results and the spider graph comparison of the two Models and the Base Case implemented in the prototype. The comparison shows that Model 2 has a better performance in almost all water management criteria except Total Phosphorus Reduction. We see this in Figure 5.10 by the fact that Model 2's "web" lies everywhere outside of or on the web for Model 1, except on the TP axis. Thus, there is a tradeoff which can be quickly approximated by using Table 5.16: compared to Model 1, Model 2 produces overall better results including costs that are lower by $8,500 at the sacrifice of 4% TP removal. If the user thinks this is a trade worth making, then Model 2 would be preferred to Model 1.

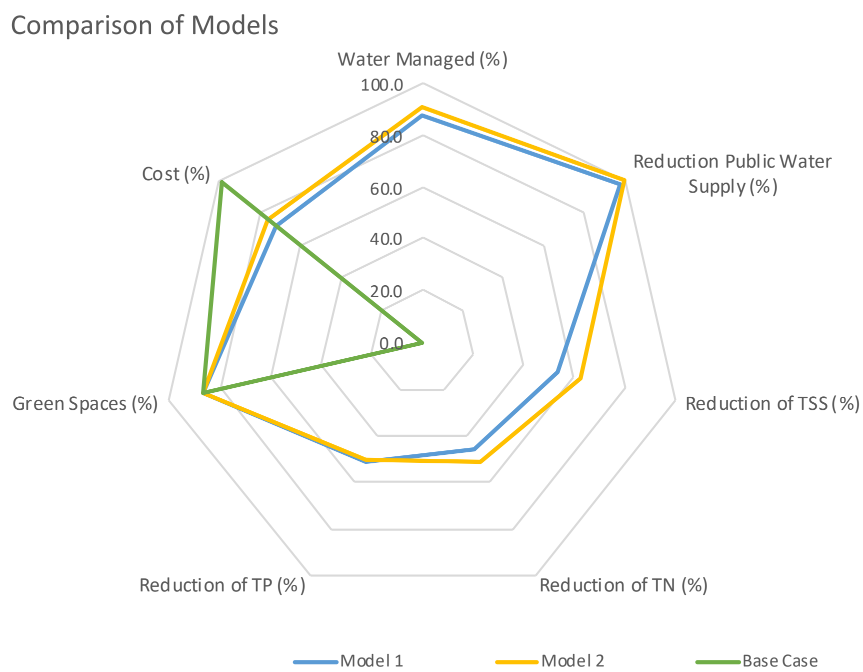


Figure 5.10. Comparison of models in spider graphs in the Prototype.
Link to the prototype: https://bit.ly/3anFO5c

Even though spider graphs allow the comparison of several solutions and show all the criteria, seeing and understanding the tradeoffs are usually more challenging than this example. Suppose there was another model whose web crossed Model 2's web on multiple axes indicating tradeoffs involving multiple criteria. With this in mind, I developed a cost-effectiveness analysis that combines the performance criteria allowing us to construct a Cost-Effectiveness Curve.

B. Cost-Effectiveness Curve

Cost-effectiveness analysis (CEA) is a technique used in fields where assigning a dollar value to non-monetary performance parameters is difficult. Environmental performance falls into this category (Park 2011). In CEA, costs are compared to a single performance measure. Therefore, in the prototype, the non-cost performance criteria are averaged, with equal weights on the criteria, to create a single value called Sustainable Water Management (SWM) performance. Each solution has a cost (NPV) and Sustainable Water Management (SWM) performance expressed as the percentage attainment of the best value. Equal weights are the default setting, but the user can change them to reflect a particular situation or set of preferences. For example, in urban watersheds with water impairment due to discharge of nutrients (Phosphorus and Nitrogen), the user might want to assign higher weights to TP and TN reduction.

The cost and sustainable water management performance of several models are used to construct cost-effectiveness (CE) curve. This provides a mechanism for straightforward comparison of models and the basis for improvements in the design (see Figures 5.11 and 5.12).

C. Demonstration of Use of the Prototype for Design

A hypothetical residential building project on a one-acre lot in Pittsburgh and to be occupied by four persons was used as a Case Study. The project's objective was to incorporate indoor and outdoor SWM strategies to achieve the principles of SWM (ILFI 2019) and evaluate their performance. The Base Case, which serves as a baseline comparison, is the project without incorporating SWM strategies. It uses standard water consumption artifacts and does not implement rainwater harvesting, LIDs, or grey- or blackwater reuse.

Model A was the first effort to achieve a sustainable water performance for the Case Study. First, Model A implements efficient artifacts, collects rainwater, and implements LIDs such as a bioretention area and a grass swale to treat and infiltrate stormwater runoff.

The results of Model A were good but well short of the LBC goals. It reduced the supply from a Publicly Owner Provider by 87%, reduced the discharge to the public sewer by 34%, and reduced the stormwater runoff volume by 31.1%. The reduction of pollutant loads was 35% for TSS, 32% for TN, and 31% for TP. It included no increase in green spaces. The NPV of Model A was 43290 USD (See Tables 5.17 and 5.18). To improve the water performance of Model A, Model B was created. Model B adds to Model A:

- the reuse of greywater for potable and non-potable supply,

implements a blackwater treatment system based on a septic tank and a drain field,

- changes 50% of Area-2's cover from grass to forest to reduce runoff volume,
- add porous pavement, and
- increase the grass swale area to treat and infiltrate stormwater runoff.

Results of Model B were better than Model A, but not quite yet achieving the LBC goals, and cost 20189 USD more. Model B reduced the supply from a Publicly Owner Provider by 98%, eliminated all the discharge to the public sewer, and reduced the stormwater runoff volume by 46.2%. The reduction of pollutant loads was 53% for TSS, 46% for TN, and 51% for TP. The NPV of Model B was 63479 USD (see Figure 5.11).

Models	Total Costs	SWM Average of percentages
	$	%
Base Case	$ 12,008	14.5
Model A	$ 43,290	54.4
Model B	$ 63,479	70.3

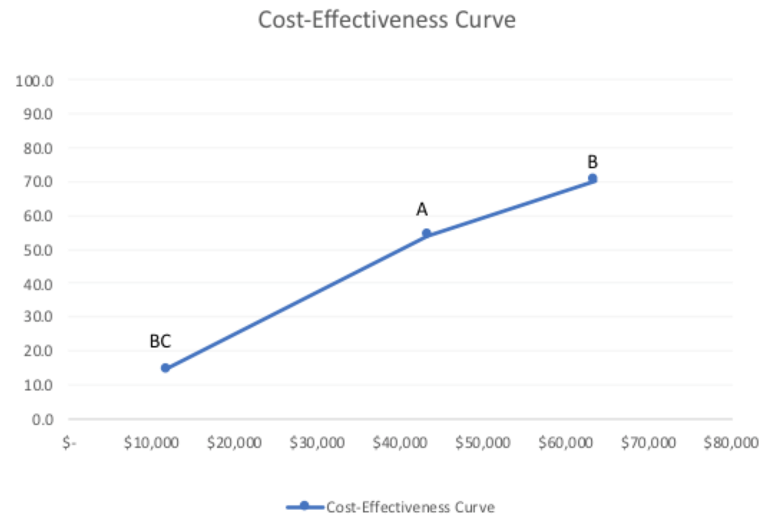


Figure 5.11. CE curve for Base Case and Models A and B

Reviewing the water balance, it was noticed that little water (1713 gal/year) was needed to cover 100% of the water supply and that was for covering landscape needs in the month of August. In addition, porous pavement has a medium to high cost (65.07 $/sq. m) of implementation compared to grass swales (0.99 $/sq. m) or bioretention systems (16.62 $/sq. m). Therefore, the next iteration (Model C) of the design included:

- Three changes were made for covering water supply: 1) raising the flow rate of bathroom faucets to increase greywater supply (but still leaving them under the efficient consumption classification), 2) increasing the roof area collection for rainwater harvesting from 2500 to 2800 sq.ft., and 3) implementing composting toilets.
- To reduce cost and maintain or improve pollutant removal, the porous pavement was reduced by 25%, and the grass swales increased to 75% of the area available (17800 sq.ft.).

The results of the three changes (individually and independently) for covering water supply are the following:

- Increasing the flow rate of bathroom faucets increased to 1751.2 gal/year the public water supply needed
- Increasing the roof area reduced to 976 gal/year the public water supply needed
- Composting toilets reduced to a 191 gal/year the public water supply needed.

Since increasing the roof area and the implementation of composting toilets reduced the public water supply needed, the next iteration was implementing both changes together. The final result was achieving 100% of the water supply from the site without public supply.

Reducing the porous pavement and increasing the grass swale area reduced the cost from 63479 USD to 60126 USD. In addition, increasing the roof area and implementing composting toilets adjusted other systems' parameters, and the final cost is even lower (58426 USD). No public water supply is needed; therefore, no connection and operation cost are incurred. Since less blackwater is produced, the septic system was reduced in cost. The changes on the roof did not generate a bigger RWH system. And even though a greater roof area and composting toilet system increased the cost at each respective category, the final NPV of the changes (Model C) was lower (see Figure 5.12 and Tables 5.17. and 5.18).

A final iteration of the design was attempted to reduce the cost while maintaining sustainable water management (Model D). Model D eliminated the porous pavement and increased the grass swale area by 5%. The changes reduced the cost from 58426 USD to 55179 USD and slightly reduced the SWM performance from 74.1% to 73.5%. Tables 5.16. and 5.17 and Figure 5.12 present the evaluation and the comparison of the models with a CE curve. A more detailed description of the Model A to D is found in the Appendix F.

Table 5.17. Water Performance Percentages and Costs for the Base Case and Models A to D

Models	Water Managed	Reduction Public Supply	Reduction of TSS	Reduction of TN	Reduction of TP	Green Spaces	Cost	Total Costs
	%	%	%	%	%	%	%	$
Base Case	0	0	0	0	0	87	99	$ 12,008
Model A	55	87	35	32	31	87	82	$ 43,290
Model B	87	98	53	46	51	87	72	$ 63,479
Model C	91	100	62.2	51.7	53.1	87	75	$ 58,426
Model D	90	100	62.7	51.2	49.7	87	76	$ 55,179

Table 5.18. Water Managed Results for the Base Case and Models 1 to 4

Models	Public Supply	Reduction of Public Supply	Sewer Discharge	Reduction of Sewer	Runoff Volume	Managed Runoff	Water Managed
	gallons	%	gallons	%	m3	%	%
Pre-development	-	-	-	-	188	-	-
Base Case	77098	0	68175	0	676	0	0
Model A	9960	87	45278	34	466	43	55
Model B	1713	98	0	100	364	64	87
Model C	0	100	0	100	326	72	91
Model D	0	100	0	100	330	71	90

Models	Total Costs	SWM Average of percentages
	$	%
Base Case	$ 12,008	14.5
Model A	$ 43,290	54.4
Model B	$ 63,479	70.3
Model C	$ 58,426	74.1
Model D	$ 55,179	73.5

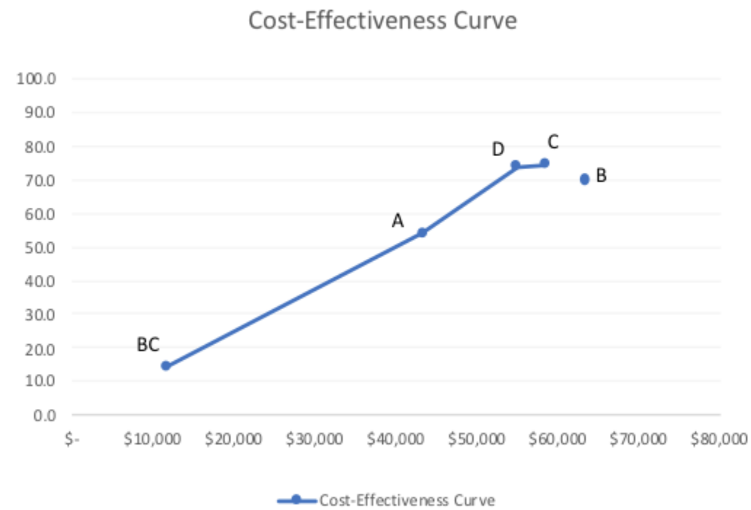


Figure 5.12. CE curve for Base Case and Models A to D

The CE curve in Figure 5.12 allows for a comparison of the design alternatives. We can see how environmental performance and cost increased as we moved from the base case to Model A and then to Model B. As we refined the design further, we produced Models C and D both of which dominate Model B, i.e. they give higher environmental performance at lower cost, which we can see at a glance in the Figure 5.12. Choosing among the points on the CE curve requires a value judgement about the tradeoffs between performance and cost which can only come from the designer and/or his or her client.

5.3.2.2. Organization of the Prototype and User Interface.

5.3.2.2.1. Prototype Organization

The prototype is divided into two parts: 1) Initial Assessment and 2) Model Development and Evaluation. The Initial Assessment purpose is, with the little site and project information, to provide a feasibility report of achieving the Sustainable Water Management goals. For the Initial Assessment, user inputs are required only for the site and the project and stormwater peak discharge calculations. All the estimations are run with default values to give a range of what the future design might achieve. This section also estimates the pre-development stormwater runoff volume and peak discharge. The initial Assessment contains 11 spreadsheets:

- Site&ProjectInformation_PRE
- Indoor Water Needs_PRE

- Other Water Needs_PRE

- Landscape Water Needs_PRE

- Rainwater Supply_PRE

- Time Concentration_PRE

- Peak Disch_NRCS Graphical_PRE

- Peak Discharge_PRE_RM (only for Chile)

Runoff Vol_Qual_RESULTS_PRE. This spreadsheet only presents the results, the runoff and quality estimations are run in the "Runoff Vol_Qual Estim" spreadsheet.

- Water Balance_Initial Assesment

- Goals

The Initial Assessment finalizes with the Goals spreadsheet where the user reviews the SWM goals, the predicted performance of the site, and project and selects which goals to pursue.

The Model Section's purpose is to form, iterate, and test an SWM solution. Each spreadsheet of this section calls for user inputs to perform the estimations. The Model Section contains 12 main spreadsheets and other seven that serves as computing and database for running the L-THIA-LID 2.1 model:

- Site&ProjectInformation_MODEL
- Time Concentration_POST
- Peak Disch_NRCS Graphical_POST
- Peak Discharge_POST_RM
- Landscape Water Needs_MODEL
- Other Water Needs_MODEL
- Rainwater Supply_MODEL
- Indoor Water Needs_MODEL
- Water Balance_MODEL
- Runoff Vol_Qual Estim (L-THIA-LID 2.1 model input spreadsheet)
- Costs_MODEL
- Evaluation_MODEL

Computing and Database for L-THIA-LID 2.1 Model

- Runoff Concent-Liu 2015 (L-THIA-LID 2.1 model calculation spreadsheet)
- Concentr-Liu 2015 (L-THIA-LID 2.1 model calculation spreadsheet)
- Irred Concent-Liu 2015 (Database)

- outf vol inf vol ratio-Liu 2015 (Database)
- Ratio concen-Liu 2015 (Database)
- CN-Liu 2015 (Database)
- EMC - original conce-Lui 2015 (Database)

Appendix D contains diagrams of the inputs, flow of information, and outputs for both prototype sections. Appendix G contains the link to the full prototype.

5.3.2.2.2. Model

A model is a representation in the prototype of a project plus a rainfall pattern. Three types of rainfall patterns are available in the prototype, Dry, Wet, and Normal. Currently, the prototype runs with one year of rainfall data (365 days). For Pittsburgh, a Dry pattern is represented with the rainfall data of 1995, a Wet pattern with rainfall data of 2004, and a Normal year with data from 2010. Precipitation comes from the Global Historical Climatology Network database (GHCN 2018). Station PITTSBURGH ASOS, PA US, GHCND: USW00094823. Pittsburgh Normal Precipitation depth is 38.19 inches (1981-2010) (Arguez et al. 2010).

5.3.2.2.3. Guidance to the user

The guidance to the user in the prototype entails three areas: Regulations, Procedures Assumptions and procedures, and Recommendations on Suitability Criteria for LIDs. Currently, the prototype manages only guidance for the city of Pittsburgh. The information incorporated as comments thought out of the prototype is detailed in the following paragraphs.

1. Information about Regulations was retrieved from the following sources:
    a. Allegheny County Health Department's Plumbing Code Article XV
    b. Incorporating Greywater into Urban Design (Chen and Fagan 2015)
    c. Pennsylvania Code. Chapter 73. Standards for Onlot Sewage Treatment Facilities
    d. Allegheny County Health Department Code. Chapter 860: Plumbing and Building Drainage.
    e. Report. Stormwater Ordinance Review: Barriers and Facilitators to Green Infrastructure and Low-Impact Development in Allegheny County, Pennsylvania (Bakshi 2013)
2. Information about Procedures Assumptions comes from each of the methods implemented in the prototype.
3. Recommendations on Suitability Criteria for LIDs were obtained from Liu (2015), Shoemaker et al. (2009), and USEPA (2004). The L-THIA-LID 2.1 model recommends following the suitability criteria for defining the location of BMPs/LIDs in a site. Table 5.19

present the default criteria for BMP/LID practice suitable locations gathered from the EPA literature (Shoemaker et al. 2009; USEPA 2004).

Table 5.19. Criteria for locating BMPs/LIDs strategies

		Site Suitability Criteria							
	BMP/LID	Drainage Area (ac)	Drainage Slope (%)	Imperviousness (%)	Hydrologic Soil Group	Road Buffer (ft)	Stream Buffer (ft)	Building Buffer (ft)	Water Table Depth (ft)
1	Green Roof	/	/	/	/	/	/	On building	/
2	Cistern	/	/	/	/	/	/	On building	/
3	Permeable patio	/	/	/	A–D	/	/	>15	>2
4	Porous Pavement	< 3	< 1	> 0	A–D	/	/	/	>2
5	Grassed Swale	< 5	< 4	> 0	A–D	< 100	/	/	>2
6	Grass strip	/	< 10	> 0	A–D	< 100	/	/	>2
7	Wetland Channel	<5	<4	> 0	A–D	< 100	/	/	>2
8	Bioretention	< 2	< 5	> 0	A–D	< 100	> 100	/	>2
9	Wet Pond	> 25	< 15	> 0	A–D	/	> 100	/	>4
10	Dry Pond	> 10	< 15	> 0	A–D	/	> 100	/	>4
11	Wetland	> 25	< 15	> 0	A–D	/	> 100	/	>4

Adapted from Liu (2015), Shoemaker et al. (2009), USEPA (2004)

5.3.2.2.4. Data Storage

Data storage is represented partially in the prototype. Data for estimations are included in each of the spreadsheets, like a database. The exception is for the Runoff Volume and water quality estimation, which uses as database six other spreadsheets. Storage of models or partial solutions was not implemented. The results of several models for performing evaluations and comparisons were manually copied and inputted were needed. Users can introduce new data into the prototype. However, no database management is in place at the current state of development of the prototype, and new data input has to be done manually. Incorporating the new data entails modifying existing database tables available, modifying the range of cells available for the drop-down menus, and modifying formulas that use tables in their estimation procedure. The performing of several changes into the prototype has the risk of modifying its well-functioning and results.

5.4. Testing

A software prototype to model key components that execute the tool's requirements was developed as a proof of concept (section 5.1). The prototype was tested using a hypothetical residential design project. The testing measured the tool's performance against designed behavior. The prototype delivers the accurate results of the assessments such as water performance, costs estimations, and evaluation.

5.4.1. Protocol and Data

For validating the prototype tool, a set of nine tasks was used in the test protocol. The protocol, the tasks and the outcome measurements developed are presented below.

The protocol is based on a case study of the generation of a hypothetical design concept and alternative solutions using a design project of a new construction single-family building in an urban lot of 1 acre located in Pittsburgh, PA. The project must be a net positive water house, according to the new LBC standard, and have four occupants, two adults, and two teenagers. The spaces and activities include a bathroom, a kitchen with a sink and a dishwasher, a laundry room with a washing machine, and outside a parking/garage area, a patio, sidewalk, driveway, and a landscaped area.

5.4.1.1. Data

Climate data for Pittsburgh, PA, was obtained from:

1. Daily and Monthly Precipitation - Air Temperatures (Maximum and minimum temperatures) from the Global Historical Climatology Network database (GHCN 2018). Station PITTSBURGH ASOS, PA US, GHCND: USW00094823.
2. Daily Global horizontal irradiance, Wind speed, and Dew point temperature from the National Solar Radiation Database (NSRDB) (NREL 2018).
3. Daily Reference Evapotranspiration (ETref) Calculator (Snyder and Eching 2000)
4. Rainfall Intensity (i) from the NOAA ATLAS 14 Version 3 (NCEI 2008)

The type of precipitation pattern used in all estimations is Normal year. Pittsburgh Normal

Precipitation depth is 38.19 inches (1981-2010) (https://gis.ncdc.noaa.gov/maps/ncei/normals). The rainfall depth of the year 2010 represents the Normal Year precipitation depth in the prototype.

Five Models have been created based on the Case Study for testing: Base Case, Model A, Model B, Model C, and Model D.

The Base Case is the Case Study without the implementation of SWM strategies, meaning there is not an implementation of efficient artifacts, rainwater harvesting, grey or blackwater reuse or treatment, and LIDs. Model A is a first attempt to achieve a net positive water performance for the case study. Model B improves Model A adding greywater and blackwater treatment. Models C and D are improvements of Model B, aiming for refining water performance in all the criteria at lower costs. Details of the Case Study, Base Case, Model A to D are below. Specific modeling settings for Models A to D is found in Appendix F.

5.4.1.2. Description of the Case Study in Detail

Location: Pittsburgh, PA, US

Site Size: 45000 (sq.ft.) – 1 Acre (131.58 ft x 342 ft)

Site Slope: 3% in the longitudinal way (Arrow in Figure 5.13)

Roof area: 2500 (sq.ft.), material: Metal Panel (Num. 1 in Figure 5.13)

Patio: 1000 (sq.ft.), Material: concrete (Num. 2 in Figure 5.13)

Driveway: 730 (sq.ft.), Material: concrete (Num. 3 in Figure 5.13)

Sidewalk: 530 (sq.ft.), Material: concrete (Num. 4 in Figure 5.13)

Parking Lot: 1000 (sq.ft.), Material: concrete (Num. 5 in Figure 5.13)

Landscape Area: 8720 (sq.ft.), Open space - grass cover > 75% (Num. 6 in Figure 5.13)

Area-1: 15250 (sq.ft.), Forest/Woods (Num. 7 in Figure 5.13)

Area 2: 15250 (sq.ft.), Grass/Pasture (Num. 8 in Figure 5.13)

Hydrologic Soil Group: C

Depth to water table: 6.56 (ft)

Number of persons: 4

Metered Indoor Water Consumption: 5166 gal

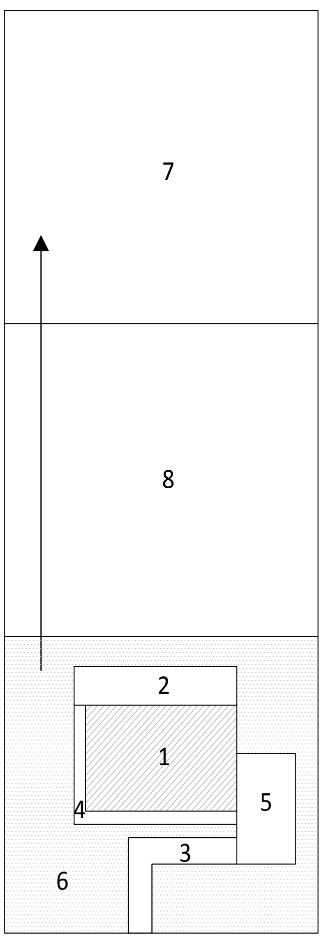


Figure 5.13. Case Study Soil Covers

Case Study Pre-development Time of Concentration (TC)

Pre-development TC is calculated using a sheet flow length of 300 (ft), slope of 0.03 ft/ft (3%), and a surface cover description of Woods dense underbrush that provides a Roughness Coefficient for sheet flow of 0.8.

Case Study Pre-development Graphical Peak Discharge

The Pre-development Peak Discharge Estimation is calculated using a TC of 1.49 hr., the rainfall distribution type II that correspond to Pittsburgh area, a soil cover of Forest/Woods with a CN value of 70 for the Hydrological Soil Group C, and 0% of Pond and Swamp Adjustment factor.

5.4.1.3. Base Case

Base Case Indoor Water Use

For indoor water use, the Base Case is the Case Study with the implementation of standard water use artifacts. Values used in the case base:

- Drinking Water Needs: 0.8 (gal/person/day), four persons.
- Bathroom Faucets: US Standard Bathroom Faucet 2.2 GPM, four persons, seven times per day, 0.3 minutes per time.
- Showerheads: US Standard 2.5 GPM, four persons, 0.7 times per day, 7 minutes per time.
- Kitchen faucets: US Standard Kitchen Faucet 2.2 GPM, one person, three times per day, 8 minutes per time.
- Bathtub: US average volume per capita day (1.69 gal/person/day), volume 1.7 gal, four persons.
- Dishwasher: US Standard 6 gal per cycle, one person, one cycle per day.
- Clothes washer: US Standard 20 gal per cycle, four persons, 0.2 number of cycles per day.
- Toilets: US Standard Single Flush 1.6 gal per flush, four persons, six flushes/person/day.
- No urinals and pre-rinse spray valves included.

Base Case Outdoor Water Use

Base Case outdoor water use includes only car washing, with a bucket, 2 times per month each month with a volume per wash of 25 gal.

Base Case Landscape Water Needs

The Base Case landscape water needs settings are an area of desert plants with a canopy covering over 80%, with a Plant Factor of 0.3 and I.E. of 0.8.

Base Case Rainwater harvesting

The Base Case does not implement RWH.

Base Case Graphical Peak Discharge Estimations

The TC estimation parameters are a sheet flow length of 200 ft, the slope of 0.03 ft/ft (3%), and a surface cover description of Woods light underbrush, shallow concentrated flow with 100 ft length, 3% slope, and paved surface, no channel flow. The pond and swamp adjustment factor are 0%.

Base Case Costs and Evaluation

The cost inputs for the Base Case are:

For artifacts:

- one Bathroom Faucet (US Standard Bathroom Faucet Zurn 2.2 GPM)
- one Kitchen Faucet (Moen 87233SRS 2.2 GPM)
- one shower (Couradric Handheld Shower Head 2.5GPM), and
- one toilet (American Standard Cadet 3, 1.6 gal/flush)

Drinking water connection and sewer service for 6000 gal of consumption per month. Interest rate: 2.5%. For the evaluation, all the water management criteria are equally weighted.

5.4.1.4. Model A

Model A is the first attempt to bring the Base Case to sustainably managing water. Model A implements efficient artifacts, collects rainwater from the roof (100% of 2500 sq.ft.) for potable and non-potable use with a rainwater tank of 7000 gal. Model A includes a bioretention area (size: 100% of the available area) and implements grass swales (size: 25% of the available area). The drinking water connection was set for 1000 gal/month, and the sewer connection was for 4000 gal/month. A rainwater disinfection system was included for 15 GPM treatment. The interest rate was set at 2.5% and all the water management criteria in the evaluation were equally weighted. The interest rate and the evaluation criteria were kept through all model's runs. The water balance and costs estimations were updated to run Model A. All other Base Case parameters were maintained in Model A.

5.4.1.5. Model B

Model B was created to improve Model A. Model B adds to Model A the use of greywater for potable and non-potable supply. The greywater system size is 75 GPD, and the blackwater treatment is based on a conventional gravity septic system and a drain field (for a 3-bedroom household). The drinking water connection was set for 1000 gal/month, and no sewer connection is required. Model B changes 50% of Area-2's cover from grass to forest to reduce runoff volume in the open areas available. It changes 50% of pavement areas to porous pavement and increases the grass swale area to treat and infiltrate stormwater runoff (size: 50% of the available area).

5.4.1.6. Model C

Model C was created with the aim to improve water performance of Model B at lower cost. After reviewing the water balance, it was noticed that little water (1712 gal/year) was needed to cover 100% of the water supply in Model B. In addition, in the cost module was saw that porous pavement has a medium to high cost (65.07 $/sq. m) of implementation compared to grass swales (0.99 $/sq. m) or bioretention systems (16.62 $/sq. m). Therefore, the following changes were tested:

1. The uses bathroom faucets with higher flow rate from 1.2 GPM to 1.5 in a manner to increase greywater supply but still leaving them under the efficient consumption classification
2. The increase the roof area collection for rainwater harvesting from 2500 to 2800 sq.ft.
3. The implementation of composting toilets
4. The porous pavement was reduced by 25%, and the grass swales increased to 75% of the area available (17800 sq.ft.) to reduce cost and maintain or improve pollutant removal

Since all water needs are covered with on-site supply, the drinking water connection was set to zero, and no sewer connection is required. The greywater system size was kept as 75 GPD and a smaller conventional gravity Septic system was set for blackwater treatment (3500 USD). The disinfection system was kept at 15 GPM for rainwater treatment since the size of the system can absorb the higher treatment volume.

5.4.1.7. Model D

Model D is the final iteration of the design. In this model, the aim was to reduce the cost while maintaining the sustainable water management performance. Model D eliminated the porous pavement and increased the grass swale area by 5%. All other parameters are maintained.

5.4.2. Testing design and Measuring Outcomes

Seven tasks, each related to one requirement (or sub-requirement) for the tool, have been defined and performed in the prototype with the objective to determine whether the system is executing the activity and delivering the right outcome. Each task was evaluated for successful or fail to achieve its objective and accuracy of the outcome delivered.

Task 1: Set Goals

The objective of this task is to verify that the system is providing the performance targets according to the SWM goals.

Task 2: Form a solution (combination of SWM)

The objective of this task is to verify that the system allows combining SWM components and connecting them.

Task 3: Form an alternative solution

The objective of this task is to verify that the system allows to create an alternative solution, selecting and combining SWM or changing design characteristics (roof area, soil cover).

Task 4: Perform water performance and cost

The objective of this task is to verify that the system is performing the estimation the water performance (i.e., demand/supply, stormwater) and costs of a solution.

Task 5: Evaluate and compare a solution

The objective of this task is to verify that the system is performing the calculation and delivering the right solution when: 1) comparing the results of the water performance of a solution with the performance targets, 2) calculating the LCC of the solution, 3) assigning percentage values to the SWM criteria, and 4) calculating and graphing the cost-effectiveness curve of the solutions for comparison.

Task 6: Make changes to the evaluation criteria

The objective of this task is to verify that the modification of weights produces new and correct results of the evaluation and comparisons of solution.

Task 7: Review access to systems capabilities, assumptions and activate regulations' alerts

The objective of this task is to verify that the system presents the messages to the user about systems capabilities and assumptions and retrieves the regulation information for a defined location and sent the respective messages.

5.4.3. Testing Results

The Case Study implementation throughout the Base Case and Models A to D helped test each of the seven tasks defined.

Task 1: Set Goals. The prototype in its Goals Settings Module allows performing Task 1, set goals. The Goals Settings Module provides an initial assessment for each of the six goals included in the Evaluation Module. The Goals Settings module allows the user to check which goal to pursue, inputting Yes or No in the spreadsheet. This decision is then carried out to the Evaluation Module, where the criteria are included or not in the final calculation. Changes from "Yes" to "No" were made to each of the six goals presented at the Goals Settings Module, and the Evaluation Module changed the weights to "0" of the criteria related. The prototype correctly modified the final percentage estimated in the Evaluation Module. Automation of the weights assignments is not implemented yet in the prototype.

Task 2: Form a solution (a combination of SWM). The prototype in its Site and Project, Water Balance and Cost Modules, allows the combining of SWM strategies. The prototype represented the Base Case and Model A to D, which contained several SWM strategies trying to achieve Sustainable Water Management. The Water Balance Module integrates indoor and outdoor water needs with different types of supply. The Cost Module integrates indoor and outdoor SWM components in its estimations.

Task 3: Form an alternative solution. The creation of Models B to D served to perform Task 3. The different modules in the prototype allowed us to create alternative solutions, select and combine SWM, and change design characteristics. A design iteration of four models based on the base case was carried out, were partial and incremental/reductional changes were made to each model for indoor or outdoor SWM strategies.

Task 4: Perform Water Performance and Cost. For performing Task 4, the following modules were used: the Water Balance, the Stormwater runoff volume and runoff pollutants loads, and the Cost Module. The prototype was tested several times to measure the outcome delivered of each of the methods implemented through its development. Each method was tested with calculation examples presented in the literature. The runoff volume and quality procedure results were reviewed against the L-THIA-LID 2.1 Python model provided by Dr. Yaoze Liu (Liu 2015). The results obtained are equal and accurate according to the L-THIA-LID 2.1 model using the same Base Case and Model A to D parameters.

Task 5: Evaluate and compare a solution. In the prototype, the Cost Module and the Evaluation Module performs the calculations that task 5 commands. The Cost Module calculated the LCC of the Base case and Model A to D. The Evaluation Module:

a. Compared the results of the water performance of the solution with the performance targets.
b. Compared the results of the water performance of a solution with the performance of other solutions.
c. Assigned percentage values to the SWM criteria.
d. Calculated and draw the cost-effectiveness curve of the solutions under comparison.

Both modules were tested several times for the accuracy of their results thought their development. The prototype performs and delivers a table and spider graphs with the results in an accurate way.

Task 6: Making Changes to Evaluation Criteria. This task was performed in the Evaluation module. The modification of weights produced new and correct results of the evaluation and comparisons of solutions.

Task 7: Review access to systems capabilities, assumptions and activate regulations' alerts. The system presented the user's messages about systems capabilities and assumptions and the Regulations' alerts at its use.

Results

The prototype performed the seven tasks defined for its testing. The prototype delivered the results of its estimations procedures correctly. Results of the Base Case and Models A to D are found in Appendix F. The link to see the full prototype is found in Appendix G.

6. SUMMARY, CONTRIBUTIONS, AND RECOMMENDATIONS

6.1. Summary

Designing for SWM in the residential sector requires a holistic approach that includes economic considerations, environmental impacts and regulatory barriers early in the design process. This is a challenging task for designers, made even more difficult by the lack of appropriate tools. The research that has been performed previously and the development of tools have focused on large-scale SWM issues rather than on small projects typical of residential design. Furthermore, existing tools for SWM design do not integrate indoor and outdoor strategies, are complex, require technical water knowledge not possessed by most users, and requires well-defined designs. And, the few simple tools that do exist cannot be customized for local data.

This dissertation's main objective was to investigate the issues related to developing a tool oriented to SWM design for the residential sector. The development of such a tool involved the identification of the tool's requirements from the perspective of the professionals who perform residential design. Five activities have been performed to fill this gap: a literature review, an ethnographic study, a national survey to help develop the SWM design process model and the tool's requirements; and assembly of a prototype tool that integrates the required functionalities and allows for further development recommendations.

The primary focus of this research was developing and testing a prototype of a suitable design tool and making recommendations for its further improvement. The built prototype served as a proof of concept and allowed studying the issues of integrating the necessary functionalities with a basic user interface and focus on the designer's needs.

The specific products of this research are:

1. The Ethnographic Studies Results (Chapter 3)
2. The Survey Results (Chapter 3)
3. A Process Model for SWM design (Chapter 4)
4. A Medium-fidelity prototype for the SWM design process (Chapter 5)
5. Recommendations for the future development of a tool that supports SWM design for the residential sector (the current chapter).

6.2. Contributions

The contributions of this dissertation are: increasing knowledge about the SWM design process in the residential sector, an ethnographic analysis of the SWM process based on a real case study in Pittsburgh, PA, a national SWM survey gathering information on the critical components of an SWM design tool developed to dovetail with the SWM design process, and a tested prototype tool built upon the principles of SWM design compiled from the ethnographic analysis and the national SWM survey cited above.

The ethnographic studies and the national survey results helped shape the process model of the SWM design for the residential sector presented in this dissertation. The development of the SWM design model advances our knowledge about design production and decision-making for SWM. Knowing more about the SWM design process is important to researchers in sustainable design, specifically in sustainable water management where there is limited existing background. The process model is a starting point for further research that leads to improved design process models. Developers of tools in green design and SWM also can benefit from the process model developed.

The prototype tool integrates the functionalities required by professionals for SWM design in the residential sector.

- The prototype provides a holistic approach to SWM design. It integrates indoor and outdoor water needs and allows SWM components to be included its management. Through a water balance table, the prototype incorporates different water supply sources (including reuse of grey and blackwater) and deploys them according to the quality needs of water uses.
- The prototype integrates costs and environmental performance in the early phases and supports multicriteria decision-making in SWM design. In addition to the water balance estimation, the prototype performs hydrological and water quality estimations and cost estimations that serve as the basis for the and comparison of alternative designs through the use of MCDM techniques. The user gains from this approach a better understanding of the range of possible designs and the tradeoffs involved in choosing from among them.
- The prototype incorporates methods of appropriate technical complexity for the early phases of design, adapted to non-expert SWM designers. Widely used procedures are used, and regulations, assumptions, and suitability criteria for SWM components are

made explicit to the user. It provides a friendly environment where it is easy to modify and test alternatives or partial solutions.

The functionalities tested in the prototype can be used as a specification for software. This will foster the integration of SWM strategies early into the design process with an approach that responds to designers' needs while adopting computational tools barrier-free.

6.3. Recommendations for Future Work

The implementation of the SWM design requirements and the testing of the prototype revealed limitations and opportunities for improvement. Six areas for recommendations are discussed: Hydrological Models, Multicriteria Decision Making, Cost Data and Modeling, Database and Database Management, Extensions to Other Cities, and User Testing.

Hydrological Models

The methods implemented in the prototype were selected with a focus on widely used hydrological models, straightforward application, integration capabilities with the Excel spreadsheets, applicability for small sites, and accuracy. However, the search for models that fulfill all the expectations showed that there is still work to be done to improve hydrological models for small sites, especially with regard to simplicity and accuracy, for estimating stormwater runoff volume, peak discharge, and groundwater recharge. Each of these is discussed further below, as well as an issue for non-US applications.

<u>Improvements to the runoff volume estimation method.</u> The prototype employed the L-THIA-LID 2.1 model that uses the NRCS 1986 Curve number method for runoff volume estimations. However, the NRCS (1986) method underestimates runoff volume for storms less than 1.5-inch in depth (PA DEP 2006), which are the storms that contribute around 80% of the non-point source pollutants to surface waters. Other methods were studied such as the Small Storm Hydrology Method (Pitt 1999). The SSHM performs well for small storm depths but it is built into a complex software package that is difficult and time-consuming to integrate into a Microsoft Excel spreadsheet. Therefore, improvements to small storm runoff volume estimation, striking the right balance between accuracy and ease of use, would be useful.

<u>Improvements to peak discharge estimation for small sites.</u> Time of Concentration (TC) is a key parameter for performing peak discharge estimates. TC for small sites can be less than 5 minutes, which is less than the lower bound for the Intensity-Duration-Frequency Rainfall Curves (IDF tables) used in the peak discharge estimation. Moreover, the conventional approach to TC

estimation does not account well for the storage provided by BMPs/LIDs systems. Therefore, its use will not provide a reliable post-development peak discharge for sites that implement these systems. One path for improvement is the development of Spatial-Temporal models proposed by Dr. Richard McCuen (McCuen, Richard H., 'comments'. Email, 2019) which would better represent the effects of the location of BMPs/LIDs and the amounts of storage they provide, resulting in better TC values to be used in small sites. Data requirements for implementation of such an approach are significant, however.

<u>Use of one estimation method for roof runoff volume in the prototype.</u> The prototype uses two different methods for estimating runoff volume from roofs, reflecting the lack of agreement among water professionals on a preferred approach. The Rational Method is used in the prototype for estimating rainwater harvesting potential, while the NRCS Curve Number is used for estimating runoff volume. This creates two different values for runoff volume from the same area. This situation has potential to create confusion for non-expert water management users. Future work is needed to explore, develop and test the use of one estimation method for roof runoff volume for the prototype.

<u>Development of groundwater recharge estimates.</u> Available groundwater recharge models require many site-specific parameters for application at a particular site. Work is needed to develop more generalized input parameters, so the data requirements for site-specific application are not quite as significant. Therefore, research and professional validation are needed for groundwater recharge models that can be applied for a range of sites and with fewer site-specific parameters.

<u>Hydrologic methods for regions outside the US.</u> The prototype's development included methods for three cities: Pittsburgh (Pennsylvania), Vancouver (Washington), and Concepcion (Chile). However, US models such as the NRCS Curve Number are not recommended for use in Chile because they are based on US rainfall-runoff data not validated for Chilean conditions. The rational method is used in Chile for runoff estimation. However, available IDF curves start at 10 minutes. Therefore, for sites with a Time of Concentration lower than 10 minutes, which is typical for small sites, the method is not accurate. Thus, the prototype may not be accurate for estimating runoff volume and quality for regions outside the US and with TC < 10 minutes. Research and validation are needed for simple runoff volume and water quality models for Chile. Extensions to other countries must also take into account difference in practices of this sort.

Multiple Criteria Decision Making (MCDM) and the Design Process

Selecting SWM designs is an MCDM problem. The current prototype includes an approach that combines the performance criteria using equal weights to create a single measure that is used in a cost-effectiveness analysis. It would be interesting and potentially very useful to experiment with one or more of the many MCDM methods to explore explicitly the tradeoffs among the performance criteria, as well as with the cost criterion.

In addition, the iterative nature of the design process requires a flexible tool that accommodates the co-evolution of goals and criteria, as well as the reuse of previous design solutions. The prototype is set up for a process that begins with identification of relevant governing criteria and establishment of design goals. While an iterative design process that involves re-visiting of goals and criteria can be done within the prototype, it is not explicitly or optimally configured for this. Future versions of the tool could be set up to accommodate explicitly adaptation and iteration in the design process.

Cost Data and Modeling

Future work is recommended in two areas: cost data storage and analysis and incorporation of costs beyond the direct costs of SWM.

In the later stages of design, when the final design has taken shape, substantial effort must be invested to create detailed and highly accurate cost estimates. This is not the case in early design phases, which is the focus of this prototype, when there are many possible alternatives and detailed cost estimation would be infeasible. Thus, the prototype relies on current (2020) cost data extracted from the literature and websites. The process is labor intensive and very time-consuming. Furthermore, there is little or no standardization of the approaches to estimating the costs found in these sources, nor is there a systematic approach to quantifying the uncertainty associated with these cost estimates. Therefore, a cost database for SWM that records all the collected estimates and includes their assumptions and uncertainties would be a valuable addition to this prototype and to SWM design in general. Inclusion of a cost inflation feature would also be desirable.

SWM provides benefits that go beyond the property limits, and those benefits and related opportunity costs are not reflected in the prototype. Currently, the prototype considers costs that are related only to SWM construction and operation, but there are costs of **not** implementing SWM. The loss of freshwater resources, the energy required for the treatment and distribution of potable water, the property damage from uncontrolled stormwater runoff, the health impacts of combined sewer overflows, and the repair or replacement of failed infrastructure all carry substantial monetary and non-monetary costs. Research is needed to include this broader definition of cost in concert with the MCDM work recommended above.

Database and Database Management

The prototype in its current development state has limited data storage capacity and did not include a database structure and a database management system such as the one mentioned in the software architecture of the proposed tool. Hence, it is recommended that a database management system be integrated into the prototype to provide the adaptability of the tool to the design process described.

Extending the Model to Other Cities

The ANSI/ASABE standard landscape water-needs estimations implemented in the prototype require data gathering and preparation for the estimation of evapotranspiration values (ETOs) according to the ASCE-EWRI standardized reference ETOs equation. The parameters needed are found from different sources and transformations are needed (e.g. solar radiation). To keep the tool quick and easy to use, it is recommended to incorporate into the prototype the capability to gather and transform the data and determine the ETOs, while extending it to include other US cities.

As a general matter, many aspects of the SWM design problem, including climate, regulations and cost data, can vary significantly from city to city and in time. Therefore, it would be desirable to allow the tool to be more customizable than it currently is. Further development of the software would be necessary to achieve this.

User Testing

Finally, while some components of the prototype tool were user tested, the complete tool has not been. User testing of a more refined prototype has two purposes. One is the validation and improvement of the SWM design process model that will provide more supporting information and a better description of the SWM design in the residential context. The second purpose is to explore the best ways to allow for adaptation and iteration in the design process within the software tool.

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APPENDICES

APPENDIX A: Ethnographic Studies

A.1. Analysis of Architectural Design and Decision-Making Meetings of the EC Project

A.1.1. Email invitation

Subject: Analysis of Architectural Design and Decision Making Meetings of the XXX Project – Alejandra Munoz – Ph.D. Candidate at Carnegie Mellon University

Professional of the Environmental Center Project,

My name is Alejandra Munoz and I am a Ph.D. Candidate at Carnegie Mellon University's School of Architecture. I am writing to request your consent to participate in my research. My research advisor is Professor Omer Akin, of Carnegie Mellon's School of Architecture.

As _______, project manager, explained in a previous email, my research topic is Sustainable Water Management. As part of my research method, I will be eliciting information about the decision making process during the design of the XXX Project in achieving the Net Zero Water goals of the Living Building Challenge Standard. The study aims to gather relevant information discussed during the weekly meetings of the project team. The focus of the study is the decision-making process of the team in a real problem setting.

During each project team's meeting, usually held on Tuesdays, I will be audio recording and transcribing the meetings. I will not interrupt or pose questions about the topics discussed during the meetings. Each audio recording will be analyzed, interpreted, and summarized. Data collected will remain confidential. All professionals who participate in the team's weekly meetings will have the choice to comment on relevant aspects of the study. Participation in this study is limited to individuals of age 18 and older.

Your participation is voluntary. You are free to stop your participation at any point. Detailed explanation of the scope of this study is found in the online consent form. Please respond to this request by accessing the online consent using the following link It will take few minutes to complete the consent form. Please complete before Wednesday, April 17th.

Thank you,

Alejandra P. Munoz Munoz
Ph.D. Candidate AECM Program
School of Architecture
Carnegie Mellon University
Pittsburgh, PA 15213, US
Phone: 412 519 2180

A.1.2. Certification of IRB Approval

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	HS13-140
Title:	Analysis of Architectural Design and Decision-Making Meetings of the Environmental Center Project
Investigator(s):	Alejandra Munoz Munoz, Omer Akin
Department(s):	Architecture
Date:	April 15, 2013

Carnegie Mellon University Institutional Review Board (IRB) reviewed the above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given **APPROVAL by Expedited Review on April 1, 2013, as authorized by 45 CFR 46.110 (6) and 21 CFR 56.110. This APPROVAL expires on March 31, 2014,** unless suspended or terminated earlier by action of the IRB.

The IRB has granted waivers of informed and written documentation of informed consent for this study.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for **at least three (3) years after completion** of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

A.1.3. Renewal of Certification of IRB Approval for data analysis only

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	HS14-056
Title:	Analysis of Architectural Design and Decision-Making Meetings of the Environmental Center Project
Investigator(s):	Alejandra Munoz Munoz and Omer Akin
Department(s):	Architecture
Date:	March 21, 2014

Carnegie Mellon University Institutional Review Board (IRB) reviewed the **renewal** above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given **APPROVAL by Expedited Review on March 21, 2014, as authorized by 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on March 31, 2015**, unless suspended or terminated earlier by action of the IRB.

This study is permanently closed to enrollment and approved for data analysis only.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for **at least three (3) years after completion** of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

A.1.4. Online Consent Form Recording of Meetings

Study Title: Analysis of Architectural Design and Decision Maiking Meetings of the Environmental Center Project

Principal Investigator (PI): Alejandra Patricia Munoz Munoz
School of Architecture, 5000 Forbes Avenue, Margaret Morrison Carnegie Hall Office 405, Pittsburgh, PA 15213, Phone: 4125192180, Email: amunoz@cmu.edu

Faculty Advisor: Dr. Omer Akin

Purpose of this Study
The purpose of this study is to unveil the decision making process during the design of the Environmental Center Project for sustainable water management. This project aims to achieve the Net Zero Water goal of the Living Building Challenge (LBC) Standard. The study seeks to gather relevant information discussed during the project team's weekly meetings. Specifically, the audio recording and its transcription will be analyzed to identify: (1) Which professional type was involved and his/her role in the project; (2) information needed and available; (3) information needed and not available; (4) the steps of the design process; (5) the methods or tools used or followed; (6) the final decisions made during the design process.

Procedures
The PI will audio-record the weekly meetings of the project team. The PI will no interrupt or make questions about the topics discussed during the weekly meetings.

Data Collection
The team project meetings are held every Tuesday at 10 am via private phone conference call. The session will be audio recorded using a computer device and the PI will collect notes. The audio recording and notes will be used to analyzed and interpret the key decisions or events that directed the design process. Access to the audio recording and note will be limited to the PI and her Faculty Advisor.

Expected Duration & Location
No extra time or effort is required from participants. The meetings usually last onehour.

Participant Requirements
Participants are professionals that are involved on the design and decision making process of the [redacted] All participants are 18 years or older

Risks & Benefits
The risks and discomfort associated with participation in this study are no greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. There may be no personal benefit from your participation in the study but the knowledge received may be of value to your design process knowledge on sustainable water management.

Compensation & Costs
You will not receive monetary compensation for your participation. There will be no cost to you if you participate in this study. The PI will provide digital copies of the final report with the analysis and results of the study, as desire by participants.

Confidentiality
By participating in the study, you understand and agree that Carnegie Mellon may be required to disclose your consent form, data and other personally identifiable information as required by law, regulation, subpoena or court order. Otherwise, your confidentiality will be maintained in the following manner:
Your data and consent form will be kept separate. Your consent form will be stored in a locked location on Carnegie Mellon property and will not be disclosed to third parties. By participating, you understand and agree that the data and information gathered during this study may be used by Carnegie Mellon and published and/or disclosed by Carnegie Mellon to others outside of Carnegie Mellon. However, your name, address, contact information and other direct personal identifiers in your consent form will not be mentioned in any such publication or dissemination of the research data and/or results by Carnegie Mellon.

Rights, Right to Ask Questions & Contact Information
Your participation is voluntary. You are free to stop your participation at any point. If you have any questions about this study, you should feel free to ask them now. If you have questions later, desire additional information, or wish to withdraw your participation please contact the Principal Investigator by mail, phone or email in accordance with the contact information listed on the first page of this consent.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irbreview@andrew.cmu.edu. Phone: 4122681901 or 4122685460.

1. Please indicate your name and role in the project.
Name:
Role in the project:

2. Voluntary Participation

I am age 18 or older	Yes	No
I have read and understand the information above	Yes	No
I want to participate in this research	Yes	No

A.1.5. Taxonomy – Excerpts of Documents obtained from the Recording of the meetings

	Taxonomy	Person	Topic/Sentence/Phrase
1	**Introducing Topic**	Participant 1	**Drawing Issuance**
2	**Delivering Information**	Participant 1	"We submitted this 50%CD set
	Delivering Information	Participant 1	There are few gaps…. I talked with Participant 3 and we will fix those minor gaps
	Delivering Information	Participant 1	Participant 2 your civil drawings, we have those and we will deliver this to Participant 3 today
3	**Comment in agreement**	Participant 2	Ok
4	**Commitment to accions**	Participant 1	We will have this (information from email about gaps) into account for future issuances
	Comment in agreement	Participant 3	Ok
	Delivering Information	Participant 1	Meeting for pricing exercise
5	**Question**	Participant 1	Confirm the participation of the following consulting teams: BCJ, PJDick, Crawford
6	**Answer**	Participant 3	Ok
7	Comments	Participant 3	kick off the pricing exercise - getting agreement - to be same page
	Comments	Participant 4	Let's people know that I will be late
	Introducing Topic	Participant 1	**Permitting side**
	Question	Participant 1	Participant 2 - do we have the original?
	Answer	Participant 2	Yes
	Delivering Information	Participant 1	We talked about Hydrant location, information taping into city lines -
	Delivering Information	Participant 1	we were corrected to show current status
	Question	Participant 1	And that is what PWSA has in hand?
	Answer	Participant 2	Yes
	Question	Participant 1	to Participant 4: confirming talking with PWSA to have this in spring?
	Answer	Participant 4	yeah: Tom P thinks it won't be a problem with that
8	**Adding Information**	Participant 4	Chester Participant 5ineering is reviewing your drawings Participant 2 - if they have questions I will send them to your way
	Adding Information	Participant 4	We will have separate meeting with PWSA to review project globally
	Delivering Information	Participant 1	Fire inspector - another meeting with fire department - another meeting
	Question	Participant 1	have we heard from him? To know where we are
	Answer	Participant 2	No
	Commitment to accions	Participant 2	will follow over it
	Adding Information	Participant 4	Mike Ridley - Head of City Parks - biggest aliad - Retiring - anything we need - reaching fire department - know is the time
9	**Introducing SubTopic**	Participant 2	I have two issues on permitting
	Answer	Participant 1	go ahead
	Delivering Information		we completed the design and permit document for the on-lot disposal system - the form
10	**Clarification/Explanation**		before submit, we are waiting because we need to submit our sewage plan and documnets first
	Clarification/Explanation		so we distributed those to the health department and city planning
	Clarification/Explanation		we are waiting for the city to make a resolution to ammend act 537
			Act 537 *Sewage Facilities Planning Authorizations*
	Clarification/Explanation		as soon as we get that we will submit to planing DEP
	Clarification/Explanation		and then after that the on-lot sewage permit application to DEP
	Question	Participant 4	Clarification about ammend Act 537 - city- so, its has to go under city council and adopt the resoultion to ammend the act 537 plan?
	Answer	Participant 2	correct
	Question	Participant 4	who is gona prepare that resolution for them?
	Answer	Participant 2	legal
	Commitment to future accions	Participant 4	ok - I'll try to make sure that happen (oversee te process)
	Question	Participant 1	what is the time line?
	Answer	Participant 2	is not in our hands at this moment in at to the city - we are waiting
	Question	Participant 1	but any hints ?
	Delivering Information	Participant 2	I have a contact phone number that take care of this resolution
	Commitment to action	Participant 2	I will call this afternoon to check on that
	Comment in agreement	Participant 4	Ok
11	**Request for action**	Participant 4	Participant 2, Let me know how that goes
	Comment	Participant 4	Mike Ridley might help
	Clarification/Explanation	Participant 2	I was given this contact information to move fast
	Question	Participant 1	What is the next step after the resolution is passed?
	Question	Participant 1	The city planning then approaves the on-site sewage system?
	Clarification/Explanation	Participant 2	The city adopts the resolution to ammend the atc 537, this act Is the sewage disposal plan for the municipality, once that resolution get passed,
	Answer	Participant 2	we will submit our sewage plan and request to the DEP
	Explaining process and actions in the future	Participant 2	we have to do sewage planing because we are not conecting to municipal system
	Explaining process and actions in the future	Participant 2	we are changing

12	**Comment of understanding**	Participant 1	Got it
	Comment of understanding	Participant 1	so DEP follows apply 537 and then they are follow a new one (537)
	Question	Participant 1	so then it goes to county health?
	Answer	Participant 2	No, it does not go to county health
	Clarification/Explanation	Participant 2	County health is a parallel track
	Clarification/Explanation	Participant 2	so we will received anything back we need from county health when needed
	Comment of understanding	Participant 1	Ok
	Question	Participant 5	Participant 2 who is you contact at County health……we need to have a letter from them
	Delivering Information	Participant 5	regarding inability to generate our own potable water on site for LBC
	Answer	Participant 2	we have been dealing with jimmy grease - but not sure if that the person you need to speak
	Commitment to action	Participant 5	ok - I can go back to the institution and see
	Adding Information	Participant 4	I think jeff….he sets a lot of the meeting
	Commitment to action	Participant 5	Ok I ll go with jeff
	Question	Participant 1	are all those your permit issues Participant 2?
	Answer	Participant 2	when we get the planning approval we will submit the on-lot sewage disposal
	Answer	Participant 2	yes, all is in our 50% submition. We are waiting for department work
	Comment of understanding	Participant 1	ok
	Introducing Topic	Participant 1	**Art Commission**
	Delivering Information	Participant 1	We are targeting the 27th meeting with the art commission - we are targeting get the documents for the 13th - that is a week from now
	Delivering Information	Participant 1	and we have some updates _______ - we have identified the location og_____
	Question	Participant 1	if I am not mistaken
	Delivering Information	Participant 1	turn out the art commission it self being under the west bridge
	Clarification/Explanation	Participant 4	past of the bridge - half of the bridge
	Clarification/Explanation	Participant 6	lower terrace area before you hit the stairs
	Comment in agreement	Participant 4	exactly
	Adding Information	Participant 6	I think is bake…should be in there
	Request for action	Participant 1	We need a discussion on what we are going to include for the 13th
	Delivering Information		we are already working on some redering, cleaning the building it self so it is the accurast possible
	Delivering Information		we need to talk specifict about quantities or sizes, but
	Question		I think we need to have that conversation with Jen and Participant 4
	Question	Participant 4	Do you want to chat at the end of this?
	Comment in agreement	Participant 6	Ok
	Comment in agreement	Participant 1	Sure
	Introducing Topic	Participant 1	**Landscape**
	Delivering Information	Participant 1	We talked about the …deptment with Brad and detailing those to matching the landscape detailing
	Request for action	Participant 1	Brad we need to talk about that more
	Comment in agreement	Participant 1	yeah
	Delivering Information	Participant 1	we talked about detail of the bridges
	Delivering Information	Participant 1	PJD reviewing those talking about merried those with building details
	Delivering Information	Participant 1	talked about hiting the average rainfall per month that has been incorporate into the spreasheet
	Delivering Information	Participant 1	we will be issuence later today for the LBC diagraming
	Delivering Information	Participant 1	we talked about the PV layout
	Delivering Information	Participant 1	and we discussion that we had with AIS
	Delivering Information	Participant 1	we have general ideas of ____ locations
	Delivering Information	Participant 1	clear PV distances for fire truck access
	Delivering Information	Participant 1	I think all being rack into the 50% set
	Request for action	Participant 1	I encourage everyone to look at closer and make sure there are no any conflicts there
	Delivering Information	Participant 1	parking underneath of PV
	Delivering Information	Participant 1	and secure fencing
	Delivering Information	Participant 1	we then went into fountain discussion
	Request for action	Participant 4	one second in the fencing
	Adding Information	Participant 4	we need something that goes down - subterranean - probably 3 ft
	Clarification/Explanation	Participant 6	for little critter I like to be sure there
	Comment of understanding	Participant 1	got it
	Clarification/Explanation	Participant 6	critter goes on that
	Delivering Information	Participant 1	we talked about the fountain
	Delivering Information	Participant 1	and we talked more about the fountain last night
	Delivering Information	Participant 1	on the water side about the conversation Participant 1 and I have last night after hang out

13	**Request of information**	Participant 1	I think we need a conversation with George Fountain to try to get some very simple basis of a evaporation and power usage based on in tree scenarios, high mediam and low -
	Comment	Participant 1	we can talked about this later
	Clarification/Explanation	Participant 5	but if it is a way to get that data on what they understand of th eepower usage could be__ 24/7 circulation pump
	Clarification/Explanation	Participant 5	and then the variables of low, mediam and high flow and how the energy increases, evaporation increases with each of those
	Clarification/Explanation	Participant 5	I think we could, if they can produce that information, we can plug that into our team set and Participant 4 has been entertainmet, in term of varing operational time and that gives us a better idea of where we might be and we can solve it not involving george fountain with that kind of minucias.
	Request for action	Participant 6	can you send them those scenarios to them
	Commitment to action	Participant 5	sure
	Comment	Participant 6	that would be great
	Delivering Information	Participant 1	The news for the team is that outside of the high flow 24/7 12' high fountain jet - outside of that particular scenario all other scenarios seems very encouraging on the net water side
			and net power is certaintly in the realm of possible it is just a Participant 1er of purchasing the right balance of PVs
	Commitment to action	Participant 5	we continue work on that
	Delivering Information	Participant 1	currently we hit the number of PV to acomody that - current plan
	Question	Participant 1	I believe that is correct, right?
	Answer	Participant 5	we have PV for the high scenario
14	**Request / Requirement**	Participant 4	we want to eliminate the PV over the corridor - that's my goal
	Request / Requirement	Participant 4	can we reduce the fountain enoughso we don’t need the PV over the corridor
	Comment in agreement	Participant 5	Ok
	Question	Participant 1	any other on Landscape?
	Answer	Participant 6	no - not really

A.2. Debriefing Session of the Architectural Design and Decision-Making Process of the EC Project

A.1.2. Email invitation

Subject: Debriefing Session of the Architectural Design and Decision Making Process of the Professional of the Environmental Center Project, Alejandra Munoz – Ph.D. Candidate at Carnegie Mellon University

Dear Professional of the Professional of the Environmental Center Project,

My name is Alejandra Munoz, and I am a Ph.D. Candidate at Carnegie Mellon University's School of Architecture. My research advisor is Professor Omer Akin, of Carnegie Mellon's School of Architecture. I am writing to request your agreement to participate in my research project.

As _____________, project manager, explained in previous emails, my research topic is Sustainable Water Management. As part of my research method, I will be eliciting information about the decision making process during the design of the Environmental Center Project in [redacted], in achieving the Net Zero Water goals of Living Building Challenge Standard.

The session in which I would like you to participate is called a "debriefing session." This term refers to the retrospective documentation of the decisions made during the design process. The session will be audio-recorded and transcribed. The audio recordings will be analyzed, interpreted, and summarized as part of my Ph.D. work. Data collected will remain strictly confidential. The format of the session will be a round-table discussion, following a preset agenda, and all professionals who participate will be invited to comment on relevant aspects of the agenda.

Due to rules pertaining to studies with human subjects, we decided to limit the age of the participants to 18 or older. Participation in the session is expected to be in person or by private phone conference call.

The session will be held on Tuesday, June 11th, at 10 am in the conference room at [redacted]. To access by phone conference call, please dial [redacted] at the start time of the session. The participant code is [redacted] The session is designed to last one hour and a half.

Please understand that your participation is entirely voluntary, but we appreciate greatly your willingness to contribute to this study. Also, after you start you will be free to stop your participation at any point, if you desire to do so.

Detailed explanation of the scope of this study can be found in the online consent form accessed through the following link: https://www.surveymonkey.com/s/[redacted]. Please read this document thoroughly and respond to this invitation at your earliest.

I look forward to your affirmative response,

Alejandra P. Munoz Munoz
Ph.D. Candidate AECM Program
Carnegie Mellon University

A.2.2. Certification of IRB Approval

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	HS13-149
Title:	Debriefing Session of the Architectural Design and Decision-Making Process of the Environmental Center Project
Investigator(s):	Alejandra Munoz Munoz, Omer Akin
Department(s):	Architecture
Date:	April 15, 2013

Carnegie Mellon University Institutional Review Board (IRB) reviewed the above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given **APPROVAL by Expedited Review on March 29, 2013, as authorized by 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on March 28, 2014,** unless suspended or terminated earlier by action of the IRB.

The IRB has granted a waiver of written documentation of informed consent for this study.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for **at least three (3) years after completion** of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

A.2.3. Renewal of Certification of IRB Approval for data analysis only

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	**HS14-057**
Title:	**Debriefing Session of the Architectural Design and Decision-Making Process of the Environmental Center Project**
Investigators:	**Alejandra Munoz Munoz, Omer Akin**
Department:	**Architecture**
Date:	**March 21, 2014**

Carnegie Mellon University Institutional Review Board (IRB) reviewed the renewal above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given APPROVAL by Expedited Review on March 20, 2014, as authorized by 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on March 28, 2015, unless suspended or terminated earlier by action of the IRB.

This study is permanently closed to enrollment and approved for data analysis only.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for at least three (3) years after completion of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. Note that submitting for continuing review in a timely manner is the responsibility of the PI.

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

A.2.4. Online Consent Form Debriefing Session

Study Title: Debriefing Session of the Architectural Design and Decision Making Process of the Environmental Center Project

Principal Investigator (PI): Alejandra Patricia Munoz Munoz
School of Architecture, 5000 Forbes Avenue, Margaret Morrison Carnegie Hall Office 405, Pittsburgh,
PA 15213, Phone: 4125192180, Email: amunoz@cmu.edu

Faculty Advisor: Dr. Omer Akin

Purpose of this Study
The purpose of this study is to unveil the decision making process during the design of the Environmental Center Project for sustainable water management. This project aims to achieve the Net Zero Water goal of the Living Building Challenge (LBC) Standard. The study seeks to gather at each decision point or key events of the decision process the following information: (1) Which professional type was involved and his/her role in the project; (2) information needed and available; (3) information needed and not available; (4) the steps of the design process; (5) the methods or tools used or followed; and (6) the final decisions made during the design process.

Procedures
You will be asked to attend a onetime debriefing session in the conference room [redacted] that will last around 60 to 120 minutes, to allow a followup interview with the PI depending on the findings of the debriefing session that will last 20 to 30 minutes, and to provide feedback about the PI's report of debriefing session. Participation on the debriefing session and followup interview is expected to be in person or via private phone call. Your feedback on the PI's report is expected to be delivered in the format of your convenience (e.g. phone, email). The debriefing session will be a group retrospective interview directed by the PI and supported by an assistant where the PI will ask questions that help to recall issues and decisions made during the design process of the project in a chronological way. The session will be audio recorded and the assistant will keep notes of participants' discussion.

Participant Requirements
Participation in this study is limited to individuals age 18 and older that have participated over the years on the design and decision-making process of the sustainable water management of the Environmental Center Project.

Risks & Benefits
The risks and discomfort associated with participation in this study are no greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. There may be no personal benefit from your participation in the study but the knowledge received may be of value to your design process knowledge on sustainable water management.

Compensation & Costs
You will not receive monetary compensation for your participation. There will be no cost to you if you participate in this study. The PI will provide digital copies of the final report with the analysis and results of the study, as desire by participants.

Confidentiality
By participating in the study, you understand and agree that Carnegie Mellon may be required to disclose your consent form, data and other personally identifiable information as required by law, regulation, subpoena or court order. Otherwise, your confidentiality will be maintained in the following manner:

Your data and consent form will be kept separate. Your IP address will not be captured. Your consent form will be stored in a locked location on Carnegie Mellon property and will not be disclosed to third parties. By participating, you understand and agree that the data and information gathered during this study may be used by Carnegie Mellon and published and/or disclosed by Carnegie Mellon to others outside of Carnegie Mellon. However, your name, address, contact information and other direct personal identifiers in your consent form will not be mentioned in any such publication or dissemination of the research data and/or results by Carnegie Mellon.

Your anonymity will be maintained during data analysis and publication/presentation of results by any or all of the following means: (1) each participant will be assigned a number, (2) the researchers will save the data and/or any audio recording by your number, not by name, (3) only the PI or Faculty Advisor will view collected data in detail, (4) any original recordings or data files will be stored in a secured location accessed only by authorized researchers.

Rights, Right to Ask Questions & Contact Information
Your participation is voluntary. You are free to stop your participation at any point. If you have any
questions about this study, you should feel free to ask them now. If you have questions later, desire additional information, or wish to withdraw your participation please contact the Principal Investigator by mail, phone or email in accordance with the contact information listed on the first page of this consent.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irbreview@andrew.cmu.edu . Phone: 4122681901 or 4122685460.

1. Please indicate your name and role in the project.
Name:
Role in the project:

2. Voluntary Participation

I am age 18 or older	Yes	No
I have read and understand the information above	Yes	No
I want to participate in this research	Yes	No

A.2.5. Excerpt of the Debriefing Session Transcript

Debriefing Session Transcript

Participants:
At the table
Architect, Architectural Design Project Manager
Landscape Architect
CPM, Client Project Manager
Const_PM, Construction Project Manager

By Phone:
FPE, Fire Protection Engineer
Mechanical Engineer
Sustainability Consultant
Stormwater Consultant

CPM: Thank you guys. I am going to turn it over to Alejandra, but this is CPM. I just want to thank you everyone very very much for taking some time this morning. I feel like this is one of the steps that we have hope to happen which is to really have the whole process, not just the building itself, but the design process being educational endeavor. So this is part of Alejandra's education, but I also think that we will learn something about our own process by participating in this. So thank you for giving us some time this morning and then I will turning over to Alejandra who is going to lead us.

Alejandra: Okay, good morning, my name is Alejandra Munoz I am a PhD candidate at Carnegie Mellon University I'm here today alone, Professor Akin couldn't make it today he is busy this morning I would like to thank you all for agreeing to participate in these research the debriefing session is focused on the design process of the environmental center at the Frick Park I would like you to think about the process when deciding and when taking steps during the design. Let's start by introductions, I like to go around the table, everyone please state your name and role in the project and then we do it on the phone.

Sure. Architect, project manager
Project drafter, and designer
Landscape Architect
CPM: Hi this is CPM, the project manager there and director of education

Architect: and on to phone
Mechanical Engineer.
Civil and Site Engineer
Stormwater Consultant
Sustainability consultant

Alejandra: Okay thank you. I have paper base consent forms for people here at the office people at the phone please go to the link that we sent in the invitation email and sign the consent

CPM: I can send it to people there is a link that you need to click on

Alejandra: yeah thank you, Please sign in the third page

[Time 2:54]

CPM: It is actually embedded, if you go to your outlook invitation for this meeting invite it's embedded in that invitation it's a survey monkey link.

[Time 3:59]
Alejandra: Ok, thank you.
As I said the purpose of this session is discover the design process of environment center and in a specific trying to learn from the design process followed by the team to achieve the Living Building Challenge and in a specific the water petal goal. I request that each participant help to make this discussion as rich as possible by contributing ideas. As the moderator I will try to limit the amount that each one has, so everyone has time to talk. I will try to conduct this session as democratically as possible. Please feel free to offer your ideas and piggy back on others' ideas.
So, to start the session, let me remind you that the goals of LBC for the water petal are two fold (1) Net Zero Water requirement and (2) Ecological Water Flow.

To initiate the conversation I pose the following questions:
I have handouts for people at the office, people at the phone please try to remember these questions.

So the question is: **What was your approach to achieve these water petals goals?**
In answering this question please consider the following:
- In what phase of the project did you start to include strategies to achieve the LBC water goals?
- Which information sets help you the most in making your decisions?
- Did you miss any information sets that were essential in making your decisions?
- Did anyone perform water balance estimations?
- Which tools and/or methods were used for water balance estimations? and
- Was cost a design factor?

I invite the architectural team to open the conversation**.**

Architect: Can I just ask for clarifications.
Alejandra: Sure
Architect: What do you mean by information sets?
Alejandra: type of climatological data, cost information
Architect: Ok
Alejandra: Any questions?

[Time 6:13]

CPM: I want to call out Mechanical Engineer, and you guys Engineers Company and maybe Stormwater Consultant to think back back to that early meeting that we have face to face at Carnegie Mellon when we really start to think about water because I think that was maybe the first time that we took into considering the water petals

Architect: so this was give me a time frame CPM, this is a schematics?

CPM: this is rain fall

Fred: this is probably before I would say prior to schematics

CPM: yeah

Mechanical Engineer: we started a very earlier this work sessions to really understand how we want to approach the whole idea of sustainability we tried to set up some principles and frameworks on I'll let Stormwater Consultant and persons at Engineers Company talk about little bit more this aspect and early on we decided what information we needed about resource, site assessment, research, and I think that's where Stormwater Consultant's group played an important role and understanding the site and more specifically rain fall and you know the whole ecological system and what was the potential redevelopment in terms of landscape or site scape that with help us calculate how much water should coming out of their site and determining the water balance

[Time 8:09]

at the time …we looked at, for instance, existing conditions, and how can we even raise the standard and make it even more pervious if you will environment and reduce the impact of water runoff. I think that is when we started focusing on making the site as soft as we could. What was the new building can generate base on a square range and then what can we capture and a store to do the kind of things we wanted to do, whether it was recycling water for irrigation or , you know, the holding tank. We've already started to talk about how the fountain can help, in term of reusing rainwater for plants.

[Time 9:07]

We started this discussion, to answer a, very early on in term of trying to understand what water balance and how much was for the wetlands which was an educational goal of the center.

Architect: Folks from Engineers Company or Stormwater Consultant would you like to add anything for that.

Stormwater Consultant: Hi this is Stormwater Consultant and I have a few items we really sort of started by evaluating kind of delineating a project, you know, impact area of the project physically all the potential areas we could preserve and we did a very detailed takeoff of the existing land cover in terms of development understanding of drainage patterns where water goes and then at first step I will be taking a few consign building in the site, we, am, take a close attention to all the materials to minimize the impact to the greatest extent possible and try to keep towards that possible and then from there with all the impervious areas we were left with, you know, we collaborated very closely talked about on how we could either elaborate or reuse or infiltrate that water in a more natural hydrologic condition. We actually have a few water balances that we actually performed. One was more that you know land cover type In which we tried to actually align with Living Building Challenge, and we design the site in such a way that would mimic more to natural conditions. A second type of water balance had we were balancing more the water inside and supply, we are talking about rainwater and graywater reuse.

Architect: So I have a question, this is fall of 2011?

CPM: May have been 2012 or 2011, must have been 2011, I have to look at it

Stormwater Consultant: One of our water balance calculation stated in October of 2011 and we updated it through the end of that year of 2011.

Architect: So my question is everything that we have discussed our all good practices something that we would jump to all these discussions with any project, but when did, was Living Building Challenge on the table on that October - November meeting and just kind interested into know maybe everyone first reactions of all these good practices we are gonna to talk about recycling water on the fountain we're going to talk about water balance strategies etc. etc. but then someone crack into living building challenge and said we really have to up our game [not clear word] everything that we're going to do it seems to be already in line with Living Building Challenge I am kind of interested on how much more efforts I know what happened in the second half of the project but early on was there at re-design or re-addressing of the strategy of how tackle this because of the Living Building Challenge?

[Time 12:53]

I can feel that here from the Engineers Company point of view to the earlier discussions we're talking about water balances both radiating to the site and the building and I think that was one of the more critical aspect of trying to meet Net zero water and I think initially when we were sorting out we were trying to honor the Living Building Challenge of petal requirements of net zero water throughout of the building and the site and we try to do these by virtue of water balance and a storage capacity that will be needed for rainwater and water use again for both the building and site that we have projected earlier as we started moving through the project though we found the they were regulation in the state of Pennsylvania that wouldn't allow complete reuse of graywater to be reuse of in the potable water system there were initial regulations related to water treatment in that point were potable water reuse it was at that time that we'd really started looking I think seriously about how do we meet the Living Building Challenge without being able to recycle water into the potable water system I think that's really where kind of start the road as far what happened with the Living Building Challenge, Architect, I think that's really where we started looking seriously how were going to address this.

Mechanical Engineer: I think that's a great assessment.

CPM: Just I like to go back in time for a minute because you're absolutely right, Mechanical Engineer, But just to that early meeting one I just want to check my memory I believe that was at that meeting that we really started to think about the site with that little miniature freatic divide that little miniature watershed split from the alley where we where looking at the north part of the site and the south part of the site differently and I think that emerged in that charrete this notion that we did have the highest elevation right at the mid line and we can use that as a design tool than the other just another couple of little thoughts one is that from our perspective something that is not necessarily Living Building Challenge but I think has influence the whole water design is that we want to water be very visible, playful and really have whatever we did with the water be a key element of the teaching tool for the building and the site and that's definitely influenced our conversation in that meeting a lot in terms of we thought about water moving or potentially moving around the building, the wetlands or how it may relate to the fountain.

[Time 16:06]

Architect: to not oversimplify, But South of the Alley we handled it centrally fairly naturally and on the north side of the site we handled it maybe more traditionally by actually capturing and storing for reuse

CPM: which I think is going to be great for walking people through that site, giving them examples of how you can manage the water differently depending on your conditions.

END OF THE EXCERPT

APPENDIX B: National Survey of SWM Practices

B.1. Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design

B.1.1. Email for requesting survey participation

Subject: Sustainable Residential Water Management Survey Invitation – Alejandra Munoz – PhD Candidate Carnegie Mellon University

Mr./Ms./Mrs. "Last Name",

I am writing to request your valuable input in my research. My name is Alejandra Munoz and I am a PhD Candidate at Carnegie Mellon University's School of Architecture. My research advisor is Professor Omer Akin, of Carnegie Mellon's School of Architecture.

My research topic is Sustainable Residential Water Management. As part of my research method, I will be eliciting information on current trends and future demands of design professionals in meeting sustainable residential water management requirements.

As a design professional knowledgeable in green design, your answers will be very helpful in my research study. You were included as a potential study participant after a random selection of the LEED Professional Directory performed only over LEED AP with specialty professionals. The professionals contacted are individuals of 18 years or older who are architects, landscape architects or engineers (civil, environmental, mechanical, electrical and plumbing).

Your response will be collectively analyzed, interpreted and summarized. All responses will remain confidential. The survey is expected to take 20 to 25 minutes at most; your time is much appreciated.

If you are interested in participating in this survey, please respond to Alejandra Munoz at amunoz@cmu.edu, and in a few days you will receive the link to access to the survey through Survey Monkey.

Thank you,

Alejandra P. Munoz Munoz
PhD Candidate AECM Program
School of Architecture
Carnegie Mellon University
Pittsburgh, PA 15213, U.S.A.
Phone: 412 519 2180

B.1.2. Email for reminding survey participation

Subject: Reminder: Sustainable Residential Water Management Survey Invitation – Alejandra Munoz – PhD Candidate Carnegie Mellon University - EN

Mr./Ms./Mrs. "Last Name",
Dear %FIRSTNAME% %LASTNAME%,

Dear

This email is a gentle reminder that you are invited to offer your valuable input in an interesting survey. My name is Alejandra Munoz and I am a PhD Candidate at Carnegie Mellon University's School of Architecture. My research advisor is Professor Omer Akin, of Carnegie Mellon's School of Architecture.

My research topic is Sustainable Residential Water Management. As part of my research method, I will be eliciting information on current trends and future demands of design professionals in meeting sustainable residential water management requirements.

As a design professional knowledgeable in green design, your answers will be very helpful in my research study. You were included as a potential study participant after a random selection of the LEED Professional Directory performed only over LEED AP with specialty professionals. The professionals contacted are individuals of 18 years or older who are architects, landscape architects or engineers (civil, environmental, mechanical, electrical and plumbing).

Your response will be collectively analyzed, interpreted and summarized. All responses will remain confidential. The survey is expected to take 20 to 25 minutes at most; your time is much appreciated.

If you are interested in participating in this survey, please respond to Alejandra Munoz at amunoz@cmu.edu, and in a few days you will receive the link to access to the survey through Survey Monkey.

Thank you,

Alejandra P. Munoz Munoz
PhD Candidate AECM Program
School of Architecture
Carnegie Mellon University
Pittsburgh, PA 15213, U.S.A.
Phone: 412 519 2180

B.1.3. Message to be sent after agreement on participation using Survey Monkey Service

From: "amunoz@cmu.edu via surveymonkey.com" <member@surveymonkey.com>

Subject: Link to Sustainable Residential Water Management Survey

Dear Design Professional,

Thank you for agreeing to participate in this survey.

This is part of a doctoral research study in Sustainable Residential Water Management. The purpose of the survey is to unveil trends in adoption of sustainable water management concepts and practices as well as the technological needs of residential designers.

Your response will be collectively analyzed, interpreted and summarized. All responses will remain confidential.

Here is a link to the consent form and the survey. After reading and answering the consent form you will be directed to the survey:
[SurveyLink]

This link is uniquely tied to this survey and your email address. Please do not forward this message.

Thanks for your participation!

Please note: If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list.
[RemoveLink]

B.1.4. Reminder Message to be sent after agreement on participation using Survey Monkey Service

From: "amunoz@cmu.edu via surveymonkey.com" <member@surveymonkey.com>

Subject: Reminder: Link to Sustainable Residential Water Management Survey

Dear Professional,

Thank you for agreeing to participate in this survey.

This email is a gentle reminder to access and complete the survey entitled *Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design.*

This is part of a doctoral research study in Sustainable Residential Water Management. The purpose of the survey is to unveil trends in adoption of sustainable water management concepts and practices as well as the technological needs of residential designers.

Your response will be collectively analyzed, interpreted and summarized. All responses will remain confidential.

Here is a link to the consent form and the survey. After reading and answering the consent form you will be directed to the survey:
[SurveyLink]

This link is uniquely tied to this survey and your email address. Please do not forward this message.

Thanks for your participation!

Please note: If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list.
[RemoveLink]

B.1.5. Certification of IRB approval

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	HS13-102
Title:	Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design
Investigator(s):	Alejandra Patricia Munoz Munoz, Omer Akin, Brian Junker
Department(s):	Architecture
Date:	March 13, 2013

Carnegie Mellon University Institutional Review Board (IRB) reviewed the above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given **APPROVAL by Expedited Review on March 6, 2013, as authorized by 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on March 4, 2014,** unless suspended or terminated earlier by action of the IRB.

The IRB has granted a waiver of written documentation of informed consent for this study.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for **at least three (3) years after completion** of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

B.1.6. Renewal of Certification of IRB Approval for data analysis only

Carnegie Mellon University

Institutional Review Board
Federalwide Assurance No: FWA00004206
IRB Registration No: IRB00000603

Office of Research Integrity and Compliance (ORIC)
Carnegie Mellon University
5000 Forbes Avenue
Warner Hall, 4th Floor
Pittsburgh, Pennsylvania 15213-3890
412.268.7166
irb-review@andrew.cmu.edu

Certification of IRB Approval

IRB Protocol Number:	**HS14-110**
Title:	**Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design**
Investigators:	**Alejandra Patricia Munoz Munoz, Omer Akin, Brian Junker**
Department:	**Architecture**
Date:	**March 3, 2014**

Carnegie Mellon University Institutional Review Board (IRB) reviewed the renewal above referenced research protocol in accordance with 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given APPROVAL by Expedited Review on February 28, 2014, as authorized by 45 CFR 46.110 (7). This APPROVAL expires on March 5, 2015, unless suspended or terminated earlier by action of the IRB.

This study is permanently closed to enrollment and approved for data analysis only.

All untoward or adverse events occurring in the course of the protocol must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation. Please refer to the above-referenced protocol number in all correspondence.

Federal regulations require that all records relating to this research protocol be maintained for at least three (3) years after completion of the research, and be accessible for inspection and copying by authorized representatives at reasonable times and in a reasonable manner.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

The IRB maintains ongoing review of all projects involving humans or human materials, and at continuing intervals, projects will require update until completion. At the end of the current approval, a continuing review form, current application/protocol and current consent form(s) must be submitted by the PI to the IRB summarizing progress on the protocol during that period. Please be advised that the continuing review form requests information pertaining to women and minorities; therefore, this information should be tracked with your participants' data. Note that submitting for continuing review in a timely manner is the responsibility of the PI.

Please call the Office of Research Integrity and Compliance at 412-268-7166 if you have any questions regarding this certification. Thank you.

David Danks, Ph.D., IRB, Chair

B.1.7. Consent Form for Participation in Research

Consent Form for Participation in Research

Study Title

Sustainable Water Management in the Residential Sector: Assessing Tendencies and Adoption in Design

This survey is part of a research study conducted by the PhD. Candidate Alejandra Munoz, Dr. Omer Akin and Dr. Brian Junker at Carnegie Mellon University.

The purpose of the research is to identify current trends and future demands of design professionals in meeting sustainable residential water management requirements. The survey aims to unveil trends in adoption of sustainable water management concepts and practices as well as the technological needs of residential designers. The population target consists of architects, landscape architects and engineers with green design background or certification that are involved with residential projects.

Procedure

You will be asked to complete a 43-questions survey. It will take around 20 - 25 minutes to complete the questionnaire.

Participant Requirements

Participation in this study is limited to individuals who are 18 and older and are an architect, landscape architect, or engineer with green design background or certification that are involved with residential projects.

Risks

There are not foreseeable risks and discomfort associated with participation in this study.

Benefits

There may be no personal benefit from your participation in the study but the knowledge received may be of value to improve design and delivery of sustainable water management practices within the residential building sector.

Compensation & Costs

There is no monetary compensation for participation in this study.

Confidentiality

The data collected for the research will not include any personally identifiable information about you. Your responses will be coded and will remain confidential. By participating in this research, you understand and agree that Carnegie Mellon may be required to disclose your consent form, data and other personally identifiable information as required by law, regulation, subpoena or court order. Otherwise, your confidentiality will be maintained in the following manner:

Your data will be kept separate and stored in a locked location on Carnegie Mellon property and will not be disclosed to

Sustainable Water Management in the Residential Sector: Assessing

third parties. By participating, you understand and agree that the data and information gathered during this study may be used by Carnegie Mellon and published and/or disclosed by Carnegie Mellon to others outside of Carnegie Mellon. However, your name, address, contact information and other direct personal identifiers in your consent form will not be mentioned in any such publication or dissemination of the research data and/or results by Carnegie Mellon.

Right to Ask Questions & Contact Information

you have any questions about this study, you should feel free to ask them by contacting the Principal Investigator now at Alejandra Patricia Munoz Munoz, PhD Candidate, School of Architecture, 5000 Forbes Avenue, Margaret Morrison Carnegie Hall Office 405, PA, 15213, phone: 412-519-2180, e-mail: amunoz@cmu.edu. If you have questions later, desire additional information, or wish to withdraw your participation please contact the Principle Investigator by mail, phone or e-mail in accordance with the contact information listed above.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irb-review@andrew.cmu.edu . Phone: 412-268-1901 or 412-268-5460.

Voluntary Participation

Your participation in this research is voluntary. You may discontinue participation at any time during the research activity.

Thank you very much for your time and support.

Please before start the survey answer the following questions:

***1. I am age 18 or older**

- Yes
- No

***2. I have read and understand the information above**

- Yes
- No

***3. I want to participate in this research and continue with the questionnaire**

- Yes
- No

B.1.8. Questionnaire

Sustainable Water Management in the Residential Sector: Assessing

Initial Questions

***4. Are you involved with residential building design in your practice? (e.g. One or two families, multifamily or mixed-use buildings)**

- Yes
- No

5. How long (in years) have you been involved with residential project design?

Background and General Information

Demographic

6. What is your gender?

- Male
- Female

7. What is your age range?

- 18-25
- 26-35
- 36-45
- 46-55
- 56-65
- 66 or older

Education and Professional Registration

8. What is the highest educational degree you have received?

- Associates
- Bachelors
- Masters
- Doctorate
- Post-doctorate

Other (please specify)

9. What is your current registration title?

- Registered Architect (RA)
- Registered Landscape Architect (RLA)
- Professional Engineer (PE)
- Intern in an Architectural Intern Development Program (IDP)
- Engineering in Training (EIT/EI)
- Intern in Landscape Architecture
- Not on a registration track
- Registered professional outside of the U.S.
- Other

(please specify)

10. In which states are you registered? Please select all that apply. If registered outside the U.S. check the corresponding box.

- Alabama
- Alaska
- American Samoa
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- District of Columbia
- Florida
- Georgia
- Guam
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Northern Marianas Islands
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Puerto Rico
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Virgin Islands
- Washington
- West Virginia
- Wisconsin
- Wyoming
- Outside of the U.S.

11. How many years have you been registered to practice?

Firm Information

12. Which of the following best represents the type of firm where you currently work? Please select all that apply.

- ☐ Architecture
- ☐ Landscape Architecture
- ☐ Engineering
- ☐ Construction
- ☐ Planning
- ☐ Building developer
- ☐ Private contractor
- ☐ Consulting
- ☐ A combination of (e.g. AEC, AE, EC, AEP) or other

(please specify)

13. How many designers (architects, engineers, or landscape architects) work at your firm on residential projects?

- ○ 1
- ○ 2-5
- ○ 6-15
- ○ 16 or more

14. Which of the following best describes your current role at your firm?

- ○ Owner
- ○ Principal
- ○ Department head / executive manager
- ○ Project manager
- ○ Project architect
- ○ Designer
- ○ Intern
- ○ Other

(please specify)

Projects Information

15. Among your residential projects, what is the average number of units you have worked on? Please select all that apply.

- ☐ 1 unit
- ☐ 2 - 3 units
- ☐ 4 - 7 units
- ☐ 8 - 50 units
- ☐ > 50 units

16. What is the average construction cost of the residential projects on which you have worked? Please select all that apply.

- ☐ less than $250,000
- ☐ $250,000 - $750,000
- ☐ $750,000 - $2.5M
- ☐ $2.5M - $7.5M
- ☐ $7.5M - $20M
- ☐ $20M - $60M
- ☐ $60M an over
- ☐ Unknown

17. For residential projects, please assign percentages to the type of client your firm serves. Your answers should add up to 100%.

Federal government	
State government	
Local municipalities	
Nonprofit organizations	
Private state-affiliated agency (e.g. Pennsylvania Housing Finance Agency)	
Real estate developers	
Contractors	
Individual Homeowners	

18. In what states are your past and current residential projects located? Please select all that apply.

- ☐ Alabama
- ☐ Alaska
- ☐ American Samoa
- ☐ Arizona
- ☐ Arkansas
- ☐ California
- ☐ Colorado
- ☐ Connecticut
- ☐ Delaware
- ☐ District of Columbia
- ☐ Florida
- ☐ Georgia
- ☐ Guam
- ☐ Hawaii
- ☐ Idaho
- ☐ Illinois
- ☐ Indiana
- ☐ Iowa
- ☐ Kansas
- ☐ Kentucky
- ☐ Louisiana
- ☐ Maine
- ☐ Maryland
- ☐ Massachusetts
- ☐ Michigan
- ☐ Minnesota
- ☐ Mississippi
- ☐ Missouri
- ☐ Montana
- ☐ Nebraska
- ☐ Nevada
- ☐ New Hampshire
- ☐ New Jersey
- ☐ New Mexico
- ☐ New York
- ☐ North Carolina
- ☐ North Dakota
- ☐ Northern Marianas Islands
- ☐ Ohio
- ☐ Oklahoma
- ☐ Oregon
- ☐ Pennsylvania
- ☐ Puerto Rico
- ☐ Rhode Island
- ☐ South Carolina
- ☐ South Dakota
- ☐ Tennessee
- ☐ Texas
- ☐ Utah
- ☐ Vermont
- ☐ Virginia
- ☐ Virgin Islands
- ☐ Washington
- ☐ West Virginia
- ☐ Wisconsin
- ☐ Wyoming
- ☐ Outside of the U.S.

19. What types of residential projects does your firm develop? Please select all that apply.

- ☐ New construction urban
- ☐ New construction suburban
- ☐ New construction rural
- ☐ Retrofit urban
- ☐ Retrofit suburban
- ☐ Retrofit rural

20. What other types of projects does your firm develop (in addition to residential projects)? Please select up to three (3) that apply.

- ☐ Cultural
- ☐ Decontamination & decommissioning
- ☐ Water/wastewater
- ☐ Industrial
- ☐ Academic
- ☐ Commercial
- ☐ Military and government facilities
- ☐ Healthcare
- ☐ Transportation
- ☐ Power
- ☐ Urban planning
- ☐ Corporate
- ☐ Construction / construction management
- ☐ Environmental
- ☐ Sport & entertainment
- ☐ Other

(please specify) ______________________

Sustainable Design

Practice

The next question asks about your familiarity with concepts of
(1) Integrated Team Process/Design Charrete
(2) Integrated Design Approach, and
(3) Integrated Project Delivery.

If you are familiar with the concepts please continue to question 19. If you are unsure, please refer to the definition given below.

Integrated Team Process/Design Charrete
"The design team and all affected stakeholders work together throughout the project phases and to evaluate the design for cost, quality-of-life, future flexibility, efficiency; overall environmental impact; productivity, creativity; and how the occupants will be enlivened." Work sessions are called design charretes. "A design charrette—a focused and collaborative brainstorming session held at the beginning of a project—encourages an exchange of ideas and information and allows truly integrated design solutions to take form." (http://www.wbdg.org/wbdg_approach.php)

Integrated Design Approach
"The "integrated" design approach asks all the members of the building stakeholder community, and the technical planning, design, and construction team to look at the project objectives, and building materials, systems, and assemblies from many different perspectives. This approach is a deviation from the typical planning and design process of relying on the expertise of specialists who work in their respective specialties somewhat isolated from each other." (http://www.wbdg.org/wbdg_approach.php)

Integrated Project Delivery
"Integrated Project Delivery (IPD) is an approach to the design and construction process that is based on a cooperative working relationship, shared risk and reward, and open exchange of information that is intended to optimize project results, increase value to the Owner, and reduce waste during all phases of the project. IPD unifies the...team at the beginning of the project with the shared goal of project success." (http://www.wbdg.org/project/deliveryteams.php)

21. How familiar are you with the following green design practices?

	Very Familiar	Familiar	Not at all Familiar
Integrated Team Process/ Design Charrete	○	○	○
Integrated Design Approach	○	○	○
Integrated Project Delivery	○	○	○

22. Of those green design practices mentioned before, please indicate the number of projects in which they have been used.

	Number of Projects
Integrated Team Process/ Design Charrete	
Integrated Design Approach	
Integrated Project Delivery	

Rating Systems/Green Standards

23. How familiar are you with the following Rating Systems/Green Standards for residential building design?

	Very Familiar	Familiar	Not at all Familiar
Federal Leadership in High Performance and Sustainable Buildings			
Green Globes			
LEED			
National Green Building Standard - NAHB			
Sustainable Sites Initiative			
Living Building Challenge			
Other not mentioned that you consider important			

(please specify)

24. Have you used the standards above to guide the design in any residential project? If so, please indicate the number of projects. Please check all that apply.

	Number of Projects
Federal Leadership in High Performance and Sustainable Buildings	
Green Globes	
LEED	
National Green Building Standard - NAHB	
Sustainable Sites Initiative	
Living Building Challenge	
Other (Indicated above)	

Water Strategies of Rating Systems/Green Standards

25. How familiar are you with the following water strategies of rating systems/green standards?

	Very Familiar	Familiar	Not at all Familiar
Site Management - Minimum disturbance of site			
Site Management - Use water efficient landscaping			
Site Management - High-efficiency irrigation system			
Minimun water use by high-efficiency fixtures and fittings			
Minimun water use by use of composting toilets/urinals			
Rainwater harvesting for non-potable water use (e.g. stormwater control, irrigation)			
Rainwater harvesting for potable water use			
Greywater on-site treatment and reuse			
Blackwater on-site treatment and reuse			
Use of municipal recycled water			

26. If the water strategies of rating systems/green standards mentioned above are familiar, please indicate the number of residential projects in which you have implemented them. Please check all that apply

	Number of Projects
Site Management - Minimum disturbance of site	
Site Management - Use water efficient landscaping	
Site Management - High-efficiency irrigation system	
Minimun water use by high-efficiency fixtures and fittings	
Minimun water use by use of composting toilets and/or urinals	
Rainwater Harvesting for non-potable water use (e.g. stormwater control, irrigation)	
Rainwater Harvesting for potable water use	
Greywater on-site treatment and reuse	
Blackwater on-site treatment and reuse	
Connected and use of municipal recycled water	

27. For water strategies of rating systems/green standards that were implemented in residential projects, what was the reasoning behind the decision? Please select all that apply.

- Government regulation, code or construction standard
- LEED credits
- Environmental footprint reduction
- Economic incentive from government
- Firm's standard practice
- Client requirement
- Unknown
- Other

(please specify)

28. In what phase of the residential project's life cycle do you include the water strategies of rating systems/green standards?

- Planning and design requirements
- Schematic design
- Detailed design
- Construction documents
- Procurement, construction, occupancy
- Other

(please specify)

29. For water strategies of rating systems/green standards NOT implemented in residential projects, what was the reasoning behind the decision? Please select all that apply.

- Challenges associated with meeting local codes
- Not required by regulations, code or construction standard requirement
- Technical non-feasibility
- High cost / out of budget
- Client rejection
- Lack of knowledge and/or experience
- Lack of tools and technology
- Unknown
- N/A (if all given alternatives were implemented)
- Other

(Please specify)

Sustainable Water Management

Overall Approaches to Sustainable Water Management

30. How familiar are you with the following concepts related to sustainable water management?

	Very Familiar	Familiar	Not at all Familiar
Ecocity			
Total Water Management			
Water Centric Sustainable Communities			
Net Zero Water			

Best Management Practices (BMPs) / Low Impact Development (LID) strategies

31. How familiar are you with the following BMPs or LID strategies?

	Very Familiar	Familiar	Not at all Familiar
Vegetated roof cover / green roof			
Riparian/ forested buffer			
Grassed / vegetated swales			
Infiltration basin			
Infiltration trench			
Porous pavement			
Bioretention (e.g. rain garden)			
Catch basin inserts			
Sand and organic filter			
Vegetated filter strip			
Dry detention ponds			
In-Line storage			
Wet ponds			
Constructed wetlands			
Other not mentioned that you consider important			

(please specify)

32. Of those types of BMPs or LID strategies selected as familiar, please indicate the number of residential projects in which you have implemented them.

	Number of Projects
Vegetated roof cover / green roof	
Riparian/ forested buffer	
Grassed / vegetated swales	
Infiltration basin	
Infiltration trench	
Porous pavement	
Bioretention (e.g. rain garden)	
Catch basin inserts	
Sand and organic filter	
Vegetated filter strip	
Dry detention ponds	
In-Line storage	
Wet ponds	
Constructed wetlands	
Other Indicated Above	

33. In what phase of the project's life cycle are BMPs or LID strategies usually included for residential projects?

- Planning and design requirements
- Schematic design
- Detailed design
- Construction documents
- Procurement
- Construction
- Occupancy

34. For projects in which BMPs or LID strategies were included in the design of residential projects, what was the reasoning behind the decision? Please select all that apply.

- Government regulation, code or construction standard
- LEED credits
- Environmental footprint reduction
- Economic incentive from government
- Firm's standard practice
- Client requirement
- Unknown
- Other

(please specify)

35. For projects in which BMPs or LID strategies were NOT included in design of residential projects, what was the reasoning behind the decision? Please check all that apply.

- Challenges associated with meeting local codes
- Not required by regulations, code or construction standard
- Technical non-feasibility
- High cost / out of budget
- Client rejection
- Lack of knowledge and/or experience
- Lack of tools and technology
- Unknown
- N/A (if all given alternatives were implemented)
- Other

(please specify)

Design Process and Tools

36. In the design process of residential projects for sustainable water management, how important are the following aspects?

	Extremely Important	Very Important	Moderately Important	Slightly Important	Not at all Important
Initial costs					
Maintenance and operation costs					
Quantity of water managed					
Quality of water discharged					
Cost-effectiveness of systems					
Integration of practices with the building and site					
Aesthetics of the project					

37. How important are the following measures, during the design process, for sustainable residential water management?

	Extremely Important	Very Important	Moderately Important	Slightly Important	Not at all Important
Initial costs					
Maintenance cost					
Pre and post-construction water balance computations					
Ability to combine strategies					
Pollutant removal calculations					

38. Which tools and/or applications do you currently use when designing for sustainable residential water management? Please select all that apply.

Please keep in mind the following activities:

- Site analysis
- Cost estimation
- Water balance / water budget estimation
- Water management performance targets definition
- Flow routing estimation
- Infiltration estimation
- Pollutant routing and removal estimation

- [ ] Hand sketches
- [ ] Spreadsheet (e.g. Excel)
- [ ] CAD drawings (e.g. AutoCAD, ArchiCAD, MicroStation)
- [ ] 3D modeling (e.g. BIM, Revit, SketchUp)
- [ ] GIS (e.g. ArcGIS, Arcview, MapWindow)
- [ ] Modeling and simulation applications (e.g. BASINS, SUSTAIN, SWMM, SET, STEPL, IDEAL)*

Please specify names if you recall them

____

* BASINS: Better Assessment Science Integrating point and Nonpoint Sources
SUSTAIN: System for Urban Stormwater Treatment and Analysis Integration Model
SWMM: Storm Water Management Model (SWMM) with LID controls
SET: Site Evaluation Tool
STEPL: Spreadsheet Tool for Estimating Pollutant Loads
IDEAL: Integrated Design and Evaluation Assessment of Loadings

39. What is the likelihood that you would use an application that combines the following features when designing for sustainable water management in a residential project?

- Initial and maintenance costs computation
- Pre and post-construction water balance computations
- Ability to combine strategies
- Pollutant removal computation

Extremely Likely	Very Likely	Moderately Likely	Slightly Likely	Not at all Likely
○	○	○	○	○

40. If an application contains the above-mentioned features (Question 37), which type of application would you prefer?

- Spreadsheet
- Separate application that can be coupled with others (i.e. CAD, GIS)
- All in one application
- All in one online application
- No preference
- Other

(please specify)

Comments Section

41. What are the main benefits of sustainable water management in residential projects?

42. When designing for sustainable water management in residential projects, what are the main difficulties or obstacles in the design process?

43. Thinking on the design process of sustainable water management in residential projects, what would you avoid doing in the future?

44. Which type of professional should lead the design and implementation of sustainable water management strategies? Why? (e.g. architects, civil engineers, landscape architects, other)

45. How do you expect your job in the field of residential architecture and water management to change over the next few years? What knowledge/skills will be needed to meet changing design demands?

APPENDIX C: Use Cases

Use case 1. Name: Entering Site Information

Primary actor: Designer
Supporting actor(s): The Controller, Output Module, and Working Memory
Goal: To input and save site characteristics, site limitations and climatic data
Pre-conditions: The database contains climatic data (average monthly rainfall and evapotranspiration), runoff coefficients of land covers, and soil hydrologic groups (A, B, C, or D) for defined locations
Main success scenario:

1. The designer enters/selects
   - Location (Default: Pittsburgh)
   - Site size (sq.ft., acres, sq. m) (Default: 0.5 acre, lengh: 215 ft, width: 100ft)
   - Slopes (ft/ft)(Default: 3%)
   - Land cover areas and materiality from menu for pre and post-development (Default: Soil with vegetation, 70%; Asphalt, 30%)
   - Runoff coefficients from menu (Default: Soil with vegetation, 0.3; Asphalt, 0.95)
   - Soil hydrologic groups for pre and post-development (A, B, C, or D) from menu (Default: B)
   - Length of flow (ft) (Default: 200ft)
2. The Controller retrieves from database the climatic data of 1) monthly rainfall and 2) evapotranspiration for the defined location (Default: Pittsburgh)
3. The designer enters additional site constraints for SWM components if any (water table depth >2ft, drainage area <5 acres or <2 acres (for bioretention components), slope <6%, and Head (vary, <6ft) (Default: None)
4. The Controller sends additional constraints information for visualization to the Output Module
5. The designer commands to save the site, climate, and additional site constraints (in the Working Memory)
6. The Controller sends information to be stored in the Working Memory
7. The Controller sends climatic data for visualization to the Output Module
8. The Output Module sends the information to the Site Information user interface (UI)

Post-conditions:

- The site information is stored in the Working Memory

Extensions:

- The designer changes any of the information entered
- The designer adds land cover areas, materiality, and runoff coefficients to the database (Use case 11)
- The designer adds climatic data to the database (Use case 11)

Failure conditions:

- The designer does not input site information (handling: Default settings)
- The designer inputs values out of the range (numeric values)
- The designer fails to command saving the information
- The Controller fails to store the site information in the Working Memory
- The Controller fails to send information for visualization

Default condition: Information of a predefined location and site will be available in case there are not inputs from the user. See Default settings in parenthesis in points 1 to 3 in the main success scenario steps.

Use case 2. Name: Guiding the Designer

Primary actor: The Controller
Supporting actor(s): Working Memory
Goal: To retrieve and select regulations and green design alerts and sends them for visualization at the UIs (UIs: Initial WB UI, Goals and Evaluation UI, Scenario Builder UI, and Solution Builder UI)
Pre-conditions: Site information is stored in the Working Memory

Main success scenario:

1. The Controller detects a location saved in the Working Memory
2. The Controller fetches the following information from database or Working Memory:
    i. Regulations related to the location. E.g. Allowed sources of water supply for potable and non-potable uses, design storm for estimating stormwater to control (24 hrs - 2 years, 10 years, 50 years, and 100 years)
    ii. Minimum site suitability
    iii. Additional site constraints
    iv. Green design guidance
3. The Controller saves regulations and green design information into the Working Memory
4. The Controller reviews, selects, and links the alerts and information
5. The Controller sends the alerts and information for visualization to the Output Module
6. The Output Module updates the UI's alerts and information

Extensions:

- The designer adds his/her own regulations or design guidance information to the Working Memory
- The designer adds regulations or guidance to the database (Use case 11)
- The designer eliminates regulations or guidance from the database (Use case 11)

Post-conditions:

- Regulations and green guidance alerts are stored in the Working Memory
- Alerts and guidance messages are visible in the UIs
- Design storms are stored in the working memory

Failure conditions:

- The Controller does not find regulation information for the location defined
- The designer fails to command saving the regulation information

Default condition: As default conditions, federal level of regulations and general green guidance will be used

Use case 3. Name: Estimating Initial Water Balance (WB)

Primary actor: Designer
Supporting actor(s): Controller, Output Module, Calculation Module, and Working Memory
Goal: To estimate water needs, potential water supply, and pre-development rainfall runoff
Pre-conditions: Site information is saved in the Working Memory (i.e. site, climate, and regulation information). Design storm information is saved in the Working Memory. Fixtures' information is stored in the database.
Default condition: Information of a predefined project will be available in case there are not inputs from the user. See parenthesis in the main success scenario steps 1 to 3.
Main success scenario:

1. The designer enters the following project information:

a. **Water needs for indoors and water supply from reuse**
    i. Number of users (Default: 4 adults)
    ii. Daily water use amount (defined by green guideline, US/state average consumption, metering information provided by the designer or by fixture)(Default: By fixtures and applying assumptions from AWWA Residential End-use Study, ultralow flush toilet, showerhead, faucets, clothes Washer, dishwasher)
    iii. Schedule of use (Default: 365 days)

b. **Water needs for outdoors**
    i. Car washing (Default: no car washing)
    ii. Pool/fountains (Default: no pools or fountains)
    iii. Others water features (Default: no water features)
    iv. Landscape
        1. Turf and/or landscape area type from menu (Default: moderate water use with average density and intense exposure)

2. Turf and/or landscaped areas (sq.ft.) (Default: 45% of site area)
3. Annual irrigation factor (Default: moderate water requirements, from table)
4. Irrigation system efficiency (if any) (Default: medium system efficiency of 65%)

c. **Water supply from Rainwater harvesting**
   i. Collection area (sq.ft.) (Default: 1500 sq.ft.)
   ii. Materiality and its runoff coefficient (Default: metal, 0.95)
   iii. Safety factor (Default: 0.90)

2. The designer commands to save the information entered
3. The Controller saves user's inputs in the Working Memory
4. The designer commands to run the initial water balance
5. The Controller fetches information for performing calculations in the Calculation Module and retrieves the results in the following order:
   i. Demand/supply (monthly volume method - Unmetered Landscaping Water Use method - Rainwater supply and rainwater runoff from ground - Greywater and black water potential supply and reuse
   ii. Storm events: NRCS Curve Number and Small Storm Hydrology Method
   iii. Ground water recharge

6. The Controller saves the results of the initial WB in the Working Memory as follows:

Demand/Supply	**Unit**	**Storm Event**	
Total water need	Gal/year, gal/month	Peak Discharge 100 years storm	Cft, gal/event
Potential groundwater	Gal/year, gal/month	Peak Discharge 50 years storm	Cft, gal/event
Potential rainwater for use	Gal/year, gal/month	Peak Discharge 10 years storm	Cft, gal/event
Potential greywater for reuse	Gal/year, gal/month	Peak Discharge 2 years storm	Cft, gal/event
Potential blackwater for reuse	Gal/year, gal/month	**Ground water recharge**	
Potable water for use	gal/year, gal/month	Ground water recharge target	Gal/year, gal/month
Potential water amount to infiltrate	Gal/year, gal/month		
Potential water amount to dispose	Gal/year, gal/month		
Can water needs be covered with rainfall, grey, black	Gal/year, gal/month		
Total water to manage in the site	Gal/year, gal/month		

7. The Controller sends the results for visualization to the Output Module
8. The Output Module sends the results to the Initial WB UI

Post-conditions:
- The project information is stored in the Working Memory (e.g. number of users, schedule of use)
- The Initial WB results are stored in the Working Memory

Extensions:
- The designer enters the total value of the landscape's water needs
- The designer makes changes to water needs information or fixtures after running the initial water balance
- The designer makes changes the schedule of use
- The designer saves car washing, pool/fountains, and others water features information in the database (Use case 11)
- The designer saves daily water use amount values in the database (Use case 11)
- The designer defines the design storm

Failure conditions:
- The designer enters an out of range value
- The designer misses to enter some value

Use case 4. Name: Defining Goals and Evaluation Criteria

Primary actor: Designer
Supporting actor(s): Controller, Working Memory, and DB Control
Goal: To set SWM goals and evaluation criteria for assessing a model or to compare alternative models
Pre-conditions: Percentage values for evaluation criteria and benefits scores are stored in the database. Regulation information is saved in the Working Memory. Initial WB results of the project are stored in the Working Memory
Main success scenario:

1. The designer selects a green standard as a goal for the project (Default: LBC)
2. The Controller queries to the DB Control for the percentage values and scores for the goal set
3. The Controller saves the goal's percentage values and scores in the Working Memory
4. The Controller fetches the regulations alerts regarding the goals set
5. The Controller fetches the initial WB results (i.e. amount of water needs, stormwater to control) from the Working Memory and associates each evaluation criteria item and its benefit score with an amount of water from the initial assessment (i.e. target value to be achieved by the solution)
6. The Controller sends information of percentages, amounts of water, scores and regulation alerts for visualization to the Output Module
7. The designers accepts percentages, amounts of water, and scores
8. The Controller saves the evaluation criteria information in the Working Memory

Extensions:

- The designer changes the goal:
    - Choosing some elements of the evaluation criteria
    - Changing percentages of the evaluation items
- The designer changes the benefits scores (i.e. weighting)

Post-conditions:

- Evaluation criteria is stored in the Working Memory

Failure conditions:

- The designer misses to enter/select a goal
- The Controller does not find the evaluation criteria for the goal set in the database
- The Controller does not send the information for visualization
- The designer does not command saving the information
- The Controller fails to save the information after the user's command

Default condition: A predefined goal, with its percentages values and scores, will be set in case of no inputs from the user

Use case 5. Name: Defining a scenario

Primary actor: Controller
Supporting actor(s): Designer, Working Memory, and Output Module
Goal: To define the climatic data and water needs for running the calculations
Pre–conditions: Rainfall data and design storms are stored in the Working Memory**.** Water needs and supply results are stored in the Working Memory
Main success scenario:

1. The designer enters to the Scenario Builder UI
2. The Controller sends the rainfall data, design storms, water needs results, and supply results to the Output Module for visualization in the Scenario Builder UI
3. The designer accepts climatic data and water needs displayed in the Scenario Builder UI
4. The Controller stores the scenario in the Working Memory

Post-condition:

- Climatic data and water needs are stored in the Working Memory as scenario information

Extensions:

- The designer rejects climatic data and water needs displayed

- The designer changes the value for water supply
- The designer changes the value for water needs
- The designer changes the rainfall data to use
- The designer changes the design storm
- The designer sets water needs to be zero and it will define the water needs when building a solution

- The designer saves more than one scenario

Failure conditions:

- The designer skips the Scenario Builder UI
- The Controller does not find the information requested to the Working Memory
- The Controller fails to save the information after user's command

Default condition: The Controller saves the climatic data and water needs stored in the Working Memory as the scenario settings

Use case 6. Name: Building a solution

Primary actor: Designer
Supporting actor(s): Controller and Output Model
Goal: To select and combine SWM components that creates a solution
Pre-conditions: The SWM components are in the database (i.e. library). Site, project information, and Initial WB results are stored in the Working Memory.
Main success scenario:

1. The designer enters to the Solution Builder UI
2. The Controller fetches the site and project's information from the Working Memory and send them to the Output Module for visualization
3. The designer accepts site and project's information
4. The Controller fetches Initial WB results from the Working Memory and send it to the Output Model for visualization
5. The Controller queries the SWM components to the DB Control and send it to the Output Model for visualization
6. The designer adds SWM components from the library to the solution
7. The designer defines the type, drainage area, and the input and output amount of water (i.e. potable, rain, grey water) that each SWM component will receive and discharge
8. The designer commands to save the solution
9. The Controller saves the solution into the Working Memory

Post-condition:

- The solution is stored in the Working Memory

Extensions:

- The designer changes site or project's information
- The designer adds one o more SWM components to the solution
- The designer deletes one o more SWM component of the solution

Failure conditions

- The designer fails to accept site or project information
- The designer fails to connect to one or more SWM components
- The designer fails to assign type of water and amount to one or more SWM components
- The designer fails to save solution

Default condition: Information of a predefined project will be available in case there are not inputs from the user. The default case is the pre-development site conditions and the project's information. It does not include SWM components other than the defined ones in the use case #3**:** Estimating Initial WB.

Use case 7. Name: Building a model

Primary actor: designer
Supporting actor(s): Controller
Goal: To link a solution to a scenario for creating a model
Pre-condition: A scenario and a solution must be stored in the Working Memory
Main success scenario:

1. The designer commands to estimate any of the following aspects of a model: water balance for demand and supply conditions, water balance for storm events, water quality, ground water recharge, biodiversity, use of chemicals and life cycle costs
2. The Controller fetches the scenario and the solution information from the Working Memory
3. The Controller saves them, the scenario and the solution, as the model

Post-condition:

- The model is stored in the Working Memory

Extensions:

- None

Failure conditions:

- The Controller does not find the scenario and the solution information
- The Controller fails to save the model information

Default condition: A default model is created from the default scenario and the default solution stored in the Working Memory

Use case 8. Name: Estimating the water performance and cost of a model

Primary actor: Designer
Supporting actor(s): Controller, Calculation Module, Working Memory, and Output Module
Goal: To estimate the water balance for demand and supply conditions, water balance for storm events, water quality, ground water recharge, biodiversity, use of chemicals, and life cycle costs of a model
Pre-condition: A model is stored in the Working Memory
Main success scenario:

1. The designer enters to the WB UI
2. The designer commands to estimate water balance for demand and supply conditions, water balance for storm events, water quality, ground water recharge, biodiversity, use of chemicals, and life cycle costs of a model
3. The Controller fetches information for performing calculations and sends it to the Calculation Module
4. The Calculation Module runs the methods in the following order and sends the results to the Controller subsequently:
    a. Demand/supply (Indoor use and rainfall retention, Outdoor use, Rainfall runoff, Outdoor retention/infiltration average rainfall conditions)
    b. Storm events (TR-55 Method, Small Storm Hydrology Method)
    c. Ground water recharge
    d. Water quality
    e. Biodiversity
    f. Life Cycle Costs (Net Present Value)
5. The Controller stores the information in the Working Memory
6. The Controller sends the information to the Output Module for visualization

Extensions:

- The designer changes the calculation parameters (e.g. lifespan of a SWM component, interest rate)

Post-condition:

- The Working Memory has stored the water balance for demand and supply conditions, water balance for storm events, water quality, ground water recharge, biodiversity, use of chemicals, and life cycle costs of a model as follows:

Demand/Supply	**Unit**	**Ground Water Recharge**	
Total water use	Gal/annual, gal/monthly	Ground water recharge	Gal/annual & monthly
Groundwater use	Gal/annual, gal/monthly	**Quality**	
Rainwater use	Gal/annual, gal/monthly	Reduction in TN, TP, TSS	%
Grey water reuse	Gal/annual, gal/monthly	**Biodiversity**	
Black water reuse	Gal/annual, gal/monthly	Total number of SWM components	Number
Potable water use	Gal/annual, gal/monthly	SWM components contributing to biodiversity	Number
Water infiltrated	Gal/annual, gal/monthly	Percentage of contributing components	%
Discharge to sewer system	Gal/annual, gal/monthly	**Costs**	
Water use covered with rainfall/grey/black	Gal/annual, gal/monthly	Initial costs	USD
Total water managed in the site	Gal/annual, gal/monthly	Maintenance Costs	USD
Components using chemicals for treatment	Gal/annual, gal/monthly	Life cycle costs	USD
Storm Event			
Peak Discharge 100, 50, 20 and 2 years storm	Cft, gal/event	Discharge to municipal system	Gal/event
Storm event managed on-site	Gal/event		

Failure conditions:
- The Controller does not find the model information
- The Controller sends incomplete information for running the calculations
- The Controller does not save the results in the Working Memory

Default condition: The calculations will use the default model

Use case 9. Name: Evaluating a Model

Primary actor: Designer
Supporting actor(s): Controller, Evaluation Module, Working Memory, and Output Module
Goal: To assign performance percentages and benefits scores to a model
Pre-condition: The Working Memory has stored the evaluation criteria, benefits scores and a model's results
Main success scenario:
1. The designer commands to run the evaluation of a model
2. The Controller sends the evaluation criteria and scores to the Evaluation Module
3. The Controller sends the model's results to the Evaluation Module
4. The Evaluation Module estimates the performance percentage of the model, assigns the scores, and estimates the benefit-cost ratio of the model
5. The Evaluation Module sends the results to the Controller
6. The Controller saves the results in the Working Memory and sends it for visualization to the Output Module

Extensions:
- The designer makes changes to the evaluation criteria and scores

Post-conditions:
- The evaluation results of a model are saved in the Working Memory
- Results of a model are visible in the Goals and Evaluation UI

Failure conditions:
- Evaluation criteria and scores information is incomplete
- The model's results are incomplete

Default condition: The evaluation will be performed to the default model

Use Case 10. Name: Comparing models

Primary actor: Designer
Supporting actor(s): Controller, Evaluation Module, and Working Memory
Goal: To compare several models
Pre-condition: Models' evaluation results are saved in the Working Memory. The models available for comparison are visible in the Goal and Evaluation UI
Main success scenario:

1. The designer commands to run the comparison of two or more models
2. The Controller sends the benefits-cost ratio of the models to the Evaluation Module
3. The Evaluation Module sorts and ranks the models (based on the benefits-cost ratio)
4. The Evaluation Module sends the rank's results to the Controller
5. The Controller stores the rank's results in the Working Memory
6. The Controller sends the rank's results to the Output Module

Post- conditions:

- The results of the comparison are saved in the Working Memory
- The results of the comparison are showed in the Goals and Evaluation UI

Extensions:

- The designer adds one or more models for comparison
- The designer erases one or more models for the comparison

Failure conditions:

- The designer commands to compare the same model
- The Controller sends incomplete information for running the comparison
- The Controller does not save the results in the Working Memory

Default condition: Two default models' results will be available for comparison

Use case 11. Name: Storing information in the database

Primary actor: Designer
Supporting actor(s): Controller, Database (DB) control
Goal: To store information in the database (i.e. site information, project information, rainfall data, a model, a scenario, a solution, and SWM components)
Pre-condition: Information is stored in the Working Memory
Main success scenario:

1. The designer commands to add information to the database
2. The Controller fetches the information from the Working Memory and sends the information to the DB Control
3. The DB Control module updates the database

Post-condition:

- The information is stored in the database

Extensions:

- The designer eliminates information from the database

Failure conditions:

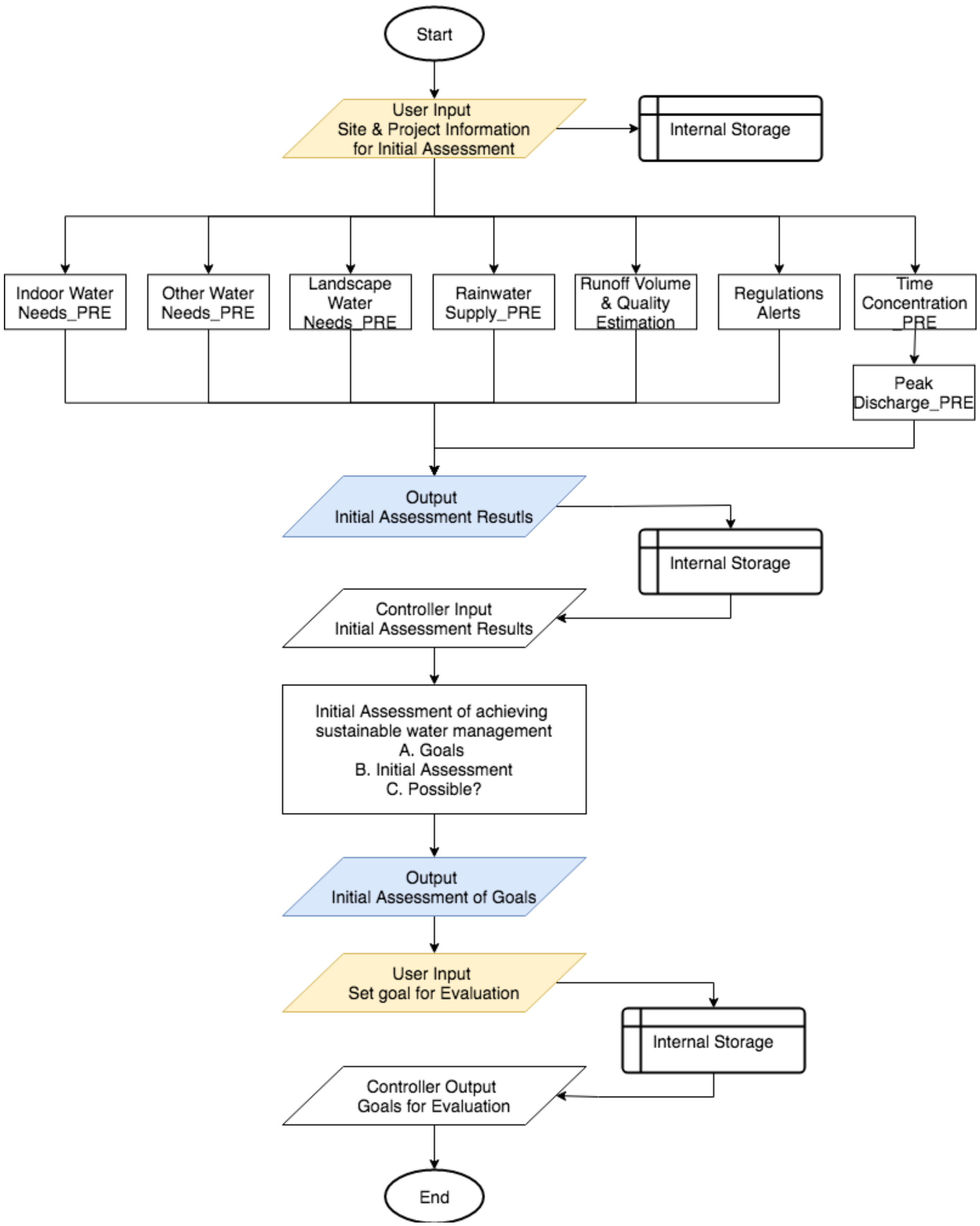
- The Controller does not send the information to the DB control
- The DB control module does not save the information in the DB

Default condition: None

APPENDIX D: Prototype Diagrams

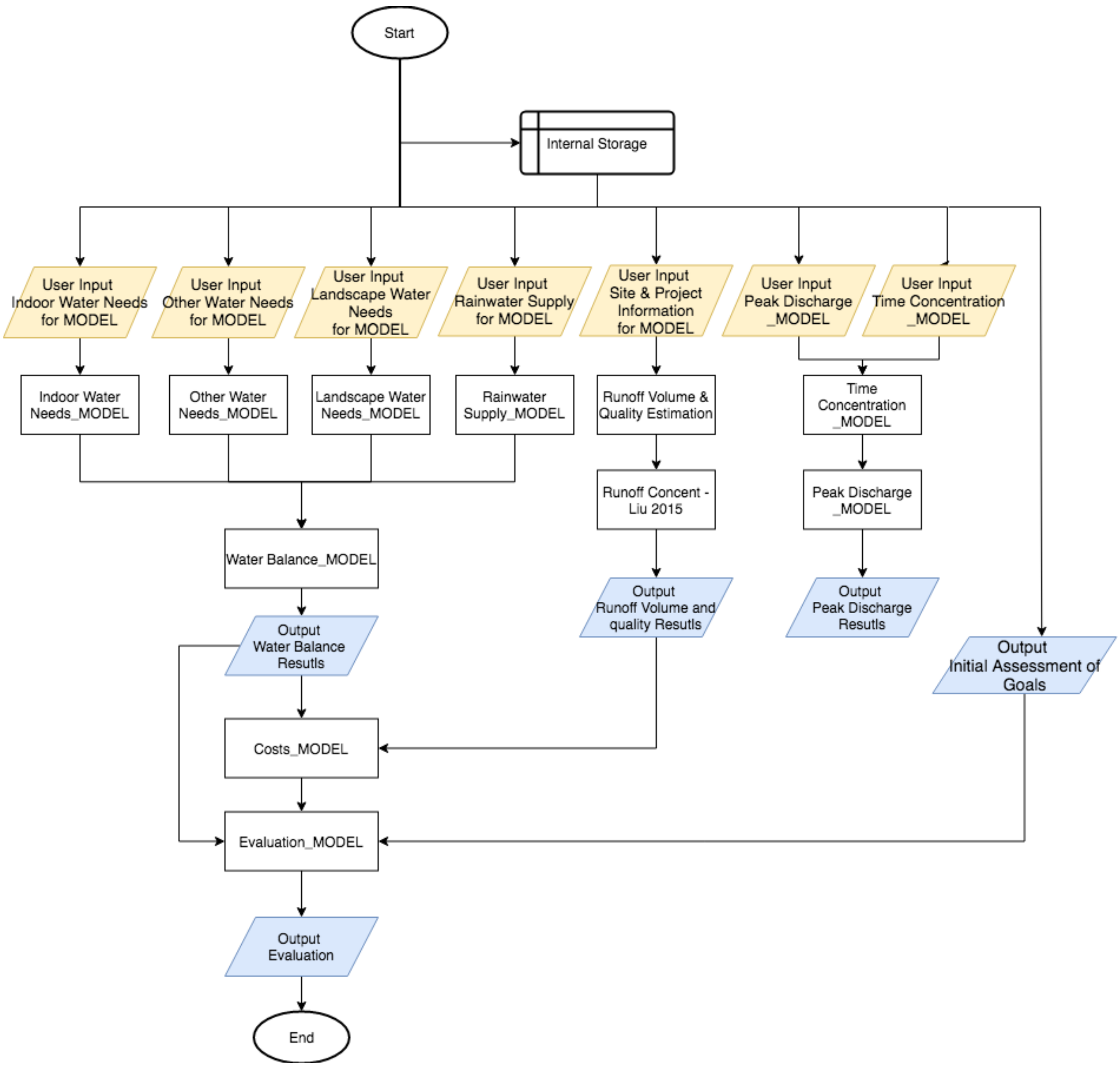
D.1. Initial Assessment Structure

From Site and Project Information for initial assessment to definition of sustainable water management goals. Boxes represent processes, parallelogram represent inputs and outputs, rounded rectangles represent storage.



D.1. Model Assessment Structure

From Site and Project Information to the evaluation of a project. Boxes represent processes, parallelogram represent inputs and outputs, rounded rectangles represent storage.



APPENDIX E: Cost Data

Artifacts. The prototype includes four types of artifacts: bathroom faucets, kitchen faucets, showerheads, and toilets. The later ones are divided into two systems: flushing and composting. **Bathroom faucets** retail prices range from 70 to 400 USD for a standard flow rate (2.2gpm) or efficient flow rate artifacts (1.5 or lower). Two models of bathroom faucets are included in the cost data:

1. Zurn Manual Activation 2.2 GPM Chrome, Straight, Retail price: 86.54 USD (https://www.grainger.com/product/ZURN-Chrome-468D45), and
2. American Standard Colony Pro 2-handle 1.2 GPM, Retail price: 90.69 USD (https://www.amazon.com/American-Standard-7075202-295-2-Handle-CENTERSET/dp/B01N95JG8H).

Installation plus supplies cost has been set as 200 USD for 2 hours of labor work at 100 USD/hour (https://porch.com/project-cost/cost-to-install-a-bathroom-faucet). It is assumed that every ten (10) years, a repair plus supplies costs are 100 USD for one hour of labor (https://porch.com/project-cost/cost-to-replace-a-bathroom-faucet). The life span of bathroom faucets is assumed to be 20 years.

Kitchen faucets retail prices range from 50 to 1000 USD for a standard flow rate (2.2gpm) or efficient flow rate artifacts (1.5 or lower). Two models of kitchen faucets are included in the cost data:

1. Moen 87233SRS Adler One-Handle 2.2 GPM with a retail price: 168 USD (https://www.amazon.com/Moen-87233SRS-One-Handle-Pulldown-Stainless/dp/B082VWC75W) , and
2. American Standard 4175300F15.002 Colony Soft 1.5 GPM with a retail price: 135 USD (https://www.amazon.com/American-Standard-4175300F15-002-PULL-DOWN-Polished/dp/B005HEE136)

Installation plus supplies cost has been set as 250 USD for 2.5 hours of labor work at 100 USD/hour (https://www.homeadvisor.com/cost/plumbing/install-a-faucet/). It is assumed that every ten (10) years, a repair plus supplies costs are 100 USD for one kitchen faucet (https://www.thumbtack.com/p/sink-repair-cost#:~:text=The%20national%20average%20cost%20to%20repair%20a%20dripping%20faucet%20is,and%20cause%20of%20the%20leak.). Kitchen faucets life span is assumed to be 20 years.

Showerheads retail prices range from 25 to 250 USD for a standard flow rate (2.5gpm) or efficient flow rate showerheads (2.0 or lower). Six models of showerheads are included in the cost data:

1. Couradric Handheld Shower Head and Rain Shower 2.5GPM with a retail price: 45 USD (https://www.amazon.com/Polished-Stainless-Pressure-Showerhead-Adjustable/dp/B077GHJFLP/ref=sr_1_42?dchild=1&keywords=plumbing+handheld+shower+fixtures+1.5gpm&qid=1609790560&sr=8-42)
2. American Standard 9038254.002 Spectra Plus Duo Shower Head 1.8 GPM with a retail price: 99.45 USD (https://www.amazon.com/American-Standard-9038254-002-4-Function-Polished/dp/B075QBLX5N)
3. American Standard Hand Held System 1.8 GPM with a retail price: 237 USD (https://www.amazon.com/American-Standard-9038824-002-Spectra-4-Function/dp/B07X5XZFJH)
4. Caroma 90222C Efficiency Shower Flow 1.5 GPM with a retail price: 35.13 USD (https://www.amazon.com/Caroma-90222C-Efficiency-Shower-Chrome/dp/B005EM15L2)
5. High Sierra's All Metal High Efficiency Showerhead 1.5 GPM with a retail price: 49.94 USD (https://www.amazon.com/High-Sierras-Efficiency-Showerhead-Available/dp/B001W2CEYA)
6. Niagara Conservation N2945BN High Efficiency Hand Shower Head 1.5 GPM with a retail price: 29.99 USD (https://www.amazon.com/Niagara-Conservation-N2945BN-Massage-Handheld/dp/B071RGXM6X)

Installation plus supplies cost has been set as 200 USD for 2 hours of labor work at 100 USD/hour (https://porch.com/project-cost/cost-to-install-a-shower-head#national-average-cost). It is assumed that every ten (10) years, a repair plus supplies costs are 100 USD for one shower head (https://homeguide.com/costs/shower-repair-cost). The life span of shower heads is assumed to be 20 years.

Flushing Toilets retail prices range from 90 to 1500 USD for residential use, with standard flush volume (1.6 GPF) or efficient flush volume (1.28 GPF or lower). Three models of toilets are included in the cost data:

1. American Standard Cadet 3 White Round Standard Height 1.6 GPF with a retail price: 203 USD (https://www.lowes.com/pd/American-Standard-Cadet-3-White-Round-Standard-Height-2-piece-Toilet-10-in-Rough-In-Size/50057615)
2. TOTO CST243EFR#01 Two-Piece Round Universal Height 1.28 GPF with a retail price: 201 USD (https://www.amazon.com/CST243EFR-01-Plumbing-Cotton-White/dp/B00QSMYZXW)
3. American Standard 2886218.020 H2Option Dual Flush 0.92/1.28 GPF with a retail price: 285.99 USD (https://www.amazon.com/American-Standard-2886218-020-H2Option-Elongated/dp/B01BWMODTS)

Installation plus supplies cost has been set as 200 USD for 2 hours of labor work at 100 USD/hour (https://porch.com/project-cost/cost-to-install-a-toilet). It is assumed that every ten (10) years, a repair plus supplies costs are 150 USD for one toilet (https://www.fixr.com/costs/toilet-repair). The life span of shower heads is assumed to be 25 years.

Composting Toilets. Composting toilets (CT) are sanitation systems known as dry, biological, bio-toilets, or waterless toilets. Composting toilets use no water or little for its conveyance system. They have two main parts: the toilet and the composting tank, and usually includes a fan and vent pipe for odor removal. The waste in the tank is digested aerobically or may use vermicomposting treatment (earthworms). The final product is a stable organic matter used as a natural fertilizer in landscapes (Anand and Apul 2014). These systems' costs are higher than conventional flushing toilets because they include the treatment systems for the waste. On the other hand, the composting toilet will not connect to public drinking and sewer services. Therefore, connection and conventional operational costs are avoided. Two models of composting toilets are included in the cost data:

1. Clivus Multrum - Self-contained, waterless, no urine diversion with a retail price 4500 USD (Berger 2009. Costs converted to 2020 USD, https://www.usinflationcalculator.com/)

2. BioLet Composting Toilet 65 - 4 persons full-time with a retail price 3299 USD (https://www.biolet.com/products/biolet-composting-toilet-65)

Installation costs has been set equal to regular toilets. Composting systems requires energy with a maximum cost of 10.37/month (http://peconicgreengrowth.org/wp-content/uploads/2016/10/FP33Clivus.pdf). BioLet toilets monthly requires addition of a mix of peat and other natural organic materials which cost 39 USD per bag. 8 bags per year are needed for 4 persons in full-time use. Repair and replacement of parts has been set at 200 USD every 5 years (http://peconicgreengrowth.org/wp-content/uploads/2016/10/FP33Clivus.pdf). The life span of composting toilets is assumed to be 20 years.

Rainwater Harvesting Systems and Low Impact Development strategies (LIDs). The costs of Rainwater harvesting (Cisterns and barrels) and LIDs have been adopted from Liu (2015). The strategies' total costs were estimated considering construction cost, maintenance cost, and opportunity cost based on Arabi et al. (2006). The life span of Rainwater harvesting and LIDs is assumed to be 20 years. Drainage areas are estimated based on the L-THIA-LID 2.1 model (Liu 2015) . Table. E.1. presents the construction costs and annual maintenance costs of BMPs/ LIDs strategies in the prototype. All costs were converted to 2020 USD. (https://www.usinflationcalculator.com/).

Table. E.1. Construction costs and annual maintenance costs of BMPs/ LIDs strategies

Strategy	Construction Cost ($/m2 drainage area) 2014 dollars	Construction Cost ($/m2 drainage area) 2020 dollars	Annual Maintenance Cost (% of Construction Cost)
Cistern	8.59	9.44	1
Rain Barrel	6.71	7.38	1
Permeable patio	121.68	133.76	1
Green Roof	168.34	185.05	6
Bioretention	15.12	16.62	6
Porous Pavement	59.2	65.07	1
Grassed Swale	0.9	0.99	6
Grass strip	0.34	0.37	3
Wetland Channel	0.9	0.99	6
Wet Pond	1.22	1.34	4
Dry Pond	1.41	1.55	4
Wetland	1.55	1.7	4

Adapted from Liu 2015. Source of cost data: Schueler 1992; Brown and Schueler 1997; CWP 1997; USEPA 1999, 2006, 2012a, and 2012b; Arabi, et al. 2006; PSBMPM 2006a and 2006b; EBRP 2007; NCDENR 2007; LIDMM 2008; CNT 2009; King and Hagan 2011; TRC and CVC 2011.

Disinfection for Rainwater Harvesting Systems. The use of rainwater as a potable supply requires disinfection treatment to make it safe for drinking purposes. Standard disinfection treatment is boiling, iodine, chlorination, solarization, UV irradiation, ozonation, microfiltration, and ultrafiltration. Standard disinfection treatment is boiling, iodine, chlorination, solarization, UV irradiation, ozonation, microfiltration, and ultrafiltration. UV irradiation is effective on bacteria and most viruses and produces minimal byproducts (Holmgreen 2012). Moreover, UV systems are easy to install and convenient to operate and maintain. The differences between the systems are their flow rate disinfection capacity, energy consumption, replacement parts such as filters and UV lamps. Three Residential UV Disinfection systems have been added to the prototype's cost database:

1. RainFlo Double 10 GPM Rainwater Purification Package with a retail cost: 1199.94 USD (https://www.rainharvest.com/rainflo-double-10-gpm-rainwater-purification-package-blue-l-r.asp)
2. RainFlo 15 GPM Double Rainwater Purification Package with a retail cost: 1295.94 USD (https://www.rainharvest.com/rainflo-15-gpm-double-rainwater-purification-package.asp)
3. RainFlo 25 GPM Double Rainwater Purification Package with a retail cost: 1379.94 USD (https://www.rainharvest.com/rainflo-25-gpm-double-rainwater-purification-package.asp)

Annual operation and maintenance costs involves energy consumption for lamps and controllers, and the replacement of filters and UV lamp. No installation costs are available in the database. The life span of disinfection systems for Rainwater harvesting is assumed to be 10 years.

Greywater Systems. The use of greywater as a potable and non-potable supply requires filtration and disinfection treatment to make it safe for its use. Two sources of cost data for greywater systems are included in the prototype. The first source is the work of Hodgson (2012) and NASEM (2016), which presents the costs of different sizes of greywater treatment that considers storage, coarse filter, and disinfection system. Plumbing is excluded. All costs were converted to 2020 USD. **Table. E.2.** presents the construction costs, Annual Chemical and Energy costs and Maintenance costs of Greywater Systems.

Table. E.2. Construction, Annual Chemical, Energy and Maintenance costs of Greywater Systems

System size (Gallons per Day)	Construction Costs 2020 dollars	Annual chemical and Energy Cost 2020 dollars	Annual Maintenance Costs 2020 dollars
Greywater System 50 GPD	2347	20	278
Greywater System 75 GPD	2347	29	278
Greywater System 85 GPD	2521	32	278
Greywater System 100 GPD	2521	38	555
Greywater System 150 GPD	2612	62	555
Greywater System 300 GPD	2604	123	555
Greywater System 500 GPD	3501	204	833
Greywater System 750 GPD	4140	307	833
Greywater System 900 GPD	4637	368	833
Greywater System 1000 GPD	4637	409	1110
Greywater System 2000 GPD	5793	818	2221
Greywater System 3000 GPD	7591	1226	3331
Greywater System 4000 GPD	9644	1634	4441
Greywater System 5000 GPD	13669	2043	5552

Adapted from Hodgson 2012 and NASEM 2016

The second group of greywater systems and their costs were retrieved from the wholesale distributor of Greywater Systems in the US, Water Wise Group, Inc. Four greywater systems are organized into two groups, for outdoor recycled water use, and for indoor recycled water use. The Aqua2use greywater systems for outdoor use have a retail price range of 400 to 1900 USD. Annual maintenance costs include the costs of two filters for replacement (159 USD/each). For the systems that incorporate a pump, annual energy costs are 20 USD (assuming a 200W pump work for two hours every day at an energy cost of 11.44 c/kWh - https://www.electricitylocal.com). Indoor use greywater systems, GWTS models, have a retail price range of 8000 to 12000 USD. These systems include biological treatment, aeration, and UV disinfection, allowing storage of water. Annual maintenance includes the replacement of two air filters ($100), a UV lamp ($120), and pre-treatment filters every six months ($318). Annual energy costs are 26 USD for pumping. The life span of all greywater systems is assumed to be ten years.

1. Aqua2use Gravity - Greywater Diversion Device (GWDD) for outdoor use. Retail price: 429 USD (https://waterwisegroup.com/greywater-systems-sale/aqua2use-gwdd/)
2. Aqua2use GWDD for outdoor use. Retail price: 720 USD (https://waterwisegroup.com/greywater-systems-sale/aqua2use-gwdd/)

3. Aqua2use Pro - GWDD - 25 GPM – 50-gallon capacity for outdoor use. Retail price: 1950 USD (https://waterwisegroup.com/greywater-systems-sale/aqua2use-pro/)
4. GWTS 1000 - Greywater Treatment System (GWTS) – filter up to 250 Gal per day for indoor use. Retail price: 9900 USD (https://www.aqua2use.com/gwts1000-green-building-grey-water-recycle-treatment-methods/)

Blackwater Treatment System. Blackwater Treatment System is an onsite wastewater treatment system (OWTS). Conventional OWTS contain a septic tank and drain field. Differences in construction, operation, and maintenance costs between conventional OWTS are based on the size of the septic tank, pumping needs, or improvement to the drain line according to soil conditions, steep slopes, or limited available space. Six residential conventional OWTS have been added to the prototype's cost database. All systems are for a household of 4 bedrooms. Construction Cost data for the six systems has been retrieved from http://www.threeoaksengineering.com/types-of-septic-systems.html.

1. Conventional Gravity Septic Systems (septic Tank and drainfield). Cost: 4500 USD
2. Conventional-Pump Septic Systems (septic Tank, Pump Tank and drainfield). Cost: 5500 USD
3. Pressure Manifold System (septic Tank, Pump Tank, pressure manifold and drainfield). Cost: 7000 USD
4. Low-Pressure Pipe (LPP) Systems (septic Tank, Pump Tank, low pressure pipes and drainfield). Cost: 13500 USD
5. Drip Disposal Systems - Anaerobic Treatment (septic tank, pump tank, hydraulic unit, and drip tubing drainfield). Cost: 20000 USD
6. Drip Disposal Systems - Aerobic Treatment (septic tanks, pump tank /aerobic pre-treatment unit, hydraulic unit/filter module, and drip tubing drainfield). Cost: 25000 USD

Maintenance costs involves pumping the septic tank every three years with an estimated cost of 300 USD (https://www.paradisevalleyseptic.com/how-much-will-it-cost-to-have-my-septic-tank-pumped/). Operating costs includes energy for pumps at 10 -15 USD per month (https://inspectapedia.com/septic/Aerobic-Septic-Operating-Cost.php).

Groundwater Systems. Residential private well has an initial cost range from 3750 to 15300 USD. Drilling and pumps are the most expensive part of the cost, and their costs depend on the depth drilled and the diameter of the well. Based on the data retrieved from the website homeguide.com, three installation costs have been estimated. The cost estimation for a 150-foot well includes drilling, well pump, well casing pipe, electrical wiring & control Box, pressure Storage tank & switch, water treatment & purification system, water quality testing, permit, and a water heater (https://homeguide.com/costs/well-drilling-cost#install).

1. GRWS 1 - Water Well, Pump and Pressure Tank, Disinfection. Cost: 5150 USD
2. GRWS 2 - Water Well, Pump and Pressure Tank, Disinfection. Cost: 11675 USD
3. GRWS 3 - Water Well, Pump and Pressure Tank, Disinfection. Cost: 18200 USD

Annual operation and maintenance costs of private wells are around 530.82 USD. These costs include electricity used by pumps, sediment filters, salt for softener system, water quality testing, and 50 feet of heat trace. Every 20 years is recommended to replace the pump, the pressure tank, and the softener system. These maintenance activities have a cost of 6189.36 USD, including labor, parts, and tools (ADEC 2017). All costs were converted to 2020 USD.

Public drinking water supply and Sewer services. The prototype includes connection and operation cost for designs that consider the potable supply from a public water system or discharge wastewater to public sewer systems. Current rates charges have been retrieved from the Pittsburgh Water and Sewer Authority website (https://www.pgh2o.com/residential-commercial-customers/rates). The initial cost includes installation, meter, permit, and tapping fee for a single-family home with a 1" service line and 5/8" meter without hydrant requirement. Tapping fees for a new construction single-family are $2,224 for water and $2,978 for sewer (https://www.pgh2o.com/). Monthly charges for metered water and sewer conveyance for a 5/8" meter size for the first 1000 gal are 27.27 USD and 8.28 USD, respectively. For every 1000 gal, the monthly charge is 11.04 USD for water and 7.43 USD for sewer.

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APPENDIX F: Description, Inputs parameters and Results of Base Case and Models

This appendix presents the description of the models presented in the tables and graphs of Chapter 5. The models are, the Base Case, Models A, B, C, 1, and 2.

F.1. Case Study and Base Case

The Base Case is the Case Study without the implementation of SWM strategies, meaning there is not an implementation of efficient artifacts, rainwater harvesting, grey or blackwater reuse or treatment, and LIDs. Model A is a first attempt to achieve a net positive water performance for the case study. Model B, C and D are improvements of Model A, aiming for refining water performance in all the criteria at a lower cost. Details of the Case Study, Base Case, Model A to B are below.

F.2. Description of the Case Study in Detail

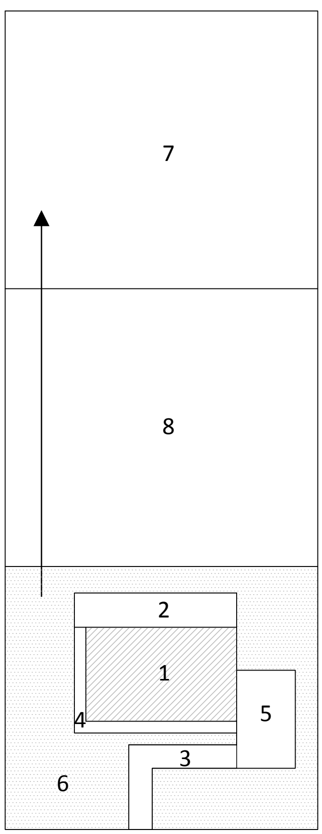

Figure F.1. Case Study Soil Covers

Location: Pittsburgh, PA, US

Site Size: 45000 (sq.ft.) – 1 Acre (131.58 ft x 342 ft)

Site Slope: 3% in the longitudinal way (Arrow in Figure F.1)

Roof area: 2500 (sq.ft.), material: Metal Panel (# 1 in Figure F.1)

Patio: 1000 (sq.ft.), Material: concrete (# 2 in Figure F.1)

Driveway: 730 (sq.ft.), Material: concrete (# 3 in Figure F.1)

Sidewalk: 530 (sq.ft.), Material: concrete (# 4 in Figure F.1)

Parking Lot: 1000 (sq.ft.), Material: concrete (# 5 in Figure F.1)

Landscape Area: 8720 (sq.ft.), Open space - grass cover > 75% (# 6 in Figure F.1)

Area-1: 15250 (sq.ft.), Forest/Woods (# 7 in Figure F.1)

Area 2: 15250 (sq.ft.), Grass/Pasture (# 8 in Figure F.1)

Hydrologic Soil Group: C

Depth to water table: 6.56 (ft)

Number of persons: 4

Metered Indoor Water Consumption: 5166 gal

Two exercises were performed with the prototype, the first one with Models A to D and the second one with Models 1 to 2.

Model A is the first attempt to bring the Base Case to sustainably managing water. Model A implements efficient artifacts, collects rainwater from the roof (100%) for potable and non-potable use, all the landscape area is designed with desert plants, includes a bioretention area (size: 100% of the available area), and implements grass swales (size: 25% of the available area).

Model B add to model A the reuse of greywater and treats blackwater onsite, changes 50% of pavement to be porous in sidewalks, driveway, and parking lot, changes 50% of Area-2's cover from grass to forest, and keeps the bioretention (size:100% of the available area) and increases the grass swales area (size: 50% of the available area).

Model C implements composting toilets, increases the area for collecting rainwater (2800 sq.ft.) for potable and non-potable use, reuse greywater and treats blackwater onsite, reduces the porous pavement to 25% of pavement to be porous in sidewalks, driveway, and parking lot, and increases the grass swales area (75% of the available area).

Model D is the final iteration of the design. In this model, the aim was to reduce the cost while maintaining sustainable water management performance. Model D eliminated the porous pavement and increased the grass swale area by 5%.

Model 1 implements efficient artifacts, collects rainwater from the roof (100%) for potable and non-potable use, reuse greywater, and treats blackwater onsite; all the landscape area is designed with desert plants, changes 50% of pavement to be porous in sidewalks, driveway and parking lot, modifies 50% of Area-2's cover from grass to forest, and bioretention (100% of the available area) and implements grass swales (50% of the available area).

Model 2 is an improvement of Model 1, aiming for refining water performance in all the criteria at a lower cost with the following changes: implementing composting toilets and changing porous pavement for another type of LIDs at a lower cost. Model 2 changes Model 1 in the following parameters: Toilet is a waterless toilet, remove porous pavement, increase of grass swale to the 75% of the available area, increase roof area to 2800 sq.ft., reduces sidewalk area (that is covered by roof now). The changes in the cost module are: the toilet is a composting toilet eliminating at the same time the connection to public water supply and reducing the size of the blackwater system because there is less water discharge (due to composting toilet implementation).

F.3. Tables of inputs' parameters and results for all models.

The following pages presents the tables with the parameters' inputs for each model, the base case and the pre-development condition and the results from the water balance estimations, runoff volume and quality estimations, life cycle assessments and evaluations.

Table F.1. Inputs' parameters for site and project Information of all models

Parameter	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
City				Pittsburgh			
Country				USA			
Type of Precipitation Pattern				Normal year			
Year				2010			
Hydrologic Soil Group				C			
Depth to water table cm				200			
Number of Persons				4			
Metered Water (gallons/month)				5166			
Surface Area (sqft)							
Site Size (sqft)				45000			
Roof (sqft)	2500	2500	2500	2800	2800	2500	2800
Patio (sqft)				1000			
Street/Road (sqft)				0			
Sidewalk (sqft)	530	530	530	230	230	530	230
Driveway (sqft)				750			
Parking lot (sqft)				1000			
Landscape Area (sqft)				8720			
Area_1 (sqft)	15250	15250	22875	22875	22875	22875	22875
Area_2 (sqft)	15250	15250	7625	7625	7625	7625	7625
Cover Area							
Roof				Roof			
Patio				Patio			
Street/Road				Street/Road			
Sidewalk				Sidewalk			
Driveway				Driveway			
Parking lot				Parking lot			
Landscape Area				Open space - wooded or grass cover > 75%			
Area_1				Forest/Woods			
Area_2				Grass/Pasture			
LIDs (%)							
Green Roof				0			
Roof with cistern	0	100	100	100	100	100	100
Green roof with cistern				0			
Permeable patio				0			
Porous pavement	0	0	50	25	0	50	0
Bioretention	0	100	100	100	100	100	100
Grass swale	0	25	50	75	80	50	75
Grass Strip				0			
Wetland Channel				0			
Surface Area (sqft)							
Green Roof				0			
Roof with cistern	2500	2500	2500	2800	2800	2500	2800
Green roof with cistern				0			
Permeable patio				0			
Porous pavement	0	0	1140	570	0	1140	0
Bioretention	0	6750	6750	6750	6750	6750	6750
Grass swale	0	5937.5	11875	17812.5	19000	11875	17812.5
Grass strip				0			
Wetland channel				0			

Table F.2. Inputs' parameters for indoor water needs estimation of all models

Parameter	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Drinking Water Needs							
Number of Persons	4						
Drinking Volume (gpcd)	0.8						
Bathroom Faucets Type	Standard	US Low Flow Rate Bathroom Faucet 1.2 GPM					
Flow Rate (GPM)	2.2	1.2					
Number of Persons	4	4					
Times per day	7	7					
Minutes per use	0.3	0.3					
Showerheads	Standard	US Low Flow Rate 1.5 GPM					
Flow Rate (GPM)	2.5	1.5					
Number of Persons	4	4					
Times per day	0.69	0.69					
Minutes per use	7	7					
Bathtub	US average	U.S. below average volume per capita day (1.4 gpcd)					
Volume (gpcd)	1.7	1.4					
Number of Persons	4	4					
Kitchen Faucets	Standard	US Low Flow Rate Kitchen Faucet 1.5 GPM					
Flow Rate (GPM)	2.2	1.5					
Number of Persons	1	1					
Times per day	3	3					
Minutes per use	8	8					
Toilet	Standard	Single	Single	No Water	No Water	Single	No Water
Number of Persons	4	4	4	4	4	4	4
Full Volume (gallons/flush)	1.6	1.28	1.28	0	0	1.28	0
Full Flushes/day	6	6	6	0	0	6	0
Reduced Volume (gallons/flush)	0						
Reduced Flushes/day	0						
Urinals	-						
Number of Persons	0						
Flush Volume (gallons/flush)	0						
Number of Flushes	0						
Dishwasher	Standard	Efficient					
Volume per Cycle (gallons)	6	3.07					
Number of cycles per day	1	1					
Number of Persons	1	1					
Clothes Washer	Standard	Efficient					
Volume per Cycle (gallons)	20	12					
Number of cycles per day	0.2	0.2					
Number of Persons	4	4					
Pre-Rinse Spray Valve	-						
Flow Rate (GPM)	1.6						
Number of Persons	0						
Times per day	0						
Minutes per use	0						

Table F.3. Inputs' parameters for other water needs, landscape water needs, and rainwater supply estimation of all models

	Other Water Needs Parameters	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Car Washing Needs	Modus				with a bucket			
	Frequency per month				2			
	Type of water needed				Non-potable			
	Type of water produced				Greywater			
	volume/wash (gallons)				25			
	Monthly volume (gallons)				50			
	Annual volume (gallons)				600			
Swimming Pool	Volume (gallons)				0			
	Type of water needed				Non-potable			
	Type of water produced				Greywater			
	Month of Filling				JULY			
	Monthly volume (gallons)				0			
	Annual volume (gallons)				0			
Other	Water Volume (gallons)				0			
	Frequency per month				3			
	Type of water needed				Non-potable			
	Type of water produced				Greywater			
	Monthly volume needs (gallons)				0			
	Annual volume needs (gallons)				0			

	Landscape Water Demands Parameters	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
High consumption	Area Surface (sqft)				8720			
	Irrigation Efficiency (I.E.)				0.8			
	Canopy Covering				>80%			
	Plant Type				Turf, cool season			
	Plant Factor				0.8			
Low consumption	Area Surface (sqft)				8720			
	Irrigation Efficiency (I.E.)				0.8			
	Canopy Covering				>80%			
	Plant Type				Desert plants			
	Plant Factor				0.3			

Rainwater Supply Parameters	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Location				Pittsburgh			
Rainfall Pattern				Normal year			
Year				2010			
Catchment Area (sqft)	2500	2500	2500	2800	2800	2500	2800
Roof Material				Roof -Metal Panel			
Runoff Coefficient				0.85			
Safety Factor				0.85			
Conversion Factor				0.623			

Climate Data	City	Pittsburgh		Year	2010		
Month	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**
Evapotranspiration - ETO (in)	0.62	0.61	2.01	3.61	4.44	4.76	5.72
Precipitations - PCP (in)	2.90	3.22	2.19	1.76	5.19	5.13	2.87
Month	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**		
Evapotranspiration - ETO (in)	4.70	3.41	2.03	1.01	0.59		
Precipitations - PCP (in)	1.68	3.28	2.12	5.97	1.57		

Table F.4. Inputs' parameters for Time of Concentration estimation for all models and its results

Parameters	Pre-development	Base Case	Model A to D	Model 1	Model 2
City	Pittsburgh				
2-year 24 hrs Rainfall Depth (P2)	2.35				
1) Sheet flow					
Lenght (L) (ft)	300	200			
Slope (s) (ft/ft)	0.03	0.03			
Surface description	Woods dense	Woods light underbrush			
Roughness coefficients for sheet flow (n)	0.8	0.4			
2-year 24 hrs Rainfall Depth (P2) (inches)	2.35	2.35			
Sheet Flow Travel Time (Tt) (hr)	**1.49**	**0.618**			
Sheet Flow Travel Time (Tt) (min)	**89.34**	**37.10**			
2) Shallow concentrated flow					
Lenght (L) (ft)	0	100			
Slope (s) (ft/ft)	0.01	0.03			
Is the surface paved?	Yes	Yes			
Unpaved Velocity (V) (ft/s)	1.61	2.79			
Paved Velocity (V) (ft/s)	2.03	3.52			
Shalow C. Travel Time (Tt) (hr)	**0**	**0.01**			
Shalow C. Travel Time (Tt) (min)	**0**	**0.47**			
3) Channel flow					
Lenght (L) (ft)	0	0			
Slope of channel (s) (ft/ft)	0.002	0.02			
Channel surface description	Mountain stream 1	Excavated or Dredged Channels Earth straight and uniform 2			
Channel Surface Description Details	No vegetation in channel	Gravel uniform section clean			
Manning´s roughness coefficients for open channel flow (n)	0.04	0.025			
Channel description					
Cross sectional flow area (a) (ft2)	1.5	1			
Wetted Perimeter (pw) (ft)	2	2			
Hydraulic radius (r) (ft)	0.75	0.5			
Average velocity (V) (ft/s)	1.38	5.31			
Channel Flow Travel Time (Tt) (hr)	**0**	**0**			
Channel Flow Travel Time (Tt) (min)	**0**	**0**			
Total TC (hr)	**1.49**	**0.63**			
Total TC (min)	**89.34**	**37.57**			

Table F.5. Inputs' parameters for Pre- and Post-development Graphical Peak Discharge estimations and its results for all models

Pre-development Parameters					
City	Pittsburgh	**HSG**	C	**TC (hr)**	1.49
Drainage area (mi2)	0.00	**Soil Cover**	Forest	**TC (min)**	89.34
Rainfall Type Distribution	II	**CN**	70		
Pond and Swamp adjustment factor	0	**Fp**	1		

Post-development Parameters	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
City				Pittsburgh			
Tc (hr)				0.63			
Drainage area (mi2)				0.00161			
Rainfall Type Distribution				II			
Hydrological Soil Group				C			
Cover (CN value) Area (mi2)							
Roof (95)	8.967.E-05	8.967.E-05	8.967.E-05	1.004.E-04	1.004.E-04	8.967.E-05	1.004.E-04
Patio (95)	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05
Street/Road (98)	0	0	0	0	0	0	0
Sidewalk (98)	1.901.E-05	1.901.E-05	1.901.E-05	8.250.E-06	8.250.E-06	1.901.E-05	8.250.E-06
Driveway (98)	2.690.E-05	2.690.E-05	2.690.E-05	2.690.E-05	2.690.E-05	2.690.E-05	2.690.E-05
Parking lot (98)	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05	3.587.E-05
Landscape Area (77)	3.128.E-04	3.128.E-04	3.128.E-04	3.128.E-04	3.128.E-04	3.128.E-04	3.128.E-04
Area 1 Cover (70)	5.470.E-04	5.470.E-04	8.205.E-04	8.205.E-04	8.205.E-04	8.205.E-04	8.205.E-04
Area 2 Cover (74)	5.470.E-04	5.470.E-04	2.735.E-04	2.735.E-04	2.735.E-04	2.735.E-04	2.735.E-04
Green Roof (85)	0	0	0	0	0	0	0
Roof with cistern (85)	0	8.967.E-05	8.967.E-05	1.004.E-04	1.004.E-04	8.967.E-05	1.004.E-04
Green roof with cistern (74)	0	0	0	0	0	0	0
Permeable patio (89)	0	0	0	0	0	0	0
Porous pavement (85)	0	0	4.089.E-05	1.776.E-05	0	4.089.E-05	0
Bioretention (35)	0	2.421.E-04	2.421.E-04	2.421.E-04	2.421.E-04	2.421.E-04	2.421.E-04
Grassed swale (35)	0	2.130.E-04	4.260.E-04	6.389.E-04	6.815.E-04	4.260.E-04	6.389.E-04
Grass Strip (35)	0	0	0	0	0	0	0
Wetland Channel (35)	0	0	0	0	0	0	0
Totals	1.614.E-03	2.159.E-03	2.413.E-03	2.613.E-03	2.638.E-03	2.413.E-03	2.596.E-03
CN (Weighted)	77	68	65	63	62	65	63
Pond and Swamp adjustment factor				0			
Fp				1			

Results	Pre-develop.	Post-development				
Peak Discharge (cfs)		**Base Case**	**Model A**	**Model B and 1**	**Model C and 2**	**Model D**
Rainfall Frecuency						
2	0.088	0.339	0.106	0.058382	0.045456	0.040
5	0.216	0.630	0.300	0.210748	0.158922	0.136
10	0.322	0.866	0.475	0.360712	0.291183	0.259
25	0.486	1.218	0.732	0.599664	0.516376	0.472
50	0.632	1.521	0.964	0.807687	0.711290	0.666
100	0.796	1.851	1.226	1.045955	0.933239	0.879

Table F.6. Inputs' parameters for Pre- and Post-development Rational Method Peak Discharge estimations and its results for the Base Case (only for Chile)

Pre-Development Base Case	
City	Concepcion
Surface description	Pasture, Woodlands
Runoff Coefficient (C)	0.15
Drainage area (acres)	1.03
Time of Concentration (Tc) (hr)	1.49
Time of Concentration (Tc) (min)	89.34

Rainfall Intensity (in/h)			**Frequency (years)**				
Minutes	1	2	5	10	25	50	100
89.34	0.69	0.82	0.99	1.12	1.30	1.44	1.57
Peak Flow (Q) (cfts/s)			**Frequency (years)**				
Minutes	1	2	5	10	25	50	100
89.34	0.11	0.13	0.15	0.17	0.20	0.22	0.24

Post-Development Base Case

City	Concepcion			
Surface Description	Cover	Runoff Coefficient (C)	Area (A) (acres)	C*A
Roof	Roofs, Roofs	0.85	5.7.E-02	4.9.E-02
Patio	Streets, Brick	0.775	2.3.E-02	1.8.E-02
Street/Road	Streets, Concrete	0.875	0	0
Sidewalk	Streets, Drives and walks	0.8	1.2.E-02	9.7.E-03
Driveway	Streets, Drives and walks	0.8	1.7.E-02	1.4.E-02
Parking lot	Streets, Drives and walks	0.8	2.3.E-02	1.8.E-02
Landscape Area	Lawns, Heavy soil flat < 2%	0.15	2.0.E-01	3.0.E-02
Area 1	Pasture, Woodlands	0.15	3.5.E-01	5.3.E-02
Area 2	Pasture, Heavy soil	0.3	3.5.E-01	1.1.E-01
Green Roof	Green Roof - Extensive	0.84	0	0
Roof with cistern	Roofs, Roofs	0.85	0	0
Green roof with cistern	Green Roof - Extensive	0.84	0	0
Permeable patio	Streets, Brick	0.775	0	0
Porous pavement	Porous Pavement	0.006	0	0
Bioretention	Bioretention cell	0.277	0	0
Grassed swale	Bioretention cell	0.277	0	0
Grass Strip	Bioretention cell	0.277	0	0
Wetland Channel	Bioretention cell	0.277	0	0
		Total	**1.03**	**0.30**

Drainage area (A) (acres)	1.03
Weighted Runoff Coefficient (C)	0.29
Time of Concentration (Tc) (hr)	0.63
Time of Concentration (Tc) (min)	37.57

Rainfall Intensity (in/h)			**Frequency (years)**				
Minutes	1	2	5	10	25	50	100
37.57	1.09	1.33	1.63	1.86	2.16	2.39	2.62
Peak Flow (Q) (cfts/s)			**Frequency (years)**				
Minutes	1	2	5	10	25	50	100
37.57	0.32	0.39	0.48	0.55	0.64	0.71	0.77

Table F.7. Base Case Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
MONTHLY TOTAL	5938	5369	5938	7124	5938	5749	7853	9815	5749	5938	5749	5938	77098
MONTHLY POTABLE NEEDS	**4016**	**3627**	**4016**	**3887**	**4016**	**3887**	**4016**	**4016**	**3887**	**4016**	**3887**	**4016**	**47286**
DRINKING	98	89	98	95	98	95	98	98	95	98	95	98	1157
BATHROOM FAUCETS	573	517	573	554	573	554	573	573	554	573	554	573	6745
SHOWERHEADS	1497	1352	1497	1449	1497	1449	1497	1497	1449	1497	1449	1497	17630
BATHTUB	211	190	211	204	211	204	211	211	204	211	204	211	2482
KITCHEN FAUCETS	1637	1478	1637	1584	1637	1584	1637	1637	1584	1637	1584	1637	19272
MONTHLY NON-POTABLE NEEDS	**1922**	**1741**	**1922**	**3237**	**1922**	**1862**	**3837**	**5799**	**1862**	**1922**	**1862**	**1922**	**29812**
TOILETS	1190	1075	1190	1152	1190	1152	1190	1190	1152	1190	1152	1190	14016
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	186	168	186	180	186	180	186	186	180	186	180	186	2190
CLOTHES WASHER	496	448	496	480	496	480	496	496	480	496	480	496	5840
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE - High Demand	0	0	3481	13654	6481	8457	21335	19834	7368	3839	0	0	84448
LANDSCAPE - Low Demand	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

Water Supply (gallons)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
RAINWATER SUPPLY	3265	3624	2468	1985	5839	5777	3225	1887	3690	2388	6721	1763	51159
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	2777	2508	2777	2687	2777	2687	2777	2777	2687	2777	2687	2777	32697
BLACK WATER	3013	2722	3013	2916	3013	2916	3013	3013	2916	3013	2916	3013	35478
PUBLIC SYSTEM							All that is left						
Potential Onsite Supply	6042	6132	5245	4672	8616	8465	6002	4664	6378	5165	9408	4540	75329

Water Discharge (gallons)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
Monthly Discharge to sewer	5790	5230	5790	5603	5790	5603	5790	5790	5603	5790	5603	5790	68175

Table F.8. Model A Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MONTHLY TOTAL	3994	3455	3820	5074	3820	3699	5735	7697	3699	3820	3699	3820	52331
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98	89	98	95	98	95	98	98	95	98	95	98	1157
BATHROOM	312	282	312	302	312	302	312	312	302	312	302	312	3679
SHOWERHEADS	898	811	898	869	898	869	898	898	869	898	869	898	10578
BATHTUB	174	157	174	168	174	168	174	174	168	174	168	174	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	1395	1265	1395	2727	1395	1352	3310	5272	1352	1395	1352	1395	23603
TOILETS	952	860	952	922	952	922	952	952	922	952	922	952	11213
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95	86	95	92	95	92	95	95	92	95	92	95	1121
CLOTHES WASHER	298	269	298	288	298	288	298	298	288	298	288	298	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

WATER SUPPLY SUMMARY

Water Supply (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
RAINWATER SUPPLY	3265	3624	2468	1985	5839	5777	3225	1887	3690	2388	6721	1763	42632.7
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19804.9
BLACK WATER	2163	1954	2163	2094	2163	2094	2163	2163	2094	2163	2094	2163	25473.4
PUBLIC SYSTEM							All that is left						

Table F.9. Model B Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
MONTHLY TOTAL	3994	3455	3820	5074	3820	3699	5735	7697	3699	3820	3699	3820	52331
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98.27	88.76	98.27	95.1	98.27	95.1	98.27	98.27	95.1	98.27	95.1	98.27	1157
BATHROOM	312.5	282.2	312.5	302.4	312.5	302.4	312.5	312.5	302.4	312.5	302.4	312.5	3679
SHOWERHEADS	898.4	811.4	898.4	869.4	898.4	869.4	898.4	898.4	869.4	898.4	869.4	898.4	10578
BATHTUB	173.6	156.8	173.6	168	173.6	168	173.6	173.6	168	173.6	168	173.6	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	1395	1265	1395	2727	1395	1352	3310	5272	1352	1395	1352	1395	23603
TOILETS	952.3	860.2	952.3	921.6	952.3	921.6	952.3	952.3	921.6	952.3	921.6	952.3	11213
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95.17	85.96	95.17	92.1	95.17	92.1	95.17	95.17	92.1	95.17	92.1	95.17	1121
CLOTHES WASHER	297.6	268.8	297.6	288	297.6	288	297.6	297.6	288	297.6	288	297.6	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	YES

WATER SUPPLY SUMMARY

Water Supply (gallons)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL**
RAINWATER SUPPLY	3265	3624	2468	1985	5839	5777	3225	1887	3690	2388	6721	1763	42633
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19805
BLACK WATER	2163	1954	2163	2094	2163	2094	2163	2163	2094	2163	2094	2163	25473
PUBLIC SYSTEM							All that is left						

Table F.10. Model C Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MONTHLY TOTAL	3042	2595	2868	4152	2868	2777	4782	6744	2777	2868	2777	2868	41118
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98.27	88.76	98.27	95.1	98.27	95.1	98.27	98.27	95.1	98.27	95.1	98.27	1157
BATHROOM	312.5	282.2	312.5	302.4	312.5	302.4	312.5	312.5	302.4	312.5	302.4	312.5	3679
SHOWERHEADS	898.4	811.4	898.4	869.4	898.4	869.4	898.4	898.4	869.4	898.4	869.4	898.4	10578
BATHTUB	173.6	156.8	173.6	168	173.6	168	173.6	173.6	168	173.6	168	173.6	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	442.8	404.8	442.8	1805	442.8	430.1	2357	4319	430.1	442.8	430.1	442.8	12391
TOILETS	0	0	0	0	0	0	0	0	0	0	0	0	0
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95.17	85.96	95.17	92.1	95.17	92.1	95.17	95.17	92.1	95.17	92.1	95.17	1121
CLOTHES WASHER	297.6	268.8	297.6	288	297.6	288	297.6	297.6	288	297.6	288	297.6	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

WATER SUPPLY SUMMARY

Water Supply (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
RAINWATER SUPPLY	3657	4059	2764	2223	6540	6470	3612	2114	4133	2674	7527	1975	47749
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19805
BLACK WATER	1211	1094	1211	1172	1211	1172	1211	1211	1172	1211	1172	1211	14261
PUBLIC SYSTEM							All that is left						

Table F.11. Model D Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MONTHLY TOTAL	3042	2595	2868	4152	2868	2777	4782	6744	2777	2868	2777	2868	41118
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98.27	88.76	98.27	95.1	98.27	95.1	98.27	98.27	95.1	98.27	95.1	98.27	1157
BATHROOM	312.5	282.2	312.5	302.4	312.5	302.4	312.5	312.5	302.4	312.5	302.4	312.5	3679
SHOWERHEADS	898.4	811.4	898.4	869.4	898.4	869.4	898.4	898.4	869.4	898.4	869.4	898.4	10578
BATHTUB	173.6	156.8	173.6	168	173.6	168	173.6	173.6	168	173.6	168	173.6	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	442.8	404.8	442.8	1805	442.8	430.1	2357	4319	430.1	442.8	430.1	442.8	12391
TOILETS	0	0	0	0	0	0	0	0	0	0	0	0	0
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95.17	85.96	95.17	92.1	95.17	92.1	95.17	95.17	92.1	95.17	92.1	95.17	1121
CLOTHES WASHER	297.6	268.8	297.6	288	297.6	288	297.6	297.6	288	297.6	288	297.6	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

WATER SUPPLY SUMMARY

Water Supply (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
RAINWATER SUPPLY	3657	4059	2764	2223	6540	6470	3612	2114	4133	2674	7527	1975	47749
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19805
BLACK WATER	1211	1094	1211	1172	1211	1172	1211	1211	1172	1211	1172	1211	14261
PUBLIC SYSTEM	All that is left												

Table F.12. Model 1 Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MONTHLY TOTAL	3994	3455	3820	5074	3820	3699	5735	7697	3699	3820	3699	3820	52331
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98	89	98	95	98	95	98	98	95	98	95	98	1157
BATHROOM	312	282	312	302	312	302	312	312	302	312	302	312	3679
SHOWERHEADS	898	811	898	869	898	869	898	898	869	898	869	898	10578
BATHTUB	174	157	174	168	174	168	174	174	168	174	168	174	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	1395	1265	1395	2727	1395	1352	3310	5272	1352	1395	1352	1395	23603
TOILETS	952	860	952	922	952	922	952	952	922	952	922	952	11213
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95	86	95	92	95	92	95	95	92	95	92	95	1121
CLOTHES WASHER	298	269	298	288	298	288	298	298	288	298	288	298	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	YES

WATER SUPPLY SUMMARY

Water Supply (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
RAINWATER SUPPLY	3265	3624	2468	1985	5839	5777	3225	1887	3690	2388	6721	1763	42633
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19805
BLACK WATER	2163	1954	2163	2094	2163	2094	2163	2163	2094	2163	2094	2163	25473
PUBLIC SYSTEM	All that is left												

Table F.13. Model 2 Water Balance Inputs Table, Water Supply and Water Discharge Estimations

Water Needs (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MONTHLY TOTAL	3042	2595	2868	4152	2868	2777	4782	6744	2777	2868	2777	2868	41118
MONTHLY POTABLE NEEDS	2599	2347	2599	2515	2599	2515	2599	2599	2515	2599	2515	2599	30598
DRINKING	98	89	98	95	98	95	98	98	95	98	95	98	1157
BATHROOM	312	282	312	302	312	302	312	312	302	312	302	312	3679
SHOWERHEADS	898	811	898	869	898	869	898	898	869	898	869	898	10578
BATHTUB	174	157	174	168	174	168	174	174	168	174	168	174	2044
KITCHEN FAUCETS	1116	1008	1116	1080	1116	1080	1116	1116	1080	1116	1080	1116	13140
MONTHLY NON-POTABLE NEEDS	443	405	443	1805	443	430	2357	4319	430	443	430	443	12391
TOILETS	0	0	0	0	0	0	0	0	0	0	0	0	0
URINALS	0	0	0	0	0	0	0	0	0	0	0	0	0
DISHWASHER	95	86	95	92	95	92	95	95	92	95	92	95	1121
CLOTHES WASHER	298	269	298	288	298	288	298	298	288	298	288	298	3504
PRE-RINSE SPRAY VALVES	0	0	0	0	0	0	0	0	0	0	0	0	0
CAR WASHING	50	50	50	50	50	50	50	50	50	50	50	50	600
SWIMMING POOL	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER USE	0	0	0	0	0	0	0	0	0	0	0	0	0
LANDSCAPE	0	0	0	1375	0	0	1915	3876	0	0	0	0	7166

WATER SUPPLY OPTIONS

RAINWATER	
TANK CAPACITY (gallons)	7000
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES
Supplementary water (gallons)	1500

GROUNDWATER	
CAPACITY (gallons)	0
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	NO

GREYWATER	
MONTHLY CAPACITY	
Bathroom F./Showerheads/Clothes washer/Bathtub	
SAFETY FACTOR	0.9
POTABLE SUPPLY	YES
NON-POTABLE SUPPLY	YES

BLACK WATER	
MONTHLY CAPACITY	
Kitchen F./Toilets/Urinals/Dishwasher/Pre-rinse valves	
SAFETY FACTOR	0.9
POTABLE SUPPLY	NO
NON-POTABLE SUPPLY	YES

WATER SUPPLY SUMMARY

Water Supply (gallons)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
RAINWATER SUPPLY	3657	4059	2764	2223	6540	6470	3612	2114	4133	2674	7527	1975	47749
GROUNDWATER	0	0	0	0	0	0	0	0	0	0	0	0	0
GREYWATER	1682	1519	1682	1628	1682	1628	1682	1682	1628	1682	1628	1682	19805
BLACK WATER	1211	1094	1211	1172	1211	1172	1211	1211	1172	1211	1172	1211	14261
PUBLIC SYSTEM	All that is left												

Table F.14. Water Balance Results

Estimation	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Project Annual Water Consumption from Public Provider (gallons)	77098	9960	1713	0	0	1713	0
Reduction of Annual Water Consumption from Public Provider (%)		87	98	100	100	98	100
Project Annual Water Discharge to Public Sewer (gallons)	68175	45278	0	0	0	0	0
Reduction of Annual Water Consumption from Public Provider (%)		34	100	100	100	100	100

Table F.15. Runoff Volume and Quality Results

Estimation	Pre-development	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Runoff Volume								
Yearly Runoff (m3)	188	676.2	465.6	364.0	326.1	330.1	364.0	340.5
Reduction (%)	0	0	31	45	50	50	45	48
Yearly Total Suspended Solids								
Yearly TSS Load (kg)	0	20.90	13.53	9.58	7.66	7.56	9.58	8.05
TSS Reduction (%)	0	0	35	53	62	63	53	60
Yearly Total Nitrogen								
TN Yearly Load (kg)	0	1.325	0.906	0.703	0.622	0.628	0.703	0.650
TN Reduction (%)	0	0	32	46	52	51	46	50
Yearly Total Phosphorus								
TP Yearly Load (kg)	0	0.196	0.135	0.095	0.089	0.096	0.095	0.099
TP Reduction (%)	0	0	31	51	53	50	51	48
Green Space (sqft)	0	3644	3644	3644	3644	3644	3644	3644
Percentage of the total (%)	0	87	87	87	87	87	87	87

Table F.16. Life Cycle Cost Estimation – Inputs and Results

RESULTS	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Interest rate (%)	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Net Present Value (NPV)	$ 12,008	$43,290	$63,479	$58,426	$55,179	$63,479	$ 54,967

ITEM	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Artifact 1/Bathroom Faucet	2	1					
Product	US Standard	American Standard Colony Pro					
GPM	2.2	1.2					
Quanity	1	1					
Retail cost	86.54	91					
Installation Cost	200	200					
O&M Costs	100	100					
O&M Period	10	10					
Life span (years)	20	20					
Artifact 2/Kitchen Faucet	2	1					
Product	Moen Adler	American Standard Colony Soft					
GPM	2.2	1.5	1.5	1.5	1.5	1.5	1.5
Quanity	1	1	1	1	1	1	1
Retail cost	168	135					
Installation Cost	250	250					
O&M Costs	100	100					
O&M Period	10	10					
Life span	20	20					
Artifact 3 - Showerhead	6	2					
Product	Couradric	Caroma Efficiency					
GPM	2.5	1.5					
Quanity	1	1					
Retail cost	45	35					
Installation Cost	200	200					
O&M Costs	100	100					
O&M Period	10	10					
Life span (years)	20	20					
Artifact 4 - Toilet	4	3	3	1	1	3	1
Product	A.S. Cadet	TOTO	TOTO	Clivus Multrum		TOTO	livus Multrum
Gallons	1.6	1.28	1.28	0	0	1.28	0
Quanity	1	1	1	1	1	1	1
Cost	203	201	201	4500	4500	201	4500
Installation Cost	200	200	200	200	200	200	200
O&M Costs 1	150	150	150	10.37	10.37	150	10.37
O&M Period 1	10 years	10 years	10 years	monthly	monthly	10 years	monthly
O&M Costs 2	0	0	0	200	200	0	200
O&M Period 2	0	0	0	Fan and pump	Fan and pump	0	Fan and pump
Life span (years)	25	25	25	20	20	25	20
Groundwater System	GRWS 5	GRWS 5	GRWS 5	GRWS 5	GRWS 5	GRWS 5	GRWS 5
System/product	No system						

Table F.16. Life Cycle Cost Estimation – Inputs and Results (continued)

ITEM	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
Greywater System	GWS 0	GWS 0			GWS 2		
System/product	No system	No system			Greywater System 75 GPD		
System size	0	0			75		
Initial Cost	0	0			2347		
Annual Chemical and	0	0			29		
Annual Maintenance	0	0			278		
Life span (years)	0	0			10		
Blackwater System	BWS 0	BWS 0	BWS 2	BWS 1	BWS 1	BWS 2	BWS 1
System/product	No system		Conventional Gravity Systems (Septic Tank and Drainfield)				
System size	0	0	4 bedroon	3 bedroon	3 bedroon	4 bedroon	3 bedroom
Initial Cost	0	0	4500	3500	3500	4500	3500
Annual Maintenance Cost	0	0			300		
Life span (years)	0	0			40		
Rainwater Harvesting	No system			Cistern			
Drainage area (m2)	0	232	232	260	260	232	260
cost per draiange area($/m2)	9.4	9	9	9	9	9	9
Total Cost	0	2192	2192	2456	2456	2192	2456
O&M cost (%)	1	1	1	1	1	1	1
Total O&M Cost	0	22	22	25	25	22	25
Life span (years)	20	20	20	20	20	20	20
LID 1 / Permeable Patio			No system				
Drainage area (m2)	0	0	0	0	0	0	0
cost per draiange area($/m2)	134	134	134	134	134	134	134
Total Cost	0	0	0	0	0	0	0
O&M cost (%)	1	1	1	1	1	1	1
Total O&M Cost	0	0	0	0	0	0	0
Life span (years)	20	20	20	20	20	20	20
LID 2 / Grass Swale	No system			Grass Swale			
Drainage area (m2)	0	552	1103	1655	1765	1103	1655
cost per draiange area($/m2)	0.99	1	1	1	1	1	1
Total Cost	0	546	1092	1638	1747	1092	1638
O&M cost (%)	6	6	6	6	6	6	6
Total O&M Cost	0	33	66	98	105	66	98
Life span (years)	20	20	20	20	20	20	20
LID 3 / Bioretention System	No system			Bioretention system			
Drainage area (m2)	0	627	627	627	627	627	627
cost per draiange area($/m2)	17	17	17	17	17	17	17
Total Cost	0	10422	10422	10422	10422	10422	10422
O&M cost (%)	6	6	6	6	6	6	6
Total O&M Cost	0	625	625	625	625	625	625
Life span (years)	20	20	20	20	20	20	20
LID 4 / Porous pavement	No system	No system	Porous pa	Porous pa	No system	Porous pa	No system
Drainage area (m2)	0	0	106	46	0	106	0
cost per draiange area($/m2)	65	65	65	65	65	65	65
Total Cost	0	0	6891	2992	0	6891	0
O&M cost (%)	1	1	1	1	1	1	1
Total O&M Cost	0	0	69	30	0	69	0
Life span (years)	20	20	20	20	20	20	20

Table F.16. Life Cycle Cost Estimation – Inputs and Results (continued)

ITEM	Base Case	Model A	Model B	Model C	Model D	Model 1	Model 2
LID 5 / Green roof + Cistern				No system			
Drainage area (m2)	0	0	0	0	0	0	0
Cost per draiange area($/m2)	194	194	194	194	194	194	194
Total Cost	0	0	0	0	0	0	0
O&M cost (%)	6	6	6	6	6	6	6
Total O&M Cost	0	0	0	0	0	0	0
Life span (years)	20	20	20	20	20	20	20
LID 6 / Green Roof				No system			
Drainage area (m2)	0	0	0	0	0	0	0
Cost per draiange area ($/m2	185	185	185	185	185	185	185
Total Cost	0	0	0	0	0	0	0
O&M cost (%)	6	6	6	6	6	6	6
Total O&M Cost	0	0	0	0	0	0	0
Life span (years)	20	20	20	20	20	20	20
LID 7 / Biofilter - grass strip				No system			
Drainage area (m2)	0	0	0	0	0	0	0
Cost per draiange area ($/m2	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Total Cost	0	0	0	0	0	0	0
O&M cost (%)	3	3	3	3	3	3	3
Total O&M Cost	0	0	0	0	0	0	0
Life span (years)	20	20	20	20	20	20	20
LID 8 / Wetland channel				No system			
Drainage area (m2)	0	0	0	0	0	0	0
Cost per draiange area ($/m2	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Total Cost	0	0	0	0	0	0	0
O&M cost (%)	6	6	6	6	6	6	6
Total O&M Cost	0	0	0	0	0	0	0
Life span (years)	20	20	20	20	20	20	20
Drinking Water Connection	PWSA	PWSA	PWSA	No	No	PWSA	No
Consumption	7000	1000	1000	0	0	1000	0
Initial Costs	2887	2887	2887	0	0	2887	0
Operation Costs	104	27	27	0	0	27	0
Sewer Connection	ALCOSAN	ALCOSAN			No		
Consumption	6000	4000					
Initial Costs	2978	2978			0		
Operation Costs	45.43	30.57			0		
Disinfection System	DS 4	DS 2	DS 2	DS 2	DS 2	DS 2	DS 2
Consumption	0			15			
Initial Costs	0			1296			
Operation Costs	0			494			

F.4. Evaluation Tables and Graphs

Models	Total Costs		SWM Average of percentages
	$		%
Base Case	$	12,008	14.5
Model A	$	43,290	54.4
Model B	$	63,479	70.3

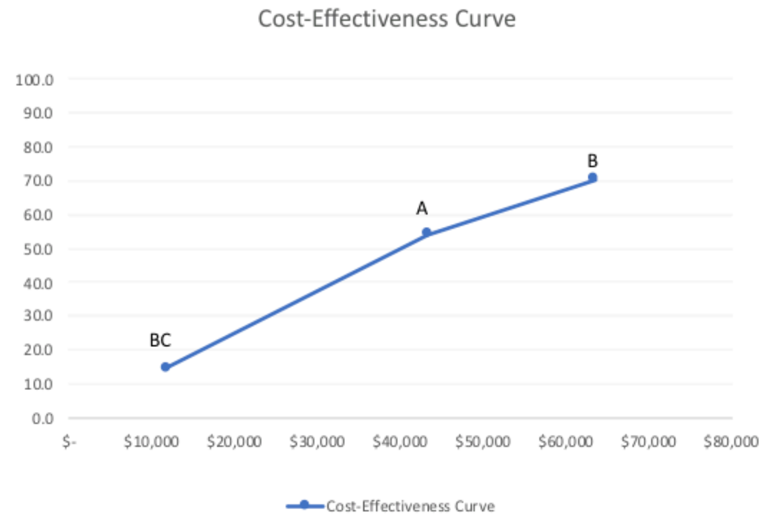

Figure F.4. CE curve for Base Case and Models A and B

Table F.17. Water Performance Percentages and Costs for the Base Case and Models A to D

Models	Water Managed	Reduction Public Supply	Reduction of TSS	Reduction of TN	Reduction of TP	Green Spaces	Cost	Total Costs	
	%	%	%	%	%	%	%	$	
Base Case	0	0	0	0	0	87	99	$	12,008
Model A	55	87	35	32	31	87	82	$	43,290
Model B	87	98	53	46	51	87	72	$	63,479
Model C	91	100	62.2	51.7	53.1	87	75	$	58,426
Model D	90	100	62.7	51.2	49.7	87	76	$	55,179

Table F.18. Water Managed Results for the Base Case and Models 1 to 4

Models	Public Supply	Reduction of Public Supply	Sewer Discharge	Reduction of Sewer	Runoff Volume	Managed Runoff	Water Managed
	gallons	%	gallons	%	m3	%	%
Pre-development	-	-	-	-	188	-	-
Base Case	77098	0	68175	0	676	0	0
Model A	9960	87	45278	34	466	43	55
Model B	1713	98	0	100	364	64	87
Model C	0	100	0	100	326	72	91
Model D	0	100	0	100	330	71	90

Models	Total Costs	SWM Average of percentages
	$	%
Base Case	$ 12,008	14.5
Model A	$ 43,290	54.4
Model B	$ 63,479	70.3
Model C	$ 58,426	74.1
Model D	$ 55,179	73.5

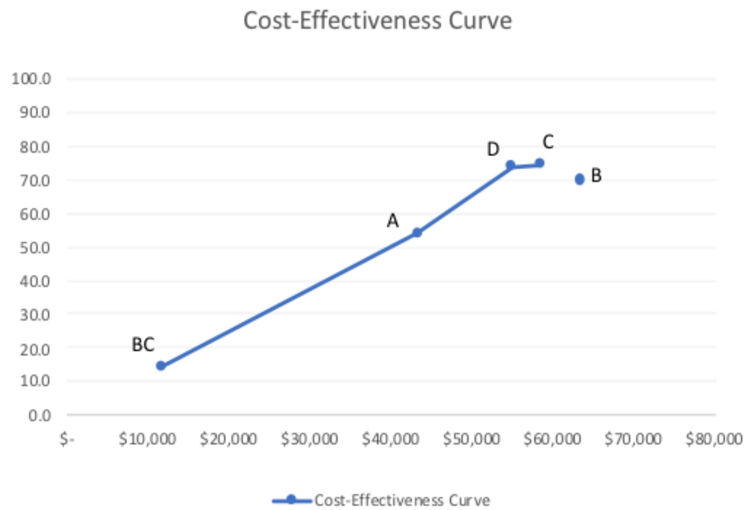

Figure F.6. CE curve for Base Case and Models A to D

Table F.19. Water Performance Results and the costs of Model 1, Model 2 and the Base Case

Models	Water Managed	Reduction Public Water Supply	Reduction of TSS	Reduction of TN	Reduction of TP	Green Spaces	Cost	Total Costs
	%	%	%	%	%	%	%	$
Base Case	0	0	0	0	0	87	99	$ 12,008
Model 1	87	98	53	46	51	87	72	$ 63,479
Model 2	90	100	60	50	48	87	76	$ 54,967

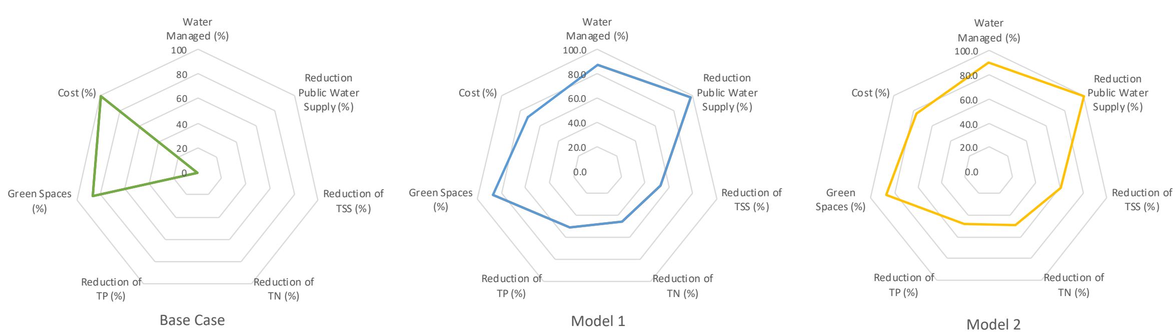

Figure F.2. Spider Graphs for Model 1, Model 2 and Base Case

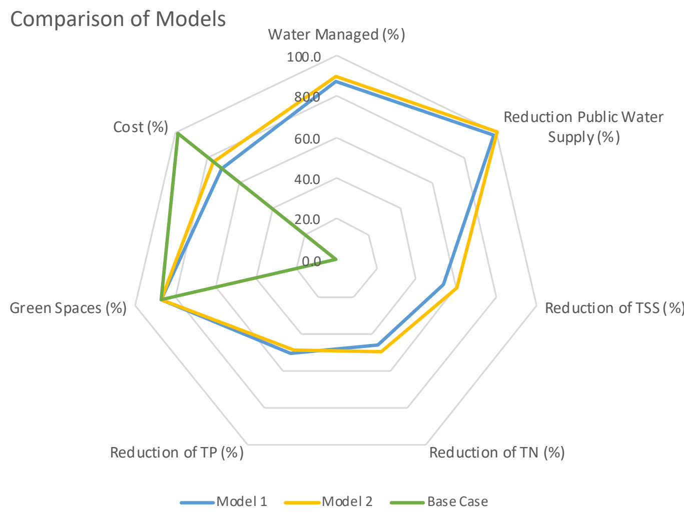

Figure F.3. Comparison of Models in Spider Graphs in the Prototype

APPENDIX G: Link to the Prototype

The prototype is found in the following link: https://bit.ly/3anFO5c

The prototype is a Microsoft Excel Workbook with 33 spreadsheets. The initial assessment section is developed in the first eleven spreadsheets. The model assessment section is set in the following twelve spreadsheets. The final ten spreadsheets have the database for the runoff volume and quality estimations, the rainfall data, the climatic data sources, and BMPs/LIDs site suitability criteria.