SUBSURFACE WASTEWATER TREATMENT WETLANDS:

UNDERSTANDING THE BARRIERS TO IMPLEMENTATION

IN THE LANDSCAPE

by

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Abstract

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The purpose of this research is to address the barriers to implementation of, the role of landscape architects in, and the potential for acceptance of constructed subsurface flow wastewater treatment wetlands. Landscape architects, engineers, and scientists are key players in the implementation of subsurface flow wastewater treatment wetlands in the landscape. Through qualitative inquiry, this research uncovers the opinions of landscape architects, engineers, and scientists regarding the potential barriers to building subsurface flow wastewater treatment wetlands and ways to overcome these barriers.

Subsurface flow wastewater treatment wetlands are a decentralized form of wastewater treatment, treating wastewater onsite using little to no power (USEPA, 2000b). While centralized wastewater treatment pumps wastewater to a distant plant where it is treated (USEPA, 2004), decentralized systems treat wastewater onsite (CGBC, 2011a). Decentralized systems reduce pressure on overloaded wastewater treatment plants and create green infrastructure (Libralato et. al, 2011). Both methods return wastewater to a freshwater source.

This research utilized interviews with landscape architects, engineers, and scientists about their experience with the implementation of subsurface flow wastewater treatment wetlands. The interviews uncovered the opinions on the limitations of using this technique as a part of onsite wastewater treatment. Emphasis was placed on the domain of landscape architecture and interactions with the public when subsurface flow wastewater treatment wetlands are included in designs. Interviews uncovered information regarding the need for landscape architects, engineers, and scientists to work together as a team throughout the design phase and during construction.

Also, the effects of education on professionals, the public, and government in relationship to acceptance of SSF are summarized. Proposals for the reuse of wastewater for irrigation, cooling, and water features are discussed as well. Findings indicate that although many barriers to implementation exist, the most prevalent is the lack of education among the public, professionals, and government regulators regarding the availability and performance of subsurface flow wastewater treatment wetlands.

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# Chapter 1

# Introduction

## 1.1 Background

The purpose of this research is to address the barriers to implementation, role of landscape architects in, and potential for acceptance of constructed subsurface flow wastewater treatment wetlands (SSF). The successful design and implementation of constructed wetlands requires the skills of landscape architects, engineers, and environmental scientists (Wildman, 2005). Through qualitative analysis, this research uncovers these key players' opinions about the potential barriers to building SSF and ways to overcome them.

The growth of urban areas, commercial spaces, and residential areas has led to the consideration of alternative strategies to traditional wastewater treatment (Ho and Anda, 2004). One alternative to the standard centralized wastewater treatment is subsurface flow wastewater treatment wetlands. SSF are man-made systems designed to mimic specific characteristics of wetland ecosystems such as nutrient uptake (Kadlec and Wallace, 2009).

Constructed landscapes are designed, engineered, and managed environments that can be adapted for the implementation of SSF. Professionals who determine if and how SSF are considered and or built include landscape architects, engineers, and other key players (Wildman, 2005).

The benefits of SSF were initially recognized by Käthe Seidel at the Max Planck Institute of Germany in 1952 (Vymazal, 2010). After wide-spread implementation of SSF in Europe, the practice appeared in the United States in the 1970s (Vymazal, 2010). Construction of wastewater treatment wetlands became more prevalent in the United States after the creation of the Clean Water Act of 1972, which mandated an increase in the amount of clean water available to residents of the United States (USEPA, 2004). Research grants for the study of water treatment subsequently increased resulting in more research on the effectiveness of alternative wastewater treatment strategies (Burian et. al, 2000).

This research examines SSFs and discusses the potential barriers to their use in landscapes across the United States. The study identifies political, monetary and public acceptance barriers as hindrances to the implementation of SSF.

## 1.2 Research Objectives

The main purpose of this study is to uncover the barriers to the implementation of SSF in the United States. By understanding the steps involved in the proposal and design of SSF, landscape architects, engineers, and environmental scientists can learn how to identify and overcome barriers to their implementation in the landscape. A secondary purpose of the study is to examine the role of landscape architects in the design and creation of SSF. These professionals benefit from this research as it identifies science and engineering techniques that landscape architects can to add to their professional service offerings.

## 1.3 Research Questions

1. What do key decision-makers believe the barriers are to the implementation of SSF?
2. How do they describe the benefits of SSF in the United States?
3. What is the role of landscape architects in the implementation of SSF?

## 1.4 Research Methods

This research uses qualitative methods based on Grounded Theory (Taylor and Bogdan, 1998) to gather data from in-depth face-to-face and telephone interviews with landscape architects, engineers, and environmental scientists, about the barriers to the acceptance of SSF. The interviewer first determined the respondent's knowledge of and professional experience with SSF. The interview then progressed in one of two paths with semi-structured, open-ended sets of questions unique to each path. The first path is provided for subjects that have a preexisting knowledge of SSF, and the second path is designed for subjects that are unfamiliar with it. The data were analyzed using theme analysis to find information on subject areas related to SSF (Taylor and Bogdan, 1998). Finally, the similarities and differences between the responses were compared.

Reviews of the literature related to SSF were conducted in order to determine what gaps in knowledge exist among key players. The literature included biological journals, engineering books, and design guidelines for landscape architects. Three precedent examples of existing SSF are presented: The Sidwell Friends Middle School, Saginaw Metal Castings, and The Advanced Green Demonstration Building at The Center for Maximum Potential Building Systems. These resources combine to form a picture of the intricacies and implications of SSF in the landscape and its potential as a viable wastewater treatment strategy.

## 1.5 Definitions of Terms

Aerobic – A life or process that occurs in the presence of oxygen (USEPA, 2004).

Anaerobic – A life or process that occurs in the absence of free oxygen (USEPA, 2004).

Biosolids – Treated sewage sludge solids that have been stabilized to destroy pathogens and meet rigorous standards allowing for safe reuse of this material as a soil amendment (USEPA, 2004).

Blackwater – Water containing human waste from toilets and urinals. Black water contains pathogens that must be neutralized before the water can be safely reused (Cascadia Green Building Council (CGBC, 2011a).

Biochemical Oxygen Demand – The amount of oxygen used by microorganisms to stabilize a given volume of wastewater with decomposable organic matter under aerobic conditions (CGBC 2011a).

Constructed Wetlands (for wastewater treatment) – A system used to treat wastewater that mimics the biological processes of a natural wetland (CGBC, 2011a).

Decentralized wastewater management – A system that provides collection, treatment and dispersal or reuse of wastewater from individual buildings or clusters of buildings at or near the location where the waste is generated. These types of systems may treat sewage on-site through natural and/or mechanical processes, or may utilize more distributed management systems to collect and treat waste at a neighborhood, district or small community scale (CGBC, 2011b).

Effluent – Water or some other liquid, raw, partially or completely treated, flowing from a reservoir, basin, treatment process or treatment plant (USEPA, 1994).

Eutrophication – The enrichment of bodies of fresh water by inorganic plant nutrients such as nitrates and phosphates. It may occur naturally but can also be the result of human activity, cultural eutrophication comes from fertilizer runoff and sewage discharge (Lawrence and Jackson, 1998).

Grey Water – Wastewater other than sewage, such as sink drainage or washing machine discharge (USEPA, 1994).

Influent – Water, wastewater, or other liquid flowing into a reservoir, basin, treatment plant, or any unit thereof (USEPA, 2004).

Leadership in Energy and Environmental Design (LEED) – A program that provides third-party verification that a building, home or community was designed and built using strategies aimed at achieving high performance in key areas of human and environmental health: Sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality (USGBC, 2013).

Municipal Sewage – Wastes (mostly liquid) originating from a community; may be composed of domestic wastewaters and/or industrial wastewaters (USEPA, 1994).

Nitrate – Compound that supplies nutrients to plants supporting plant body growth (Kadlec and Wallace, 2009).

Pathogens – Disease-causing microorganisms, including pathogenic bacteria, viruses, and protozoans (USEPA, 2004).

Phosphorus – A nutrient that is essential to life, but in excess, contributes to the eutrophication of lakes and other water bodies (USEPA, 2004).

Suspended Solids – The small particles suspended in water or wastewater (USEPA, 2004).

Wastewater – Any water used for residential, commercial, or industrial purposes that can contain various pollutants from those users (Tomar, 1999).

Wetland – Any number of tidal and nontidal areas characterized by saturated or nearly saturated soils most of the year that form an interface between terrestrial (land-based) and aquatic environments; including freshwater marshes around ponds and channels (rivers and streams), brackish and salt marshes; other common names include swamps and bogs (USEPA, 1994).

## 1.6 Significance

Although subsurface flow wastewater treatment wetlands (SSF) are viewed by some as a new alternative strategy for the treatment of wastewater, they have been in use for over fifty years (Vyzamal, 2010). SSF are traditionally designed by engineers without the use of landscape architects (Steinfeld and Del Porto, 2004). The population of landscape architects designing SSF is limited to a small number of specialists. By discovering the barriers related to the implementation of SSF landscape architects can be better prepared to propose and use this technique (Steinfeld and Del Porto, 2004). Also, landscape architects have the ability to design landscapes that are both aesthetically pleasing and work to treat wastewater.

SSF are a decentralized wastewater treatment technique. In April 1997, the United States Environmental Protection Agency (EPA) reported to Congress the benefits of decentralized wastewater treatment systems, including a reduction in water and power usage and pollution (USEPA, 1997). Within ten years after that report, decentralized wastewater treatment systems in the United States rose by only 0.3 percent (US Census Bureau, 2009). Existing wastewater treatment techniques must give rise to a new set of solutions for water conservation. These may include subsurface flow wastewater treatment wetlands, which can benefit the residents of the United States.

## 1.7 Limitations and Delimitations

This research focuses on SSF only, omitting other types of onsite wastewater treatment wetlands. Research into other types of onsite wastewater treatment wetlands, including their effectiveness when used alone or in combination with SSF, would be a beneficial line of additional research. The population of interview respondents was limited by time constraints.

## 1.8 Chapter Outline

The literature review in Chapter 2 outlines the history, components, benefits, and limitations of SSF to determine the current knowledge base on the subject. Chapter 3 presents a layout of data collection methods and analysis techniques used. Analysis of the interviews and findings associated with them are presented in Chapter 4, focusing on determining the knowledge gap barrier that exists among key players in the implementation of SSF. In Chapter 5, conclusions summarize the findings, show the significance of the research to the profession of landscape architecture, and recommend areas for future research into SSF that will promote greater understanding of the subject.

# Chapter 2

## Literature Review

This chapter starts with a brief overview of the history of wastewater treatment and the first scientific studies regarding the effectiveness of treating wastewater with subsurface flow wastewater treatment wetlands (SSF). A brief comparison is provided of centralized versus decentralized wastewater treatment, with emphasis given to research on the effectiveness of SSF. The components necessary for the design and construction of SSF are explained. Agencies regulating wastewater in the United States and their jurisdiction are reviewed. Finally, three existing SSF sites are presented to show how this process has been implemented in a variety of settings across the United States.

### 2.1 History of Wastewater Treatment

Modern wastewater treatment started in 1860 with the invention of the septic tank by Louis Moureas (Kahn**,** 2000). Prior to this, wastewater was sent into streets or drains that transported the waste directly into rivers or other water bodies. In 1854, Dr. John Snow proved that cholera outbreaks in London were caused by sewage water mixing with drinking water sources; his research led to the first water treatment laws in 1855 (Rosenberg, 1962). By 1895, wastewater in 20 major United States cities was treated offsite using physical and chemical filtration to reduce pathogens (Evolution of Sewage Treatment, 2013).

Wastewater treatment originally focused on minimizing the spread of waterborne, infectious diseases. As technology advanced, wastewater treatment’s role has expanded to include the prevention of chronic health risks and environmental concerns (Burks & Minnis, 1994). Present-day treatments include the removal of heavy metals, pharmaceuticals, and the control of nitrogen and phosphorus levels (USEPA, 2004a). The development of new mechanical and biological technologies is required as the scope of wastewater treatment continues to broaden (USEPA, 2004a).

## 2.2 Types of Wastewater Treatment

There are two major classifications of wastewater treatment, centralized and decentralized. Centralized treatment sends wastewater to be treated offsite. Decentralized treatment keeps the water onsite for treatment. The SSF studied in this research are decentralized systems.

### *2.2.1 Centralized*

Centralized design is the most common form of wastewater treatment in the United States. In 2004, over 16,000 publicly-owned wastewater treatment plants (WTPs) were in operation in the United States, receiving a total of more than 33 billion gallons of influent flow per day (USEPA, 2008b). These publicly-owned wastewater plants serve approximately 222 million Americans or 80 percent of the United States population (Figure 2-1). According to the 2009 American Housing Survey, 103 million homes used a centralized system (US Census Bureau, 2009). In this process, wastewater from commercial, industrial, and residential locations is pumped to a central WTP that treats the water mechanically, electrically, and biologically, and then returns it to a freshwater source (USEPA, 2004a). These treatment processes are carefully engineered to remove contaminants from wastewater.

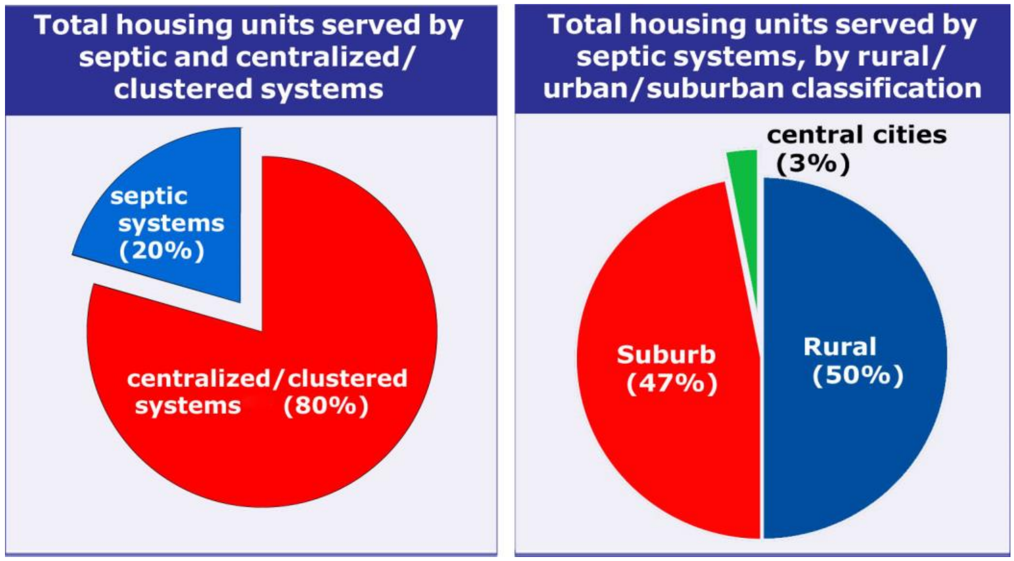


Figure 2-1 Comparison of Housing Units Served by Centralized or Decentralized Wastewater Treatment (EPA, 2008a)

WTPs are often miles away from the wastewater's point of origin due to a variety of concerns including bad odors and health risks from biologically and chemically contaminated water (USEPA, 1997). Centralized design systems are more removed from the user as the WTPs tend to be out of sight where the water treatment cannot be seen (USEPA, 1998). The ability to have the WTP far away from the point of origin is useful in densely populated areas, since it reduces the probability of human contact with wastewater (USEPA, 2004a).

Some of the biggest problems facing centralized wastewater treatment are: aging systems, shortage of capacity, higher quantities of contaminants in wastewater prior to treatment, and increasing pollution coming from farms and urbanization (USEPA, 2004a). The problems identified result in higher rates of electricity usage, leakage from broken pipes, and increased maintenance of wastewater treatment plants (USEPA, 2008b).

### *2.2.2 Decentralized*

Decentralized systems treat wastewater onsite for one or a cluster of buildings using biologic processes such as septic tanks or wastewater treatment wetlands. The wastewater is then returned to a freshwater source above or below the ground (USEPA, 2004). According to the 2009 American Housing Survey, approximately 26 million U.S. households used decentralized systems (US Census Bureau, 2009). These systems are widely used in rural areas as the amount of pipe required to reach a centralized plant is cost prohibitive (USEPA, 1997). Also, the high cost of building and operating a centralized plant is unreasonable for small towns that may not have the money or skilled technicians required for operation (Wolverton and Wolverton, 2001).

## 2.2 History of Wastewater Treatment Wetlands

Evidence of naturally occurring wetlands being used for wastewater treatment comes from as long ago as the 1360s in England (Evolution of Sewage Treatment, 2013). However, the use of constructed wetlands for wastewater treatment did not begin until the 1950s. The first documented scientific study on the effectiveness of this type of wastewater treatment was conducted by Käthe Seidel at the Max Planck institute in Plon, Germany in 1953. The study confirmed that bulrush (*Typha latifolia*) is able to remove phenols, pathogenic bacteria, and other pollutants in the wastewater treatment process (Bastian and Hammer, 1993).

After the passage of the Clean Water Act in 1972, construction of wastewater treatment wetlands (WWTW) became more prevalent in the United States, and grants available for water research increased dramatically (Campbell and Ogden, 1999). As the popularity of WWTW grew, conferences were held and details of their operation were widely dispersed (Kadlec and Wallace, 2009). Although the use of SSF as part of WWTW has grown in popularity among wastewater treatment professionals, the practice is not widely known to the public.

## 2.3 Types of Wastewater Treatment Wetlands

Treatment wetlands use gravity to passively move water through vegetated cells that remove nitrogen, phosphorus, harmful bacteria, and heavy metals from the water before it drains into a fresh water source (Libralato et. al., 2011). Treatment wetlands are divided into two types: subsurface flow (SSF), and free water surface flow (FWS). A description of wastewater treatment wetland systems and an explanation of how each type operates are explained in the following sections.

### *2.3.1 Subsurface Flow (SSF)*

The most common definition of a SSF wetland is “a wetland consisting of a sealed basin with a porous substrate, or media, of rock or gravel. The water level is designed to remain below the top of the substrate” (Kadlec and Wallace, 2009 p.5). The SSF may function through horizontal or vertical flow SSF.

#### 2.3.1.1 Horizontal Subsurface Flow

As influent enters the horizontal SSF wetland at the inlet, it is dispersed evenly across a large media section (Figure 2-2). The water, maintained below the surface of the bed, flows horizontally down a minimum one-percent slope to the outlet which is lower than the inlet. Between the inlet and outlet, water passes through media and a network of plant roots that remove waste (Kadlec and Wallace, 2009).

#### 2.3.1.2 Vertical Subsurface Flow

Vertical SSF wetlands (Figure 2-3) distribute water across the surface of a sand or gravel bed planted with wetland vegetation. The water is treated by bacteria and plants as it percolates through the plant root zone (Kadlec and Wallace, 2009). Vertical SSF are a less common type of wastewater treatment wetland since current designs are not as efficient as horizontal SSF or free water surface systems (Kadlec and Wallace, 2009). For the purpose of this research, subsurface flow wetlands refer to horizontal SSF only.

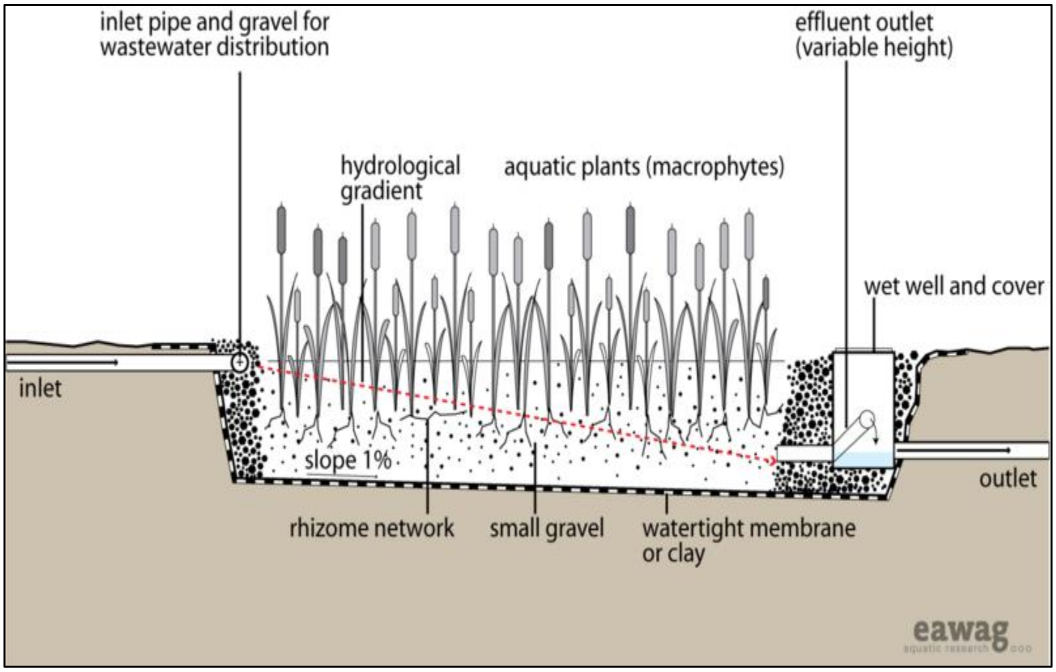


Figure 2-2 Horizontal Subsurface Flow Wetland Profile (Sandec/Eawag, 2009)

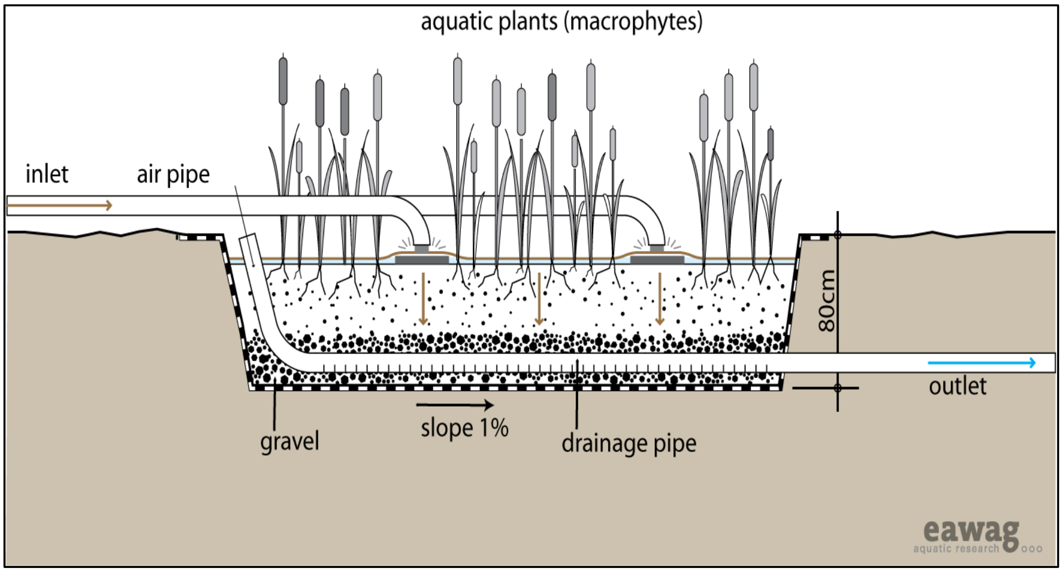


Figure 2-3 Vertical Flow Wetland Profile (Sandec/Eawag, 2009)

*2.3.2 Free Water Surface*

Free water surface (FWS) (Figure 2-4) wetlands resemble natural marshes with areas of open water (Kadlec and Wallace, 2009). FWS wetlands provide wildlife habitat and aesthetic value while treating wastewater (Ocean Arks International, 2013). Many FWS wetlands, such as the Arcata marsh in Humboldt County California, also function as nature preserves. Creating recreational landscapes encourages community involvement and, in turn, creates a more positive public attitude towards FWS wetlands (Benjamin, 1993). FWS are less efficient by square foot than SSF since smaller amounts of attached bacteria, which assist in wastewater treatment, are available to process wastewater (Hammer, 1989). The low efficiency ratio indicates that FWS wetlands need more square footage than SSF to treat the same amount of wastewater.

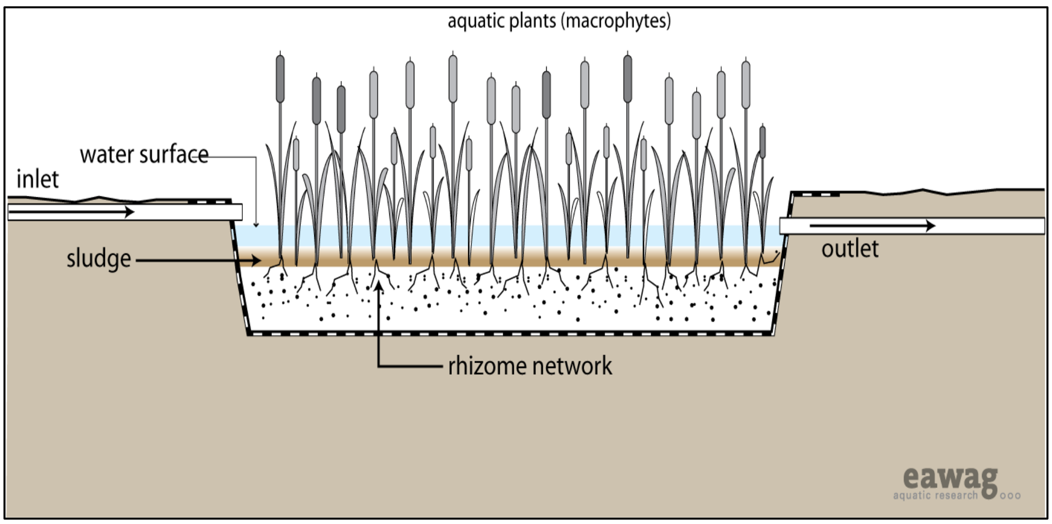


Figure 2-4 Free Water Surface Wetland (Sandec/Eawag, 2009)

*2.3.3 Wetlands Summary*

Both wetland systems use biotic means to treat water and can be configured in various forms depending on the level of treatment desired, amount of water to be treated, available land, etc. The two types may be used together as a hybrid system for more efficient pollutant removal (Kadlec and Wallace, 2009).

Each type of treatment has advantages and disadvantages related to the treatment process. Both open-air systems (FWS and vertical SSF) have increased aerobic filtration compared to horizontal SSF. Although horizontal SSF have lower aerobic filtration, odor and disease vectors are more controlled, since wastewater does not contact the open air during the treatment process. Both SSF systems require less land compared to FWS in order to treat the same amount of wastewater because of the greater surface area within the media (USEPA, 2000b). SSF and FWS can be combined to maximize wastewater treatment (USEPA, 2000a).

## 2.4 Material Components of SSF

SSF are built using a liner, media, plants, and pumps as needed. The liner, media, and pumps determine the speed of water through the SSF. The media and plants remove contaminants from the water through biological and physical filtration.

### *2.4.2 Liner components*

The bottom layer of a SSF wetland consists of an impermeable liner used to prevent, "seepage to sensitive ground waters" (USEPA, 2000b). Liners can be clay soil, ethylene propylene dien monomer (EPDM), or concrete. Native or imported soil can be used in areas with low natural infiltration rates. Soil liners can be problematic if accurate tests have not been performed to ensure low infiltration rates (Kadlec and Wallace, 2009). In some areas, a second treatment cell is created without a liner for the purpose of allowing water to infiltrate into the water table.

Synthetic liners are used in areas where the underlying soil has high infiltration rates; however, they cost more than soil liners. It is difficult to locate leaks in synthetic liners that have been torn or pierced.

### *2.4.3 Media components*

The substrate consists of media, usually at a depth of two to three feet, which water passes through from the inlet to the outlet. There are many types of media used for substrate including sand, gravel, and rock. The size and types of typical substrate media are listed below along with generalized pros and cons of each type (Figure 2-5). Particle diameter determines the pore size, also known as the porosity, of the substrate. In turn, the porosity determines the microorganism population, the size of particles being filtered, and the maximum effective speed or hydraulic conductivity of water through the constructed wetland media (TAMU, n.d.). All vegetation for the SSF is planted in the media.

*2.4.2 Plants*

Plants play a significant role in the build-up of microbial populations in SSF wetlands. Microbial populations are the most important factor in the reduction of contaminants during the treatment process (Moshiri, 1993). Aerobic and anaerobic conditions must exist within the substrate in order to remove the maximum amount of contaminants (CGBC, 2011b). Underwater conditions in the substrate create anaerobic conditions while "the roots of the emergent wetland vegetation supply oxygen to bacteria within the sand or gravel media matrix; hence, aerobic wastewater treatment processes occur even though the media are continuously saturated" (Moshiri, 1993). As plants release oxygen, an underground oxygen-rich zone develops surrounding the root systems where aerobic filtration occurs (TAMU, n.d.). Since aerobic conditions only exist in the root zone area, it is necessary to use plants with deep roots and a high degree of rhizome spread (Vymazal, 2010). Plant roots must grow deep in order to reach the wastewater maintained below the surface.

The three plants most widely used in WWTW are the common bulrush (*Typha latifolia*), common reed (*Phragmites australis),* and reed canary grass (*Phragmites arundinacea*), all of which are invasive species in the United States (Kadlec and Wallace, 2009). Although these plants work well in FWS, results from a 2010 study indicate that sedges (*Cyeracea*) and rush (*Juncaceae*) performed well at reducing biological oxygen demand, an indicator used to determine water quality (Taylor et al., 2011). This result supports the potential use of a wider range of plant

| Particle size | Pros | Cons |
|---|---|---|
| **Sand** | Readily available | Difficult to obtain clean sand<br>Easily clogged as microbes grow<br>Pore size too small |
| **Gravel (⅜ inch)** | Readily available | Pore size too small<br>Easily clogged as microbes grow |
| **Gravel (⅝ to ¾ inch)** | Ideal size<br>Good porosity | Not readily available<br>Costs more because of limited availability<br>Good barrier to odors |
| **Concrete gravel (½ to 2 inches)** | Ideal bulk porosity (32 percent)<br>Readily available | Nongraded (most small particles removed)<br>Fewer large openings because of variability in media sizes |
| **Gravel (more than 2 inches)** | Good permeability<br>Lower plugging potential | Less surface area for microorganisms<br>Large openings may allow vectors such as mosquitoes to enter and odors to exit |
| **Chipped tires** | Relatively inexpensive | Appearance, low aesthetic value<br>Lightweight<br>Steel rusts and discolors effluent |

Figure 2-5 Comparison of Media Used in SSF (TAMU, n.d.)

species, for both aesthetic and ecological purposes, than are typically recommended (Wallace and Knight, 2006). Continued research into the efficiency of alternate species as well as plant community interaction is necessary to improve the design and operation of SSF in the future (Taylor et al., 2010). SSF have the flexibility to combine plants that treat wastewater with ornamental plants (Campbell and Ogden, 1999).

## 2.5 Functional Components of SFF

Physical and biologic filtration are necessary components of wastewater treatment. Physical filtration removes the total suspended solids using screens and media. Biologic filtration occurs through bacteria attached to the plant roots and media (Massoud et. al., 2009).

### *2.5.1 Physical Filtration*

Physical filtration is necessary to remove total suspended solids (TSS), the small particles suspended in water, and other contaminants from wastewater before it enters the SSF (CGBC, 2011a). This is a two-stage treatment process that begins with a filter or screen to remove large solids. Then, the septic tank allows grease and oil to float to the top of the water while large solids settle at the bottom. A clarifier or septic tank removes 40-50 percent of the TSS before the wastewater enters the SSF (Pfafflin and Ziegler, 1992). As effluent passes through the media, remaining TSS are captured in the pore spaces and on plant roots forming a biofilm (USEPA, 2000). The captured particles then settle to the bottom of the substrate to break down under anaerobic conditions. Eventually the biofilm expands filling the pores and clogging the media, requiring the replacement of substrate or a rest period for the SSF. Even in well-designed systems, the media will eventually become completely clogged requiring replacement (Campbell and Ogden, 1999). However, proper primary treatment prevents clogging and extends the life of the SSF. Clogging can also be reduced by properly sizing the SSF proportionately to the hydraulic loads entering the system (USEPA, 1993).

*2.5.2 Biologic Filtration*

Removal of TSS, which are visible to the naked eye, is a small part of wastewater treatment. Effluent passing through the pores of the media feed microorganisms that forage on microscopic waste and remove it from the water (TAMU, n.d.). Contaminants attach to the media, or biofilm through the force of adsorption. Subsequently, the contaminants are assimilated into the microorganisms and plants (TAMU, n.d.). Biologic filtration below the surface and within the substrate is the process that defines the characteristic of a SSF wetland.

The biological processes used to treat the water are anaerobic, meaning there is little or no oxygen present while bacteria break down or absorb nutrients and pathogens in the water (Massoud et. al., 2009). Some aerobic activity is known to take place on microsites surrounding the plant roots in the rhizosphere, where oxygen is present, while the media is in anaerobic conditions (USFWS, 1993). The low level of aerobic activity in SSF reduces the amount of ammonia that can be removed, when compared to systems with more aerobic activity such as FWS (Kadlec and Wallace, 2009). Since wastewater contains high amounts of ammonia this is a limiting factor of SSF. Aerobic activity is increased by using trickling filters, dosing, or bubblers (USEPA, 2000a). These methods result in the use of more equipment, power, and monitoring of the SSF.

## 2.6 Water Treatment Plants

Centralized wastewater treatment typically employs a water treatment plant (WTP). Mechanical wastewater treatment begins with pumping water into sludge tanks that remove suspended solids and then through multiple filters and reactors until the water is deemed potable (CGBC, 2011). The filters collect sludge that needs to be cleaned out and disposed of regularly. Sludge disposal methods include removal to a landfill or conversion to fertilizer (USEPA, 1998). Most WTP rely on mechanical, chemical, and electrical processes to filter and purify wastewater. The greatest amount of the electricity used to treat wastewater at a WTP comes from the operation of pumps and grinders designed to move the water. UV clarifiers, chlorine, and other chemicals effectively treat water in the final disinfection stage (USEPA, 1998). This type of wastewater treatment has been used effectively since the early 20$^{th}$ century in the United States (Burian, 2000).

Alternatives to the traditional WTP that reduce or combine the stages of treatment in order to save energy and reduce the footprint of a facility are being implemented. Additionally, WTP have implemented WWTW at various stages of the treatment process. This strategy helps reduce the pressure on aging or overloaded facilities (USEPA, 2000a).

## 2.7 Levels of Wastewater Treatment

Wastewater treatment is divided into levels that define what types of contaminants have been removed. The levels are used to determine the type of treatment required to purify the water to the next level of cleanliness (EPA, 2004). Since SSF are more likely to be part of the secondary or tertiary portion of treatment, a primary clarifier, such as a septic tank, is used in conjunction with SSF systems (Massoud et. al., 2009).

1. Primary – Settling of biosolids to the bottom of the water and grease to the top.
2. Secondary – Removal of dissolved biosolids using bacteria; done with activated sludge, aerobic and anaerobic conditions
3. Tertiary – Removal of nitrogen and phosphorus using sand filters, coal membranes, etc (USEPA, 1998).

### *2.7.1 Pathogens*

Part of the primary and secondary treatment stages involves the removal of pathogens since they “are present in untreated domestic wastewaters” (Kadlec and Wallace, 2009). Figure 2-6 lists the most common pathogens in human wastewater, including harmful bacteria and viruses. Within wastewater treatment, pathogens are defined as, “disease causing microorganisms, including pathogenic bacteria, viruses, and protozoans” (USEPA 2004). Since all pathogens cannot be detected easily, indicator species of pathogens have been chosen to monitor the quality of treated wastewater. Although there are no perfect indicator organisms, coliforms are the most widely used indicator species (Kadlec and Wallace, 2009). The use of indicator species to determine water quality is “a guide to the removal of more seriously pathogenic organisms” (Rivera et. al., 1995). As the amount of fecal coliforms decrease, so do the risks of other pathogens living within the wastewater. Fecal coliforms are measured by regulatory agencies when discharging effluent for irrigation or greywater use.

## 2.8 Regulatory Agencies

As stated in 2.1, laws regulating the treatment of wastewater have existed since the mid nineteenth century. The Clean Water Act of 1972, created by the United States Environmental Protection Agency (USEPA), regulates the quality of wastewater treatment in the United States (Nelson, 2008). Jurisdictional bodies regulating wastewater treatment under this act, including wastewater treatment wetlands, are the USEPA at the federal level, and state, county, or city health departments at local levels (USEPA, 2002). These agencies oversee the regulations and permitting of SSF.

An interagency group of representatives from several federal agencies developed guidelines for the design of wastewater treatment wetlands (WWTW). Five guidelines state that WWTW shall:

1. Receive no credit as mitigation wetlands;
2. Be subject to the same rules as treatment lagoons regarding liner requirements;
3. Be subject to the same monitoring requirements as treatment lagoons;
4. Should not be constructed in the waters of the United States, including existing natural wetlands; and
5. Will not be considered Waters of the United States upon abandonment if the first and the fourth conditions are met (EPA, 2000a p. 17).

## Some Human Pathogens Typical of Domestic Wastewater

| | Pathogen | Illness |
|---|---|---|
| **Viruses** | Adenovirus (31 types) | Respiratory disease |
| | Enteroviruses (67 types) | Diarrhea, respiratory disease, polio |
| | Hepatitis A | Infectious hepatitis |
| | Norwalk agent | Gastroenteritis |
| | Rotavirus | Diarrhea |
| | Reovirus | Gastroenteritis |
| | HIV | AIDS |
| **Bacteria** | *Campylobacter jejuni* | Diarrhea |
| | *Escherichia coli* | Diarrhea |
| | *Legionella pneumophila* | Fever, respiratory tract infections |
| | *Leptospira* (150 spp.) | Leptospirosis |
| | *Salmonella typhi* | Typhoid fever |
| | *Salmonella* (~1,700 spp.) | Salmonellosis |
| | *Shigella* (4 spp.) | Diarrhea, dysentery |
| | *Vibrio* spp. | Cholera, diarrhea |
| | *Yersinia* spp. | Yersiniosis |
| **Fungi** | *Aspergillus fumigatus* | Aspergillosis |
| | *Candida albicans* | Fungal infections |
| **Protozoa** | *Balantidium coli* | Diarrhea, dysentery |
| | *Cryptosporidium parvum* | Diarrhea |
| | *Entamoeba histolytica* | Diarrhea, dysentery |
| | *Giardia lamblia* | Diarrhea |
| **Helminths** | *Ascaris lumbricoides* | Roundworm |
| | *Clonorchis sinensis* | Bile duct infection |
| | *Diphyllobothrium latum* | Fish tapeworm |
| | *Enterobius vericularis* | Pinworm |
| | *Fasciola hepatica* | Liver fluke |
| | *Fasciolopsis buski* | Intestinal fluke |
| | *Hymenolepis nana* | Dwarf tapeworm |
| | *Necator americanus* | Hookworm |
| | *Opisthorchis* spp. | Bile duct infection |
| | *Schistosoma* spp. | Schistosomiasis |
| | *Taenia* spp. | Tapeworm |
| | *Trichuris trichura* | Whipworm |

Figure 2-6 Typical Pathogens in Human Wastewater (Kadlec and Wallace, 2009)

### *2.8.1 National Pollution Discharge Elimination System*

The National Pollution Discharge Elimination System permit program, authorized by the Clean Water Act, controls point sources that discharge pollutants into waters of the United States through permitting (Nelson, 2008). Point sources are conveyance systems such as pipes or ditches. The purpose of this permit is to control what is being discharged into the waters of the United States which are defined by the Clean Water Act as, “navigable waters, tributaries to navigable waters, interstate waters, the oceans out to 200 miles, and intrastate waters which are used: by interstate travelers for recreation or other purposes, as a source of fish or shellfish sold in interstate commerce, or for industrial purposes by industries engaged in interstate commerce” (EPA, 1973). Although individual homes with a septic or SSF system do not need a permit, industrial, municipal, and other facilities need permits if their discharge goes into surface waters (Nelson, 2008).

### *2.8.2 Texas Commission on Environmental Quality*

State and county health departments control the approval of onsite WWT (USEPA, 1993). Since regulations vary from state to state, this research is limited to one example: the Texas Commission on Environmental Quality (TCEQ). The TCEQ has jurisdiction over environmental quality regulation on the state level, including wastewater treatment. The TCEQ relegates the approval of SSF permits to cities and counties (TCEQ, 2013). Additionally, discharge permits are required if water is returned to an existing water source or if water is reused, as in irrigation (TCEQ, 2013). Discharge permits also require water quality reviews by a TCEQ licensed onsite sewage facility representative (TCEQ, 2013).

## 2.9 Precedent Examples

Three precedent examples are presented to show how SSF have been implemented in landscapes in the United States. First is the landscape surrounding the 2006 expansion of the Sidwell Friends School in Washington D.C. Second, built in 2002, is the office building of the

Saginaw Metal Castings Operation in Saginaw, Michigan. Third is the Advanced Green Builder Demonstration building, at the Center for Maximum Potential Building Systems, built in 1998, in Austin, Texas.

*2.9.1 The Sidwell Friends School*

Founded in 1883, the Sidwell Friends School is for students pre-K through 12$^{th}$ grade. In 2006, a 39,000 square-foot, LEED platinum expansion to the existing 55-year-old middle school was completed (Figure 2-7). The school promotes Quaker values including caring for the environment, which guided the design process to focus on environmentally sensitive design solutions (Malin, 2007).

Figure 2-7 Sidwell Friends School Courtyard

The preliminary design phase included plans for onsite wastewater treatment using an indoor Living Machine. Bill Reed, American Institute of Architects, proposed an outdoor option, using constructed wetlands as part of the landscape. The school received approval for the system as a pilot study, from the Washington D.C. Health department. Part of the approval included a quality monitoring protocol (Malin, 2007).

The new landscape includes a 3,000-gallon-per-day SSF as part of the wastewater treatment (Figure 2-8). Prior to entering the SSF, the wastewater is pre-treated in an anaerobic septic tank located in the school's basement which settles suspended solids out of the wastewater. The treated wastewater then exits the building as effluent and is pumped to a three-terrace SSF where it resides for three to five days before exiting the system (CGBC, 2011a). Finally, the effluent runs through a trickling filter and UV light. The treated water is stored in greywater tanks prior to reuse for flushing, irrigation, and cooling towers (ASLA, 2013).

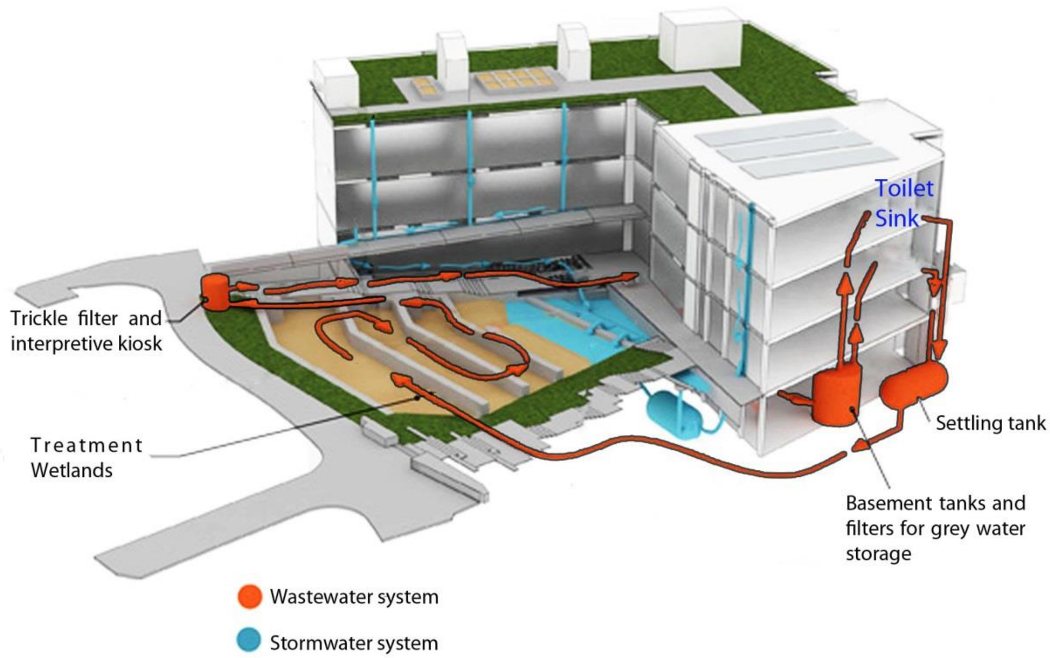


Figure 2-8 Wastewater Flow in the Landscape (Andropogon Associates)

With the assistance of wastewater engineer consultants, over 80 plant species were chosen based on their performance for waste removal and adaptability to the soils. In addition to treating wastewater, the plants are an example of using native species in the landscape. The treatment system is integrated into the school curriculum in several ways, including water testing by students (ASLA, 2013).

The school continues to receive positive attention while educating visitors on the value of SSF. According to the Sidwell Friends website, over 10,000 guests visit the property every year (Sidwell, 2013). Visitors learn about alternative wastewater treatment through educational signage. The example of Sidwell Friends School is a demonstration of integrating alternative wastewater treatment with a conventional landscape aesthetic.

#### *2.9.2 Saginaw Metal Castings Operations*

Owned by General Motors, Saginaw Metal Castings Operation (SMCO) is a 400-acre property located along the Saginaw River in Saginaw, Michigan. Thirty-five acres of the property are set aside for wildlife habitat projects (WHC, 2013).

In 2002, SMCO proposed a wetlands demonstration area in the lobby of their office building (Figure 2-9). The scope of the project included a diorama, an aquarium, signs, and diagrams explaining the importance of wetlands. The landscape architect proposed the use of a working SSF as an alternative to the original concept of an indoor demonstration area (Designscapes, 2013).

Figure 2-9 Subsurface Flow Wastewater Treatment Wetland at Saginaw Metal Castings

The SSF is designed to treat 1,200 gallons-per-day from the office building. As seen in in the landscape plan (Figure 2-10) the process begins as wastewater is pumped from the sanitary sewer into a septic tank for anaerobic treatment. Effluent from the tank is gravity fed through the SSF and into the water feature pond. The effluent is also used for irrigating plants around the office complex. Water exiting the SSF has levels of nitrogen, phosphorus, and TSS 90 percent lower than when it exits the septic tank (WHC, 2013).

Figure 2-10 Saginaw Metal Castings plan (Designscapes, 2013)

Prior to planting, EPDM liner for the SSF was extended across the entire landscape. As water flows horizontally through the system, the whole landscape is irrigated. Through the use of angled grading, different water zones were created allowing for the use of marginal plants and plants accustomed to lower water use (Designscapes, 2013).

Starting in 2003, SMCO partnered with local universities to use the SSF as a real-world laboratory. Local Boy Scout troops and grade-school classes visit to learn about wetlands and their place in the ecosystem (Figure 2-11) (General Motors, 2013).


Figure 2-11 Saginaw Metal Casting Operations' Senior Environmental Engineer Teaches Scouts About Wetlands (General Motors, 2013)

### *2.9.3 Advanced Green Builder Demonstration Building*

Located in Austin, Texas and built in 1998, the Advanced Green Builder Demonstration (AGDB) is a structure designed to demonstrate sustainable building techniques. The building is part of the Center for Maximum Potential Building Systems (CMPBS); a nonprofit designed to demonstrate sustainable building techniques.  Funding for the AGBD came from a $100,000-grant provided by the State of Texas in partnership with the U.S. Department of Energy.

Outside of the building is a 13,200-gallon rainwater harvesting system (CMPBS, 2013). Surrounding the two rainwater tanks is a SSF used to treat wastewater from the AGBD (Figure 2-12). The cisterns and SSF are incorporated into the main entryway of the AGDB.

Figure 2-12 Entry to the Advanced Green Demonstration Building, Subsurface Flow Wetland Highlighted on Right Side of Walk (Courtesy Jesse Wilson)

The system starts with low-flow toilets connected to a septic tank for primary treatment. Water from the tank travels through a SSF originally planted with carizzo (*Arundo donax)* and common reed (*Phragmite australis).* The plants were replaced with cana lilies (*Cana x generalis)*, calla lilies (*Zantedeschia aethiopica)*, irises (*iris sp.)*, and other less invasive species. After passing through the SSF, wastewater is held in preparation for use in subsurface irrigation.

The wastewater treatment design standard for water use in Austin and Travis County is 160 gallons per capita per day (City of Austin, 2010). Through the use of low-flow fixtures in the AGDB, water use was decreased to 25 gallons of water per person per day allowing for a SSF 83 percent smaller than required by city standards (CMPBS, 2013). Although the AGDB was designed to be an example for residential use, it currently houses the main offices for the CMPBS.

*2.9.4 Precedent Example Summary*

The precedent examples show various options available when implementing SSF. Observation of the three sites presents how the processes described earlier in the chapter are used in real world situations. The precedents demonstrate a diversity of treatment scales and water reuse opportunities available when using SSF. Each site uses educational methods to teach visitors about the process of treating wastewater using SSF. The precedents also assisted the researcher to be more informed of built SSF projects in preparation for interviews and data analysis.

## 2.10 Conclusion

This chapter focused on defining wastewater treatment, specifically wastewater treatment wetlands. The history and current practices of centralized and decentralized wastewater treatment were summarized to show how wastewater treatment has developed. The two main types of wastewater wetlands, SSF and FWS, were defined. The components of SSF were laid out in order to understand the design and operation requirements necessary for these systems. Additionally, the laws regulating wastewater treatment were discussed as they relate to SSF.

As portrayed in the precedents, SSF can be designed to treat wastewater at many scales, from a small house to a large school. Also, the shape of a SSF can be altered according to site needs, which is beneficial since landscape requirements vary from site to site. Although each precedent came from a different region of the United States, all reused water for irrigation. The precedents showed how landscape architects can implement SSF into a variety of landscapes.

As presented in this chapter, SSF have been proven to be effective for wastewater treatment since 1952. The systems require knowledge based on engineering, biology, aesthetics, and laws. Landscape architects use similar knowledge to design landscapes. The literature review provided information regarding SSF in order to prepare the researcher to answer the research questions presented in Chapter 1.

# Chapter 3

# Research Methods

## 3.1 Introduction

This chapter focuses on the methodology used to collect data on the barriers to implementation of subsurface flow wastewater treatment wetlands (SSF). Qualitative research methods were used to gather the opinions of landscape architects, engineers, and environmental scientists on the barriers to implementing SSF (Taylor and Bogdan, 1998). Data was collected from in-depth interviews with professionals related to the implementation of SSF. Respondents were chosen through research of existing SSF projects and from the literature and references provided by those interviewed using the snowball technique (Castillo, 2009). The objective was to gather opinions of those who are involved or may be involved with SSF regarding the barriers related to implementation.

## 3.2 Data Collection Methods

### *3.2.1 Interviews*

In-depth interviews were used to collect data for the research (Taylor and Bogdan, 1998). These interviews were designed to gather respondents' opinions, experiences, or situations stated in their own words (Taylor and Bogdan, 1998). The interviews were performed both face-to-face or over the telephone to gather information about the respondent's professional experience with and/or opinions regarding the barriers to the implementation of SSF.

#### 3.2.1.1 Selecting interviewees

The population of respondents consisted of professionals involved in the implementation of SSF, which includes landscape architects, engineers, and environmental scientists. The first set of respondents consisted of professionals with and without preexisting knowledge of SSF. Before the interviews, respondents were divided into two categories:  those with preexisting knowledge of

SSF and those without it. Respondents with preexisting knowledge of SSF were identified by researching professionals involved with the Net Zero Building Energy Challenge, LEED platinum projects, and authors of literature related to SSF. The respondents without preexisting knowledge of SSF were located using LEED certified project lists. Additional respondents were generated using exponential Non-Discriminative Snowball Sampling as shown in Figure 3.1 (Castillo, 2009). Snowball sampling works like a chain referral system. After interviewing each respondent, the researcher asks for assistance to identify other subjects with a similar interest, generating an exponentially larger set of respondents with each tier of interviews (Castillo, 2009).

The snowball sampling method is simple and cost-efficient compared to other sampling techniques. Additionally, the referral process allows the researcher to reach populations that are difficult to sample when using other sampling methods. This technique requires less planning and fewer work hours compared to other sampling techniques, since the interviewees provide potential many respondents for the researcher (Castillo, 2009).

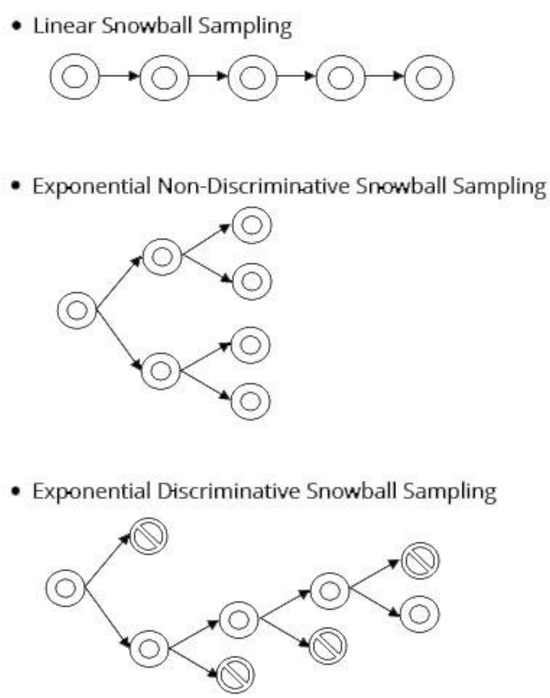


Figure 3-1 Types of Snowball Sampling (Castillo, 2009)

There are a few disadvantages when using non-discriminative snowball sampling. The researcher has little control over the results of sampling efforts as the list of respondents is heavily dependent on those previously interviewed. An accurate representation of the population is not guaranteed as the researcher does not know the actual distribution of the population compared to the sample. Because initial subjects nominate people they know well or have worked with on previous projects, sampling bias is a possibility. This possibility presents a potential problem as the researcher may obtain a small subgroup of the entire population (Castillo, 2009). In an attempt to overcome this barrier, the first set of interviews came from carefully qualified respondents in many different areas of the United States. The first set of respondents was chosen according to their previous work with SSF, frequent appearances in relevant literature, and their location.

#### 3.2.1.2 Institutional Review Board approval

Approval from the Institutional Review Board (IRB) was granted prior to the interviews. This process began with approval of the population of respondents and the interview questions. Also, a consent form was designed in order to protect the identities of the respondents and to confirm that they were participating of their own accord. The IRB process was an important step in preparation for the interviews.

#### 3.2.1.3 Interview design

Interviews began with the researcher introducing the thesis. Since the respondents reside in various parts of the United States, it was necessary to perform some interviews over the phone. Respondents that reside near the researcher were interviewed face-to-face. Telephone interviewees were read a consent form and used a verbal “yes” or “no” to consent to or decline the interview. The interviewer then signs and dates a physical consent form. Face-to-face interviewees receive a physical copy of the consent form that they and the interviewer sign and date. Additionally, the consent documents contain information explaining the research and the purpose of the interviews.

Interviews were recorded in order to allow the researcher to focus on the interview instead of taking notes. Face-to-face interviews were recorded digitally using an Olympus digital voice recorder. Telephone interviews were recorded digitally using the Total Recall android phone application. Interviews were then professionally transcribed in preparation for analysis.

3.2.1.4 Interview profile questions

Profile questions, listed below, were designed to categorize each respondent according to their profession: landscape architect, engineer, or scientist. The third profile question asks each interviewee about their familiarity with SSF in order to determine which set of interview questions will be used next. The profile question responses were also used to organize respondent transcripts in preparation for analysis.

1. What is your profession?
2. How long have you been practicing?
3. Are you familiar with subsurface flow wastewater treatment wetlands (SSF)?
    a. If yes proceed to Path One questions (see 3.2.1.6)
    b. If no proceed to Path Two questions (see 3.2.1.7)

3.2.1.5 In-depth interview questions

The interviews were designed using open ended questions to produce qualitative data with a variety of responses. Path One is designed for interviewees with previous knowledge or experience with SSF and includes questions formulated to gather data on the subjects' experiences with the barriers to implementation of SSF. Path Two is designed for interviewees with no previous knowledge of SSF. These questions are designed to gather data on the subjects' opinion of what the potential barriers to implementation might be.

3.2.1.6 Path One: Interview questions for subjects with preexisting knowledge of or experience with SSF

1. How long have you been working with SSF?

2. What SSF projects have you worked on?
3. Are there advantages to SSF?
4. Are there disadvantages to SSF?
5. How does the technical complexity of SSF affect your designs?
6. What are the barriers to implementing SSF?
    a. Have you run into political barriers?
        i. If so, what governmental entities regulate SSF?
        ii. How did those entities affect decision making?
    b. Have you run into cost barriers?
    c. Have you run into barriers with particular professionals working on the project design team?
    d. What responses have you received on projects that have been implemented?
7. How does SSF apply to the domain of landscape architecture?
8. Is there anything else you would like to say?
9. Who else do you know that is working on these types of projects?

3.2.1.7 Path Two: Interview questions for subjects with no preexisting knowledge or experience with SSF

Prior to the interview, subjects not familiar with SSF were given two letter-sized pages, depicting a diagram and a picture of existing SSF projects (Figures 3-2 and 3-3). The second page contained a short paragraph, included below (3.2.2). This paragraph describes the functions of SSF. This information is intended to give the interviewee a basic understanding of SSF prior to the interview.

*3.2.2 Path Two Diagram Explanation*

Wastewater from the building is sent to a primary clarification, or septic, tank first. Water then passes underground through the SSF media and plant roots where wastewater contaminants are removed. As treated water leaves through the outlet, it is dispersed into the soil, sent to storage tanks for use as gray water, or other uses. At no point in time is the water above ground.

Path Two Interview Questions: No preexisting knowledge of SSF.

1. Do you see any value in using SSF?
2. Could SSF fit into your type of project work?
3. What barriers do you think exist for the implementation of SSF?
4. How does your perception of the technical complexity required for the implementation of SSF affect its potential inclusion in a wastewater design?
5. How does SSF apply to the domain of landscape architecture?
6. Is there anything else you would like to say?

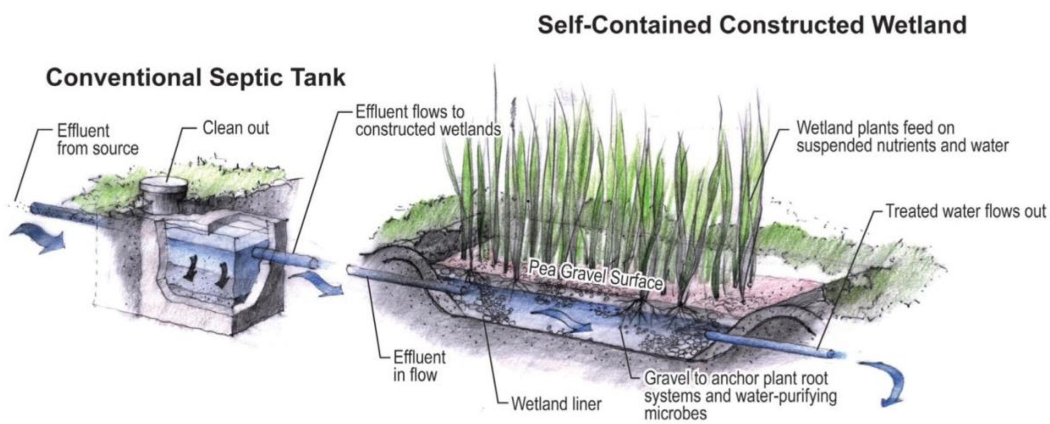


Figure 3-2 Constructed Wetland Section One

Figure 3-3 Implemented Subsurface Flow Wastewater Wetland (Courtesy Roth Ecological Design)

## 3.3 Data Analysis

“Coding is a way of developing and refining interpretations of the data,” (Taylor and Bogdan, 1998). Data gathered from the interviews were coded according to themes in preparation for further analysis. During analysis, major themes were listed and used to divide the information for more in-depth analysis. As the analysis progressed, new themes emerged. After the data was analyzed, the themes were studied and kept or discarded according to their relevance to the research. Themes that relate to each other were placed under larger headings (Taylor and Bogdan, 1998). By coding the data in a dynamic fashion, the themes corroborate with the data and not vice versa (Taylor and Bogdan, 1998).

## 3.4 Methodological Significance and Limitations

This study gathered data from experts experienced with implementing subsurface flow wastewater treatment wetlands (SSF) as well as those not familiar with SSF. During the literature review, no precedent was discovered for research using multiple professions to gather data on the barriers to implementing SSF. Information was gathered regarding the role of politics, costs, and public perception in the implementation of SSF. By compiling information on barriers from key informants, landscape architects can better understand what steps should be taken before proposing the installation of SSF.

Challenges to this research included finding the initial population of key informants with experience implementing SSF projects. Additionally, since many of the sites studied are far from the researcher, travel expenses limited site visits. Limitations to the snowballing technique, discussed above, effected the population of respondents as well.

## 3.5 Summary

The goal of this study is to discuss the barriers to the implementation of SSF in the landsdcape. In-depth interviews were used to gather the opinions of landscape architects, engineers, and environmental scientists related to the implementation of SSF. The interview process was divided into separate lines of questioning for interviewees with and without previous knowledge of SSF. The interviews were then recorded and transcribed in prepartion for data analysis. Telephone interviews and the snowball sampling method were used to get a larger population of respondents from around the country. The following chapter focuses on the analysis of data gathered from the interview process.

Chapter 4

# Analysis and Findings

## 4.1 Introduction

This chapter focuses on the analysis and findings of the data collected from interviews. The findings are organized according to themes that emerge from analysis of the interviews. Many of the themes overlap creating a more cohesive analysis of the barriers to implementing SSF.

Seventeen professionals who work in fields related to the implementation of SSF were interviewed. The respondents consisted of eight landscape architects (LAs), four professional engineers (PEs), and five environmental scientists (SCIs) (Figure 4-1).

| *Respondents* | *With Experience* | *Without Experience* | *Total* |
|---|---|---|---|
| Landscape Architect | 5 | 3 | 8 |
| Engineer | 3 | 1 | 4 |
| Scientist | 4 | 0 | 4 |

Figure 4-1 Respondents by Profession and Experience with SSF

. The scientists interviewed consisted of a biologist (SCI 1), a professional wetland scientist (SCI 3), and two ecologists (SCI 2, 4). Since the scientists interviewed all work with wetlands they are referred to as environmental scientists for convenience. Three LAs and one PE were questioned from the path two line of questioning since they had no previous experience with SSF. The average amount of experience with SSF is fifteen years and the highest is forty-four years (Table 4-2).

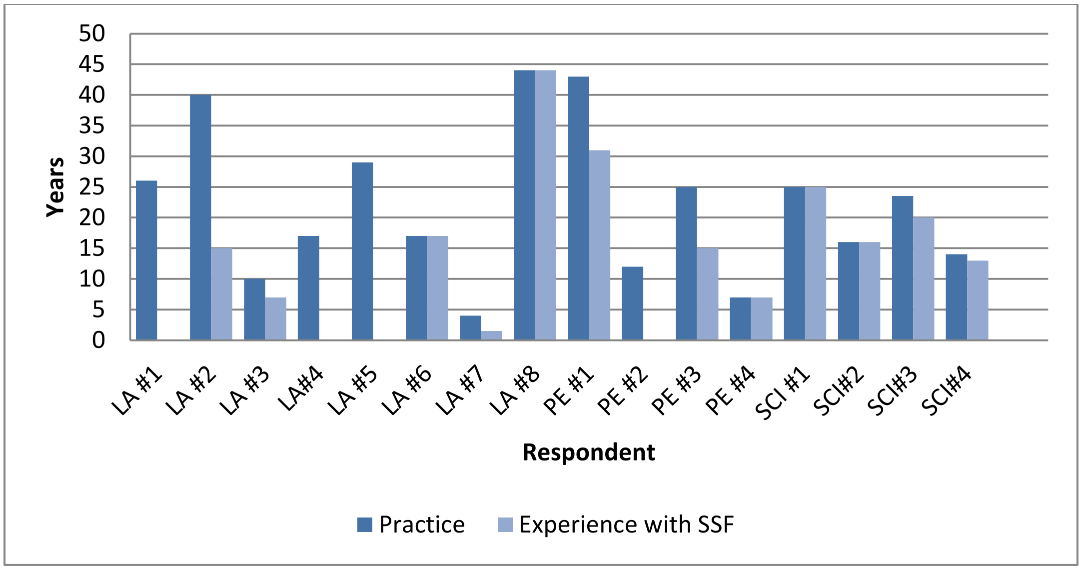


Figure 4-2 Total Years of Practice and Years of Experience with SSF by Respondent

## 4.2 Themes

The data were analyzed using grounded theory to identify themes from the interviews (Taylor and Bogdan, 1998). Using this method, the researcher repeatedly read and listened to each of the interviews, discovering additional themes until nothing new appeared. The themes discovered in this set of interviews are presented and discussed below (Figure 4-3).

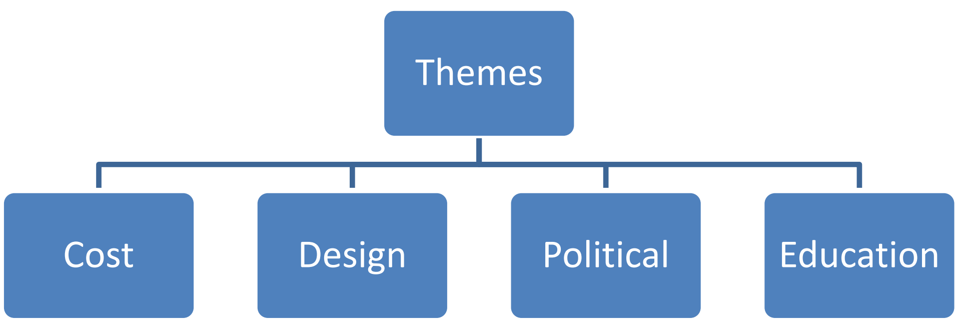


Figure 4-3 Flowchart of the Four Themes Discovered during Analysis

## 4.2 Cost

Cost was a common topic discussed by all of the respondents. The cost of implementing a SSF includes the capital cost or initial outlay, the operation and maintenance costs, and costs incurred during the repair cycle (Figure 4-4).

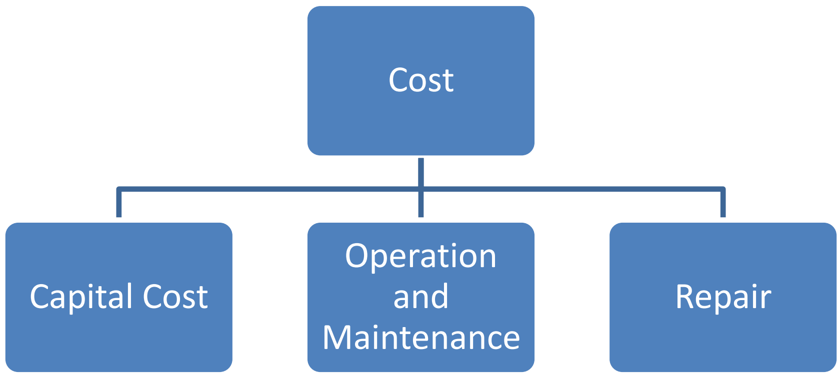


Figure 4-4 Flowchart of the Cost Subthemes

### *4.2.1 Capital Cost*

Capital costs are the costs associated with the design and construction of the SSF. Seven respondents identified SSF as having higher capital costs when compared to a standard septic tank or municipal wastewater hookup. The higher costs are "due to extra design fees, more land, additional earthwork, and the incorporation of media [rock, gravel, sand]" (SCI 2).

Three respondents indicated that the capital cost is equal to other onsite engineered systems, such as a three-compartment septic tank. SCI 1 stated, "Although the cost is the same as an engineered system, government regulations force you to oversize [the SSF] resulting in a price so high the client will not pay for it." SCI 3 had a similar experience with a wetland that did not perform efficiently because regulations required it to be sized according to the building and not the number of occupants.

*4.2.2 Operation and Maintenance*

"The biggest advantages of using wetland systems…are that you have a more green infrastructure that requires less energy input, less electricity, less operation and maintenance" (SCI 3). According to the respondents, the main operation and maintenance costs are incurred by power consumption, water quality testing, and operators or technicians. The respondents indicated that the comparatively low power consumption over the SSF lifecycle recoups the capital costs. SCI 1 stated that their "treatment and reuse scenarios were deployed at the cost of a traditional household residential sewer service."

SSF systems are a "passive treatment technology, meaning it doesn't necessarily require energy to operate the system…they are designed to operate using little or no power, simply relying on gravity to pull wastewater through the system" (SCI 4). Although the flow of water through the SSF is passive, pumps may be necessary to transport water to a desired location for reuse or dispersal. Pumps and ultraviolet lights, which eradicate bacteria in the water, contribute to the operation and maintenance costs.

According to sources in the literature review and SCI 4, SSF operators require less training than operators at a centralized wastewater treatment plant (WTP). SCI 4 and PE 4 emphasized the importance of having operators trained specifically for SSF since "they don't always come with a licensed, trained operator, so the engineering firm has to typically train an operator" (SCI 4). Three respondents stated that engineering companies typically employ trained operators to perform scheduled maintenance of SSF. Although PE 4 suggested that, "proper maintenance is required one to two times per week to prevent system failure," LA 2 and SCI 4 stated that it is only required monthly to yearly. Proper maintenance includes observation and care of plants, water flow, and other parts of the system. This maintenance is valuable in reducing the repair costs and preserving the public image of SSF. System failure can be caused by clogged media that prevents water flow causing water to pool above ground.

*4.2.3 Repair*

As specified in the literature review, clogging can cause SSF to fail. Eight respondents identified clogging as a concern for all SSF. PE 4 indicated that, “clogging caused by biofilm buildup can cause water to pool or pond above the ground surface.” Clogging can be prevented by correctly designing the system according the hydraulic load requirements.

Two respondents stated that once a system is clogged, the media has to be excavated and cleaned. LA 8 specified that “the roots will seek out and destroy the inlets and outlets, so removing and replacing plants and their roots should be part of the maintenance plan.” In direct contradiction to LA 8, SCI 3 emphasized, “you don’t want them disrupting the plants and stuff that are in there that are performing a lot of the work with their roots' system.” Though buildup of the biofilm can clog the media this can be prevented by "pretreating the water and removing most of the suspended solids from the effluent prior to it entering the SSF (LA2). If the pretreatment is sufficient then “there is an unlimited lifespan to the SSF” (LA2).

## 4.3 Design

Two design subthemes emerged from the data analysis: proper engineering and the inclusion of aesthetic design (Figure4-5). A SSF must be engineered properly in order to operate most efficiently. Engineering components that were discussed by respondents include hydraulic design, sizing, footprint, and regulations. Second, aesthetic design is significant since SSF is “the only onsite system where the interface on the surface is desirable” (SCI 1) and can be aesthetically pleasing (LA 2, SCI 4).

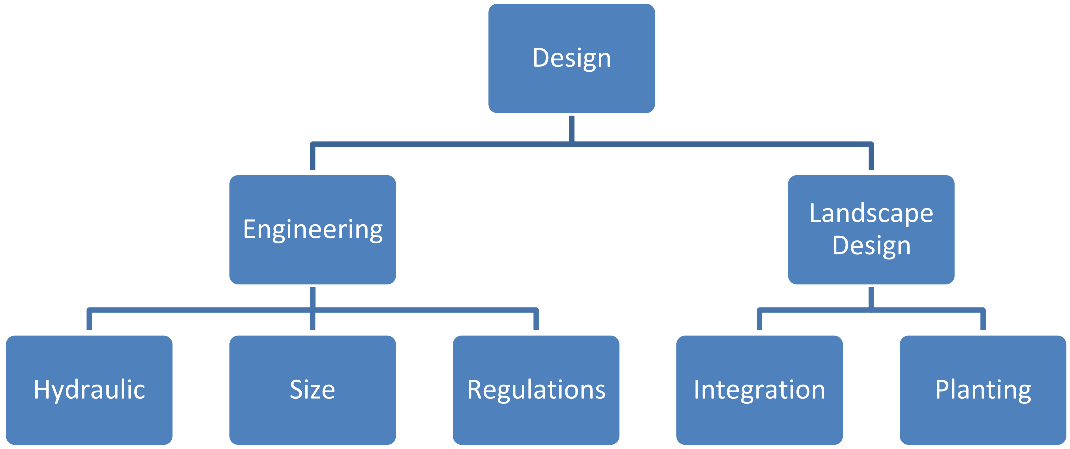


Figure 4-5 Flowchart of Design with Subthemes

*4.3.1 Engineering Design*

Engineering design includes hydraulics, sizing, footprint, and adherence to a variety of other regulations. Three respondents specified proper hydraulics, water flow, and sizing as the most complex issues related to the design of SSF. Eleven respondents indicated that designs are affected politically due to hydraulic sizing requirements. When asked about the complexity of SSF, six respondents identified the systems as fairly simple and not technically complicated. PE 4 indicated that the biologic processes and interaction of the wastewater with the biofilm, media, and plants can be complex, stating, “Although they look simple from the surface, they are very complex underneath.”

4.3.1.1 Hydraulic design

Hydraulics were mentioned specifically by thirteen respondents as a critical part of the SSF design. Hydraulics relate to the flow of water through media in the SSF. PE 1 stated that “SSF can provide excellent treatment if designed and operated correctly.” All three of the PEs experienced with SSF indicated that many designs fail early in the process, “some fail from the start because of poor design practices that have been adopted” (PE 3). Improper hydraulic loading leads to clogging, which causes water to pool on the top of the soil (PE 4), while a lack of water flow can lead to plant and bacteria die-off reducing the effectiveness of the SSF (PE 1). Two respondents identified a lack of understanding regarding the requirements of hydraulic design as the most common aspect of poor design.

4.3.1.2 Size

As summarized in the literature review, the size or square footage required for a SSF to function efficiently is determined by the amount of water to be treated. This is calculated by the number of users of the site multiplied by a standard gallons used per person per day. LA 8 stated, "The original guidelines for SSF construction required a length to width ratio of ten to one." According to three respondents, new research has shown that a ratio between one to one and three to one treats wastewater most efficiently.

4.3.1.3 Footprint

The footprint of the SSF depends on two factors: the available land and the required treatment size. PE 4 specified rectangles as the most common shape of a SSF, however, SSF can blend into the landscape because, "it can be any shape, not just a rectangle." Three respondents indicated that the shape of a SSF can vary according to the needs of the site, if it is designed correctly, with correct length-to-width ratios and hydraulic flow. In regards to incorrectly designed footprints, SCI 3 stated, "when…you are not getting effective flow…your total treatment area might be utilizing 35 to 40 percent…and you end up having very large dead spots."

Conflicting responses were given regarding the footprint size of SSF compared to other systems. Three respondents specified SSF as more land-intensive when compared to other onsite wastewater treatment options. Six respondents stated that SSF use less area for treatment when compared to other onsite treatments, such as a leach field, which conflicts with the three. SCI 3 blamed inefficient design for SSF systems that are unnecessarily land intensive. According to PE 1, an advantage of SSF is that "the area required is not such that it's gonna really impinge on the site…you've got little places you can fit them in." LA 7 and SCI 1 agreed, saying SSF are great because they can fit into tight spaces. "We can make the footprints remarkably small compared to what a traditional sort of wetland concept might be" (SCI 1).

4.3.1.4 Political regulations

Codes for SSF state that a system must be designed according to the number of users in a building, calculated by the square footage of a building or the number of bedrooms in a house (LA 2, SCI 3). Four respondents identified that the regulations calculating the number of users often result in systems that are larger than needed, reducing the effectiveness of the SSF. A system that is designed for more effluent than it receives requires users to flush more often in order to keep the SSF bacteria and plants alive (LA 2).

Current codes are written for non-water efficient buildings and do not take into account low flow fixtures or other water saving devices that are commonly found in buildings where SSF are being implemented (LA 3). Through the use of water efficient design, the SSF for the Advanced Green Building Demonstration (Precedent 3) have been functioning since 1998 at thirty percent of the square footage required for treatment by the City of Austin.

*4.3.2 Landscape Design*

Two subthemes of landscape design emerged from data in the interviews. Landscape integration involves blending the SSF into the existing landscape, while planting design refers to plant selection based on wastewater treatment methods and aesthetic appeal. The two subthemes specify how the skills a landscape architect already possesses can be used to implement SSF.

4.3.2.1 Landscape integration

SSF can be integrated into the landscape using a variety of methods. Eight of the respondents touched on this topic in their interviews. PE 1 indicated that integration involves "using the SSF as part of the landscape as opposed to having a fenced off area," creating a dual-purpose landscape. Since SSF do not have open water, LAs 2 and 3 have been able to use SSF as central features of the entry to multimillion dollar residential and commercial buildings. SSFs can appear as planters, water features, planting beds, etc. SCI 4 stated that they, "try to incorporate (SSF) with the surrounding landscape so it can blend in and try to flow naturally with the rest of the site as much as possible."

#### 4.3.2.2 Planting

Plants are the visual interface between SSF and the landscape. Thirteen respondents discussed the impact of plants relating to their function within SSF or their aesthetic appeal. The selection, performance, and secondary uses of plants were also mentioned.

Six respondents indicated that the plant palette required to treat wastewater can vary according to the landscape design. According to LA 8 and research by Kath Seidel, the original SSF plant palette was *Typha latifolia,* and *Phragmites Australis.* LA 8's plant palette has evolved and changed since new research shows the effectiveness of a variety of plants. SCI 4 stated, "We typically don't have landscape architects looking at our plant selections…we choose based off of plants that we know just succeed in various waste strengths, and for their ability to produce maybe the best roots or grow to a certain size; for their ability to remove the nutrients out of the water." According to LA 2, "There are a number of plants that will work in a subsurface flow wetland, some that are almost a requirement to have because each plant does a little bit different function." Two respondents specified native plants as preferential since they handle local conditions better than some ornamentals. After working with well-known SSF experts, SCI 3 was able to say, "You just need the right plant type, not necessarily a fixed plant list."

According to two respondents, plants used for SSF do not generally appeal to the public because they are not part of the typical manicured landscape to which people are accustomed. Common bulrush and reeds are referred to as "the SSF" plants by two respondents. Alternately, SCI 3 stated, "there's this whole range of opportunities available to integrate visually, aromatically, interesting plants" LA 2 mentioned the value of using irises and calla lilies to make the area more aesthetically pleasing, while LA 8 has used a SSF to grow flowers for cutting.

Plant growth is regulated by the amount of nutrients and water passing through the SSF. Since there is little soil within the SSF, "the wastewater is kind of important to keep the plants healthy, because that's a nutrient source" (LA 2). As plants take up contaminants and nutrients, they act as a visible, long term bio-monitoring unit for the SSF (SCI 1).  With the above ground monitoring, "you can see visually, almost like a bar graph [the] sort of limiting nutrient concept, where the same plants are just shorter towards the outlet" (SCI 3) Observing plant growth reduces the need to dig up media to determine if there are problems with water flow or clogging.

## 4.4 Government Regulations

All respondents identified political barriers related to implementing SSF. These barriers include the hierarchies of regulatory agencies, required permits, and extant or absent laws (Figure 4-6). Many of the barriers described by respondents have been overcome in some areas of the country through work with the various regulatory agencies.

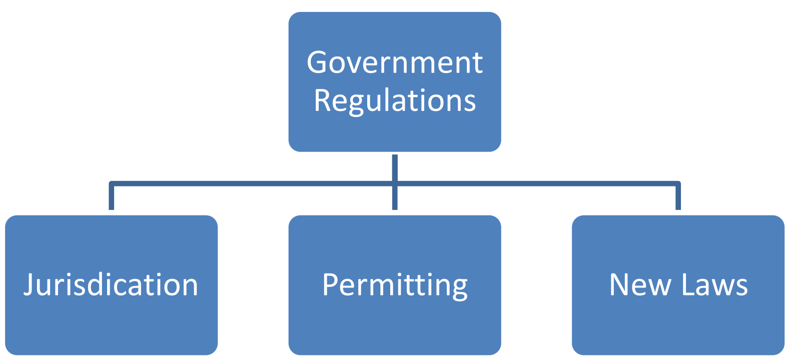


Figure 4-6 Flowchart of Government Regulations and Subthemes

### *4.4.1 Jurisdiction*

Two respondents identified that permits for SSF in their state come from the county while five respondents said SSF permits go through the state. LA 4 mentioned that approval on the national level, from the Army Corp of Engineers, “is only needed if the SSF crosses an existing natural wetland.” Although they may exist, the researcher did not uncover any SSF that required approval from the Army Corp of Engineers.

LA 3 stated, “The agencies do not know what to do with you so they pass you back and forth to other departments.” Both LA 3 and SCI 3 expressed frustration about being passed back and forth among agencies that did not know who was in charge of issuing a permit. SCI 1 expressed frustration in dealing with the hierarchy of state agencies: “It seems like the further you go up the sort of jurisdictional food pyramid, the less logic prevails and the more, process for process sake, sort of takes over.” In many states, the hierarchy slows down the process of receiving approval for SSF.

*4.4.2 Permitting*

Permits from the county or state government, are required to build and operate SSF. PE 4 said, “They [state agencies] like to see evidence from their own state before they give approval.” SCI 4 worked on a demonstration project for one year before approval since, “any technology that's new to the state, sometimes requires a treatment performance record.” PE 4 was asked for, “a three year pilot study,” prior to being granted permission to build. In total, four respondents were allowed permits after a pilot study was performed with well documented results lasting from one to three years. Although pilot projects can provide valuable data, PE 4 specified that, “the three year pilot study regulations do not fit into the client’s timeframe…the SSF will not get built.” SCI 1 worked for three years to obtain a permit to construct “an onsite system with technology we’ve been using for twenty five years.” Two respondents stated that permits were easier to get after the pilot studies proved the performance of SSF.

*4.4.3 New Laws*

As stated in Chapter 2, many of the laws regarding wastewater treatment originated with the 1972 Clean Water Act. SCI 1 indicated that the codes used in their state have changed little since 1972. When trying to obtain permits for construction, “they literally had to insert definitions for what a constructed wetland is” (SCI 1). SCI 1 and SCI 4 specified that their states are working on changing the current wastewater management codes. LA 3 stated, “Some municipalities have us write the regulations [for SSF] after the SSF are installed,” and “after these regulations are inserted into the code, it is easy to do these projects” (LA 3).

Two respondents stated that, although their states are known for having progressive water laws, receiving permits for SSF is very difficult. LA 7 stated that, though California is very progressive, it is hard to get a permit for greywater treatment. When seeking a permit, “there are a ton of hoops and outdated laws” (LA7). Four respondents also indicated that it is difficult to get permits for greywater treatment in the landscape; therefore wastewater would be much more difficult to get permitted. According to LA 8, their state is not known for being progressive; however, SSF have been in the code for at least fifteen years. Also, their county “accepts these alternative practices as long as there is an engineering stamp on it.”

### 4.5 Education

The theme of education emerged from the interviews and can apply to three subsets of people:  the public, the government, and professionals (Figure 4-7). During analysis, the topic of public education often overlapped with government and professional education. Four respondents indicated that when SSF are implemented correctly and receive positive attention, they are more welcome by the public, government, and professionals involved with SSF.

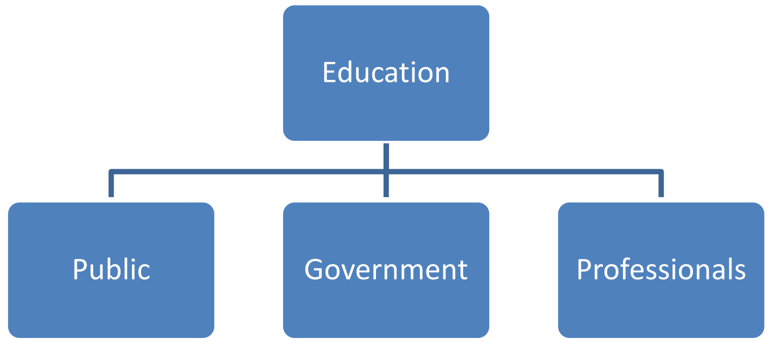


Figure 4-7  Flowchart of Education Theme and Subthemes

*4.5.1 Public Education*

Three respondents specified that it is important to reach out to the public before and after the implementation of SSF. Public outreach can come in the form of demonstration gardens, or the use of the installed SSF as an amenity. Fieldtrips with students to see SSF and learn how they operate are valuable since "anything positive done with kids goes up through the parents and on to city councils" (SCI 3). Both the Saginaw Metal Castings Operation and the Sidwell Friends School have children and/or students interact with the SSF to learn how it functions. The interaction leads "people [to] suddenly become aware of what they put down the drain; they have a visible monitoring system," whereas previously the "engineering divorced humans from this obvious connection" (SCI 1).

PE 2 conjectured "there would be resistance from 99.9 percent of the public, who would not want poop floating in their yard." Three respondents stated that the public often has a negative reaction to SSF before learning what the systems do. Nine respondents indicated that the public has positive responses once they see a SSF and understand how it works. Regarding public education, SCI 4 stated "Once we get a project implemented and once people understand how it works, generally everyone tends to come around and be on board." LA 3 referenced the study of the Arcata marsh wastewater wetlands in Arcata, California where the wastewater wetlands were regarded as an amenity and supported by the community after being educated.

*4.5.2 Government Education*

According to LA 2, "it takes a little bit of education with the local jurisdictional body," to approve new types of wastewater treatment. LA 2 and SCI 3 related experiences with county jurisdictional bodies that were excited to implement SSF after attending educational seminars that explain the function of SSF. SCI 3 stated that they received a "tremendous positive response from the department of health folks that were involved." LA 2 stated, "Each health department needs to learn about SSF before they will approve them for construction."

Three respondents indicated that codes for SSF already exist in their state. SCI 3 and 4 stated that regulators in their states only approved SSF after performance data from pilot projects in their state were submitted. Initially, regulators in SCI 3's state were not positive about SSF because they had spoken with regulators in other states where systems failed; "they don't even want to talk to you about wetlands because they don't believe they work." According to two respondents, hydraulic failure can be so detrimental to the image of SSF that some municipalities refuse to implement them. LA 3 stated, "Failure will make the public think they don't work." Since SSF are so simple in their operation, they are, "seen as a novelty, [the] rustic quality belies treatment effectiveness" (PE 4).

*4.5.3 Professional Education*

*4.5.3.1 Exposure.* Three respondents stated that there has not been enough exposure to SSF in the field of landscape architecture. PE 1 said, "There's a lot of bad designs out there because people haven't had the exposure they needed…before they started putting them in."

According to SCI 1, SSF, "tend to be... perceived as a new technology, when it has been deployed worldwide successfully for well over…fifty years now." PE 1 stated, "I wrote about natural-type systems…in 1982," after they met Dr. Bill Wolverton, a pioneer in natural wastewater treatment systems.

LA 6 stated SSF is "an up and coming discipline." PE 4 reported that SSF and other forms of alternative wastewater treatment were discussed at two national American Society of Landscape Architect meetings in recent years. Although SSF have been used for decades, their presence is continually spreading. LA 8 stated that when landscape architects visit their SSF, "they come in all the time and say, 'Wow, what is this?'" Although SSF are not new, exposure to them is uneven, creating a division among professionals as to the novelty of SSF.

4.5.3.2 Required skillset

PE 4 wishes that, "LAs had a toolbox, or set of guidelines, they can use to know when it is appropriate to propose SSF before they contact the engineers," to begin the design process. This toolbox would assist LAs when proposing or designing SSF for a client. According to LA 8 the SITES initiative relates to LAs more than Net Zero or LEED so, "it should have a SSF design toolbox that landscape architects can use."

Ten respondents referred to the understanding of the chemical and biological process as necessary for any professional designing SSF. LA 6 stated, "As… landscape architects, we don't understand the chemistry involved in the treatment process as well as we should. If we understood that better, we might be able to [prepare] for the challenges."

4.5.3.3 Design team interaction

Since SSF rely on multiple disciplines, design teams are almost always required. PE 1 was the only respondent that implemented SSF without a team. When asked about design team interaction, six respondents had a positive view citing previous project collaborations. SCI 3 related positive and negative experiences stating that it will "vary depending on the egos that you're working with."

Three respondents identified that each part of the team would have a specific role during the design process. LA 3 stated that one problem is the "fuzzy boundaries between professions" that collaborate to design SSF. As part of a team, LA 1 believed that they "would be… more inclined to be… just involved with plants and growing media rather than the flow characteristics." Also, LA 1 indicated that, "you [as the landscape architect] would have to understand everything a little bit so that you could do your part so you know best about how to add to the team." PE 4 cited one project team with a LA who "sold the design…because an engineer can make rectangles, not interesting landscapes or renderings."

*4.5.4 Environmental Rating Systems*

Three environmental rating systems were discussed during the interviews: LEED, SITES, and the Net Zero Energy Building Certification. All three of these programs present certifications for buildings and/or landscapes that meet criteria using environmentally sound practices. When the team designing a building has the goal of receiving a certification such as LEED platinum, the highest LEED certification, systems like SSF are expected (LA 3).

SCI 2 stated, "Institutional buildings, like a fire station, will seek out a LEED certification to receive positive public relations." As described in the precedent examples in Chapter 2, the Sidwell Friends School received LEED platinum status. Since the school welcomes over 10,000 visitors per year, the school advertises their SSF as part of the reason for LEED platinum status. LA 3 referred to a Net Zero Energy Building that hosted a conference with former President Clinton. While attending the conference, Mr. Clinton received a tour of the alternative wastewater treatment system, which includes a SSF as part of the treatment train. Environmental rating systems promote alternative projects like SSF through media attention and public involvement.

## 4.6 Path Two Respondents

LA 1, 4, 5, and PE 2 had no previous experience with SSF. Combined, all four respondents were able to identify that cost, government regulations, design team interaction, and interaction with the public are possible barriers to implementation. Results presented above, such as public education, included quotes from path two respondents. The path two respondents averaged 21 years of professional experience, so they drew from previous experience with waste water treatment, such as greywater, to answer questions.

## 4.7 Summary

This chapter summarized the opinions of interviewees gathered from their responses during interviews. The data was divided into themes and analyzed in preparation for the results and conclusions of the research. Data suggests that the respondents had positive attitudes toward the implementation of SSF. Many barriers do exist that limit the implementation of SSF, including design skills, education, and collaboration between disciplines.

# Chapter 5

# Conclusion

## 5.1 Introduction

The purpose of this research is to discuss the barriers to the implementation of subsurface flow wastewater treatment wetlands. This is accomplished through an extensive literature review, that includes the presentation of three precedent examples, and a summary of the history of, design principles of, and laws related to SSF. The qualitative approach of Grounded Theory (Taylor and Bogdan, 1998) was used to define the research methods, which focused primarily on interviews of key players related to the implementation of SSF. The data retrieved were divided into themes to drive findings and conclusions. This chapter discusses conclusions derived from the analysis and how it relates to the research questions.

## 5.2 Research Summary

1. What do key decision-makers believe the barriers are to the implementation of SSF?
2. How do they describe the benefits of SSF in the United States?
3. What is the role of landscape architects in the implementation of SSF?

The literature review summarizes the history of wastewater treatment including the history of SSF. The different types of wastewater treatment wetlands (subsurface flow, vertical flow, and free water surface flow) are presented and compared. The basic design and operation of SSF based on previous definitions by wastewater treatment experts, is delineated. Finally, the laws and regulatory agencies that control the implementation of SSF are identified.

Three precedents are presented to show how SSF is currently operating in diverse landscapes. Each precedent is presented using the categories of building type, number of gallons treated per day, monetary source, original design proposal, and type of water reuse. These precedents show how SSF in the landscape can vary in scale, footprint, cost, and water reuse.

Research methods, outlines the methods used to gather qualitative data for analysis. Grounded Theory (Taylor and Bogdan, 1998) was used to prepare questions used in in-depth interviews of professionals involved with the implementation of SSF. The snowball method of using interviewees to find more interview candidates is defined (Castillo, 2009). The interview questions used are also presented.

Analysis and findings, presents the data gathered during interviews. The data was sorted by themes using Grounded Theory (Taylor and Bogdan, 1998). The major themes discovered included cost, design, politics, and education. Each theme was divided into multiple subthemes. Although the information was divided by theme, many pieces of data overlapped categories. The analysis prepared the data for the final conclusions presented in Chapter 5.

## 5.2 Summary of Interviews/Themes

Interviews were conducted with professionals involved with the implementation of SSF, including landscape architects, engineers, and environmental scientists. Overall respondents experienced with SSF had similar statements regarding the barriers to implementing SSF. Some experienced respondents gave conflicting information resulting in ambiguous data. Results of interviews with inexperienced respondents indicated that opinions of the barriers to SSF are similar to barriers delineated by experienced respondents.

The main barriers to the implementation of SSF in the landscape, the four themes discovered during the analysis, are, cost, design, politics, and education. The data within the themes often overlapped, indicating that in order to overcome barriers to implementation, they must be viewed holistically.

### *5.2.1 Cost*

Capital costs are the first barrier to implementing SSF in the landscape. When compared to a standard municipal sewer hookup, SSF have higher upfront costs. When compared to an onsite engineered system three respondents stated that SSF are equal to or less expensive to build.

Also, several respondents stated that there is a perception among developers, landscape architects, and others involved with the implementation of SSF that they will cost more than other wastewater treatment systems regardless of type. In order to alleviate the cost of land required, SSF can be designed to fit into small spaces in the landscape, which is valuable in urban areas where land is expensive. Also, construction and design fees contribute to the capital costs, which are higher compared to septic tanks or sanitary sewer connections.

Respondents indicated that higher capital costs are recouped through operation and maintenance over the life of the system. Reduced power and water usage are the primary source of cost reduction in the operation and maintenance phases. Since SSF are passive systems that rely on gravity flow, little to no power is consumed in the filtration process. SCI 1 shows, "cities that ninety percent of their electricity usage is by wastewater treatment plants." Also, buildings with SSF can recycle enough water to help sustain the needs of users without using as much water from a municipal source. If SSF are viewed as a long term solution to mitigate the upfront capital costs, then they could be implemented more often. Clients such as the Sidwell Friends School and the Advanced Green Builder Demonstration Building are educational institutions that are using long range goals to influence the future.

Clogging is a maintenance issue, mentioned many times during the interviews. Plant roots often contribute to the clogging and failure of a system. Although various maintenance plans to prevent clogging were suggested, the recurring theme indicates that users should design and plan for clogging to occur. Information from the interviews shows that plant maintenance is comparable to typical landscape maintenance costs.

One respondent suggested that a client would be more accepting of a SSF, if a cost analysis was shown indicating the savings over the lifetime of a system. The analysis would be valuable since it shows the lifecycle cost savings versus the initial outlay.

*5.2.2 Design*

The design of SSF consists of both engineering and form considerations. Engineering and landscape design have to work together for a system to work both functionally and aesthetically. Engineering involves aspects such as hydraulics and sizing, while landscape design consists of the planting design, shape and placement of SSF, and other criteria. Engineering and landscape design principles work together to implement SSF that are efficient and better integrated with the site.

Data from the interviews indicate that proper hydraulic design, or flow, is one of the most valuable parts of a SSF since it determines the effectiveness of treatment. Improper hydraulic design is a barrier since it leads to clogging, inefficient treatment, and in some cases, system-failure. According to the opinion of PE 2, “it’s a nice and easy system… with a step by step methodology.” If the proper engineering steps such as sizing and maintaining the correct hydraulic flow, are taken the SSF will function well.

Landscape design focuses on the placement of the SSF within the landscape and the plant pallet used. SSF are, “the only onsite system where the interface on the surface is desirable,” (SCI 1) so they can be part of the overall landscape design.  The value of SSF is that they perform a function by treating wastewater while looking like a typical part of the landscape. Respondents stated that they can be hidden in a landscape or used as a central feature of a landscape.

According to the literature review and PE 4, the footprint of SSF can be any shape. SCI 3 stated that shapes with improper hydraulic flow treat wastewater at a lower rate requiring a more land intensive treatment system. LA 3 stated that landscape architects need to be flexible with the shapes of SSF as they consult with engineers to get the correct hydraulic flow. Shape is a barrier if designers try to insert SSF after the landscape plan is complete. Landscape architects that are more flexible with their design can integrate SSF into the landscape more easily.

SSF can be used freely as they are safe to interact with. There is no open water, odor is controlled, and disease vectors such as mosquitos are regulated. Also, according to SCI 3, unless there are large amounts of heavy metals in the wastewater, the plants are not toxic. Safe interaction of people with the landscape is a major appeal for landscape architects since it allows visitors to enjoy SSF without having to worry about proximity.

The location of SSF according to climate was brought up by four respondents. PE 1 stated that SSF are not appropriate for warm climates since wastewater will evaporate before it reaches the end of the cell. After seeing the interview diagrams for Path Two, LA 1 stated “you have to flush the toilet a lot of times in order to get enough water for the landscape.” Designing the system to irrigate itself is important, especially in hot climates where saving water is valuable. Three respondents stated that SSF are good for colder climates since the water is below ground which prevents it from freezing.

Landscape architects evolve and grow their plant palette as new research shows the effectiveness of a variety of plants. Having a pre-determined list of plants that remove waste efficiently is valuable to the designer since they assist in the aesthetics and proper waste treatment. Similar to an engineer, SCI 4 uses a pre-determined list of high performing plants to circumvent the need for a landscape architect. Also, research into the effectiveness of other plants at removing waste continues to be done.

### *5.2.3 Politics*

Although the Clean Water Act and the EPA are federal mandates, SSF are regulated by city or state entities. According to LA 2 this is necessary since different areas of the country vary so widely according to soil, water, and plant types. According to LA 8, many of those agencies already have laws that permit SSF and guidelines relating to their construction. Two respondents stated that even with existing laws, state and county agencies do not know who is in charge of providing the permit since SSF are not regularly implemented. The lack of knowledge regarding the jurisdiction of SSF permitting is a barrier to implementation since the amount of time spent on a project costs money.

Regulators are more receptive to the idea of SSF after seeing results from built projects. Four respondents were required to build a pilot project, far from the public, before receiving a permit to build SSF within a public landscape. The Sidwell Friends School was designated as a pilot project after being approved with no special designation. The Sidwell Friends School provides an example of municipalities accepting pilot projects that are used as part of a landscape design close to human contact. Sidwell receives political attention from Washington D.C. regulators since many of their children attend the school. Although pilot projects are valuable, most are not compatible with a client's construction timetable.

*5.2.4 Education*

Results indicate that education is vital to the acceptance of SSF. Education can begin with outreach to the community before and after implementation. This is achieved through positive press from certifications such as LEED, Net Zero Energy, or the Sustainable SITES initiative. The sites that receive certificates often explain what practices were used to achieve their goal. As the public is exposed to these practices, they are more accepting of them. SCI 3 stated "anything that you're doing positive with the kids, with public schools, will come right back up through the parents and up through the city councils."

LA 3 suggests that as government regulators are educated and interact with SSF, systems will receive permits more easily. Information regarding the performance of SSF reinforces the acceptance of this technique by regulators. According to one respondent, municipalities in various states discuss their positive and negative experiences with new technologies (including SSF) with each other. It is vital to implement properly designed systems; one failure can set back the image of SSF among government regulators as contact with wastewater is such a sensitive subject. Since regulators communicate with each other about new technologies, successful projects will be discussed as well. The spread of information among regulators can determine the amount of work a designer will need to do in order to receive approval for a new SSF.

## 5.3 Relevance to Landscape Architecture

All interview respondents stated that SSF applies well to the domain of landscape architecture. One respondent said that the design of SSF involves water, plants, and soil which landscape architects are using already. SCI 2 stated that, “it is a niche [SSF design] that not many people specialize in. Since one, “could fit (SSF) into the architecture as planting beds, as a landscape feature, that would be by far the most ideal way to fit them in, as opposed to having to dedicate, land… [or] fence off an area for them… [you can] make dual use of the land as well as the water.”

Landscape architects should  evolve as they learn new methods and technologies that push the dual use of landscapes that treat wastewater. In reference to the evolving nature of the profession regarding wastewater treatment wetlands, LA 8 stated that, “the field of landscape architecture has been stagnant for the past forty years.” LA 8 believes that wastewater treatment wetlands should be more common than they currently are, since he began using them 44 years ago. Possible reasons for SSF not being prevalent could be a lack of education, unwillingness to branch out, or lack of demand.  Education is a valuable tool that landscape architects can use to diversify into new areas of practice such as SSF. As water resources and quality decline, SSF could become a more important tool for landscape architects to be able use.

The data suggests that, SSF research regarding components, shapes, and plants continues to develop. Landscape architects working with SSF should be using this research to design more efficient and more aesthetically pleasing landscapes. As more aesthetically pleasing and efficient SSF are installed, they will be more accepted by the profession.

This research indicates that engineers implementing SSF desire to work with landscape architects. When proposing alternative forms of wastewater treatment and water reuse in the landscape in urban areas, Dr. Bill Wolverton, a pioneer in alternative wastewater treatment, suggested that, “perhaps we need landscape architects to operate the wastewater treatment systems" (2001). Dr Wolverton was discussing the integration of alternative types of wastewater treatment in urban areas and is often quoted in research correlating SSF to landscape architecture. Two respondents emphasized that landscape architects have the ability to incorporate SSF into the landscape.

Since so many respondents stated that SSF apply to the domain of landscape architecture, it would be a logical avenue for the profession to follow. The landscape architecture profession involves landscape design and some engineering which correlate with SSF. Landscape architects should be in a position to implement landscapes that serve an aesthetic function while performing an engineering utility as well.

## 5.4 Future Research

Future research into the following categories would be valuable in order to expand the knowledge base of subsurface flow wastewater treatment wetlands (SSF) and help designers to better implement them.

Since SSF are not widely known among landscape architects creating guidelines or a "toolbox" for designers to use when proposing and implementing SSF would be valuable. The toolbox could include basic size and shape information, plant lists, possible media, and water reuse options. Researching diverse shapes of existing SSF and how effective they are at treatment would be beneficial. Researching the functionality of various plants and creating a plant palette list would assist in the aesthetic design and reduce research time associated with SSF.

Additionally, recreating this research with a focus on one geographical area would assist regional designers. SSF designs rely on specific knowledge of the local soil to determine the percolation rates, permeability, and other soil characteristics. The local climate determines the depth of media and the plant palette available to the designer. The topography of a site influences the design since SSF need a minimum of a one-percent slope. If designers had ready access to data about local soil conditions, plant palettes, climate, and topography, they would be more prepared to propose SSF.

Surveys of government regulators and the public would be advantageous as they are important constituencies controlling the implementation of SSF. These surveys would allow landscape architects, engineers, and environmental scientists to learn more about public opinion and spread information about SSF. Interviews with government regulators would provide insight into the existing laws or lack thereof as well as individuals' understanding of them.

Research into a cost analysis could examine and compare other alternative strategies such as solar power, composting toilets, or impervious surface materials. Using a life-cycle cost analysis to sell SSF, could be part of the toolbox referred to above. Studying the use of SSF for agricultural use in urban areas could assist in justifying the use of expensive land. Agricultural use has been proven safe and effective outside of the United States, so research is required to discover what new permitting regulations would be required. Expanding this research would be valuable to increase the knowledge base of a lesser known wastewater treatment technique.

## 5.5 Conclusion

This research has shown that subsurface flow wastewater treatment wetlands are perceived as both a new and an old strategy available to treat wastewater onsite. Professionals that have used SSF for years tend to be frustrated that this is seen as a new, alternative strategy that requires performance data before implementation, while young professionals, or those new to the topic, are accepting of a new type of treatment system. Professionals unfamiliar with the technique seemed to support the idea of implementing SSF after overcoming the barriers that were identified.

Although SSF have been proven to effectively treat wastewater, they are not a treatment solution for all situations. The availability of land, soil characteristics, climate, or amount of wastewater to be treated can be barriers to using SSF. Also, some users do not have the desire to maintain an onsite wastewater treatment system when a sanitary sewer connection is available SSF could benefit large populations by reducing power and water consumption in small patches throughout larger city networks. This would create communal wastewater treatment systems that uses both centralized and a variety of onsite treatments. Combining different types of wastewater treatment systems can result in more efficient and less expensive wastewater treatment networks.

The research indicates that although many barriers to implementation exist, education about the availability and performance of SSF is the largest obstacle. One of the most valuable audiences for education is children, who have a direct influence on their parents who, in turn, influence government officials (SCI 3). Also, children educated about SSF will view it as a more normative option for wastewater treatment as they grow up and become the decision makers. Educating landscape architects, engineers, environmental scientists, the public, and government regulators is the most valuable path forward to overcoming the barriers to implementing subsurface flow wastewater treatment wetlands.

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Appendix A

IRB Approval

## UT Arlington
## Informed Consent Document

**PRINCIPAL INVESTIGATOR**

Geoffrey Hall, Masters Program in Landscape Architecture
Contact: Geoffrey.hall@mavs.uta.edu Phone 717-579-9440

**FACULTY ADVISOR**

David Hopman, School of Architecture, Associate Professor of Landscape Architecture
Contact: dhopman@uta.edu Phone 817-272-2801

**TITLE OF PROJECT**

Subsurface wastewater treatment wetlands: understanding the barriers to implementation in the landscape.

**INTRODUCTION CALL SCRIPT**

Hello, my name is Geoff Hall and we recently scheduled a phone interview regarding my thesis. Is this a good time? I will begin my interview by reading a form asking for your consent to continue.

**INTRODUCTION**

You are being asked to participate in a research study about subsurface flow wastewater treatment wetlands. Your participation is voluntary. Refusal to participate or discontinuing your participation at any time will involve no penalty or loss of benefits to which you are otherwise entitled. Please ask questions if there is anything you do not understand.

**PURPOSE**

The purpose of this research is to address the barriers and potential acceptance of subsurface flow wastewater treatment wetlands in the landscape. This research studies the opinions of key decision makers in the implementation of subsurface flow wastewater treatment wetlands. Also, what role do landscape architects play in the process of implementing subsurface flow wastewater treatment wetlands in the landscape.

**DURATION**

Participation in this study will last approximately 60 minutes.

**NUMBER OF PARTICIPANTS**

The number of anticipated participants in this research study is 50.



IRB Approval Date: SEP 3 0 2013

IRB Expiration Date:

# UT Arlington
# Informed Consent Document

**PROCEDURES**
The procedures which you will be involved as a research participant include:

1. In-person interview
2. Or phone interview

The interview will be audio recorded. After the interview, the tape will be transcribed, meaning they will be typed word for word, by the researcher. The tape will be destroyed after transcription. There will be no future use for these tapes.

**CONTACT FOR QUESTIONS**
Questions about this research study may be directed to David Hopman, Associate Professor of Landscape Architecture. His contact information is Contact: dhopman@uta.edu Phone 817-272-2801
Any questions you may have about your rights as a research participant or a research-related injury may be directed to the Office of Research Administration; Regulatory Services at 817-272-2105 or regulatoryservices@uta.edu.

**As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study:**

______________________________________________
**Signature and printed name of principal investigator or person obtaining consent** **Date**

**CONSENT**

By continuing this interview, you confirm that you are 18 years of age or older and have read or had this document read to you. You have been informed about this study's purpose, procedures, possible benefits and risks. You have been given the opportunity to ask questions before you continue, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. By continuing, you are not waiving any of your legal rights. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits, to which you are otherwise entitled. Would you like to continue with the research study questions?

______________________________________________
**Signature and printed name of principal investigator or person obtaining consent** **Time/Date**

SEP 3 0 2013

IRB Approval Date:

2

IRB Expiration Date:

Appendix B

Recruitment Email

October xx, 2013

Dear Mr. /Mrs. John Doe:

I am a MLA student in the Program in Landscape Architecture at The University of Texas at Arlington completing a thesis on the barriers to the implementation of subsurface flow wastewater wetlands. Your participation in an important research project will help landscape architects, engineers, and architects in their efforts in the future. My thesis topic is The Barriers to the Implementation of Subsurface Flow Wastewater Treatment Wetlands in the Landscape. The reason that I am working on this particular topic is because I believe that it is a topic that needs to be further explored and examined for its use in the domain of landscape architecture.

I would like to request your participation in this research via an interview. The interview will take approximately 60 minutes of your time.

Are you available to be interviewed at one of the following dates and times:

October xx, 2013 xx:xx am

October xx, 2013 xx:xx pm

Feel free to call or email me if you have any questions. Thank you for your time and consideration. It is only through the generous support of people like you that our research can be successful.

Sincerely,

Geoffrey B. Hall
Graduate Student
Program in Landscape Architecture
The University of Texas at Arlington

References


American Society of Civil Engineers. (ASCE). (2011). *Failure to Act: The Economic Impact of Current Wastewater Treatment Infrastructure*. American Society of Civil Engineers, Reston, Virginia.

American Society of Landscape Architects. (ASLA). (2013). Interview with Jose Alminana, http://www.asla.org/ContentDetail.aspx?id=22550 (accessed, Nov 9, 2013).

Bastian, R.K. and D.A. Hammer. (1993). *The Use of Constructed Wetlands for Wastewater Treatment and Recycling*. Constructed Wetlands for Water Quality Improvement, Lewis Publishers, Boca Raton, Florida

Benjamin, Thomas S., (1993) *Alternative Wastewater Treatment Methods as Community Resources: Arcata Marsh and Beyond* Thomas Benjamin University of California, Berkeley.

Burian, Steven J. Burian, Stephan J. Nix, Robert E. Pitt, and S. Rocky Durrans. (2000). Urban Wastewater Management in the United States: Past, Present, and Future. Journal of Urban Technology, Volume 7, Number 3, pages 33-62

Burks, B.D., and M.M. Minnis. (1994). *Onsite Wastewater Treatment Systems*. Madison, WI: Hogarth House, Ltd.

Campbell, Craig S and Michael Ogden. (1999). Constructed Wetlands in the Sustainable Landscape. John Wiley and Sons, New York, New York.

Cascadia Green Building Council. (CGBC) (2011 a). *Clean water, healthy sound, a life cycle analysis of alternative wastewater treatment strategies in the Puget Sound area*. Cascadia Green Building Council Seattle, WA.

Cascadia Green Building Council. (CGBC) (2011 b). *Toward Net Zero Water: Best Management Practices for Decentralized Sourcing and Treatment*. Cascadia Green Building Council Seattle, WA.

City of Austin. (2010). Austin Water 140 GPCD Conservation Plan December 16, 2010. City of Austin, Texas

City of Dallas (2010). Water Utilities Department FY 10-11 Proposed 2010 water budget city of Dallas. Dallas City Hall 1500 Marilla Street Dallas, TX 75201

City of Dallas. (2008). Dallas City Hall. Wastewater System Overview http://www.dallascityhall.com/images/WastewaterSystemOverview.jpg (accessed Oct, 31 2013).

CMPBS. http://www.cmpbs.org/ The Center for Maximum Potential Building Systems. (accessed October 1, 2013)

Consortium of Institutes for Decentralized Wastewater Treatment. (CIDWT). (2009). CIDWT Decentralized Wastewater Glossary. http;//onsiteconsortium.org/glossary.html (accessed October 1, 2013).

Designscapes. http://www.dscapes.com/ Designscapes Inc. (accessed Oct 15, 2013)

Field, R., Heaney, J. P., & Pitt, R. (2000). *Innovative urban wet-weather flow management systems*. Lancaster, PA.: Technomic Pub. Company.

France, Robert L., (2003). *Wetland Design, Principles and Practices for Landscape Architects and Land-Use Planners*. W.W. Norton & Company, Inc. New York, New York.

General Motors. http://fastlane.gm.com/2013/01/14/be-eco-prepared-boys-scouts-visit-gm-plants-wildlife-habitat/ General Motors Beyond Now. (accessed October 5, 2013)

Giovanni et. al. (2012). Giovanni Libralato, Annamaria Volpi Ghirardini, Francesco Avezzù, To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management, Journal of Environmental Management, Volume 94, Issue 1, February 2012, Pages 61-68,

Hammer, Donald A. (1989). *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural.* Lewis Publishers, Inc

Ho, G., Anda, M. (2004). *Centralised versus decentralised wastewater systems in an urban context: the sustainability dimension*. Second IWA Leading-Edge Conference on Sustainability.

Hoffman et. al. (2011). Heike Hoffman, Christopher Platzer, Martina Winker, Elizabeth von Muench, *Technology review of constructed wetlands: Subsurface flow constructed wetlands for greywater and domestic wastewater treatment*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Sustainable sanitation -ecosan program Postfach 5180, 65726 Eschborn, Germany

Kadlec, R. H. and S. D. Wallace. (2009). *Treatment Wetlands,* Second Edition. CRC Press, Boca Raton FL

Kahn, L. (2000). The Septic System Owner's Manual. Lloyd Kahn and Shelter Publications Inc.

Lawrence, E., Jackson, A.R.W., and Jackson, J.M. (1998). *Eutrophication*. Longman Dictionary of Environmental Science: London, England, Addison Wesley Longman Limited, p. 144-145.

Libralato, Giovanni, Ghirardini, Annamaria Volpi, Avezzu, Francesco. (2011). To Centralise or to Decentralise: An overview of the Most Recent Trends in Wasetwater Management. Journal of Environmental Management, vol. 94 pp. 61-68.

Malin, Nadav. (2007). Case Study: Sidwell Friends Middle School. Green Source Magazine, July 2007.

Massoud, May A. Tarhini, Akram, Nasr, Joumana A. (2009). Decentralized Approaches to Wastewater Treatment and Management: Applicability in Developing Countries. Environmental Management 90 pp. 652-659. Elsevier Ltd.

Moshiri, Gerald A. (1993). *Constructed Wetlands for Water Quality Improvement*. Lewis Publishers, Boca Raton, Florida

Nelson, Valerie l. (2008). *Institutional Challenges and Opportunities: Decentralized and Integrated Water Resource Infrastructure*. Coalition for Alternative Wastewater Treatment Gloucester, Massachusetts.

Nelson, Mark and Wolverton, B.C. (2011*). Plants soil/wetland microbes: Food crop systems that also clean air and water*. Advances in Space Research, Volume 47, Issue 4, 15 February 2011, Pages 582-590

Ocean Arks International. http://www.oceanarksint.org/ (last accessed November 13, 2013)

Onsite Wastewater Demonstration Project. Evolution of Sewage Treatment. http://www.cefns.nau.edu/Projects/WDP/resources/History/History.htm (accessed November 02, 2013).

Pfafflin, James R. and Edward N. Ziegler. (1992). Encyclopedia of Environmental Science and Engineering, Volume 2. Gordon and Breach, Science Publishers, Inc.Langhorne, Pennsylvania.

Rivera F., Warren, Al., Ramierez, E., O., Bonilla, P., Gallegos, E., Calderon, A. and Sanchez J.T. (1995). Removal of Pathogens From Wastewater by the Rootzone Method (RZM). Water Science Tech. 32, 211-218.

Rosenberg, C.E. (1962). *The Cholera Years.* The University of Chicago Press, Chicago, IL.

Sidwell http://www.sidwell.edu/middle_school/ms-green-building/index.aspx Sidwell Friends School (accessed Oct 28, 2013).

Southwest Wetland Group (SWG). (1995). *The New American Village: Economical and Ecological Options for Wastewater Treatment and Collection*, Santa Fe, N.M.

Steinfeld, Carol and Del Porto, David. (2004). *Growing Away Wastewater*. Landscape Architecture Magazine January 2004, pp. 44-53

Stillwell, Ashlynn S., King, Carey W., Webber, Michael E., Duncan, Ian J., Hardberger, Amy, (2009), *Energy-Water Nexus in Texas*. The University of Texas at Austin.

Taylor, Steven J. and Robert Bogdan. (1998). *Introduction to Qualitative Research Methods: A Guidebook and Resource*. John Wiley & Sons, Inc. New York, New York.

Taylor, Carrie R., Hook, Paul B., Stein, Otto R., Zabinski, Cathy A. (2011). *Seasonal Effects of 19 Plant Species on COD Removal in Subsurface Treatment Wetland Microcosms*. Ecological Engineering 37 pp. 703-710. Elsevier Ltd.

Texas A&M Agrilife Extension. (TAMU). (n.d.) Constructed Wetland Media. L5459. Texas A&M University, College Station, Texas.

Tomar, Mamta. (1999). *Quality Assessment of Water and Wastewater.* CRC Press Boca Raton, Florida.

U.S. Census Bureau. (2009). Current Housing Reports, Series H150/09, American Housing Survey for the United States: 2009, U.S. Government Printing Office, Washington, DC, 20401.

US Environmental Protection Agency (USEPA). (1993). *Subsurface Flow Constructed Wetlands for Wastewater Treatment*. EPA 832-R-93-008. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (1994). *A Dictionary of Technical and Legal Terms Related to Drinking Water*. EPA 810-B-94-006. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (1998). *How Wastewater Treatment Works… The Basics*. EPA 833-F-98-002. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (2000a). Constructed Wetlands Treatment of Municipal Wastewaters. EPA-625-R-99-010. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (2000b). *Wastewater Technology Fact Sheet Wetlands: Subsurface Flow*. EPA 832-F-00-023. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (2004a). *Primer for Municipal Wastewater Treatment Systems.* EPA 832-R-04-001. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (2004b). *Constructed Treatment Wetlands. EPA 843-F-03-013*. United States Environmental Protection Agency. Washington, D.C.

US Environmental Protection Agency (USEPA). (2008a). *Septic Systems Fact Sheet*. EPA 832-F-08-057. United States Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). (2008b) *EPA's 2008 Report on the Environment. National Center for Environmental Assessment*. EPA/600/R-07/045F. United States Environmental Protection Agency. Washington, D.C.

U.S. Fish & Wildlife Service (USFWS). (1993). *U.S. Fish & Wildlife Service manual*. 660 FW 2 092. U.S. Fish & Wildlife Service. Washington, D.C.

US Geologic Survey-Natural Resource Conservation Service (USGS-NRCS) (n.d.). *A Handbook of Constructed Wetlands vol.1 General Considerations*. (PS5384RSEZ). (L. Davis, Compiler). Washington D.C.: US Government Printing Office.

US Green Building Council. (USGBC). (2013). http://www.usgbc.org/leed/why-leed (accessed November 20, 2013).

Vymazal, Jan. (2009). The Use Constructed Wetlands With Horizontal Sub-Surface Flow for Various Types of Wastewater. Ecological Engineering vol. 35 pp. 1-17.

Vymazal, Jan. (2010). Constructed Wetlands for Wastewater Treatment. Water, 2010, 2, pp. 530-549.

Wang, Lawrence K. (2010). Handbook of Environmental Bioengineering. Humana Press, c/o Springer Science+Business Media, LLC, 233 Spring Street, New York, NY 10013, USA.

WHC. http://www.wildlifehc.org/registry/general-motors-llc-12/ Wildlife Habitat Council. (accessed September 27, 2013).

Wildman, Matthew. (2005). A “green” alternative for wastewater treatment.CE News Issue: October 2005. Zweig White Fayetteville, Arkansas

Wolfe, P. (1999). *World of Water 2000 – The Past, Present and Future*. Water World/Water and Wastewater International Supplement to PennWell Magazines, Tulsa, OH, USA, pp. 167.

Wolverton, B.C., Wolverton, John (2001). Growing Clean Water Nature’s Solution to Water Pollution. WES Inc. Picayune, Mississippi.

## Biographical Information

Geoff Hall was born in Denver, Colorado and grew up in Grapevine, Texas. He developed a love of the outdoors while working at a family sheep ranch in the Rocky Mountains, camping as a Boy Scout, and many other experiences with nature. He received his Undergraduate degree in Landscape Management from Brigham Young University focusing which involved courses such as landscape design, arboriculture, and pest management. His work in the landscape industry has been as a landscape designer, in landscape construction, irrigation design, as a nurseryman, and estimating for a large landscape construction company. He has always enjoyed being in the water whether in the pool, building water features, or by keeping tropical fish in an aquarium. Geoff first learned about bio filtration through keeping aquariums and combined it with his love of water use in the landscape to find the topic of his thesis.