Construct wetlands for wastewater treatment and reuse in North Carolina: Case Study and Community Perceptions.

Abstract:
In the U.S., about 20% of the population is decentralized from wastewater treatment and disposal. The majority of decentralized populations (65%) are located in rural areas where most households rely on the use of conventional onsite treatment such as septic systems for the disposal of their wastewater. Alternative wastewater treatment systems, such as constructed wetlands (CWs) aim to replace conventional systems by offering improved options for onsite wastewater treatment. This includes water reuse which is mainly practiced at centralized communities; however, with population growth and climate change both threatening to reduce water quantity and quality, saving water of highest quality for potable needs should be encouraged and reclaimed wastewater could plug the gap in water demand. Water reuse projects often face barriers related to a negative public perception but these could be mitigated by including impacted stakeholders at the early stages of project design and implementation through community participation and education strategies.

This report provides a review of wastewater treatment and reuse with CWs and a case study on the state of CWs as a water reuse and wastewater management tool in North Carolina. An assessment of community perception from 5 decentralized, resource-poor communities in
North Carolina using a qualitative research tool and key informant interviews is presented. The results from this project demonstrate CWs as an emerging approach in the decentralized wastewater sector of North Carolina. Perception towards acceptance of water reuse is varied within and across the communities interviewed and dependent on the following factors: trust in water officials, water availability, cost, economic gain and proposed endpoint use of reclaimed water. Nevertheless, community representatives tended to perceive CWs somewhat positively in terms of their attractive features for community wastewater management and reuse capabilities. It becomes clear, however, that CWs can only evolve as a viable alternative to onsite treatment with a program of education and outreach.
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Chapter 1

Introduction

Summary:
This chapter will focus on giving an overview on the state of wastewater decentralization and management, the terminology associated with the sector and implication for residential households. Additionally, the concept of natural systems for decentralized wastewater treatment and reuse is introduced focusing on one specific option, namely constructed wetlands (CWs).

1.1—Decentralization and domestic wastewater treatment

Common terminology

A. Domestic wastewater

Domestic wastewater, also referred to as domestic sewage or sanitary sewer, consists of any wastewater generated at residential areas such as from bathing, washing dishes, doing laundry, and flushing toilets (see Figure 1.1). Furthermore, domestic wastewater can be divided into graywater and blackwater as follows:

Graywater is wastewater generated from bathing and washing and not from human or food waste (Asano et al., 2007). It is highly concentrated with salt and minerals from substances
such as detergents and soaps. *Blackwater (sewage)* is wastewater that is concentrated human waste from flushing toilets and food waste from kitchens. It is composed of high concentrations of organic matter, nutrients and pathogens (WHO, 2006).

Generally speaking, domestic wastewater can come from residential, commercial, institutional, recreational and industrial facilities, with comparable chemical and biological compositions at the household level, with differences in flow and volume variation as well as peak production. Some examples of sources are (Crites and Tchobanoglous, 1998):

- Residential: apartment, hotels, trailer parks
- Commercial: airports, bars, department stores, restaurant and shopping centers
- Institutional: school, hospitals
- Recreational: resorts, campgrounds

Composition of wastewater varies across regions and households. Graywater accounts for 70-75% of all wastewater produced at European homes (NSW Health, 2000; Jefferson et al., 2000); while in the U.S it comprises about 50% (U.S. EPA, 2002). Toilet flushing is attributed to 41% of all indoor residential water consumption in the U.S. (see Figure 1.1, U.S. EPA, 2002). Domestic wastewater is also characterized by the variation of wastewater flow at homes, as illustrated in Figure 1.2, which

![Figure 1.1. Typical breakdown of interior water use in the U.S (U.S. EPA, 2003).](image-url)
shows peak flows at a single family residence over a period of 24 hour day (U.S. EPA, 2002).

**Domestic wastewater in small communities**

A small community system by definition is one with effluent discharge of less than 44 L/s or the equivalent of 1 million gallons per day (mgd) (Crites and Tchobanoglous, 1998). Small community systems of interest for this study are decentralized from the sewage distribution system without any treatment and have limited collection (i.e. septic tanks). Anything higher than 44 L/s is usually treated at a municipal level, although CWs may treat higher flows (Stanford et al., 2012)

![Figure 1.2. Peak wastewater flows for single family home (U.S. EPA, 2002).](image)

**B. Conventional wastewater treatment**

Conventional wastewater treatment usually consists of three stages: primary, secondary and tertiary treatment. Primary treatment physically separates suspended solids or solid matter from liquid waste. Secondary treatment consists of breakdown of organic matter through exposure to aerobic bacteria, as well as removal of pathogens and other contaminants. Many municipal wastewater treatment plants use processes such as activated sludge which essentially consists of the loading of microbial communities to provide secondary treatment.
Finally, tertiary treatment or polishing, further removes contaminants remaining in the water (such as nutrients), disinfects to comply with stringent regulations, and produces a stabilizing buffer before intrusion into receiving water bodies.

C. Decentralized wastewater treatment

Decentralized wastewater treatment refers to the collection, treatment and reuse of wastewater at or near its source of generation. The term 'on-site' means close to the location where such treatment would occur. On-site wastewater treatment systems can usually consist of (Crites and Tchobanoglous, 1998):

- conventional systems composed of septic and soil absorption components
- filtration using media such as sand
- natural systems such as wetlands, ponds and lagoons
- separation (gray vs. black water)
- disinfection systems using UV or chlorine.

Conventional methods of wastewater treatment and disposal at decentralized locations usually consists of a septic tank (primary treatment) followed by a soil absorption application such as drainfields or trenches, where water percolates through the soil and is filtered until it reaches the water table (secondary treatment and disposal).

In the U.S, an estimated 20-25% of the population lack centralized wastewater management (U.S. EPA, 2002). Almost half of these are located either in rural U.S and/or the Southeast. As of 2005, 14% of the population, or 45 million people, supplied their own water for domestic
usage from wells (Kenny et al., 2009). Although high urbanization rates attempted to decrease this number, the reality is that a complete centralization of wastewater treatment is unrealistic at times due to factors such as geographical location, lack of resources, rapid population growth and public preferences. Today, we know that one-fourth of all new developments are built with decentralized wastewater treatment (U.S. EPA, 2008). Therefore, appropriate on-site wastewater treatment practices hold a great level of importance for communities from rural to urban areas given that development growth and urbanization is happening at a fast rate.

Decentralization of wastewater treatment has environmental and economic advantages while offering safe and reliable solutions similar to those provided by municipal treatment facilities as well as other benefits (Nelson, 2008). Such systems are flexible and provide alternatives for a wide array of applications for industrial, businesses, clusters or individuals. The most noted benefits have to do with cost effectiveness, sustainability and safety. Other benefits are water quality improvement, creation of green spaces, energy savings, and reuse. However, there continues to be a big push to centralization of wastewater management practices that relies on large infrastructure design and construction which are expensive and are many times cost prohibitive to communities in need. The lack of attention to decentralization is attributed to the disjointed relationships across stakeholders in the wastewater sector (Nelson, 2008).

The environmental benefits of decentralized systems are the links between water conservation and reuse, climate change projections of extreme weather instability, rapid population growth, environmentally sustainable alternatives and integration of natural systems in the complete
water cycle. Additionally, decentralized wastewater treatment plays a role in public health protection. Added incentives to this idea are the possibilities to treat water and reuse the treated effluent for beneficial nonpotable uses. This treated water can serve several functions in un-sewered communities such as recirculation for a direct/indirect potable usage that may be relevant to crop and landscape irrigation, and augmentation of well water. However, the barriers to decentralization have to do with the practical and scientific knowledge heavily shifted toward conventional methods, along with already institutionalized frameworks of wastewater treatment.

1.2—Introduction to constructed wetlands

Wetlands are land areas where there is mostly a water saturated zone in conjunction with soil and vegetation. Saturation can be seasonal or permanent affecting the nature of the soils, type of plants and animal communities according to the U.S. Environmental Protection Agency (U.S. EPA, 2003). Wetlands are found in every continent except for Antarctica, making them important landscape ecosystems for communities. As of 2009 the U.S Fish and Wild life Service reported an estimated 110.1 million acres of wetlands in the conterminous United States (Dahl, 2005). Wetlands have important features that have extensive beneficial characteristics to the entire ecosystem comprised of people, and other living species. Among those benefits, wetlands play an important role in water quality by providing flood control, filtering out pollution, and augmenting receiving waters with improved quality water, among others. Because of these properties, wetlands are often called the earth’s kidneys (U.S. EPA, 2004). In
general, water quality in wetlands is affected by landscape position, water flow, topography, type of soil and vegetation, climate, water chemistry and hydrology.

The inherited natural properties in wetlands that improve water quality have been mimicked in water resource engineering to design systems known as constructed wetlands. Constructed wetlands (CW) are natural treatment systems engineered to replicate the functions of natural existing wetlands. CWs were designed as land-based wastewater treatment consisting of water saturated zones containing either floating or emergent-rooted vegetation. Because of their biological diversity and productivity, natural and constructed wetlands are complex systems involving microorganisms, plants and soils through filtration and transformation processes to remove pollutants from water. Therefore, constructed wetlands take advantage of these properties to treat wastewaters with different characteristics. Some of the types of applications of CWs for different wastewaters range from treatment of acid mine drainage, landfill leachate, and stormwater, to reclamation and reuse. There are two types of constructed wetlands: free water surface flow (FWS) sometimes referred to as surface flow (SF) and subsurface flow (SSF). For the purpose of this report, an evaluation of SSF is presented given its multiple advantages for domestic wastewater treatment over FWS such as odor and vector control, smaller surface area and other design requirements that will be discussed later. SSF constructed wetlands are found in the literature with a variety of names such as artificial and man-made wetlands (in earlier literature), root zone method, hydrobotanical system, soil filter trench, biological-macrophytic, marsh bed, vegetated submerged bed, engineered
wetlands, reed bed, and anaerobic wetlands (U.S. EPA, 1993; Cooper & Hobson, 1989; Skousen, 1997).

**History of Constructed Wetlands**

The use of wetlands to treat water pollution is not novel; they were used by Chinese and Egyptian cultures for wastewater disposal as early as 1904 (Brix, 1994). However, in the 1950s the technology was studied by German scientists at the Max-Planck Institute lead by Dr. Käthe Seidel. Dr. Seidel’s experiments demonstrated that certain vegetative species along with media had the ability to remove contaminants of concern, a range of bacteria, and degrade heavy metals and hydrocarbons. The laboratory findings were demonstrated at full scale trials for different wastewaters in Europe ranging from domestic to industrial and documented significant removal capacities. Later in the 1960s, another German scientist joined the work of Dr. Seidel, (Dr. Kickuth) and laid the ground for what is known as the root zone method, essentially another term for SSF CW that at the time was recognized as a stable format for wastewater treatment by several researchers (Conley et al., 1991).

In the U.S., the study of natural wetlands for treatment of wastewater was undertaken in the early 1970s (U.S. EPA, 1999) when researchers soon realized the environmental impact of dumping waste onto these natural systems where 500,000 wetland acres had been lost each year prior to protective regulations. Given the distress of the nation’s water bodies, the 1972 Clean Water Act (CWA) restricted ‘discharge of dredged or fill material’ to any waters of the U.S., including natural wetlands (Section 404, CWA). Without a doubt, the physical, biological
and chemical characteristics of wetlands facilitated the clean-up of wastewater. However, this came at an elevated ecological price destroying the habitat for many animal and vegetative species, increasing the risk for algal blooms due to higher levels of nutrient infiltration, higher risks of floods due to uncontrolled water flow, alteration of stream and river chemistry and morphology. The clean-up aspect of wetlands sparked an interest in the water resources sector to shift the use of natural wetlands to engineered systems with the same properties. Most of the research in constructed wetlands in the U.S. took place in the 1980s. CWs appeared to be a low cost low maintenance practice for continued use of wetland processes to treat wastewater. Entities such as the National Aeronautics and Space Administration (NASA) and the National Academy of Sciences (NAS) published documents supporting the technology and its potential impact by using variation within the systems design (i.e. different vegetation, substrates, etc.), and combining different systems declaring them hybrid and as solutions for waste management (Wolverton & McDonald, 1976; NAS, 1976; Wolverton, 1982; Nelson et al., 1999; Nelson et al., 2001; Nelson & Wolverton, 2011). In the 1990s, there was an increase in the expansion of wetlands for waste treatment. As of 2004, the EPA reported Europe to have over 5000 CWs, while the U.S had about 1000 (U.S. EPA, 2004).

Natural systems

Natural systems to remediate wastewater, also known as natural wastewater treatment systems, are a widely accepted technology used worldwide. They receive the term due to the enhancement, and integration of existing natural processes that are mimicked to treat wastewater. Some conventional wastewater treatment facilities have integrated natural
systems such as ponds and constructed wetlands components to the overall treatment and to achieve high quality of water. Likewise, natural systems alone have the capability to remediate wastewater through a series of physical, biological and chemical processes. Natural systems can be coupled with pretreatment or with other types of natural systems, known as hybrid systems, to enhance water quality such as having a horizontal wetland structure with plants and media followed by a vertical sand/gravel filter or a pond. Natural systems are a valuable technology for decentralized locations providing plenty of opportunities for successful on-site wastewater treatment for discharge, non-discharge and reuse purposes.

There are several attractive factors encouraging the adaptation of natural systems to treat wastewater; in particular, the low cost and low operation/maintenance (O&M), the flexibility in design specifications to treat different kinds of wastewaters (i.e. industrial vs. domestic, urban vs. rural), and promising combination of treatments for optimization of contaminant removal (Jóźwiakowski, 2009; Vymazal, 2005). The increase in the number of published studies (21 articles in 1991 to 460 in 2011) related to natural systems for treatment of wastewater indicate the potential benefits to adapting such technologies at a larger global scale (Zhi & Ji, 2012).

The main types of natural systems are treatment ponds, treatment wetlands, and terrestrial treatment units. Wetlands consist of natural marshes and constructed wetlands, while terrestrial units consists of slow rate systems, soil-aquifer treatment, overland flow and on-site systems. Some examples of each natural system are waste stabilization ponds or lagoons, free water surface constructed wetlands and soil absorption drain fields. CWs are treatment
systems designed to improve water quality taking advantage of processes found in natural wetlands an in a survey of reuse systems were found to be the most commonly used (Stanford et al., 2012 in press). There are two main kinds of constructed wetlands; free surface and subsurface flow. At the domestic level, SSF is widely accepted as a better treatment system due to beneficial aesthetics effects, and lack of wastewater surface exposure along with other attractive qualities that do not exist in the FWS type.

**Free water surface flow vs. subsurface flow constructed wetlands**

Constructed wetlands can treat common contaminants in wastewater such as nutrients (usually referring to nitrogen and phosphorus), total suspended solids (TSS), organic and inorganic constituents and even bacteria. In FWS water is exposed to the surface while in SSF the water is below the surface (U.S. EPA, 1993; Crites & Tchobanoglous, 1998). Compared to conventional treatment of wastewater, there are many advantages in constructed wetlands, including:

- providing flood protection
- having the capacity to treat multiple contaminants
- considerable lower cost
- serving as a habitat for plants and wildlife
- lowering water and air emissions and secondary waste

Some limitations over conventional wastewater treatment are:

- requirement of larger land areas
• variable consistency in performance depending on climate
• require a constant flow of water
• the anaerobic conditions can produce odors
• treatment may be slower
• they may provide breeding issues for mosquitoes and other pests

In FWS design, flooded emergent vegetation is in a relatively shallow water depth (4-18 in or 1-4.5 cm) with media at the bottom for support. The wastewater is exposed to the air and is treated as it flows horizontally. In a SSF constructed wetland, flow can be horizontal (HSSF) and vertical (VSSF), depending on the design. The emergent vegetation is planted in a suitable depth of porous media that ranges from coarse gravel to sand. The depth of the media bed ranges from 1.5-3.3 ft or 0.45-1 m and there is usually a slope to induce flow in the HSSF (Crites and Tchobanoglous, 1998). The main advantages of the SSF type vs. FWS are:
• flow of wastewater occurs by the roots of the vegetation as opposed to the surface
• reduced risk of odor, exposure to untreated wastewater and insect vectors since water is kept under the media surface
• media provides greater available surface area for treatment at a reduced land area requirement resulting in higher contaminant removal rates
• thermal protection during seasonal changes

Figure 1.3 shows how the different types of constructed wetlands can be integrated into the municipal or domestic wastewater treatment process. Municipal wastewater usually refers to
wastewater of domestic, commercial and industrial origin. The responsibility of municipal entities consists of collection, treatment, analysis and discharge of wastewater in order to comply with the stipulated regulations and permits established through the CWA.

![Diagram of wetland types](image)

**Figure 1.3.** Diagram of the types of constructed wetland and main wastewater treatment method (*WW means wastewater).

Several documents related to constructed wetlands design, performance and maintenance give detailed information about the technology. In particular, one summary article by the U.S. Environmental Protection Agency highlights the design and planning considerations suggesting construction at uplands (high or hilly lands) and outside of floodplains (areas adjacent to water bodies) to protect naturally occurring wetlands and other natural water bodies (U.S. EPA, 2004). The literature and reports also consider the role of the wetland in terms of impact on water quality and land uses in surrounding areas among others. Site-specific factors such as type of media, plants, effect on wildlife habitat are discussed and control measures that tolerate changes of water quality, quantity, depth and flow are encouraged. Finally, the need to allocate a long-term management plan is recognized (U.S. EPA, 2004).
National and international examples of constructed wetlands

At first, constructed wetlands were used in the U.S. for domestic and municipal sewage, but they are now implemented to treat different types of wastewater. The application of CWs for waste treatment of the following has been documented:

- Runoff – urban, agricultural, stormwater (Line et al., 2008)
- Mine drainage (Mays & Edwards, 2001)
- Industrial – chemicals, paper mill, oil refineries (Simi & Mitchell, 1999)
- Food processing – winery, meat, cheese and milk production (Wallace, 1999)
- Landfill leachate (Rash & Liehr, 1999)
- Domestic household water (House et al., 1999)
- Reclamation and reuse (Masi & Martinuzzi, 2007)

The following are brief examples of use of SSF CW for treatment of different kinds of wastewater:

- *Kleru University College in Iringa, Tanzania:* Prior to the installation of a HSSF CW, wastewater treatment at the college used a mechanical aeration system and a pond but ceased operation given the inability of the college to meet the electricity costs. A HSSF CW was then constructed and deemed operational in 2003 to replace the pond while the mechanical aeration system was to be replaced by a septic tank. This aimed to solve issues from the malfunctioning pond that was releasing untreated domestic effluent to the communities downstream (Njau et al., 2011). Some of the effluent water is used for irrigation of vegetable gardens, while the rest is discharged into surface waters. Some
of the general specifications of the system are: 4 HSSF CW cells covering about 625 m² planted initially with a native vegetation species (*Phragmites mauritianus*). The system treats wastewater from 800 students.

- **Tertiary treatment of effluent from a conventional treatment plant in Southern Italy, Sicily:** Full scale HSSF CW at the plant is used for ‘polishing’ the effluent from a conventional wastewater treatment meeting discharge regulations to receiving waters (Barbagallo et al., 2011).

- **Marine Aquaculture Research Center (MARC) in Marshallberg, North Carolina, U.S.:** This is a pilot scale recirculating CW for the treatment of the effluent stream from the MARC facility. The design of the CW is VSSF in combination with FWS cells. The wetland system was reported to successfully treat wastewater prior to discharge with some reuse of the treated effluent for the growth of fish species (Guerdat, 2012).

**International to domestic impact of CW**

Constructed wetlands have had a clear impact in international approaches to mitigate water pollution due to attractive characteristics which include low in cost, easy operation, low maintenance and energy requirements, particularly in nations where waste management continues to pose a significant burden of disease according to the World Health Organization (WHO), and for communities of low socio-economic status or high water scarcity (WHO, 2006). In the U.S. along with other developed nations, the issues concerning waste management are
linked to a more structured approach where most urban and peri-urban locations obtain basic services such as safe water distribution and collection through tax payments. However, even developed nations compared to less developed ones have to deal with fundamental issues of watershed protection, water scarcity and public perception of waste, all of which can inhibit developments of water reuse projects.

**Project Rationale**

Many decentralized communities around the world do not have adequate waste disposal strategies to ensure protection of environment and public health. Although, the use of conventional onsite waste disposal such as septic tanks followed by soil percolation is prevalent, these systems threaten to contaminate water tables, neighboring well supplies, and ultimately receiving waters. In fact, according to the U.S. Environmental Protection Agency (EPA) there are about 41,503 impaired water bodies under the 303(d) section of the CWA. These waters are impaired, meaning with chronic or recurring violations to the water quality criteria, due to contamination of pathogens, nutrients, metals and oxygen depletion. The EPA defines nonpoint sources of pollution as contamination not directly released to the environment but rather originating from several sources over a large area. Among the leading causes of water quality impairment are combined sewer overflows, land disposal, failed septic systems, urban runoff, storm sewers, and other nonpoint sources. Due to this issue, the evaluation of economically feasible and public health/environmentally protective domestic wastewater treatment systems is necessary. This report evaluates constructed wetlands as a
domestic wastewater treatment option for decentralized communities in terms of practice and public perception.

In addition to public and environmental health protection, decentralization in the U.S. comprises over 25% of the population with septic tanks, with over 65% located in rural areas. High urbanization rates cause 1 in 3 developments to be decentralized. Worldwide, it is estimated that the numbers are higher. Imminent events such as population growth and effects of climate change call for a need to protect our water bodies and draw attention to technologies such as constructed wetlands for effective water pollution control. Additionally, issues related to water scarcity in many regions of the U.S. as well as internationally, may emphasize saving water for the highest level of potable need, such as direct human consumption. This has encouraged water reuse such as recycling and reclamation of wastewater for several endpoints, among them replenishment of existing water bodies, agriculture, landscaping, and toilet flushing (Asano et al., 2007).

Decentralized communities are often located in rural areas or far enough from main sewer lines making connections economically unfeasible. These communities can usually be found in clusters, which offer an advantage to technologies such as constructed wetlands. In the Southern U.S., there is an interest to advocate for underserved communities that are either low income or minorities due to the lack of proper sewage infrastructure which cause environmental and public health burdens. As an example, domestic wastewater disposal issues pertaining to these communities in North Carolina is linked to environmental justice issues such
as extraterritorial land use laws (Brulle & Pellow, 2006). Part of this report will discuss the feasibility of introducing constructed wetlands into these communities from the perspective of a range of stakeholders including community organizers, researchers/engineers and local health representatives.

Objectives and Approach

The main objectives of this Master’s report are:

- to give a detailed background on constructed wetlands for treatment of domestic wastewater and water reclamation,

- to gather insight and records from stakeholders associated with decentralized wastewater management in the state of North Carolina as it relates to constructed wetlands, and

- to involve decentralized, resource-poor communities in North Carolina by assessing public perception on wastewater management issues, water reuse and potential implementation of constructed wetlands as an alternative wastewater treatment.
References


Chapter 2

Design of Constructed Wetlands and Implications for Decentralized Domestic Households

Summary

An in-depth review of the components, contaminant removal and design characteristic of CWs is described followed by opportunities for water reuse offered by these systems. Finally, CWs are discussed in terms of three important concepts; (i) economies of scale or cost, (ii) regulations and permitting, and (iii) the notion of viewing wastewater as a resource, instead of for immediate disposal.

2.1—Design components in constructed wetlands

An overview of the most common design parameters driven by pollutant removal is presented. Given the attention CWs received as a potential clean up technology over the past 50 years, several manuals and documentation about the proper design of constructed wetlands for wastewater treatment have been published (Kadlec & Wallace, 2008; U.S. EPA, 1999). A summary on design specifications, removal capabilities and considerations will be discussed in the context of domestic wastewater treatment and reuse capabilities of CW technology.

Constructed wetlands provide secondary treatment at the domestic level without the need to introduce microbes given the inherent microbial communities already in the natural
components of the wetland. CWs also have the capacity to treat wastewater to tertiary treatment standard. In terms of onsite wastewater treatment, CW produces high quality effluents that resemble secondary and tertiary effluent quality (Vymazal & Kröpfelová, 2009)

Conventional methods of wastewater treatment and disposal at decentralized locations usually consist of a septic tank (primary treatment) followed by a soil absorption application such as drainfields or trenches, where water percolates through the soil and is filtered until it reaches the water table (secondary treatment and disposal). Constructed wetlands provide an opportunity to treat effluent to a higher quality than septic tanks prior to discharge into the soil and are often used for secondary and tertiary treatment of wastewater (also known as advanced treatment). At the municipal level, CWs are most often used as a polishing step to ensure nutrient rich waters are further treated (see Figure 2.1), or serve as a natural buffer to replenish surface water, known as indirect potable reuse (IPR).

![Diagram of wastewater treatment process using constructed wetlands.](image)

**Figure 2.1.** Schematic of the wastewater treatment process using constructed wetlands.

The main physical components responsible for water quality improvement in wetlands are vegetation, media, microorganisms, and the influent water itself. These can be further classified as the physicochemical environment, biota and hydrology. Together these systems
influence how treatment is carried out to provide effective design performance for optimal removal efficiencies of wastewater constituents.

**Wetland biota/flora**

Biota in wetlands consists of the animal and plant life (microorganisms and vegetation). In terms of plant life, vegetation are used in FWS and SSF CW with distinctions on the type of plants such as emergent, submerged, free floating or floating leaved. SSF uses only emergent vegetation, meaning that plants are rooted in soil but also have the ability to grow in water and extend out to air surface. Wetlands provide a suitable environment for growth of microbial organisms that are involved in a large proportion of pollutant transformation and removal processes.

**A. Vegetation:**

The general requirements for plant suitability in constructed wetlands to treat wastewater were outlined as follows by Tanner (1996):

- ecological acceptability; i.e., no significant weed or disease risks/danger to the ecological or genetic integrity of surrounding natural ecosystems;
- tolerance to local climatic conditions, pests and diseases;
- tolerance towards pollutants and hypertrophic waterlogged conditions;
- ready propagation, rapid establishment, spread and growth;
- high pollutant removal capacity either through direct assimilation and storage or indirectly by enhancement of microbial transformations such as nitrification (via root-zone oxygen release) and denitrification (via production of carbon substrates).

Aquatic plant diversity has been observed in natural wetlands ranging from large trees to smaller plants, such as cypressess, willows and bulrushes. However, CWs usually incorporate smaller to medium-sized plants mostly to control for root depth. CW designs using different types of aquatic plants have been documented with differences observed on FWS vs. SSF type. Most commonly used plants in CWs are emergent aquatic macrophytes with root penetration between 30 and 60 cm (1-2 ft.) below the soil surface (Brix, 2003). Some examples of emergent aquatic macrophytes used are reeds, bulrushes, sedges, rushes and cattails all of which are found worldwide. Other types of aquatic macrophytes found in natural wetlands are floating and submerged aquatic macrophytes such as duckweeds and elodeids, respectively, which are often used in FWS CW designs. In the U.S., the most predominant emergent type of plants used in CWs are bulrushes and cattails or a combination of the two species. In Europe, reeds such as Phragmites are the dominant type. Table 2.1 summarizes the advantages and disadvantages between the emergent aquatic macrophytes in SSF CW wastewater treatment.

The pH of wastewater usually ranges from 6.5 to 8 (Wilhelm et al., 2005). Therefore, plants that have a large buffering capacity are preferred since they will be directly impacted by the fluctuations in wastewater pH. Another important requirement for plant function is their survival under dry and flood conditions. SSF CWs prefer plant species with rapid growth and
which can tolerate inundation as well as drought periods to avoid issues with complex vegetation management and establishment. Depending on geographical location, high salinity tolerance may be preferred. Usually, species are combined to enhance overall treatment and compliment treatment processes. However, differences affected by geography are notable. For example, invasive nonnative plant species such as Phragmites have been avoided in the U.S due to their aggressive growth and this despite their widely documented use at CW sites in Europe. Instead, cattails are more widely accepted for CWs in the U.S. as an emergent plant species.

Vegetation in CWs is attributed to have several aesthetic beneficial effects such as habitat enhancement, attraction of diverse wildlife, and provision of green spaces. These may not always be feasible. In FWS CW, aquatic animal species are such as muskrats, moose and birds are seen frequently while in SSF CWs, wildlife is less desirable due to limited land area and lack of exposed water. Some emergent aquatic plants are preferred when they serve as a food source or nesting habitat for some species when the endpoint is habitat enhancement, while in other cases this may be a nuisance. The use of other plant species such as canna lilies, elephant ear, and irises for added aesthetic value and appearance has been documented (Surrency, 1993; Neralla et al., 1998; Konnerup et al., 2009).
Table 2.1. Advantages and disadvantages on typical macrophytes vegetation for SSF CWs (Crites et al., 2005; Brix, 1993, Stottmeister et al., 2003, USDA-NCRS, 2003)

<table>
<thead>
<tr>
<th>Type of Emergent Species</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Cattails (Typha angustifolia, Typha latifolia) | • Wide range pH 4 to 10  
• Rapid growth  
• Some species have high salinity tolerance (15-30 ppt)  
• Can be permanently inundated and support droughts | • Shallow root penetration  
• Some species (broad leaf) have low salinity tolerance  
• Seeds are a food source for other animal life  
• Nesting for birds |
| Bulrushes (Scirpus acutus, Scirpus cypernianus, Scirpus fluviatilis) | • Optimum pH 4 to 9  
• Can be permanently inundated  
• Some species have rapid growth  
• Large deep root plant  
• Winter hardy  
• Positive impact on treatment | • Some can tolerate droughts  
• Some species have moderate growth  
• Seeds and rhizomes serve as food source for wildlife  
• Most species have low salinity tolerance (1-5 ppt) |
| Reeds (Phragmites australis) | • Optimum pH is 2 to 8  
• High salinity tolerance (<45 ppt)  
• Very rapid growth  
• Deep root penetration (1.5 ft. or 0.4 m)  
• Low food value for animal species  
• Pest resistant  
• Can be permanently inundated—Winter hardy  
• Very drought resistant | • Invasive pest species in wetlands |
| Rushes (Juncus articulates, Juncus balticus, Juncus effuses) | • Salinity tolerance (0-25 ppt)  
• Well suited for peripheral planting and habitat enhancement  
• Good winter season survival  
• Grows 3 ft. in height and colonizes rock filters well | • Optimum pH 5 to 7.5  
• Slow growth in lateral spread and dense coverage  
• Provide food to bird species and roots eaten by muskrats  
• Can tolerate inundation for < 1 ft. or 0.3 m only  
• Prefer dry down periods |
| Sedges (Carex aquatilis, Carex lacustris, Carex stricata) | • Some species can sustain permanent inundation  
• Well suited for peripheral planting for habitat enhancement | • Optimum pH is 5 to 7.5  
• Salinity tolerance (<0.5 ppt)  
• Growth is moderate to slow  
• Food source to several birds and moose  
• Some species require dry-down period |
Some of the main functions of vegetation in CW are to add surface area for biological growth, help in the filtration of solids remaining from primary treatment, increase the amount of available oxygen entering through the roots, and improve soil permeability (Wood, 1990; Crites & Tchobanoglous, 1998). A particular area of interest in plant function in wetlands is the uptake of nutrients and other wastewater constituents which is usually neglected in the design and overall water quality endpoint objective. In SSF CWs, plants are the major source of oxygen which is responsible for much of the secondary treatment, with limitations on transport from roots to the water column (Brix, 2003). Thermal protection is increased by a litter layer at the top of the wetland. Additionally, plant selection is important as they play an important role in microbial life, hydrologic buffering capacity and water quality achievement. Other enhancements achieved through vegetation are carefully explained by Brix (2003) and Wood (1990) highlighting the importance of macrophytes (see list below). The main roles are physical effects, effects on soil hydraulic conductivity, surface area for attached microbial growth, nutrient uptake, and root oxygen release.

Summary of the major roles of macrophytes in CW (adapted from Brix, 2003).

- insulation during cold climate
- aesthetic pleasing appearance of system
- provide surface area for biofilm attachment
- reduce flow velocity and increase rate of contact with wetland materials
- part of the filtering effect
- contaminant uptake (high removal of metals and nutrients)
• provide oxygen through roots to increase aerobic degradation processes
• prevent clogging of media (particularly in vertical flow systems)

B. Microorganisms in the soil-water matrix:

Microbial communities in CW regulate the vital functions of wastewater treatment within the wetland (Wetzel, 1993). The CW environment is a combination of aerobic and anaerobic spatial gradients in which complex habitats of microbes are supported including bacteria, protozoa, fungi and viruses (Zhou et al., 2009). The two main kinds of microbes responsible for wetland treatment are bacteria and fungi due to the assimilation, transformation and recycling of chemical constituents (Kadlec and Wallace, 2008). For the most part, SSF CWs are anaerobic. However, oxygen transport from the roots of the vegetation enables aerobic population of microorganisms to foster as well. Therefore, the transformation and mineralization of wastewater constituents such as nutrients and organic pollutants are carried out by microorganisms in CW (Stotlmeister et al., 2003). Accepted pathways of contaminant metabolism are aerobic (mainly at the roots) and anaerobic processes such as nitrification-denitrification and sulfate reduction (Cooper et al., 1996; Vymazal, 2005). The structure of microbial communities and their role in removing contaminants in CW has been given a lot of attention lately with studies focused on pathogen removal, metabolism of pollutants and their overall impact in the wastewater treatment in CWs (Gersberg et al., 1989; Rivera et al., 1995; Perkins & Hunter, 2000; Quiñónez-Diaz et al., 2001; among others).
Microbial communities in SSF CW are predominantly attributed to the transformation and removal of not only pollutants but also reduction of pathogens of concern through processes such as predation, and interaction with biofilms. Several processes affect the microbial ecosystem formation in CWs to increase efficiency and removal of pathogens and microorganisms. Primarily for SSF CWs, the microbial growth occurs directly on the media (usually sand or gravel) and at the roots or submerged parts of the plants. Therefore, treatment performance improves with detention and contact time and is dependent on oxygen availability and temperature (Crites et al., 2005).

Physiochemical environment

A. Substrate media:

For SSF CW, the media has a direct role on physical and chemical processes for removal including filtering any remaining solids or particles after pretreatment, serving as a surface for bacteria attachment, and establishing a base for plant growth. Inherently, the soil matrix has a decisive influence on the level of treatment achieved by impacting hydraulic processes based on chemical soil composition and other physical parameters. Some of the most important substrate physical parameters are: type, size, uniformity, porosity, surface area, and hydraulic conductivity (Stottmeister et al., 2003). Selection of media based on these parameters is critical at the design stages of CWs to ensure appropriate flow conditions and overall performance.

The substrate used in CWs is generally inert material allowing a period of colonization of bacteria that with time forms biofilm sheets around the surface area of media grains. The void
spaces created in the media bed lining serve as flow channels in SSF and the overall treatment is a combination of microbes attached to roots, rhizomes and media surface. At the bottom of the CW, impermeable lining is recommended to avoid infiltration below the treatment cell and seepage of contaminants, and to encourage water saturation by inhibiting percolation. Clay liner or geotextile is often used followed by compacted top soil (minimum thickness of 12 inches). However, alternative synthetic liners have been studied such as asphalt, butyl rubber and plastic membranes.

The standard types of substrate media more widely accepted for domestic wastewaters in the treatment bed are gravel and sand due to their high specific surface area and medium porosity (~20-50%) which facilitate improved Biochemical Oxygen Demand (BOD) removal and nitrification (Burgoon et al., 1995). To avoid clogging, gravel is usually pre-cleaned and free of fines and the largest-diameter medium is placed in the inlet zone. Some common values for gravel size used for the treatment bed are between 0.12 in to 1.25 in (3-32 mm) which is a range between coarse sand, gravelly sand and medium gravel (effective size, d10, are 2, 8 and 32 mm, respectively). Sand is sometimes used to filter smaller particles that usually bypass the gravel material due to their grain size. Sand is inexpensive and has an ideal texture when planting emergent vegetation (Davis, 1995). The depth of SSF CW is in the range 18-30 in (450 mm to 750 mm) while typical rooting depths are from 6 to 12 in (Crites & Tchobanoglous, 1998).
In summary, the following are important characteristics of substrates in constructed wetlands (Davis, 1995):

- support living organisms in wetlands
- movement of water due to substrate permeability
- chemical and biological transformation take place within substrates
- microbial attachment and increase of organic matter breakdown drives biological reactions
- water saturation enhances a reducing environment for removal of nitrogen and metals.

Hydrology

Hydrological conditions are the most important feature in the performance and functional indicator of wetlands success. To fully mimic the efficient environment of a natural wetland, a functional CW needs to create and maintain the correct water depth and flow. Hydrological conditions influence soil and nutrients which determine the character of the biota. The length of time water spends in the treatment zone depends on the flow and storage volume capacity of the wetland. The properties of water movement, distribution and quality are all connected in the wetland design affected by hydraulic factors related to bed media size, conductivity and clogging. Flow of water through porous media, roots and rhizomes is not a simple mechanism and dismisses assumptions of steady flow conditions generally used in water design. Instead, hydrological considerations in the design of wetlands should take into account several concepts around depth and flow, namely: volume of water, hydroperiod, infiltrative capacity, evapotranspiration, hydraulic loading rate (HLR) and hydraulic residence time (HRT), water
budget and balance, wetland storage, and climate-weather. In CWs there is flexibility to
maneuver the design to cover a range of scenarios and applications. Long term sustainability is
attributed to hydrological conditions, and design and sizing of wetlands are partly based on
flow rate and gradients (Hedges et al., 2008). An explanation of the hydrological factors listed
above now follows (Reed, 1990; Kadlec and Wallace, 2008; Hedges et al., 2008):

- **Hydroperiod**: refers to the depth and duration of a flooding according to seasonal
  pattern of water level fluctuations. Therefore, hydroperiod is a key determinant for the plant
  community structure which is essential for the successful operational design of CWs. The
  selection of plants for treatment should be based on tolerance of hydrological conditions, such
  as survival in low oxygen soils, and continuous flooding (Mitsch and Gosselink, 2000).

- **Hydraulic loading rate (HLR)**: refers to the loading on a water volume per unit area
  basis. It can be described in the equation, HLR = (parameter concentration)(water volume/
  area). Proper sizing of CW is needed for effective treatment to avoid water flows that are too
  rapid or stagnant. Additionally, permanently flooded wetlands perform better than those that
  seasonally dry out.

- **Hydraulic residence time (HRT)**: refers to the average time that water remains in
  the wetlands, and it can be expressed in the following equation:

  \[
  HRT = \frac{\text{mean volume}}{\text{mean outflow rate}}
  \]

  It is closely related to HLR because the length of time water stays in the wetland enhances
  treatment processes such as sedimentation, adsorption, nutrient retention and other
  biochemical reactions. HRT is dependent on the wetland size and outlet zone. The outlet zone
is recommended to be smaller than the inlet zone to increase HRT allowing water to remain longer in the treatment bed resulting in higher effluent quality.

- **Infiltration capacity**: refers to the ability of water to move across the wetland media onto the soil bed and percolate vertically or laterally affecting flow and retention of water. To avoid pollutant infiltration, liners are used.

- **Water budget and balance**: relates to the inflow, storage, and outflow of water in a CW over a period of time. The major contributors to the water balance are drainage, precipitation and evapotranspiration (evaporation or plant transpiration). The amount of inflowing wastewater along with runoff and rainfall add to the total water volume. In SSF CWs, the outflow and water loss is governed by the outlet zone where treated water goes, infiltration of water passed the treatment bed (usually negligible when liners are used), and losses to the atmosphere. Water balances need to be estimated at the design phase to account for seasonal variation and expected wastewater production. Choices on the design components are made accordingly for the selection of appropriate vegetation, media (size, type and distribution). The following equation, assuming steady state, describes the water storage capacity of a wetland:

  \[
  \text{Net change in storage} = \text{Inflow (wastewater, rainfall and runoff)} - \text{outflow (evapotranspiration, treated water out, net infiltration)}
  \]

- **Climate and weather**: SSF CWs are not open to the atmosphere which allows for water to be treated year round regardless of the climatic conditions (Mæhlum & Stålnacke, 1999). Usually contaminant removal in CWs increases with higher temperatures due to enhanced rates of biological reactions (Shammas, 1986; Mæhlum & Stålnacke, 1999; Akratos & Tsihrintzis, 2007).
In general the processes by which wetlands remove pollutants and pathogens continue to be studied; however, the consensus in the scientific community credits pollutant removal and efficiency to the complex interactions between the ecosystems of plants, soils and microbes.

Figure 2.2. Schematic showing the design components of CWs and relationship within wetland components (Mitsch & Gosselink, 2000).

Figure 2.2 (above) shows the integrated relationship that exists between the physiochemical environment, biota and hydrology of CW as explained throughout this section. Externalities that can affect the treatment process of CW as shown in the graph are climate and geomorphology given that they are inherent to the environment, site-specific and unable to be controlled by design.

2.2—Common wastewater constituents in CWs and their removal

The constituents of wastewater are highly dependent on the previous use of the water be it from industrial, municipal or domestic operations in terms of quantity and occurrence. As
mentioned earlier, wastewater treatment is a three-step process; primary, secondary and tertiary treatment. Primary and secondary treatments remove most of the BOD and suspended solids. However, in order to comply with U.S. regulations such as those prescribed by the National Pollutant Discharge Elimination System (NPDES) permits and/or water reuse guidelines, a tertiary treatment is also used. Nutrients such as nitrogen and phosphorus have more complex pathways of removal needing oxygen for transformation reactions to enhance nitrification-denitrification and also adsorptive capacity for physical removal of phosphorus (Crites & Tchobanoglous, 1998; Vymazal, 2007). When high quality water is achieved it may be recycled in order to increase water supply availability directly or indirectly, and even replenish water bodies without a high pollution load which could otherwise cause issues such as eutrophication and algal blooms.

The removal and uptake of these wastewater constituents has been studied extensively in hybrid natural systems, which increase the removal rates significantly producing high quality water (Vymazal, 2005). Hybrid natural systems are combinations of treatment technologies; for example, SSF CW can be coupled with an anaerobic filtration step to enhance total nitrogen and phosphorus removal given that the design of the wetland alone may not satisfy the water reuse guidelines. A summary of the most common constituents and pollutants in wastewater, with an emphasis on removal mechanisms as they relate to domestic wastewater treatment through CWs, is presented below. Depending on the concentration of pollutants, wastewater is classified as low or high strength. Table 2.2 displays the concentration of untreated domestic
wastewater as it relates to the most common contaminants removal efficiencies found in the literature.

Table 2.2. Range of pollutant concentrations found in untreated domestic wastewater and their removal efficiencies in CWs

<table>
<thead>
<tr>
<th>Contaminant (mg/L)*</th>
<th>Range (Low to High Strength)</th>
<th>Removal (%)^*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>100-350</td>
<td>87-93</td>
</tr>
<tr>
<td>BOD 5 day, 20 C</td>
<td>110-400</td>
<td>65-86</td>
</tr>
<tr>
<td>Nitrogen total as N</td>
<td>20-85</td>
<td>20-70</td>
</tr>
<tr>
<td>Organic</td>
<td>8-35</td>
<td>--</td>
</tr>
<tr>
<td>Free ammonia</td>
<td>12-50</td>
<td>--</td>
</tr>
<tr>
<td>Phosphorus total P</td>
<td>4-15</td>
<td>10-40</td>
</tr>
<tr>
<td>Organic</td>
<td>1-5</td>
<td>--</td>
</tr>
<tr>
<td>Inorganic</td>
<td>3-10</td>
<td>--</td>
</tr>
<tr>
<td>Total coliform (CFU/100 mL)</td>
<td>$10^6 \text{ to } 10^9$</td>
<td>99 (2 log)</td>
</tr>
<tr>
<td>Fecal coliform (CFU/100 mL)</td>
<td>$10^3 \text{ to } 10^7$</td>
<td></td>
</tr>
<tr>
<td>Cryptosporidium oocyst (CFU/100 mL)</td>
<td>$10^3 \text{ to } 10^2$</td>
<td>44-100</td>
</tr>
<tr>
<td>Giardia lamblia cysts (CFU/100 mL)</td>
<td>$10^{-3} \text{ to } 10^3$</td>
<td>88-100</td>
</tr>
</tbody>
</table>

*Concentration is mg/L unless otherwise specified  ^CFU stands for colony forming units
^Values obtained from Gersberg et al., 1989; Graczyk et al., 2009; Solano et al., 2004; Crites and Tchobanoglous, 1998)

A. Metals

These are comprised of mostly minerals and metals in their elemental form such as sodium (Na), calcium (Ca), copper (Cu) and zinc (Zn). Metals can originate from a wide variety of sources such as stormwater runoff, and leaching of piping materials (Sansalone & Buchberger, 1997; Sörme & Lagerkvist, 2002).

B. Organic Matter

Organic matter is a complex mixture of compounds such as proteins, carbohydrates, lipids, and emerging contaminants within a multi-step process of degradation. Removal of organic matter
is largely attributed to aerobic and anaerobic zones in wetlands. Aerobic bacteria break down organics by using oxygen with an end product of energy and biomass, while anaerobic bacteria break down organics producing methane. An indication of the presence of organic matter is usually provided through BOD which measures the amount of oxygen consumed by microorganisms to break down organics.

- **Other constituents of concern:** Common wastewater constituents in domestic wastewater in CWs have been extensively studied. However, other relevant contaminants of concern in terms of occurrence in wastewaters represent an emerging research area as natural wastewater treatment technologies are more widely accepted. Some examples are steroids and hormones, alkyl phenols, pesticides, and pharmaceutical and personal care products (PPCPs).

- **Oil and Grease:** Combination of fats, oils, waxes and other lipid-like products found in domestic wastewater originate primarily from bathrooms and kitchens. Bacteria breakdown is slow and so these can be a nuisance in pretreatment such as the settling tank by adding a scum layer and causing clogging due to compaction. At the pretreatment phase, oil and grease tend to float and can inhibit oxygen from reaching the water, thus increasing its overall oxygen demand and enticing anaerobic conditions for gas formation such as hydrogen sulfide and nitrogen gas. Oil/grease removal and inhibition entering the treatment wetland is achieved by adding grease traps in the
design or accounting for pretreatment basins that will ensure separation from effluent water (Crites & Tchobanoglous, 1998).

C. Nutrients

Wastewater is often loaded with large amounts of nitrogen and phosphorus in the forms of nitrate and phosphate, which promote plant growth. Failure to treat for nutrients can result in eutrophication, growth of aquatic plants, and oxygen depletion which can be devastating to the ecosystem of receiving waters.

• Nitrogen: There are several forms of nitrogen species important in the wastewater treatment cycle, listed below. Organic matter and ammonia are the primary forms of nitrogen in raw wastewater.

  • Organic nitrogen: refers to carbon-bound nitrogen and constitutes the main type of nitrogen found in fecal matter. This also includes urea, which is the primary component of urine. Through hydrolysis reactions, organic-nitrogen is converted to ammonia.

  • Nitrate (NO$_3^-$): is a regulated groundwater pollutant (10 mg/L as NO3-N). It is the most highly oxidized form of nitrogen.

  • Nitrite (NO$_2^-$): is an easily oxidized and unstable nitrogen form that quickly forms nitrate. It is toxic to fish and other aquatic species when it exceeds 1 mg/L after stabilization. It is usually formed through biochemical reactions that involve microbes.

  • Ammonium (NH$_4^+$): by-product of the simple digestion of organic nitrogen.
- **Nitrogen gas (N₂):** is an inert/non-reactive form of nitrogen. It is readily available in the atmosphere but it can also be produced through the nitrogen cycle.

Nitrification is the biological oxidation of ammonia to nitrate. It consists of a two-step process that starts with the oxidation of ammonia to nitrite and then nitrite to nitrate. The nitrification process is attributed to two groups of chemolithotrophic bacteria, which are microorganisms that use inorganic compounds as energy sources: strictly chemolithotrophic, or strictly aerobic bacteria (i.e. *Nitrosomonas*), for the oxidation of ammonia to nitrite, and the facultative chemolithotrophic bacteria, or organisms that mix different sources of energy (i.e. *Nitrobacter*), for the oxidation of nitrite to nitrate (Vymazal, 2007). The most frequently used parameter to test for removal efficiency of nitrogen is total nitrogen (TN) which accounts for the sum of ammonia, nitrate, nitrite and organic nitrogen, but not nitrogen gas. Optimal removal of nitrogen requires aerobic and anaerobic environments. A two-step process known as nitrification-denitrification allows for incoming nitrogen to be transformed through aerobic bacteria metabolisms that interact with ammonia (NH₃) and carbon dioxide (CO₂) to form nitrates (NO₃) and hydrogen gas (H₂). Denitrification is anaerobic and it occurs as carbon interacts with NO₃ forming nitrogen (N₂) and CO₂. However, if denitrification is not complete harmful compounds such as nitrates and nitrous oxides can be released into the effluent. The overall nitrogen cycle and processes are summarized in Table 2.3 and in Figure 2.3.
<table>
<thead>
<tr>
<th>Process</th>
<th>Process Description</th>
<th>Transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatilization</td>
<td>Physicochemical</td>
<td>ammonia-N (aq) → ammonia-N (g)</td>
</tr>
<tr>
<td>Ammonification (Mineralization)</td>
<td>Multi-step biological conversion through biochemical process that releases energy</td>
<td>organic-N → ammonia-N</td>
</tr>
<tr>
<td>Nitrification</td>
<td>Two-step biological oxidation mainly done by bacteria from the Nitroso group</td>
<td>ammonia-N → nitrite-N (intermediate) → nitrate-N</td>
</tr>
<tr>
<td>Nitrate-ammonification</td>
<td>Anoxic oxidation after oxygen depletion done by nitrate reducing bacteria</td>
<td>nitrate-N → ammonia-N</td>
</tr>
<tr>
<td>Denitrification</td>
<td>Irreversible nitrate conversion only in anaerobic or anoxic conditions</td>
<td>nitrate-N → nitrite-N → gaseous N₂, N₂O</td>
</tr>
<tr>
<td>N₂ Fixation</td>
<td>Conversion using a complex enzyme, <em>nitrogenase</em></td>
<td>gaseous N₂ → ammonia-N (organic-N)</td>
</tr>
<tr>
<td>Plant/microbial uptake (assimilation)</td>
<td>Variety of biological process inorganic nitrogen forms into organic</td>
<td>ammonia-, nitrite-, nitrate-N → organic-N</td>
</tr>
<tr>
<td>Ammonia adsorption</td>
<td>Cation exchange</td>
<td>--</td>
</tr>
<tr>
<td>Organic nitrogen burial</td>
<td>Fractions of organic nitrogen that become unavailable for nutrient cycling</td>
<td>--</td>
</tr>
<tr>
<td>ANAMMox (anaerobic ammonia oxidation)</td>
<td>Anaerobic conversion</td>
<td>ammonia-N → gaseous N₂</td>
</tr>
</tbody>
</table>
Figure 2.3. Simplified Nitrogen Cycle (NESC, 2012).

- **Phosphorus (P):** In wastewaters, phosphorus is often in the form of orthophosphates (PO$_4^{3-}$) to the most hydrogenated form (H$_3$PO$_4$ as a function of pH), polyphosphates and organic phosphates (Asano et al., 2007). Orthophosphates are available for biological metabolism without further breakdown while polyphosphates can have several P atoms in a molecule and can revert to orthophosphates through a slow hydrolysis process (Crites & Tchobanoglous, 1998).
Contribution of phosphorus in domestic wastewater is from food residue, human waste and consumer products such as detergents. Phosphorus is also a limiting nutrient in freshwater making it the main cause of eutrophication in surface waters (Yeoman et al, 1988). Optimal removal of phosphorus is dependent on chemically bonding to or adsorbing onto treatment media, loading rate, detention time, and plant uptake (Crites and Tchobanoglous, 1998). Other removal mechanisms of phosphorus in CWs are complexation and precipitation reactions with metals such as aluminum (Al) and calcium (Ca).

D. Suspended solids
Removal of suspended solids in SSF wetlands is highly dependent on hydraulic design (settling velocity and aspect ratio) and microbial characteristics. Most of the removal happens at the pretreatment or the inlet zone. Given that domestic wastewater contains a significant amount of solids, pretreatment is necessary prior to entering the SSF CW to avoid clogging and further reduction of hydraulic conductivity.

E. Pathogens
Pathogenic organisms are broadly classified as bacteria, parasites (protozoa and helminthes) and viruses. Many pathogenic organisms are present in the fecal matter; therefore, they are a main component of domestic wastewater. There are several factors affecting the removal of pathogens in wetlands that can increase the CW process efficiency: soil type, temperature, adsorption, soil clogging, soil moisture, predation, antagonism, and nutrients.

- Soil type – lower porosity better at removing, physical straining
- Temperature – thrive at body temperature
- Adsorption – adsorbed to soil particles; the smaller the particle size, the greater the surface area
- Soil clogging – biomat increases the removal efficiency
- Soil moisture – need moisture to survive and will usually die off in dry soils
- Predation – part of the food chain in other microbial communities
- Antagonism – antibiotics present in water may cause them to die-off
- Nutrients – die-off if there is a lack of nutrients

Table 2.4. Domestic wastewater constituents and removal mechanisms compared to current issues and solutions in SSF CWs (Crites & Tchobanoglous, 1998; Crites et al., 2005; Kadlec & Wallace, 2008)

<table>
<thead>
<tr>
<th>Wastewater constituents (parameter tested)</th>
<th>Removal mechanism</th>
<th>Issues</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids Turbidity (NTU) or TSS (mg/L)</td>
<td>Sedimentation, interception, filtration</td>
<td>Accumulation at the inlet zone, biological growth in media, clogging</td>
<td>Effective primary treatment, using different types of media</td>
</tr>
<tr>
<td>Organic matter ( \text{BOD}_2 ) or Other used such as ( \text{COD} )</td>
<td>biodegradation, sedimentation and filtration</td>
<td>Variation on organic matter, Oxygen limitation</td>
<td>Plants that provide higher oxygen transfer rates, hybrid systems</td>
</tr>
<tr>
<td>Nitrogen ( \text{(Total Nitrogen (TN), and other N species) } )</td>
<td>Biodegradation, plant uptake, volatilization</td>
<td>Aerobic and anaerobic conditions are needed</td>
<td>Add oxygen units in the design. Hybrid systems</td>
</tr>
<tr>
<td>Phosphorus ( \text{Total Phosphorus (TP) } )</td>
<td>Adsorption, sedimentation, plant uptake</td>
<td>Removal is limited to adsorptive capacity</td>
<td>Increase adsorption sites in CW. Use hybrid systems</td>
</tr>
<tr>
<td>Pathogens ( \text{Indicator bacteria in colony forming units (CFU) } )</td>
<td>Sedimentation, filtration, crop uptake, predation, natural decay</td>
<td>High removals achieved but disinfection is still require to comply with regulation</td>
<td>Add physical disinfection such as UV to avoid introduction of chemical disinfectants</td>
</tr>
</tbody>
</table>
2.3—Design considerations in CW

One of the main issues in SSF CWs directly connected with hydrological parameters is clogging, and flow resistance. The hydraulic conductivity equations for CWs are based on steady flow conditions using the flow regime of water through porous media modeled by Darcy's law (U.S. EPA, 1993; Kadlec & Wallace, 2008). Darcy's law assumes laminar flow that is constant and uniform (steady state); more turbulent flows are modeled with the Ergun equation (Kadlec & Wallace, 2008). However, these equations are largely dependent on characteristics of media such as mean particle diameter, shape, porosity, arrangement and variance. Wetlands should be designed and constructed to have a wide media size distribution, with larger particle size at the inlet zone to avoid clogging and smaller sized particles in the treatment bed for effective treatment. Particle size distribution is also dependent on the type of SSF CW (i.e. VSSF or HSSF). Additionally, water flow variation is likely in wetlands given the outflows and inflows described in the water budget, uneven media porosity and construction flaws (Crites et al., 2005). Darcy's law can only give reasonable approximations when gains and losses are considered, moderate sized gravel is used as media, proper construction that avoid short circuiting is done and gradient or slope are added.

Since CWs are built with washed media or 'clean bed' to avoid further clogging from fine dust or soil, at the beginning of use no biota establishment has occurred. With time, plant roots, rhizomes and biofilms establish in the wetland contributing to clogging which adds resistance to the flow of water beyond what was projected for the media alone. Once the wetland is
operational, there will be a decrease in hydraulic conductivity caused by sediment deposition and accumulation at the inlet zone, precipitation of chemicals and biomat formation (Kadlec & Wallace, 2008). In order to overcome the resistance, energy is required. This energy can be obtained by creating a differential head pressure between the inlet and outlet of the wetland (and a slope or gradient at the bottom as shown in Figure 2.4. Other ways to compensate for issues related to clogging in the design is the aspect ratio, or length-to-width, since resistance increases as length increases. High aspect ratios are not necessary and have caused wastewater overflow in many operational systems (Crites et al., 2005), additional physical attributes that need to be considered when deciding on aspect ratios are flow rate, outlet height, hydrology and vertical percolation. Clogging causes vary with the system design and operation conditions dealing with biomass, root networks, plant detritus, and loss of media porosity (Vymazal, 2010).

![Typical SSF CW Configuration](image)

**Figure 2.4.** Typical configuration of a SSF CW (WERF, 2010)

A design manual by Kayombo et al. (2005) showed the use of natural systems (waste stabilization ponds and constructed wetlands) to remediate water in Tanzania, Africa. The
proposed design highlights the importance of these two systems in tropical climates and how CWs should receive more attention as an alternative wastewater treatment. The design limitations in CWs identified in this manual were:

- **process rates** where factors such as temperatures, oxygen and pH can determine the rate at which chemical and biological processes occur. Higher temperatures enhance pollutant removal due to higher metabolic activity while low temperature has the opposite effect. Oxygen availability can affect aerobic processes and, hence, anaerobic processes are also impacted. In terms of degradation, pH is important to treatment.

- **hydrological limitations** are mentioned in terms of the capacity of a wetland with respect to quantity of water and pollutants. An overload of water and/or pollutants beyond the design capacity affects the retention time needed for optimized pollutant removal.

- **wetland nitrogen process** recognizes the complexity involved with the reactions of nitrogen species in the wastewater through nitrification-denitrification, biological processes which are affected by the presence of the appropriate bacteria, oxygen availability with an appropriate BOD concentration, temperature, and pH.

- **phosphorus removal** which occurs through several underlying processes (sedimentation, adsorption, and filtration). However, low removal is attributed to a redox potential where low oxygen (anaerobic) content affects the phosphorus cycling mechanism by liberating it from media onto water.
The main design criteria relevant to domestic small decentralized communities are the primary and secondary treatment schemes that can be achieved through natural hybrid systems. Several EPA documents outline the design parameters relevant to the common wastewater contaminants described earlier. Most, if not all documents reviewed, agreed on the importance of having a primary treatment that traps or settles suspended solids. Additionally, at the secondary steps, plants are a major component on CWs; their roots are essential to the treatment process due to the uptake of chemicals, addition of oxygen that aids pollutant transformation into less toxic forms through aerobic processes, and they also foster conditions for aerobic microorganisms to proliferate.

2.4—Water reuse capabilities of CWs

Water reuse is currently a major area of research due to its direct value impact on drought-prone and water scarce areas such as in the Western U.S, United Arab Emirates and Australia. The field is often described as water reclamation or water recycling and involves the treatment of wastewater to a quality level that permits for reuse of water for a beneficial purpose. The end product is referred to as reclaimed or recycled water. Water reuse aims to produce higher quality water according to its next allocated purpose such as aquifer recharge, crop irrigation, or toilet flushing. Historically, the widespread acceptance of water reuse has been unnecessary due to abundant availability of natural water supplies causing people to perceive water as a one-time use only instead of a renewable resource. Therefore, the management of wastewater has largely been fixed by using a template of design and infrastructure with little room for innovation. Ideas related to “flush and forget” at a centralized level or “drop and store” at
decentralized locations have impacted public acceptance of wastewater reuse. As water scarcity grows, negative perceptions on water reuse may decrease allowing for expansion on applications of indirect and direct potable use. A focal point of this document is to evaluate perceptions in communities that are rural, underserved, decentralized or lack proper wastewater management practices.

In September 2012, the EPA released an updated version of the Water Reuse guidelines (U.S. EPA, 2012). Besides public perception, other concerns about water reuse in terms of pollutant removal are an area of extensive research. Common domestic wastewater constituents recorded in the literature are nitrogen, phosphorus, TSS, turbidity, fecal coliform and BOD. Extensive research literature has demonstrated that at the domestic level and with implementation of natural wastewater treatment, the removal of wastewater pollutants can be achieved at high rates (House et al., 1999; Konnerup et al., 2009; Kayranli et al., 2010). Table 2.5 compiles the pollutant level guidelines for various levels of water reuse that may be relevant to decentralized systems.

With respect to water reuse guidelines and natural systems for water reuse, there are two main categories relevant to the subject of onsite wastewater treatment and reuse for agricultural and environmental purposes. *Agricultural use* implies for food crops (destined for human consumption, Type 2—regulated in 27 states) and processed food/non-food crops (processed before consumption or not for human consumption, Type 1—regulated in 43 states).
**Environmental use** (regulated in 17 states) refers to the reuse of water to 'create, enhance, sustain, or augment water bodies including wetlands, aquatic habitats, or stream flow.'

**Table 2.5.** 2012 water reuse guidelines for urban, environmental and agricultural reuse (extracted from U.S. EPA, 2012).

<table>
<thead>
<tr>
<th>Wastewater constituent</th>
<th>Urban un/restricted</th>
<th>Environmental use</th>
<th>Agricultural use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BOD (daily max)</strong></td>
<td>15 mg/L</td>
<td>15 mg/L</td>
<td>15 mg/L</td>
</tr>
<tr>
<td><strong>TSS (daily max)</strong></td>
<td>10 mg/L</td>
<td>10 mg/L</td>
<td>10 mg/L</td>
</tr>
<tr>
<td><strong>Turbidity (max)</strong></td>
<td>10 NTU*</td>
<td>Missing this guideline</td>
<td>10 NTU</td>
</tr>
<tr>
<td><strong>Bacterial indicators</strong></td>
<td>25/100 mL</td>
<td>25/100 mL</td>
<td>25/100 mL</td>
</tr>
<tr>
<td><strong>Ammonia as NH3-N</strong></td>
<td>6 mg/L*</td>
<td>6 mg/L</td>
<td>6 mg/L</td>
</tr>
<tr>
<td><strong>Phosphorus</strong></td>
<td>-</td>
<td></td>
<td>1 mg/L</td>
</tr>
<tr>
<td><strong>Nitrogen</strong></td>
<td>-</td>
<td></td>
<td>4 mg/L</td>
</tr>
</tbody>
</table>

Some consequences of onsite wastewater treatment discussed in the 2012 guidelines are related to intensification of monitoring and stringent water quality standards, concerns about human health protection and public acceptance. Residential treatment technologies for water reuse require increased levels of monitoring and the use of advanced filtration and disinfection. Another challenge for implementing water reuse is the wide level of variability on water quality standards at the global scale for irrigation purposes. Concerns about untreated wastewater for irrigation have been addressed by World Health Organization (WHO, 2006). In general, the EPA guidelines make a distinction between gray and black waters, demonstrating more public acceptance on reuse of gray water systems that exclude toilet waste.
Unfortunately, the 2012 guidelines provide little information on domestic wastewater
treatment technologies for reuse purposes. It is clear that some states such as Arizona and
California have regulations and documentation that support the widespread use of water reuse
whether it is for indirect or direct potable use. Likewise, drought-prone areas across the globe,
such as the Middle East, view water as a precious resource and water reuse is widely practiced
without much burden caused by public perception. For the most part in North Carolina, the
current regulatory laws on water reuse restrict applications to those with indirect human
contact, prohibiting replenishment of hot water bodies (spas, hot tubs, or swimming pools) and
direct reuse for raw potable supply (NC DENR, 2011). However, irrigation of food chain crops
with reclaimed water is allowed as specified earlier depending on the type of crop (Type 1 or 2)
(NC DENR, 2011).

Table 2.6 outlines the performance of 14 SSF wetland monitored by EPA in 1993 by comparing
to the 2012 water reuse guidelines for each contaminant in the environmental reuse category
(Environmental reuse is defined by EPA as “the use of reclaimed water to create, enhance,
sustain, or augment water bodies including wetlands, aquatic habitats, or stream flow”).

<table>
<thead>
<tr>
<th>Wastewater Constituents</th>
<th>Mean SSF Effluent Concentration (mg/L)</th>
<th>Mean Percent Removal (%)</th>
<th>Environmental Reuse guidelines (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅</td>
<td>8* (1-15)§</td>
<td>71</td>
<td>&lt;30</td>
</tr>
<tr>
<td>TSS</td>
<td>10 (3-23)</td>
<td>83</td>
<td>&lt;30</td>
</tr>
<tr>
<td>TKN as N</td>
<td>9 (2-18)</td>
<td>40</td>
<td>--</td>
</tr>
<tr>
<td>NH₃/NH₄</td>
<td>5 (2-10)</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>NO₃ as N</td>
<td>3 (0.1-13)</td>
<td>67</td>
<td>--</td>
</tr>
<tr>
<td>TN</td>
<td>9 (7-12)</td>
<td>55</td>
<td>4</td>
</tr>
<tr>
<td>TP</td>
<td>2 (0.2-3)</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Fecal coliforms (CFU/100 mL)</td>
<td>57000** (10-330,000)</td>
<td>79</td>
<td>200</td>
</tr>
</tbody>
</table>

*Mean value  
**Requires disinfection of 1mg/l chlorine residual according to most recent EPA Water Reuse Guidelines.  
§Range of values

The performance of SSF CWs, according to Table 2.6, shows a significant removal of common domestic wastewater contaminants. When compared to the EPA guidelines for environmental reuse, the treatment achieved was optimal except for TN, TP and fecal coliforms levels. However, the levels of other parameters such as BOD, TSS, as well as other nitrogen species were well below the reuse guidelines which may allow more flexible applications, such as agricultural reuse Type 1. This indicates that SSF CWs have the ability to treat wastewater to high quality effluents, although disinfection and advanced treatment is needed for removal of pathogens as well as nutrients. The values from the performance of the SSF CWs were obtained in 1993 but given that CW designs have improved and are better understood, more recent studies on performance of these systems might indicate even better pollutant removal.
Public perception

Given that public perception is a major barrier to water reuse, chapter 4 of this report will give a detailed review documenting the factors that affect individual and community decisions to adopt reuse technologies. Furthermore, the chapter will include a perception study in 4 rural decentralized communities in Eastern North Carolina.

2.5—Economies of scale in CW

Overall CW represents a low cost technology when compared to big-pipe wastewater infrastructure projects. However, there are factors that affect the cost of CW such as treatment goals, media type, pretreatment type, number of cells, availability of plant/media materials and terrain (ITRC, 2003). Capital cost is largely driven by (Crites et al., 2005):

- land costs
- site investigation: Includes surveying costs and investigations about soil and groundwater conditions
- clearing and grubbing: Removing vegetation or other construction nuisances at the site
- excavation and earthwork
- liners and plants: Different materials may be used depending on regulatory requirements to protect underlying groundwater. Plants should be locally sourced and could include building an onsite nursery. For small scale CW plantation can occur by hand.
- inlet and outlet structures: Requires purchase of pipes
• Distribution systems: Piping is required for transporting wastewater from where is
generated to the wetland.

Other miscellaneous cost items such as additional fees related to engineering design, regulatory
framework and construction should also be considered.

The high capital cost is mainly affected by gravel and liners (about 53%), although other
components contribute but to a lesser extent. The construction cost to install a conventional
municipal wastewater treatment plant with a capacity of 3 mgd is in the range of one to three
million dollars (U.S. EPA, 1993). Constructed wetlands, by comparison, are 50-90% lower and
operating costs are low (Kadlec & Wallace, 2008). Cost and feasibility of SSF CW can be
impacted by site specific conditions such as total land area to be used, construction consistency
with design terms, landscape and energy requirements, regulation requirements for effluent
quality and maintenance. SSF CW had capital costs in the U.S. of about $200,000 per hectare
while for FWS CW it was about $50,000 (U.S. EPA, 1993). However, SSF CWs treat wastewater
faster which has an economic advantage to the productivity of the system, along with added
protection from exposure to and higher observed removal of common pollutants (U.S. EPA,
1993; ITRC, 2003).

2.6—Regulations and permitting process overview

CWs are used at a wide range of locations including homes, public places and commercial
development and so it is critical to look at the regulatory framework involved in their adoption.
Discharges from CWs are normally regulated under the NPDES permits. Water reuse applications are managed at the state level given that they are not federally regulated. Many states have internal oversight and work closely with local departments to ensure domestic level applications and are following protocols or developing new ones as the technology starts expanding. Constructed wetland implementation encounters other regulatory issues with regard to performance, contingency plans, and potential ecological impacts. Some important considerations include (ITRC, 2003):

- plan selection (nonnative, invasive or noxious)
- identification of treatment mechanism
- accounting for seasonal variation in terms of performance and maintenance
- time from design to operation
- sustainability with regards to future use and population growth
- balance between water quality improvement and regulatory standards.

In the state of North Carolina, water reuse occurs at domestic, municipal and industrial facilities. The management of wastewater is mainly governed by its "hazardousness" and endpoint such as discharge to surface water, onto land surface or on-site (Safrit, 2010). Discharge into surface water is regulated through the NPDES permit program. This program mainly applies to municipal and industrial facilities since according to the regulation 'individual homes that are [either] connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit.' Under the NPDES permit, domestic wastewater facilities are classified as homes, schools, shopping/business centers, and places
that generate domestic quality wastewater. As of 2010, NC had 495 domestic wastewater
cfacilities with an NPDES permit (Safrit, 2010). Additionally, non-discharge wastewater
management is regulated by the state through the NC Division of Water Quality (DWQ). Non-
discharge permits are usually related to land surface application of treated wastewater with
limited applicability since effluent fails to meet reclaimed water standards. Some of the non-
discharge domestic applications in NC treating 7 mgd or less are single family spray systems,
lagoon systems and high rate infiltration systems. There were a total of 56 permitted private
domestic water reuse systems, mainly for irrigation, infiltration, and energy with varying
capacities. As an example, the Jordan Lake business center located in Chatham County, NC is a
water reclamation and reuse facility that serves over 60 employees generating about 60 mgd
using hybrid natural system technologies.

The EPA Water Reuse Guidelines (2012) confirms that the state of North Carolina undertakes
reuse of reclaimed water for several categories such as agricultural reuse. The guidelines show
no regulation of indirect potable reuse (IPR) or for groundwater recharge to a nonpotable
aquifer except for storage and recovery in accordance with statute G.S 143-214.2 that prohibits
discharges of waste to subsurface or groundwater unless for a groundwater remediation
system. Environmental reuse and restricted and unrestricted impoundments regulations are not
specified in the state. However, water reuse for agricultural purposes whether it is for direct
consumption or not has been regulated depending on the crop type (edible, Type 2 or non-
edible crops, Type 1). Type 2 represents higher quality water and the regulation requires a dual
disinfection. Additionally, NC is the only state in the 2012 guidelines that has added regulations for two other indicator organisms (Coliphages and C. perfins) (U.S. EPA, 2012).

2.7—Turning waste into a resource:
Given the extent to which decentralized onsite wastewater treatment is practiced in the U.S. and around the world, there is a need to address and pay attention to the challenges faced in this field. Treated wastewater is already reused on a regular basis either by direct (i.e. golf course irrigation) or indirect applications such as discharge into surface waters that provide downstream drinking water sources for others. Therefore, the notion that water is a one-time use resource is incorrect. The nature of water is to be recycled and renewed and systems such as constructed wetlands demonstrate that optimal onsite treatment can be achieved for discharge and reuse applications. Some advantages to CWs in terms of turning waste into a resource at decentralized locations are to provide additional water sources for nonpotable use and during dry periods, further treat wastewater beyond conventional onsite methods (i.e. septic tank) to protect the integrity of other drinking water sources such as wells, improve water conservation measures through reuse, and add a valuable aesthetic effect through emergent vegetation or green spaces.

Some of the major challenges inhibiting widespread use of wastewater as a resource are (Converse, 2004):

- Poor to no management
• Lack of education across stakeholders
• Lack of national organizations for promotion
• Public perception

Domestic wastewater is about 99.8% water, and the terminology associated with it usually has undesirable connotations that enhance further negative perceptions. Drought-prone areas have demonstrated successful projects on water reuse and continue to be used as a template to propagate the technology.
References


National Environmental Service Center (2012). Minimizing nitrogen discharges from onsite wastewater systems. Pipeline, 23(1).


Chapter 3

State and local regulations for onsite wastewater treatment and water reuse and utilization of constructed wetlands: Case study of North Carolina

Summary:

Conventional methods for onsite wastewater treatment, also known as septic systems, continue to be the main type of wastewater treatment used at households in the state of North Carolina (NC). This chapter starts by placing septic systems in the context of environment and public health protection, and displaying relevant details related to design and performance at the household level. Consequently, this chapter summarizes the current regulatory framework for onsite wastewater management (treatment and reuse) at the state and county level, as it relates to conventional septic systems and to the use of constructed wetlands. To better grasp the extent of constructed wetland applications in NC, examples are provided from current systems used for stormwater, industrial and domestic level wastewater treatment and reuse providing general motives for CW installation, design and public acceptability.

3.1—Septic systems and groundwater: Design, failure and public health protection

The most widely used onsite wastewater treatment in NC is conventional septic tank followed by a drainfield (see Figure 3.1 for a diagram of the basic design). The septic tank aims to retard wastewater flow to form a sludge layer at the bottom and a lighter floating scum layer at the top. The liquid in-between is the effective volume and this overflows to the drainfield. The wastewater retention time for septic tanks is a minimum of 24 hours; however, this can be
affected by buildup of scum and sludge layers if they are not pumped out of the system or maintained. At the septic tank the major pollutant removal, especially BOD and TSS, occurs by separation of solids (settling) and their anaerobic degradation (digestion) which is enhanced by the limited supply of oxygen. Through fermentation and anaerobic oxidation microorganisms hydrolyze organic molecules, produce gases (methane, carbon dioxide, nitrogen gas, and others at trace amounts), and reduced ammonia (Wilhelm et al., 2005). The extent to which some pollutant removal occurs at septic tanks is also a function of retention time of the wastewater.

**Figure 3.1.** Cross sectional view of a conventional septic tank (adopted from the Florida Department of Health, Charlotte County website: http://www.doh.state.fl.us/chdcharlotte/EH/BasicSeptic.html)

Strictly speaking according to NC state rules, the drainfield is a set of perforated pipes (at least 6 inches) below the soil surface connected to and protruding (at least 24 inches beyond) from the septic tank outlet to discharge the clarified effluent either through a pump or in some instances gravity feed. Pumps are installed to ensure uniform discharge throughout the piping,
while in gravity feeds there are pipes favored for discharge into soil due to the lack of pressure and design. In general, smaller systems rely on the overflow of effluent from the septic tank to then be transported to the drainfield, whether by pumps or gravity. The depth of the drainfield trench ranges from 6 inches to 3 feet below the soil cover. The discharged effluent into a subsurface gravel trench allows water to infiltrate into the soil where microorganisms consume the organic matter and particles that remain in the effluent are entrapped. With time, the growth of bacteria creates a biomat in the soil between the interface of the naturally occurring unsaturated soil and the gravel serving as a biological filter. Hydraulic conductivity is affected by grain and pore size, as well as effluent loading that contributes to the rate of infiltration. Once the effluent goes through the biomat, the environment is mostly aerobic with unsaturated soils initially that enhance degradation. As the soil becomes saturated, anaerobic conditions increase which limits sorption and degradation and ultimately leads to septic system failure. The size of the septic system usually depends on the household size (number of bedrooms) and soil percolation rates, or the long term acceptance, which is a measure of the capacity of the soil to accept effluent infiltration (Konsler, personal communication, 2013).

Septic tank failure is largely attributed to high levels of suspended solids and BOD leaving the septic tank, which in turn can affect the infiltration capacity at the drainfield causing hydraulic failure and surfacing of effluent or ‘back-up’ (Charles et al., 2005). The effectiveness of the biomat is reduced when septic tank clean-up is inadequate causing an overload of excess organic material and accumulation of solids in the effluent. Biomats are attributed the
hydraulic conductivity of the system and not the soil (Wilhem, 1994). Other causes of septic tank failure are:

- Uneven distribution of effluent into the drainfield: This leads to higher loading in some areas which result in saturated flow and decreased infiltration (Reneau et al., 1989).
  
  Clogging can be prevented through uniform distribution of effluent.

- Changes in the infiltration rate can decrease efficiency of treatment. Slow infiltration rate can cause ponding and clogging of the wetland, while fast infiltration rates have the opposite effect in which effluent bypasses the soil without adequate treatment (Cogger et al., 1988).

- Soil clogging can develop from improper septic tank treatment which leads to concentrated effluents, increasing the accumulation of organic matter

- Grease capping is caused by accumulation of lipids that cuts off oxygen intrusion

- Outdated designs or lifetime of septic tanks.

- Improper design or installation and inadequate maintenance

- Excess water usage and unsuitable soil conditions.

Many of the issues related to system malfunction are associated with lack of maintenance or operation. Overall, failing septic systems can be attributed to two main types of failure: 

*hydraulic failure or treatment failure*. Hydraulic failure, which is more common, occurs when infiltration rates are exceeded by the loading rate of effluent into the drainfield and as a result water surfaces. Treatment failure is less obvious and can lead to groundwater with either a
shallow water table or surrounded by saturated soils infiltrated with effluent that has not been adequately treated (Beal et al., 2005).

The rate of failure in septic tanks across the U.S. has been reported to be between 1 and 5% each year (De Walle, 1981). However, higher percentages have been seen in some regions with some states reporting failure rates of 30% or higher (Vedachalam et al., 2012); data for the state of North Carolina are non-existent. The U.S. EPA indicated 20% of all septic systems are either malfunctioning or over 30 years old (US EPA, 2002). The lack of data and recent studies on septic failure estimates, even at a national level, show that there is not a comprehensive data set, and that there is lack of literature on the subject. Leachate from septic systems has been identified as a major potential source of ground water contamination due to intrusion of pathogens, nutrients, pharmaceuticals, hormones and other household chemicals (Hagedorn et al., 1981; Yates, 1985 Seiler et al., 1999; Gerba and Smith, 2005), all contaminants of concern in domestic wastewater. Likewise, many residences with septic systems depend on wells as a drinking water source which can also be at potential risk for contamination (DeSimone et al., 2009). The close proximity of wells and septic systems make them particularly vulnerable to pathogen contamination when there are high sand fraction soils and shallow unconfined aquifers (Scandura & Sobsey, 1997; Humphrey et al., 2010; Henry 2012). Another concern with groundwater contamination has to do with nutrient loading specifically from nitrogen in the form of nitrate in the effluent that causes blue baby syndrome (Knobeloch et al., 2000). Additionally, the most common cause of water borne disease outbreaks have been due to well water contamination by septic systems (Yates, 1985). In 2003, the U.S. EPA reported more than
168,000 viral and 34,000 bacterial illnesses due to inadequately treated contaminated groundwater used for drinking purposes (U.S. EPA, 2002). Between the years 1971-2006, Craun et al. (2010) found an inverse correlation in waterborne outbreaks increasing from individual wells and decreasing from public drinking water systems. The occurrence of outbreaks was linked to surface water intrusion or sewage discharges (Craun et al., 2010) with 71% of them traced to private residencies. Recent studies predict that rural domestic well water in North Carolina is threatened by infiltration of land applied pesticides, naturally occurring metals deposits such as arsenic, and fecal contamination from septic systems (Sahoo et al., 2005; Sanders et al, 2012, Heaney, 2004). Concerns about microbial contamination from septic systems into surface water bodies, such as the Neuse River Estuary in NC, have been documented (Fries et al., 2006).

State and local departments regulate domestic wells and septic systems in terms of design and maintenance. However, many of the regulations were set prior to the construction of existing infrastructure. Regulation to prevent contamination uses minimum requirements usually set by horizontal distances between wells and drainfields/trenches. These old regulatory measures were not usually established from any scientific evidence, which has triggered a few recent studies to provide more regulatory guidance on approaches that can help determine appropriate setback distances using modeling (Horn & Harter, 2011). Additionally, the addition of advanced treatment technologies to septic tanks may assist in compliance regulations and site conditions but could also protect groundwater from contamination.
3.2—Permitting agencies in North Carolina

In terms of wastewater treatment and disposal, two main state agencies provide oversight and permits; the Department of Health and Human Services (NC DHHS) and the Department of Environment and Natural Resources (NC DENR). The On-Site Water Protection Branch (OSWPB) in the environmental health section of the NC DHHS implements statewide regulations related to collection and subsurface onsite wastewater treatment and disposal in conjunction with the Division of Environmental Health (DEH) at the local health departments. NC DENR houses the NC Division of Water Quality responsible for overseeing North Carolina's NPDES and the Aquifer Protection Service (APS) Division program aiming to protect NC surface and ground waters (U.S. EPA, 2002). Any entity (individual or industrial or community) wishing to discharge treated or untreated wastewater to any surface water must obtain an NPDES permit, while those interested in discharging wastewater through subsurface land application obtain an APS permit. Given that permitting of onsite wastewater systems is based on the endpoint of the treated water, domestic locations including individual homes or clusters, and businesses could be permitted by either agency. For example, a septic system that discharges treated wastewater to a stream or by surface drip irrigation will be permitted by NC DENR while a conventional drainfield with wastewater percolating through the soil into the water table requires permits from the NC DHHS.

Relevant regulations for households with onsite wastewater systems

More than one-third of the homes in the southeastern states depend on septic systems for wastewater disposal, including 48% of homes in North Carolina. At the federal level, the U.S.
EPA has supported the use of drainfields for dispersion of onsite wastewater due to simplicity and low cost as long as site conditions are suitable (U.S. EPA, 2002). However, the U.S. EPA does not federally regulate these systems; instead, regulations are set by the states. Regulations for onsite wastewater treatment, such as septic systems and advanced wastewater pretreatment systems (AWPS, systems that are placed after septic tanks prior to the drainfield) in NC are implemented by individual counties, based on the status quo set by the state standards. In NC, only three counties (Orange, Guilford and Wake Counties) made slight adjustments to the state regulations (Berkowitz, personal communications, 2013).

I. **Subsurface disposal at households: Environmental Health Services county health department**

In North Carolina, the counties have an important role in setting standards related to septic systems, as well as their operation and maintenance. All counties are to abide by state regulation but have the power to set more stringent parameters or add new ones. For example, the NC regulation specifies all parameters in which counties are to comply but the counties can decide to follow state regulation or adopt county specific guidelines. Given this notion, one area where there can be variability in septic system regulation is the vertical distance allowed between the bottom of the drainfield trenches and the seasonal water table. This vertical distance set by NC regulation is about 30 cm but there is evidence that this distance is too small to ensure adequate treatment and protect groundwater (Cogger et al., 1988) without accounting for system design/flaws or seasonal changes on water table. As a
result, treated water from conventional onsite treatment systems may leach into the groundwater (Woodson, 2003).

County health departments can choose to adopt the Laws and Rules for Sewage Treatment and Disposal Systems (15A NCAC 18A .1900 et. seq.) or place more stringent parameters to permit septic systems and AWPS. There are three main application steps through the DEH at local health departments to comply with requirements prior to the building of dwellings for sewage treatment and disposal in this order; 1) an improvement permit, 2) a construction authorization permit, and 3) an operation permit. An improvement permit is issued for sites that have acceptable soil conditions to support a septic system. Following that, a construction authorization allows for the installation of septic system prior to issuance of any building permits. Finally, an operation permit is issued specifying the system type, performance, operation, maintenance, monitoring and reporting (see Table 3.1). Therefore, county health departments regulate septic system installation by conducting soil and site evaluations and ultimately permitting for design and installation to comply with regulations related to other water body proximity (i.e. 100 feet from public/private water source and 50 feet from lakes for conventional septic system), as well as drainfield depths and other site specific conditions.
### Table 3.1. Classification, description and maintenance requirements for onsite wastewater treatment systems regulated by NC DHHS (adopted from the 15A NCAC 18A. 1900).

<table>
<thead>
<tr>
<th>System Classification</th>
<th>System Description*</th>
<th>Management Entity</th>
<th>Minimum Inspection or Maintenance Frequency</th>
<th>Reporting Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Privy, chemical toilet, incinerating toilet, other toilet system, grease trap</td>
<td>Owner</td>
<td>N/A(^1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Type II</td>
<td>Conventional septic system (single family or ≤ 480 gpd(^2)), conventional system with shallow placement or with 750 linear feet of nitrification line or less</td>
<td>Owner</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Type III</td>
<td>Conventional septic system &gt; 480 gpd excluding single family residence, septic system with single effluent pump or siphon, gravity fill or dual gravity field system, PPBPS(^2) system (gravity dosed), other nonconventional trench systems</td>
<td>Owner</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Type IV</td>
<td>Any system with low-pressure pipe (LPP) distribution, systems with more than one pump or siphon</td>
<td>Public management entity with a certified operator or a private certified operator</td>
<td>2/yr.</td>
<td>12 months</td>
</tr>
<tr>
<td>Type V</td>
<td>Sand filter pretreatment, any &gt;3000 gpd septic system with a nitrification field designed for &gt;1500 gpd, Aerobic Treatment Unit (ATU), other mechanical, biological, chemical pretreatment plant (&lt;3000 gpd)</td>
<td>Public management entity with a certified operator or a private certified operator</td>
<td>Varies between 1/week to 12/yr. depending on system size</td>
<td>6 months</td>
</tr>
<tr>
<td>Type VI</td>
<td>Any &gt; 3000 gpd system with mechanical, biological or chemical pretreatment system plant, wastewater reuse/recycle</td>
<td>Public management entity with a certified operator</td>
<td>Varies between 1/week to 12/yr.</td>
<td>3 months</td>
</tr>
</tbody>
</table>

\(^{1}\) gpd= gallons per day  
* All the systems require the following permits: improvement, construction authorization, and operation  
\(^{2}\) N/A = does not required minimum inspection, maintenance or reporting frequency by state regulation  
\(^{2}\) PPBPS prefabricated permeable block panel systems.
In the NC state regulations, there is a classification system and level of management for onsite wastewater treatment systems (see Table 3.1). AWPSs are often used to obtain permitting on sites that otherwise would have been denied for conventional septic systems. The type of AWPS used can be determined by three effluent parameter limits (described in Table 3.2); NSF-40, TS-I, and TS-II. NSF-40 systems refers to individual residential wastewater systems in accordance to the standards set by NSF International under NSF/ANSI standard 40 that are approved and listed by the General Statutes (G.S. 130A-342). TS-I and TS-II refers to AWPS approved in accordance to effluent quality standards set by state rule 15A NCAC 18A .1970. The level of treatment required is specified on a case-by-case basis. Most subsurface treatment requires influent sampling from the septic tank prior to entering the advanced treatment unit (See Table 3.2 for specification on state regulations).

Table 3.2. Influent and effluent quality standards for AWPS under 15A NCAC 18A .1900 rules.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent Quality Standards</th>
<th>Effluent quality standards depending on treatment endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NSF-40*</td>
</tr>
<tr>
<td>Carbonaceous Biochemical Oxygen Demand\textsuperscript{3} (CBOD, mg/l)</td>
<td>N/A</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/l)</td>
<td>200</td>
<td>&lt;30</td>
</tr>
<tr>
<td>Ammonium Nitrogen (NH4-N, mg/l)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Nitrogen (TN, mg/l) (TN is Kjeldahl Nitrogen plus Nitrate + Nitrite-Nitrogen)</td>
<td>100\textsuperscript{*}</td>
<td>N/A</td>
</tr>
<tr>
<td>Fecal Coliform (FC, colonies/100 ml)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fats, Grease and Oil (FOG, mg/l)</td>
<td>30</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\textsuperscript{3}CBOD differs from BOD, in that it only measures the oxidation of carbons present in water, while BOD measures oxidation of carbons and nitrogenous compounds.

\textsuperscript{*}Refers to the level of treatment required NSF-40, TS-I and TS-II.

\textsuperscript{*}Units are in Total Kjeldahl Nitrogen, TKN instead of TN
In case a permitted system fails, the local health departments will work with owners and/or contractors, whichever the case may be, to fix the problem and avoid any penalties; however, failure to repair within a certain period of time can lead to court action or administrative fees. County health departments are notified of failing septic tanks by homeowners or operators, as well as complaints; however, there is no comprehensive program on the documentation of septic system failure. At the county level, when a septic system fails, the owner is to apply to the DEH for an improvement permit to repair.

Some county health departments provide inspections on septic systems and other onsite wastewater treatment for those seeking a building permit to make changes or purchasing real estate property. A cost is usually associated with the inspection either by the local health department or private companies with certified inspectors through the North Carolina Onsite Wastewater Contractor Inspector Certification Board (NCOWCICB). In general, conventional septic systems are the cheapest option for onsite wastewater treatment and disposal requiring minimal oversight from external contractors once a permit is obtained (usually Type I-III system classifications in Table 3.1). High rates of permit denial for improvement permits in some NC counties are common due largely to unsuitability of soil and other restrictive factors set by shallow aquifers, and setback distances (Konsler, personal communication, 2013). Potential property buyers or homeowners then have the option to consider installation of advanced wastewater pretreatment systems to offset these challenges, and overcome factors affecting the permitting process in order to comply with current rules. However, conventional systems
are much cheaper to build, while advanced pretreatment system are priced at a premium. The commitment to build on a certain lot of land may drive the use of alternative options for onsite wastewater treatment particularly for land owners. However, site specific economic development (commercial and industrial dwellings) is usually impacted by improvement permit denials in which dwellers explore sites that enable the cheaper solution to onsite wastewater management; i.e. conventional septic systems.

The DHHS issues an Onsite Wastewater Activity Report that documents the information reported to the On-Site Wastewater section by the county health departments. The report shows the number of new or denied permits (improvement, construction authorization and operation permits), types of permit and well activity among other description subjects. The reports are available online (http://ehs.ncpublichealth.com/osww_new/new1/progimprovteam.htm) and date back to 1995. Those dated from 1995-2004 have a more complete and specified listing of the type of operation permit (Type I through IV, shown in Table 3.1), while those from 2005 to 2010 specify operation permits by specific system installed instead of the type. Most conventional septic systems are type I-III (Personal Communications with Steve Berkowitz, 2013); therefore, the reports prior to 2005 facilitate the estimation of malfunctioning conventional systems with some assumptions. Figure 3.2 show the statewide data reported from counties from 1995 to 2010 (except 2005, since it is not available) on improvement permit denial and repairs along with construction authorization repairs. In particular, improvement permit denials are associated with site and soil conditions that inhibit the placement of conventional septic systems, opening a door for alternative pretreatment options for
developers, homeowners, etc. Improvement permit repairs have also declined over time possibly due to the overturn of site conditions by taking advantage of pretreatment options, or less development. However, stratification of the data by county may illustrate areas where conventional onsite wastewater permitting is less likely. The county does not keep records on the number of failing septic tanks. Some of the AWPS approved by the DEH are subsurface drip irrigations systems, intermittent pressure dosed sand filters, and many other innovative and experimental designs.

![Onsite wastewater treatment permits--denial and repairs from 1995-2010*](image)

*Data for 2005 is not available.

**Figure 3.2.** Improvement and construction permit denial and repairs from 1995-2010

Under state regulations, beyond conventional, modified or alternative systems, there are other onsite wastewater treatments systems not specified in the rules for AWPS and are categorized as innovative and experimental systems (I&E). These are classified in four categories:
innovative, controlled demonstration, accepted and experimental systems. These technologies can include pretreatment, soil absorption methods, and other onsite wastewater treatment and disposal. In order to be approved and included in the state rules, an application needs to be submitted to the NC DHHS followed by a presentation to the I&E committee followed by a round of reviews and a vote (15A NCAC 18A .1969). Currently, constructed wetlands in NC are approved as an experimental wastewater system.

II. Surface disposal at households in North Carolina: NC DENR regulations

The permitted effluent parameters set by DENR and DHHS differ in terms of limits and monitoring requirements. The parameters set by DENR are BOD, TSS, fecal coliform and total residual chlorine (see Table 3.3), while DHHS looks at the same parameters plus nitrogen species and fats, oils and grease (FOG) as shown in Table 3.2. It is possible for households and/or residential clusters to be permitted through DENR if the endpoint of the treated wastewater is discharged through surface, such as spray/drip irrigation systems. However, in terms of public health protection measurements at households, the parameters set by DENR have less stringent effluent limits and monitoring frequency than those permitted by DHHS. DENR general single family residence (SFR) permits (< 1000 gpd domestic wastewater) for NPDES are described in Table 3.3, which are currently the same parameter guidelines used by the APS permitting. SFR are not required to operate and maintain systems through a certified operator and sampling procedures for the parameters tested are carried out annually. The limits are specified in the general permit; however, they do not specify how monthly average and daily maximum values relate to annual monitoring requirements.
Table 3.3. Single family residence (SFR) general NPDES permit with effluent limitation and monitoring requirements adopted from NPDES wastewater permit # NCG550000-SFR" (Adopted from http://portal.ncdenr.org/c/document_library/get_file?uuid=022feeb9-4eb7-49bd-ba7e-e9a92adadbf8&groupid=38364).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limits</th>
<th>Monitoring requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly Average</td>
<td>Daily Maximum</td>
</tr>
<tr>
<td>Flow</td>
<td>Annually</td>
<td>Estimate</td>
</tr>
<tr>
<td>BOD₅, 20°C</td>
<td>30.0 mg/L</td>
<td>45.0 mg/L</td>
</tr>
<tr>
<td>TSS</td>
<td>30.0 mg/L</td>
<td>45.0 mg/L</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>200 / 100 mL</td>
<td>400 / 100 mL</td>
</tr>
<tr>
<td>Total Residual</td>
<td>Annually</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"wastewater discharge flow may not exceed 1000 gpd

"Instream chlorine levels are not to exceed 17 μg/L. The sample shall be taken from the effluent pipe, prior to discharge.

"Given this is the general permit used as a template by NC DENR for SFR, the limits are not representative. As of April 4th, 2013, NC DENR released a Notice of Intent to Reissue the SFR general NPDES permit.

**Construct wetlands in the permitting process**

Construct wetlands for sewage treatment is widely practiced in the U.S. particularly in the southern states of Florida, Georgia and Louisiana. Under the current NC state regulations, CWs are an approved experimental treatment technology that can be used between a septic tank and the drainfield. This poses an alternative option for permitting sites lacking suitable soil conditions to install conventional systems. The attraction of the technology compared to other onsite advanced treatment systems is the added aesthetic effects by the emergent vegetation, low cost and maintenance as well as low energy requirements. However, the level of treatment (secondary to tertiary) produced by CW has elicited some attention for water reuse applications in place of discharge to soil. Such application requires another permit usually through the NC DENR APS division, or treated on a case-by-case basis through the DHHS.
Discharge or Non-discharge wastewater? NPDES and Water Reuse permits at the State level

The regulatory framework for wastewater management in NC is determined by the following (Safrit, 2010):

i. whether wastewater is considered hazardous or non-hazardous, or

ii. whether wastewater is discharged to surface waters (NPDES), onto the land surface (non-discharge), or subsurface (on-site).

The NPDES discharge program manages three categories; domestic, municipal or industrial. Domestic refers to homes, business centers, schools and other locations that generate similar domestic quality wastewater. In the case of municipal and industrial wastewater the categories are refined in major or minor facilities that are determined by amount of flow and complexity of wastewater. As of 2010, there were a total of 1026 permitted facilities in NC under the NPDES disposal program with 495 facilities being categorized as domestic.

Non-discharge categories for wastewater management are divided into 4 main categories (NC DENR, 1996): high rate infiltration systems, spray irrigation systems, lagoon systems and single family spray systems. Under these categories, there were 818 non-discharge facilities in NC as of 2010 of which 497 where single family spray systems with an average flow of 0.2 mgd occupying 1 Ac-Ft/Day or a total of 250 Ac-Ft/Yr (Safrit, 2010). Other types of non-discharge facilities are the 115 water reuse systems with an average flow of 59 mgd of which 58 are non-municipal water reuse systems including 56 which were private-domestic with an average flow
of 0.21 mgd (Safrit, 2010). The non-municipal reclaimed water is used mainly for energy/industry (20%), infiltration (13%) and irrigation (67%) purposes.

**Current water reuse regulations in North Carolina**

Recently, North Carolina has updated the water reuse rules developed in 1988 under the 15A NCAC 2H. Reuse applications for golf course irrigations had been permitted by DWQ as early as 1988, along with other smaller domestic reuse/reclamation projects in Chatham County.

However, the extent of water reuse had been limited to unrestricted and restricted urban reuse and industrial reuse (U.S. EPA, 2004), which correspond to 3 out of 10 categories of water reuse. This inhibited the expansion of water reuse applications such as groundwater recharge, environmental reuse and indirect potable reuse.

Currently, North Carolina has only moderate experience with small reuse systems, but there has been a growing recognition that water reclamation would offer relief from a number of water quality and supply pressures in the state (Okun, 2002; Safrit, 1995; Manuel, 2008; Bastian, 2008). The reclaimed water standards in NC (15A NCAC 02U) require effluent to be treated to tertiary quality prior to storage, distribution, or irrigation and are shown in Table 3.4. There are two primary uses for reclaimed water under state rules; 1) used in a beneficial manner, and 2) for conservation purposes in order to reduce water resource usage.
Table 3.4. Current reclaimed water effluent standards in North Carolina (NC DENR, 2011).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type 1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Type 2&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly average</td>
<td>Daily maximum</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (BOD&lt;sub&gt;5&lt;/sub&gt;, mg/L)</td>
<td>≤ 10</td>
<td>≤ 15</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/L)</td>
<td>≤ 5</td>
<td>≤ 10</td>
</tr>
<tr>
<td>Ammonium (NH&lt;sub&gt;3&lt;/sub&gt;, mg/L)</td>
<td>≤ 4</td>
<td>≤ 6</td>
</tr>
<tr>
<td>E. coli/Fecal Coliform (FC, colonies/100 mL)</td>
<td>≤ 14</td>
<td>≤ 25</td>
</tr>
<tr>
<td>Coliphage (colonies/100 mL)</td>
<td>NR&lt;sup&gt;c&lt;/sup&gt;</td>
<td>NR</td>
</tr>
<tr>
<td>Clostridium perfringens (colonies/100 mL)</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Turbidity (maximum, NTU)</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<sup>c</sup> NR= not regulated

<sup>a</sup> Type 1 treated wastewater effluent is applied for wetland augmentation, land surface, direct or indirect irrigation of food chain crops that will be peeled, skinned, cooked or thermally processed before consumption.

<sup>b</sup> Type 2 treated wastewater effluent can be applied for indirect contact irrigation of food chain crops that will not be peeled, skinned, cooked or thermally processed before consumption.

Note: reclaimed water cannot be utilized for direct contact irrigation with food chain crops that will not be peeled, skinned, cooked or thermally processed before consumption.

The design criteria for wastewater treatment facilities using reclaimed water are described for new and expanding conjunctive vs. non-conjunctive system rules. A conjunctive system as defined by the state rules is "a system where the reclaimed water option is not necessary to meet the wastewater disposal needs of the facility and where other wastewater utilization or disposal methods (e.g., NPDES permit) are available to the facility at all times," while a non-conjunctive system is the opposite. Conjunctive and non-conjunctive systems both require continuous on-line monitoring and recording of flow and turbidity. In case that turbidity exceeds 10 NTUs or bacteria standards are not met then alternate wastewater management (i.e. storage), or disposal options need to be available. In the case of non-conjunctive systems,
the disposal option is limited to a lined five-day side-stream detention pond, as well as extra
design criteria not listed here. In both cases, Type 2 reclaimed water requires dual disinfection
(usually UV disinfection and chlorination), and a certified operator on call 24 hours/day. The
design criteria for non-conjunctive systems have considerably more requirements associated
with extra piping and pumps, additional water storage, public access restrictions and
groundwater separation.

Other regulated reclaimed water uses by the state rules are wetland augmentation and
irrigation to food chain crops with Type 1 or Type 2 standards, as described in the footnotes of
Table 3.4.

3.3—The extent of constructed wetlands for wastewater treatment in NC

Currently in NC, constructed wetlands (FWS and SSF designs) for wastewater treatment are
being used for municipal, domestic, industrial and stormwater applications. The most common
type of application found in the state is for stormwater remediation. A few examples from
constructed wetlands in NC are presented.

1. Stormwater wetlands

The use of FWS CWs is widely documented throughout North Carolina as constructed
stormwater wetlands (CSWs) (Line et al, 2008; Hathaway & Hunt, 2009; Throughout the state,
CSWs have been located on small watersheds (4-5 acres), but they are more commonly placed
for larger 15-100 acres drainage areas (Wossink & Hunt, 2003). The Wetlands and Stormwater
Branch of NC DENR is responsible for the permitting associated with CSWs, and recognizes it as one of the best management practices (BMPs) to mitigate the effects of stormwater runoff (see Table 3.5). CSWs are effective on stormwater treatment; however, there are two major limitations such as large amount of space needed, public perception, and potential of slow moving water serving as a mosquito sources (Wossink & Hunt, 2003), while the main advantages have to do with optimal pollutant removal such as nutrients (see Table 3.5).

Table 3.5. BMPs for the consideration of CSWs. (Adopted from NC DENR, 2009).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Removal (%)</th>
<th>Feasibility Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>85</td>
<td>High Land Requirement</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>Cost of Construction</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>40</td>
<td>Med-High Treatable Basin Size</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Med Possible Site Constraints</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>40</td>
<td>Med Community Acceptance</td>
</tr>
</tbody>
</table>

Two examples of CSWs implemented in NC will be presented in terms of design criteria, public perception and acceptance and general history.

a. Boone Greenway wetlands: Stormwater remediation (Boone, NC)

In 2009, the town of Boone, Watauga County Cooperative Extension and North Carolina State University Biological and Agricultural Engineering (NCSU BAE) along with funds from the NC Clean Water Management Trust Fund (CWMTF) established a FWS CW to mitigate stormwater runoff from entering the New River. After two successful wetlands in different municipalities of Banner Elk and New Land, the 1.4-acre stormwater wetland along the greenway trail in
Boone was built in the vacant floodplain (North Carolina Cooperative Extension, 2009). The floodplain area where the wetland is located used to be residential (13 houses and a 100 bed nursing home) with frequent evacuations in times of heavy rain and flooding. The forgotten past is now the main feature of the park visited by thousands of people yearly. The Boone Greenway houses pavilions and picnic tables as well as educational signs along the trail highlighting how nature can clean water. The wetland is permitted by the DWQ, given that the town of Boone is not part of the NPDES stormwater regulations; water quality testing is not required, even though the receiving water body (New River) is listed as a 303d impaired river by the EPA (U.S. EPA, 2010).

**Public acceptance and participation:** Initial concerns by residents expressed at town council had to do with pests and mosquitos attracted to the wetland. The residents were educated about the potential of wildlife and the possibility to expand a forgotten land area prone to flooding into a positive green space. Additional outreach to keep the community informed at the initial stages was executed through newspaper articles inviting residents to explore the site while the wetland construction was taking place. The wetlands have served as a great resource for students from elementary school all the way to the university level for educational and research purposes. In terms of water quality improvement, one study showed significant metal removal through entrapment and sedimentation (Keller, 2011). The Watauga County Cooperative extension often plans for plant walks and tours throughout the year, and currently the site has over 10,000 native plants established largely by volunteers (Papropsky, personal communication, 2013).
b. Constructed stormwater wetland at commercial retail location in east Raleigh

The details on this site are from an article by Hunt et al. (2011) which documented how poor design and inadequate management can cause a constructed stormwater wetland to turn into wet ponds. Wet ponds are also listed under the BMPs; however, high water tables in eastern NC have caused CSWs to be a preferred design for the region. The conversion from CSWs to wet ponds results in three main nuisances; reduction in efficiency of pollutant removal, lack of biodiversity that can cause an increased risk for mosquito harvesting, and degradation of aesthetics.

The wetland site serves as two cell drainage catchments with a total area of 4.9 ha or 12.1 acres. The combined surface area of each cell is 0.5 acres. The topography at the wetland site enables diversity of plant species for colonization depending on the levels of inundation. The issues at the wetland site were mainly due to construction details (even though specified in the design) such as deep water elevation which inhibited vegetation growth, and lack of flow regulating devices to increase retention time. Over a period of 1.5 years after construction, the CSWs turned into a wet pond partially colonized by cattails (*Typha spp.*) due to their inundation tolerance and aggressive growth over other species planted. Although the CSW project failed, cattails still contributed to water quality improvement. Therefore, the main concern with CSWs turning into wet ponds are the mosquito breeding capabilities that could potentially be a public health hazard to commercial property that attracts large groups of visitors daily. Studies on the wetland showed no mosquito presence (Hunt et al., 2006). Figure 3.3a shows the wetland 3
months after construction with no sign of vegetation, while Figure 3.3b shows a monoculture of cattails after 1.75 years of construction.

Figure 3.3. Vegetation establishment of a CSW in east Raleigh a) three months after construction b) 1.75 years after construction.

For sites that have or are considering CSWs for stormwater control measures there are a few take away points:

- Maintenance programs should be implemented
  - Considering on-site inspections and any post construction repairs.

- Avoid overlooking details on the design

- Proper installation

- CSWs are shallow water systems and need to be designed and constructed as such to avoid ponding, vegetation inundation, and flooding.

Public acceptance and participation: Since neither evidence of public involvement nor public feedback on the design of this system is available another example related to perception of
CSWs in NC will be discussed here. In 2012, the Public Works Stormwater Services called for public input on a proposed South Ellerbe Creek wetland concept plan at the former Duke Diet and Fitness Center located in Durham, NC. Three presentations were initially scheduled at different locations and dates encouraging the public to attend, ask questions and learn about the plan. Twelve public meetings were held attracting over 250 people. The outreach materials used to involve the public included a frequently asked questions newsletter, presentations, general information brochures, newspaper articles and a website. The presentation also displayed the support from several organizations (i.e. Environmental Affairs Board, Downtown Durham Inc., Durham Open Space Trails, Ellerbe Creek Watershed Association, among others), updates related to project feasibility and the next steps. It is important to note that public input was the fourth step out of 14 towards implementation (Wilbur & Wiebke, 2012).

II. Industrial/Municipal constructed wetlands

a. New Hanover County Landfill leachate constructed wetlands

Since 1981, New Hanover County has housed the first lined landfill in North Carolina where leachate is collected and treated onsite by a conventional wastewater treatment system. Ultimately, the treated leachate is permitted to discharge to the Northeast Cape Fear River through a NPDES permit (see the 2004 permitted parameters in Table 3.6). The conventional
treatment of the leachate consists of a primary treatment at a lagoon (2.5 acre, 4 million gallons) which is then introduced to an extended aeration or activated sludge process with a capacity of 50,000 gpd. Constructed wetlands were considered at the facility primarily to improve pollutant removal, particularly nitrogen, in order to meet the new water quality permit limits required by DWQ. Other reasons for CW consideration were to stop the discharge of treated leachate to the river, and to eventually replace the activated sludge process for a technology that will require less maintenance and energy.

Table 3.6. 2004 NPDES effluent limitations from the wastewater treatment plant to the Northeast Cape River.

<table>
<thead>
<tr>
<th>Parameter tested</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly average</td>
</tr>
<tr>
<td>Flow (gpd)</td>
<td>50,000</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (BOD₅, mg/L)</td>
<td>30</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/L)</td>
<td>27.0</td>
</tr>
<tr>
<td>Ammonium (NH₃, mg/L)</td>
<td>4.9</td>
</tr>
</tbody>
</table>

# NR = Not regulated

Other added benefits of CW were to have an alternative treatment of leachate post landfill closure (landfill is permitted until 2018), the responsiveness to public opinion and acceptance, and an educational component for research training and public involvement; the last two objectives received funds through the Coastal Area Management Act from the North Carolina Division of Coastal Management to develop and coordinate an educational program with the co-current pilot study on CWs.
Due to foreseen benefits of using CWs for wastewater treatment, one main pilot study was conducted to evaluate 5 configuration types of CWs to treat high nitrogen containing wastewater with some of the objectives being comparison of SSF and FWS CWs types, and providing a demonstration project for alternative treatment technologies for educational purposes (Lierh & Sloop, 1996). The pilot study received grant funding through the Water Environment Research Foundation (WERF) and the results helped determine that a FWS wetland was more appropriate for the removal of nitrogen species and complied with regulations needed for discharge by irrigation. Based on these results, the New Hanover Department of Environmental Management received grant funds from the CMWTF for the full scale construction and operation of the CWs.

Today, the full scale 5.6-acre constructed wetland and irrigation system, preceding the pretreatment lagoon, is designed to handle up to 60,000 gpd with the endpoint water discharged by drip irrigation. The facility is permitted by the solid waste management division at NC DENR, precluding discharge from the constructed wetlands to the

**Figure 3.5.** FWS CW at the New Hanover landfill (adopted from http://www.nhcgov.com/Environmental/Pages/Wetlands.aspx
Northeast Cape Fear River. The landfill continues to operate the wastewater treatment plant; however, currently most of the leachate is treated onsite and discharged to the land by irrigation.

**Public participation and acceptance:** New Hanover County's department of environmental management was awarded the Coastal area management act grant from the North Carolina division of coastal management to include an education component connected with the pilot project (Church, 2002). The pilot project enables the participation of students to conduct research for Masters and PhD theses, particularly those located at the University of North Carolina—Wilmington

b. **Municipal wastewater treatment—Goldsboro, NC**

In 1995, the City of Goldsboro, NC was prompted to find alternative options to mitigate the water pollution discharged by the City's wastewater treatment plant into the nutrient sensitive Neuse River. In 1997, the NC CWMTF board approved a project for a wetland to polish treated wastewater effluent from the City of Goldsboro wastewater treatment facility. The City of Goldsboro in conjunction with the NC CWMTF spent $3,372,000 to build 40 acres of FWS constructed wetlands as a nutrient (mainly nitrogen) reduction project. In addition, the City also built a jointed water reclamation facility that uses an advanced treatment process followed by disinfection for irrigation applications at golf courses and farms. In both instances, the project objectives were geared towards environmental protection by preventing nutrients from reaching the Neuse River (Brashear, 2004).
The FWS CW serves as a polishing or tertiary treatment of the wastewater with a capacity to treat up to 4 mgd. Initially, 52,000 plants of 13 different species were used. There is a total of 4 wetland cells with a clay liner (1 ft. deep) to prevent water intrusion to the groundwater. Ultimately, the endpoint of the treated wastewater regulated by NPDES permit is discharged to the river (see permit in Table 3.7). The polished reclaimed water product from the wetlands is not reused for any other application; the reclamation facility serves that purpose.

With regards to operation and maintenance, the system requires grass to be mowed on the dike berms, usually to avoid overflow beyond the structure of the wetland cell, and to control nuisance species (both plants and animals). The design and construction of the wetland was by a well-known wetland engineering firm in Florida (Post, Buckley, Schuh, & Jernigan), who according to the public utility director claimed that the CWs would eventually come to an equilibrium and would require minimal maintenance. However, the maintenance requirements by the CWs were substantial after wetland establishment (Brashear, personal communication, 2013). One parameter that has been a struggle for the facility has been the high effluent pH causing Notice of Violation (NOV) due to failure to comply with the permit limits. In numerous instances in order to avoid the NOV, the facility has prevented wastewater effluent from flowing into wetlands that discharge onto the Neuse basin. Due to consistent failure from the wetlands to keep the pH up to the permitted levels, the City of Goldsboro has twice requested a NPDES permit modification that will allow a higher pH (see Table 3.7). The modifications have
been denied (Brashear, personal communication, 2013). As a result, the utility director does not recommend the use of constructed wetlands to other cities due to issues regarding NOV.

Table 3.7. NPDES effluent limitations for the constructed wetland at Goldsboro, NC.

<table>
<thead>
<tr>
<th>Parameter tested</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly average</td>
</tr>
<tr>
<td>Flow (gpd)</td>
<td>40,000</td>
</tr>
<tr>
<td>Carbonaceous Biochemical Oxygen Demand (CBOD&lt;sub&gt;5&lt;/sub&gt; mg/l; April 1-Oct 31, Nov 1-March 31)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>4.0, 8.0</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/l)</td>
<td>27.0</td>
</tr>
<tr>
<td>Ammonium (NH&lt;sub&gt;3&lt;/sub&gt;, mg/l; April 1-Oct 31, Nov 1-March 31)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.0, 2.0</td>
</tr>
<tr>
<td>Fecal Coliform (FC, colonies/100 ml)</td>
<td>200</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>N/R</td>
</tr>
</tbody>
</table>

*NR= Not regulated  Different limitation during the summer and winter terms

Table 3.7 shows the NPDES effluent limitations for tertiary treatment performed by the FWS CWs. The CBOD and ammonium effluent limits differ for the summer and winter seasons given that CWs are documented to have enhanced removal at higher temperatures. In terms of pH requirements, the wastewater composition at Goldsboro, NC is likely to be much more industrial than domestic which could be a factor impacting the performance of the wetlands. When compared to other industrial NPDES permit (Table 3.6), CBOD parameters are tested instead of BOD. The CWA rules for municipal water treatment allow for parameter substitution from BOD to CBOD (U.S. EPA, 2003). However, in terms of pH the rules specify that limits are to be kept between 6.0 and 9.0 unless the municipal plant can demonstrate no contribution from inorganic chemicals in the treatment process or industrial contributions that can impact the pH.
Public acceptance: The wetland site has been well received by the Goldsboro community, serving as an educational site for school and college field trips. However, no documented newspaper articles or outreach about the level of public involvement was found. The City of Goldsboro website (http://www.ci.goldsboro.nc.us/wetlands.aspx) appears to be the main source of outreach regarding the constructed wetlands. The website gives some details about the technology but there is no indication of the issues faced by the facility. The CWs are promoted as an ‘innovative project’ aside from the water reclamation project, and highlights the natural processes that enable polishing of wastewater, the ‘lush aquatic vegetation’ which includes flowering plants (Blue Flag Iris, Fragrant Water Lily, Spatterdock, Pickerel Weed, and American Lotus), and the scenic tours. Plant species at the wetlands are: Coontail, Spikerush, Duck Potato, Arrowhead, Swithgrass, Bullrush, Arrow Arum, Lizard’s Tail, and Soft Rush.

The director of the City’s wastewater and reclamation plants indicated that the public has not provided any negative feedback regarding the constructed wetlands or water reclamation projects (Brashear, personal communication, 2013).
III. Domestic wastewater constructed wetland treatment

a. Northern Guilford Middle School (Greensboro, NC)

The system installed in Guilford County is permitted by the county health department to treat 6,000 gpd of blackwater produced by toilets in the Northern Guilford middle school (~500 students). The system consists of the trademarked and patented design by Worrell Water Technologies called a “Living Machine,” a biological wastewater treatment that mimics wetlands. The “Living Machine” installed at the middle school consists of a grease trap, septic tank, equalization tanks, horizontal SSF wetlands with two cells (52 by 205 feet), tidal flow wetland (32 by 32 feet), a storage tank, a two stage disinfection using ultraviolet light and chlorine, and a drip irrigation zone (see Figure 3.6). No wastewater is discharged onto the surface or into ground waters. Instead, the treated water is discharged by subsurface drip irrigation. The “living machine” designs are also used for the Northern Guilford high school which extends the capacity of the system to 30,000 gpd. The system is a Type VI in accordance with 15A NCAC18A.1961 as described in Table 2.1, “any > 3000 gpd system with mechanical, biological or chemical pretreatment system plant, wastewater reuse/recycle.”

Operation and maintenance is carried out by a certified wastewater treatment plant operator. The operator is required to visit the facility daily, except on weekends and holidays, and properly manage and document daily operation and maintenance. The parameters set by the Guilford County health department differ from those set by NPDES permits at the New Hanover
landfill and the Goldsboro municipal facility discussed earlier. In general, all parameters except for pH and TSS are less stringent at the schools.

Figure 3.6. Schematic of the wastewater collection, treatment and disposal at the Northern Guilford middle schools (adopted from Worrellwater.com).

The treatment wetlands are designed in two stages. Stage 1 consists of three tidal flow wetlands responsible for removal of pollutants through biofilm interaction. A tidal flow wetland is a system that employs two or more flood and drain cycles during a day. The treatment aims to provide significant nitrogen removal through cation exchange capacity of the media by oxygen saturation and adsorption and desorption of nitrogen species. Stage 2 consists of one horizontal flow wetland for polishing and removing organic material, ammonia and TSS. The wetland functions as a recirculating system and the media used in the “living machine” is lightweight expanded shale aggregate (LESA).
The high quality effluent (see Table 3.8) is often used for irrigation of sport areas around the school (football field and practice areas) using a conjunctive system for dispersal of effluent when needed and to minimize the use of potable water supplies. Subsurface irrigation using reclaimed water at Guilford County has higher effluent limits from those set by the state rules for surface irrigation or general reuse applications. The actual performance of the system, as shown in Table 3.9, demonstrates that the effluent meets the permit requirements for TN, TSS and CBOD significantly. However, no actual data about the fecal coliform parameter was reported but according to the Guilford County Health Department, the system is operating within permitted levels.

Table 3.8. Permit parameters set by the Guilford County health department for effluent water prior to irrigation.

<table>
<thead>
<tr>
<th>Parameters*</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (gpd)</td>
<td>Monthly average</td>
</tr>
<tr>
<td>6,000 gpd (4,500 gpd to the drainfields)</td>
<td></td>
</tr>
<tr>
<td>Carbonaceous Biochemical Oxygen Demand (CBOD₅, mg/L)*</td>
<td>15</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/L)</td>
<td>15</td>
</tr>
<tr>
<td>Total Nitrogen (TN, mg/L)</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Ammonia Nitrogen (NH₃-N, mg/L)*</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Fecal Coliform (FC, colonies/100 mL)</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>6.0 and 9.0</td>
</tr>
</tbody>
</table>

*The sampling frequency for all parameters is once per month. If more than one sample is collected then the monthly averages (arithmetic mean) are to be reported.
Table 3.9. Performance summary data reported by Sustainable Water*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured Influent</th>
<th>Measured Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonaceous Biochemical Oxygen Demand</td>
<td>241</td>
<td>1.97</td>
</tr>
<tr>
<td>(CBOD₅, mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>150</td>
<td>0.2</td>
</tr>
<tr>
<td>(TSS, mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>199</td>
<td>10.6</td>
</tr>
<tr>
<td>(TN, mg/L)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Information obtained from the Sustainable Water living machines website under url: [http://sustainablewater.com/pdf/livingmachine/Guilford%20County%20Schools.pdf](http://sustainablewater.com/pdf/livingmachine/Guilford%20County%20Schools.pdf)

In terms of groundwater protection, 8 monitoring wells, adjacent to the drainfields and irrigation areas, are sampled for nitrates, fecal coliform, water level and pH. The testing of the wells is done quarterly and the results are submitted through a compliance report form to the NC DENR Division of Environmental Health On-site Wastewater section (DENR-DEH-OSWS).

The planted community in the wetlands is a mixture of 9 plant species:

- Juncus effusus, Soft rush
- Scirpus spp, Bulrush
- Hibiscus moscheutos, Rose mallow
- Saururus cernuus, Lizard’s tail
- Typha angustifolia, Narrow leaved cattail
- Sacciolepis striata, American Cupscale
- Phytolacca Americana, Pokeberry
- Chasmanthium latifolium, River Oats
- Aristida stricta, Wiregrass

**Public acceptance and participation:** Prior to building the schools, construction costs to connect to the nearest municipal wastewater treatment plant were estimated at about $4 million.
Instead, the school board along with taxpayers decided to invest in an onsite system that would allow considerable savings and enhance ecological and sustainability measures. The primary stakeholders in the decision process were the Guilford County Schools Facilities Department and the Guilford County Board of Education’s Construction Advisory Committee. Documentation about public involvement in 2006 discussed the ‘green’ features of the school (Buckingham, 2006). However, no articles were found on earlier public outreach or promotion of water reuse applications associated with the “Living Machine”, which is often advertised as a wastewater treatment without inclusion of water reuse terminology. The Northern Guilford School has been an excellent example for integrating and promoting sustainable green strategies and design. In addition to the treatment and water reuse capabilities of the wetland component, there are several different green features such as rainwater harvesting, and applications to maximize solar energy use.

The school is frequently visited by developers and interested groups (i.e. Wake Technical Community College) due to its environmental friendly features. A newspaper article described the impact as “an environment where the actual facility can be a teaching tool” (cited by Rawlins, 2007). However, the school’s design as a whole has received some negative attention due to the high energy costs observed for operation over time (Clark, 2010), although sustainable or green buildings are estimated to have a higher capital cost, but with lower energy costs in the long run. When it comes to just the ‘living machine’ the capital costs were about $500,000 using about half an acre of space with monitoring costs of about $78,000/yr (McNair, 2009). The Guilford County Health Department has attributed the success of the
“Living Machine” system to daily operator checkups, and his knowledge about the system. Additionally, officials at the health department admitted to “folks express[ing] skepticism about having a half-acre "sewage field" near a school, but the representative from the Guilford Health Department says, “it’s now seen as a community-embraced model that wins visits from all over North Carolina” (as cited in McNair, 2009).

b. Jordan Lake Business Center (Apex, NC)
The Jordan Lake Business Park previously housed the Old Triangle School and due to its remote location, soil unsuitability and close proximity to the nutrient sensitive Jordan Lake, municipal or conventional wastewater treatment methods had not been an option for further development. The building was closed in the 1970s but in 1993, wastewater management using constructed wetlands helped revive this isolated location into a functional office building. The facility is permitted for a 1200 gpd capacity by the DWQ at NC DENR and serves about 60 employees. The system includes constructed wetlands, a greenhouse, and planter boxes that treat septic tank wastewater for toilet flushing and landscape irrigation (House et al., 1996).

The system is currently maintained through an operator, as required by the permit. The design of the system consists of: septic tank, combination sand filter, horizontal subsurface flow constructed wetland (998 square feet) with gravel substrate, horizontal subsurface flow constructed wetlands with sand substrate, sand filters within a greenhouse, tablet chlorination, irrigation disposal area, and surface irrigation (dripper lines) (see Figure 3.7 and 3.8 for the design scheme). Several pumps are located throughout the system, particularly two for supply
of the reuse tank and to maintain pressure on reuse lines that supply the toilet flushing water supply. The system does not discharge waste into surface water and is labeled as a non-conjunctive wastewater treatment and reclaimed water utilization system. The effluent limits for this reclamation system (shown in Table 3.10) are more stringent than those reported for subsurface irrigation at Northern Guilford Middle Schools (Table 3.8).

Table 3.10. Effluent limits set by the DWQ NC DENR permit issued for the Jordan Lake Business Center for water reuse (toilet flushing or greenhouse) (Stanford et al, 2012 in press)

<table>
<thead>
<tr>
<th>Parameter *</th>
<th>Effluent limits</th>
<th>Reclaimed water average quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow (gpd)</strong></td>
<td>Monthly Average</td>
<td>Daily Maximum</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (BOD₅, mg/L)</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS, mg/L)</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Total Nitrogen (TN, mg/L)</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Total Residual Chlorine (mg/L as Cl₂)</td>
<td>N/R</td>
<td>0.5²</td>
</tr>
<tr>
<td>Fecal Coliform (FC, colonies/100 mL)</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>6.0 - 9.0</td>
<td>N/R</td>
</tr>
</tbody>
</table>

* Other average water quality of treated reclaimed water: Chemical Oxygen Demand, COD as 6.4 mg/l, 11.6 mg/l (measured as Total Nitrogen, TN), and Turbidity at 10 NTUs.
²N/A refers to no data available and N/R refers to not regulated
³Value represents a daily minimum instead of maximum
Figure 3.7. Schematic of the water reuse system in Jordan Lake Business Center (Stanford et al., 2012 in press)

Figure 3.8. Horizontal flow CW design at the Jordan Lake Business Center along with a picture of the greenhouse irrigated with reclaimed water effluent (Adopted from House et al., 1996 and waterrecycling.com).
Public acceptance and participation: The Jordan Lake Business Center wetland system was the first water reuse and reclamation project in the state of North Carolina. The site has served as a pilot location for similar projects around the state such as the Chatham Central Community College (CCCC) and other new developments. Several studies by graduate students at UNC and NCSU have been undertaken (e.g. Chalew, 2006; Stanford, 2007; Vasquez, 2010). The facility currently houses the Jordan Lake Environment Education Center whose mission is to provide opportunity for students to gain knowledge and awareness about environmental conservation and also facilitate environmental studies related to STEAM (Science, Technology, Engineering, Arts and Mathematics).

Lessons Learned from the state of domestic wastewater treatment and reuse using CWs in NC

Part of this project’s objectives has been to evaluate the extent of constructed wetlands for wastewater treatment and reuse for domestic wastewater in NC. Although the technology is being utilized across the state, it is used primarily for mitigation of stormwater pollution with FWS designs. At the domestic level, CWs are not widely known as a wastewater treatment and information about their use is limited to local health departments. The extent of SSF CWs is limited in North Carolina, although other southern states (Florida, Tennessee, and Georgia) use the technology effectively to a much larger degree, even at domestic and residential locations (Safrit, 2010). In addition to the case study locations utilizing CWs discussed previously, there are other domestic wastewater generating facilities that have implemented CWs for treatment and reuse (see Table 3.11 for overview details).
Table 3.11. Other residential/domestic facilities utilizing CWs for wastewater treatment in NC

<table>
<thead>
<tr>
<th>Facility</th>
<th>County</th>
<th>Type of wetland</th>
<th>Endpoint of effluent water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moyock Commons Shopping Center and</td>
<td>Currituck</td>
<td>FWS</td>
<td>Infiltration</td>
</tr>
<tr>
<td>Currituck Commercial Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aurora WWTP</td>
<td>Beaufort</td>
<td>FWS</td>
<td>Tar-Pamlico River Basin</td>
</tr>
<tr>
<td>Summerfield Shopping Center</td>
<td>Guilford</td>
<td>HSSF</td>
<td>Surface Irrigation</td>
</tr>
<tr>
<td>Central Carolina Community College</td>
<td>Wake</td>
<td>VSSF</td>
<td>Toilet flushing, cooling towers, landscape irrigation and drip irrigation</td>
</tr>
</tbody>
</table>

Given that on-site wastewater treatment systems are widely used for wastewater disposal in NC while the soil and site conditions can frequently inhibit development and further use of land, it is important to explore alternative options that are cost effective. One particular suggestion for the use of CWs at domestic locations is for schools, and residential clusters. The technology is generally qualified as Type IV and above which requires an operator and increases the overall cost of the technology making it, in many instances, unaffordable to individual homeowners. However, for locations that can generate larger flows of domestic wastewater and that can also benefit from having an educational tool and green open spaces, CWs offer a significant upgrade from conventional onsite wastewater treatment. In the case of residences and households, as a cluster wastewater management tool, CWs have the potential to treat wastewater effectively and provide a high effluent product that can be used in water reuse applications.
Under the DWQ division at NC DENR, one permit has recently been issued for a 2200 gpd conjunctive and non-conjunctive reclaimed water and wastewater irrigation system using CW as part of the treatment. However, the system has not been constructed yet. Moreover, NC DENR and NC DHHS permitting agencies did not have a comprehensive database to locate systems that include CWs in their treatment. Instead, most of the examples shown in this report were pulled from personal and professional references, engineering firms, on-site wastewater researchers, and conference proceedings. Once the data location of the facility was identified, NC DENR provided some of the permits and effluent quality data presented in this report.

**Stakeholders associated with onsite wastewater treatment and reuse using CWs in NC**

The primary groups identifiable in the onsite wastewater treatment and reuse sector are:

- **NC DENR** (primarily DWQ-APS and NPDES)

- **NC DHHS Environmental health—On-site waster protection Branch**
  - Local county health department under the division of environmental health

- Wastewater and reclamation engineering firms

- **NCOWCICB—Contractor, operators and inspectors**

- Domestic wastewater generating facilities (schools, households, shopping centers, apartment buildings, etc.)
References


Berkowitz, S. (2013) Telephone interview. Engineering Team Leader, On-Site Water Protection Branch, N.C. Department of Health and Human Services


NC DENR (1996) 15A NCAC 02H, Procedures for Permits: Approval, Section .0219(k) Waste Not Discharged to Surface Waters, Reclaimed Water Use, Raleigh, NC.


Okun, D. A. (2002). Water reuse introduces the need to integrate both water supply and wastewater management at local and regulatory levels. Water Science and Technology, 46(6-7), 273-280.


Chapter 4

Public Perception of Water Reuse: a small scale assessment in low resource communities in NC

Summary:
Public perception has been determined as one of the major barriers to water reuse applications. This chapter provides a review of the current literature that examines the role of public perception in the water reuse sector along with the supporting documents that encourage community engagement and public outreach in the context of environmental justice. In an effort to document community perception at decentralized low resource locations in North Carolina, qualitative data in the form of key informant interviews (KII) were conducted. KIIs were designed to obtain information from five communities about current water and wastewater management issues, general knowledge and acceptability of water reuse and use of constructed wetlands for onsite wastewater treatment and reuse. The results from the KIIs were structured into trends found among communities.

4.1—Public Perception and Water Reuse

I. Public Perception Review
One of the major barriers associated with water reuse implementation has been public perception and acceptance. In general, water reuse projects have been undertaken without much input from the public. However, there is a trend away from ineffective persuasive
campaigns to recognizing that acceptance is more likely when public perception and concerns are addressed. This has led to an increase in social research on factors that influence acceptability (see Table 4.1).

**Table 4.1.** Factors involved in public acceptance of water reuse (Hartley, 2006; Po et al., 2003).

<table>
<thead>
<tr>
<th>Factors that influence behavioral acceptability of a reuse scheme to the general community</th>
<th>The public acceptance of water reuse in the U.S. increases when:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Disgust or “Yuck” factor&lt;br&gt;• Perceptions of risk associated with using recycled water&lt;br&gt;• The specific uses of recycled water&lt;br&gt;• The sources of water to be recycled&lt;br&gt;• The issue of choice&lt;br&gt;• Trust and knowledge&lt;br&gt;• Attitudes toward the environment&lt;br&gt;• Environmental justice issues&lt;br&gt;• The cost of recycled water&lt;br&gt;• Socio-demographic factors</td>
<td>• Degree of human contact is minimal&lt;br&gt;• Protection of public health is clear&lt;br&gt;• Protection of the environment is a clear benefit of the reuse&lt;br&gt;• Promotion of water conservation is a clear benefit of the reuse&lt;br&gt;• Cost of treatment and distribution technologies and systems is reasonable&lt;br&gt;• Perception of wastewater as the source of reclaimed water is minimal&lt;br&gt;• Awareness of water supply problems in the community is high&lt;br&gt;• Role of reclaimed water in overall water supply scheme is clear&lt;br&gt;• Perception of the quality of reclaimed water is high&lt;br&gt;• Confidence in local management of public utilities and technologies is high</td>
</tr>
</tbody>
</table>

Water reuse is becoming more widespread and recognized as an integral component towards effective wastewater management. In the U.S., many nonpotable water reuse applications are practiced such as irrigation (lands, golf courses, landscaping), industrial processes, groundwater recharge, environmental enhancement and others such as fire protection, air conditioning and toilet flushing (Siemak et al., 2001). There are a few indirect potable reuse (IPR) projects
successfully implemented in the U.S. such as the Upper Occoquan Sewerage Authority Water Recycling project in Virginia and the Clayton County Water Authority Wetlands in Georgia. However, in order to implement a successful reclaimed water project, public outreach and education have been demonstrated to be an essential component during the planning phase in order to overcome issues related to negative perception, that can be caused by the use of insensitive terminology such as ‘toilet to tap,’ even after public outreach was conducted and previously indicated favorable results and acceptability (Recycled Water Task Force, 2003; Katz & Tennyson, 1997).

Given the recognition of public perception in the field, there have been several articles and reports dedicated to this area. Among them, “The Psychology of Water Reclamation and Reuse” documents and evaluates the human response to water reclamation and reuse focusing on attitudes, beliefs, decision and choices that are based on notions related to social psychology, and judgment and decision making (Haddad et al., 2009). One chapter of this report is dedicated to presenting the results from a nationwide survey that focused on beliefs about water, attitudes towards water reclamation and reuse, possible predictors of attitudes in terms of demographics and psychology, and persuasion routes towards a more positive reuse outlook. Some of the findings provided insight to water agencies. There was a broad willingness to use recycled water across groups who favored indirect potable reuse measures when reintroducing reclaimed water to streams or groundwater recharge prior to human consumption. Those more likely to reject water reuse were generally less trusting of institutions and science, less pro-technology and contagion sensitive. Those most likely to

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accept and use safe recycled water were found to be 1) aware of the recurring water cycle, 2) previously exposed to statements about levels of water purity, 3) forced due to external conditions (i.e. severe droughts), and 4) confident that they will get used to the concept over time. The study also showed that sources of information regarding water reuse acceptability were deemed credible if they originate from scientists (independent or from government). In terms of attitudes and beliefs around water reuse, the factors that contribute to the degree of public acceptance have been documented in several articles summarized earlier in Table 4.1.

II. Review of water reuse public perception research: community, domestic reuse and other stakeholders

Community and domestic reuse studies

- **Public Perceptions On Water Reuse Options: The Case Of Sulaibiya Wastewater Treatment Plant In Kuwait** (Alhumoud & Madzikanda, 2010)

This article assesses public perception and acceptance of recycled water in metropolitan Kuwait by 1540 completed surveys from households. The main objective of the study was to examine the attitude and willingness of using treated wastewater for different purposes, but mainly for domestic consumption. Some of the results indicated 75% of respondents would not use reclaimed water for drinking. In contrast the majority did not object to using reclaimed water for other nonpotable uses such as agricultural irrigation (75%), car washing (67%) and house washing (55%). Disregarding the level of knowledge about the subject, respondents strongly opposed water reuse for human use such as bathing and clothes washing as well as cooking.
Rejection for water reuse in decreasing order of importance were linked to health reasons, psychological reasons, religious beliefs, lack of trust toward utilities, fear of mechanical breakdown, and other reasons not listed in the article.

- **Benefits and Costs of Water Reuse Programs in Texas (Luther & Dixon, 2011)**

  Through an online survey tool, the study aim was to characterize residents' perception concerning water reuse, convincing factors to accept reuse plans, and willingness to utilize direct-to-reuse water sources. About 97% of all survey respondents viewed water reuse as a valid conservation tool for preserving potable water sources. Although, the general consensus among the resident surveys suggested concerns with water demands, population growth, and droughts, only 8% would accept direct potable reuse. There was a broad spectrum on acceptable uses such as any type of irrigation (73%), and car washing (27%) with other uses including toilet flushing, industrial, and potable use falling from 11% to 15%. Over 90% of community members expressed interest in public involvement in planning and education strategies towards water reuse.

- **City of San Diego Water Reuse Study—Final Draft Report (City of San Diego, 2006)**

  Strong public opposition to the San Diego Purification project halted the implementation of the indirect potable reuse project passed by the city without prior public consultation. In an effort to address those concerns, the City of San Diego developed this report highlighting the public outreach activities and strategic plans towards implementation, including a water purification demonstration project. Some of the methods used for community input were telephone and
website surveys which resulted in 60% favoring using advanced treated recycle water as a
drinking water source. Other outlets used for outreach were focus groups, speakers' bureau,
media coverage, stakeholder interviews, facility tours and a telephone hotline. In 2013, the
demonstration will be concluded followed by a year of testing toward a full-scale project.

III. U.S. EPA Guidelines

The most recent U.S. EPA Guidelines for Water Reuse were published in September 2012 (U.S.
"Public Outreach, Participation, and Consultation" highlights the key elements involved in public
involvement and points to them as critical to the success of any water reuse program (U.S. EPA,
2012a). The extent of public involvement in developing the 2004 guidelines was described in
the chapter titled "Public Information Programs". The 2012 Guidelines help raise awareness of
the growth of the water reuse sector nationally in terms of applications as well as an increase in
informative and supporting research to understand the role of public perception.

The 2004 Guidelines showcased four case studies in Florida and California, states which at the
time and until this day continue to be the leaders in water reuse alternatives. Two particular
case studies in Florida show how successful a reuse project can be when the public is involved
at the beginning stages. Here is a summary of the two cases studies (U.S. EPA, 2004):

- All the water customers in Venice, Florida were sent a cover letter with an explanation
  of the project along with a survey to assess irrigation practices and their knowledge on
  water reuse. This was coupled with public workshops by public health experts, as well
as presentations at homeowners associations. As a result, a high response rate of the survey helped the city address public concerns early in the decision-making process.

- Cape Coral, Florida, was a rapidly developing community which brought out issues regarding water supply and demand for potable water. Their current water supply is a saline groundwater aquifer which requires energy intensive treatment by reverse osmosis. Therefore, the city developed a plan called the “Water Independence in Cape Coral” that consisted of dual water systems for potable and nonpotable reclaimed water. The lack of public involvement including awareness and education programs caused the implementation to require over 6 years for completion (Curran & Kiss, 1993).

The 2012 Guidelines highlight an increase in public dialogue about water reuse and general knowledge as demonstration of the effectiveness of public participation when there is a two-way communication instead of a “top-down approach”. Public participation in many instances determines project success and can help to inform constituency and build trust. Generally, people expect and demand to be a part of the decision-making process involving utilities and other governing bodies.

IV. Situational Analysis: Environmental Justice

The 2012 EPA Water Reuse Guidelines also include an important concept in the community outreach and engagement piece of water reuse “Situational Analysis and Environmental Justice”. The situational analysis process examines factors to assess a community given its current political environment, economic, social and environmental issues, public awareness and
knowledge of water related issues, history and reputation of utilities (trust), potential
supporters and opponents, media advertisements, and trusted sources of information (U.S.
EPA, 2012a). The findings associated with these factors are expected to differ based on
geographic and demographics among communities.

As defined by the U.S. EPA, environmental justice is ‘the fair treatment and meaningful
involvement of all people regardless of race, color, national origin, or income with respect to
the development, implementation, and enforcement of environmental laws, regulations, and
policies.” The idea behind *fair treatment* is that no group of people should carry a
disproportionate burden of negative environmental consequences whether from operations or
policies (industrial, governmental, or commercial). *Meaningful involvement* has to do with
providing opportunities for input and seeking out the community to be an integral part of the
decision making process particularly on issues that can impact environment and health.
Therefore, procedural inequities can occur when there is no ‘meaningful involvement,’ while
geographic inequities arise when there is disproportionate share of projects located in
disadvantaged areas that can impact property values, access to and availability of water.

In terms of water reuse acceptability and environmental justice, the San Diego Purification
project faced strong opposition due to perceived injustice by some community members
feeling that the recycle water was aimed at low to medium-income communities (Recycled
Water Task Force, 2003). There was a lack of consultation and involvement of impacted
community members in the conception stages which resulted in project failure. The inclusion
of environmental justice in the 2012 EPA Water Reuse Guidelines is a big step forward in recognizing the existing procedural and geographic inequities and calling out for involvement of communities in the educational and decision-making process.

Acknowledgement of the environmental justice issue is critical when reaching out to expand water reuse to communities that are historically or economically disadvantaged, in order to address such issues and be successful. Therefore, assessing the potential for environmental justice impact in water reuse projects as well as wastewater management and current issues regarding water is a fundamental strategy that needs to be understood as the expansion of water reuse is necessitated during droughts, periods of water scarcity, and to protect drinking water from contamination especially in decentralized locations that include rural residences. As of 2000, North Carolina was ranked among the top 10 U.S. states for occupied housing units lacking complete plumbing facilities with a total of 19,295 households. Halifax County in particular had 22,122 occupied housing units with a total of 530 households lacking complete plumbing affecting about 1143 residents (see Figure 4.1). Similarly, Orange County and Robeson County had 297 and 341 such households (Gasteyer & Vaswani, 2004). The three counties described here indicate that there continues to be a wastewater management gap marked by the lack of plumbing facilities. Although environmental justice may seem a disjointed field when assessing the lack of plumbing facilities, it is relevant to understand other environmental health burdens faced by communities related to water and wastewater. Additionally, environmental issues faced at many isolated rural locations do not garner the attention they deserve to avoid ongoing negative experiences caused and/or better current
conditions. Therefore, the involvement of affected communities in projects can inform external stakeholders about best practices while educating and building capacity about a relevant topic of interest is crucial.

Figure 4.1. Total occupied housing units lacking complete plumbing facilities in the counties in NC (Adopted from Gasteyer & Vaswani, 2004).

4.2—Key Informant Interviews

Environmental justice issues tied to water reuse can best be addressed when community engagement and public input especially from minority or underserved communities is part of the project development (U.S., EPA, 2012b). Likewise, there is an urgent need to understand and address attitudes and perception values for these communities since shifts in water
infrastructure and development are happening at a fast pace to address water security issues (Baird, 2008; Karl et al., 2009)

Assessing public opinion and perception is usually carried out using qualitative research tools such as surveys, interviews and focus groups which serve to compliment other areas of research. Among the diverse methodologies for qualitative data collection, the most familiar strategies are interviews which can be framed to seek answers to particular research questions.

In order to understand current wastewater management issues faced at some decentralized communities of color in North Carolina, a key informant interview guide was assembled. Key informant interviews are usually semi-structured with mostly open-ended questions (DiCicco-Bloom & Crabtree, 2006). The interviewer or key informant is considered an expert about the community, its membership, the environment and other relevant issues. The advantages of using key informant interviews is that it allows for in-depth exploration on subject matter, flexibility and discovery of information that otherwise might not be obtained through a more structured tool such as surveys. The key informant approach allows for a wider population sample and variety instead of focusing on one particular sample subset.

The aim of the interview was to discuss and receive feedback on current issues with drinking water and wastewater management with representatives of five communities in North Carolina. The interview results can inform other stakeholders in the water sector about
competent decision-making processes and strategies that take into account residents’
perceptions including from those communities of color facing environmental justice concerns.
Furthermore, the interview aimed to assess the knowledge and perceptions associated with
water reuse at the community level and the likelihood of adopting constructed wetlands as an
alternative to conventional wastewater treatment technology and water reclamation tool.
The 2012 EPA Water Reuse Guidelines encouraged outreach to organized groups through
strategies that provide information in a way that adds credibility, and addresses concerns. For
example, water reuse terminology used by the water industry has been demonstrated to cause
confusion, not be well received, and add to mistrust and lack of acceptance by the public
(Macpherson & Slovic, 2011). In focus group settings, the responses related to water reuse
perception are impacted by the information participants receive prior to interview. In one
study, the results of which are shown in Figure 4.2, the participants were asked to choose one
out of three mindsets ("don’t mind at all," "minded a little," or "minded a lot") with respect to
drinking reclaimed water. As shown in Figure 4.2, the role of information in changing opinion in
the water reuse sector is a key strategy for water reuse assessment.
Figure 4.2. Value of information before and after describing perception of drinking reclaimed water in a focus group (Figure adopted from U.S. EPA, 2012a based on the Macpherson & Slovic, 2011 study).

This current project's original study design was to give community presentations informing about water reuse and constructed wetlands to each of the 5 participating communities prior to the interview. The idea was to provide an educational component and opportunity for communities interested in learning more about domestic small-scale water reuse and wastewater management to be empowered and up-to-date on current technological advances focused on constructed wetlands. However, due to time limitations only two community presentations were given; one at a Chambers of Commerce and another at a Seniors Dedicated Citizens Group. The communities and key informants were selected based on having the following general criteria; predominantly Black or American Indian organized community groups, a history of current or past environmental justice concerns, and being a low resource decentralized wastewater management location. As a result, 8 communities were asked to participate in the study located in several counties in NC (Warren, Orange, Alamance, Halifax, and, Robeson counties). Five key informants were interviewed in this study from three
counties: Orange, Halifax and Robeson. Halifax County had three participants that represented three different organized groups and populations.

Key informants were asked to answer interview questions by relating to community perception instead of their own unless relevant to the community as a whole. A total of 5 interviews were conducted that lasted between one and two hours. Permission to record the interview was granted by the informants in order to accurately transcribe the responses. The recording was then permanently deleted. An agreement to avoid using any self-identifiable data was made; instead, group responses in terms of trends found are reported. The study was approved by the University of North Carolina under the Institutional Review Board (IRB) number 13-1319 titled, “Assessment of constructed wetlands as an alternative for wastewater management in decentralized communities.” Since the data collection is assessed through key informants’ perception about their community as a whole, the IRB application was exempt. Under this IRB exemption, comments and direct quotes from the interviews are permitted to support the assessment without disclosing any personal identifying data.

The NC interviews were conducted in 3 counties; Halifax, Robeson and Orange. All locations had one key informant except for Hollister which had two representing Black and Native American residents. In particular, two of the communities have faced marked environmental racism and injustice related to geographic inequities such as the placement of confined animal feeding operations and landfills adjacent to their properties. The interview guide document is attached in Appendix A.
Demographic facts about the communities represented

In the (2011) U.S. Census, 24% of the population of Halifax County subsisted below the poverty level. Poverty level is estimated based on poverty thresholds set by the size of the family and age of the members. If the total family income is below their calculate threshold then they are declared to be ‘below poverty level’. The demographics were documented to be 53% Black and 3.8% American Indian and Alaska Natives which is much higher than the state averages of 22% and 1.5%, respectively. Robeson County residents are about 25% Black and 39% American Indian and Alaska Natives, while Orange County is about 12% Black and 0.7% American Indian and Alaska Natives.

4.3—Trends and Findings from Key Informant Interviews

Leadership involvement:

All of the key informants were current members of the community with most reported as residents of the community for over 50 years. Key informants currently held a leadership role in their community organizing, directing or handling administrative tasks. All informants have held several leadership positions in the community prior to their current position.
A. Water services, issues and conservation

- Drinking water

All communities had optional access to municipal drinking water services in their households to substitute well water supply. Municipal water was reported to be installed fairly recently (in some instances within the last seven years). Some informants reported that connections to county water lines or 'city water' were in response to documented groundwater pollution from nearby lagoons in industrial hog farms operations or unlined landfills.

Connection to a municipal water supply was seen as an improvement over well water since there is no regular testing of water quality in wells. Generally, community members perceived well water as 'presumably safe to drink,' until testing indicated some sort of pollution. Others fear the 'unknown' given the lack of regular testing of their wells and potential sources of contamination such as landfills or hog lagoons.

- Perception regarding primary issues with drinking water:

There was variability in the responses to questions about primary issues with drinking water. One key informant perceived there were no issues since the majority of the community is centralized, while others expressed concerns about contamination of groundwater for those households that chose to not connect to 'city water.' Most key informants reported that there were community members who chose not to connect to city water and still used wells on their property as their primary source of drinking water. Some community members are still waiting
for their promised connection assured by local officials due to possibility of well water contamination.

For those still dependent on well water, there are concerns about water quantity. When water wells have dried out in the past or turn into 'quicksand' community members are driven to connect to municipal water. However, the expense of connecting long after community-wide water infrastructure has been built results in much higher expenses. These were reported by some informants to be in the range of $30 to $80 during initial construction to between $500 and $1500 after. The informants' estimates for tap fees (or cost of connecting to potable water lines) coincide with a report which documents fees at $400 to $1000 (Eskaf & Nida, 2009)

In general, municipal water is not available to all households in the communities, where some members continue to rely of well water for their day-to-day needs. In some instances, municipal water connectivity has been carried out piecemeal around the community over time. The informants perceived that the proportion of houses dependent on well water for each community varied between 5% and 30%; however, for most informants this number was based on recall and not on actual data.

Past issues with well water prior to municipal water connections across the communities included; (1) high concentrations of iron or phosphorus from old testing carried out because of residents' concerns about water quality, (2) lack of access to wells due to poor soil conditions led to sharing of wells, and (3) use of surface water (i.e. creeks, lakes, etc.) as a source of
drinking water. One informant reported well water to have a bad odor, appearance and taste which tested positive for petroleum based by-products and bacteria such as fecal coliform.

- **Community involvement in decisions related to new water infrastructure**

One community recalled a few public hearings for people to get acquainted with new water infrastructure coming to the community but not a lot of involvement once construction began. Some communities did not recall public hearings but instead received a letter notifying when the water lines were to be installed. One key informant described the community involvement as a ‘constant fight’ with local officials to obtain access to basic services including water and sewer infrastructure. In many instances, the absence of water and sewer infrastructure was considered a significant barrier towards economic development initiatives in communities.

- **Conservation of water**

Some of the informants reported no need for water conservation measures given that water is ‘plentiful.’ No community recalled any educational campaigns about water conservation. Two communities recalled placing a few tips on water conservation in the local newsletter or taking advantages of annual community events to support the idea. They also reported that those on well water were fearful, that the wells would run dry.

There was some discrepancy regarding problems with quality vs. quantity. Some communities perceived quantity as an issue while quality was a concern to others. In terms of quantity and lack of water conservation one informant mentioned that even though there had been
droughts, people are not being taught or educated about how to conserve water. Cost was not mentioned as a factor in water conservation.

- Community measures for water conservation during past droughts

Those communities connected to municipal water during drought periods expressed little to no concern about running out of water. For those that still had wells during dry periods, low water tables were an issue that caused community members to use filters and reported severe damage to indoor plumbing fixtures such as sinks and toilets. Some had to dig deeper or new wells altogether. Irrigation of gardens and other nonpotable uses of water were reported to be diminished significantly. With regards to measures taken, an informant reported that ‘community members were orientated [by tribal administration/local leaders] to bucket in water...simply use their neighbors’ water or wherever they can get water.”

B. Wastewater management

- Waste disposal issues

The main method of wastewater disposal among the communities was conventional septic systems. Two communities specifically mentioned studies on the septic systems performance and reported problems with failing septic tanks, including straight piping also referred to as blackwater or graywater piping. The development of land has been hindered significantly by unsuitable soil conditions for septic systems. In order to fix current problems with straight piping and failing septic systems, community level approaches to remediate problems were taken to perform the pertinent repairs in collaboration to the respective local health
departments to avoid the feared consequences of 'condemning or shutting down' a residence. Also, two key informants from the same geographic location expressed being part of a sewer district citizen advisory board looking at an alternative wastewater treatment cluster system. They both indicated a lack of support at meetings from community members with major concerns about the cost associated with an added utility bill.

Some comments related to this issue were:

"I really don't think the people pay any attention to the upkeep of their waste systems until there is a problem"

"Well, we have some problems here; we have a 33% failure rate on septic systems"

"The real issue no one has gotten sick. If you have an E.coli outbreak and people are getting sick than it will become an issue"

"There are still some homes in this area that do not have indoor plumbing...that have to bring water into their home and to dispose of 'it.' It's taken out in buckets and thrown into the woods."

"Outdoor toilets...you heard of that? ...Okay, we still have some of those."

- Other issues brought out by key informants were:
  - Land requirement for drainfields, in case a septic tank fails, is a concern since there may not be enough available space.
  - Frequent maintenance requirements of septic tanks such as pumping out are burdensome and likely to result in neglect and failure.
- Lack of education about how to properly maintain septic tanks
- Common practices to increase the lifetime of septic tanks or avoid maintenance among community members were to add bleach or other additives such as yeast packets.
- Public locations around some of the communities had access to sewer disposal while individual homes did not.
- Septic systems provide limits to the amount of waste you can safely generate and dispose of onsite based on soil condition.
- Standards for new septic systems are different to those for septic tanks already existing in the community.

At this portion of the interview, issues related to health and costs were not directly raised by informants. Usually cost associations were linked to property and use of land, and maintenance requirements by septic system units. Health was only mentioned by one informant referring to waterborne outbreaks as a way that recurring issues with water and wastewater systems may receive more attention.

With regards to other types of sewage disposal, all communities reported only using septic systems and sewer connections. Maintenance of wells was not common in the communities. One informant reported that for taste and odor problems, ‘most people know to put bleach.’ Also, there were concerns about well pump maintenance and how it was advantageous to have municipal water especially because it allows for water supply independent from the electricity.
• **Education**

All community informants were highly in favor of and advocating for educational campaigns that can enhance and educate about proper waste disposal management either with their current systems or for alternative systems such as the cluster system explored in one of the communities. They stressed the importance to get people to talk about it, but expressed concerns about privacy and pride when exposing those issues publicly.

• **Level of satisfaction with current wastewater disposal and management**

The community informants provided varied responses regarding level of satisfaction on wastewater disposal and current management. The highest levels of dissatisfaction were linked either to 1) the inability to build septic systems that will enable new developments or replace existing malfunctioning ones given soil conditions and setback distance requirements, or 2) unfulfillment on past promises by local official towards completion of sewer connections throughout community. One participant thought community residents were satisfied given that septic systems are the only option they know in terms of wastewater management. Two communities explained their level of dissatisfaction in terms of not wanting their children growing up in an environment that lacks basic services such as a ‘a clean glass of water’ or having ‘community bathrooms.’

In general, informants expressed their community’s desire to keep and stay in their property and stressed that ideas and solutions to current wastewater management issues may enable
them to do so. In line with that idea, strong family and land ties appear to be recurring themes with high perceived value by communities recognizing that development may enable economic growth, improve current poverty and employment and encourage younger generations to stay in their communities.

- *Trust in public utilities or external groups*

All communities expressed some lack of trust in public entities to provide water or wastewater disposal services. The key informants expressed how community members are not included in decisions related to water infrastructure or even being informed about alternative options that could potentially alleviate current wastewater disposal problems.

- *Alternative systems for wastewater treatment and disposal*

Three key informants from the same county were familiar with cluster systems for wastewater disposal. One informant indicated that economic development will not happen in their community unless an appropriate wastewater disposal is installed. One informant did not know about having any other options and mentioned that the community went from ‘outdoor privies to septic tanks’ but that given they are aware of other communities with similar issues exploring alternative technologies, they would be receptive to it. Thus, septic systems were perceived, by one community, as a significant improvement that indicated a step up from low socioeconomic status to middle class, compared to previous rudimentary methods of wastewater management. One informant reported having considered lagoons followed by spray systems as an alternative.
C. Water reuse and recycling

- Perceived benefits of water recycling or seeing wastewater as a resource

Some informants suggested that most members have not really thought about whether water should be recycled and whether it should be a one-time resource or not. Informants understood that compared to larger urban areas, rural areas have different dynamics related to water recycling. Major water problems such as droughts, were seen as one of the few scenarios for which it would be advantageous to reuse water. Water reuse for irrigation purposes was also perceived positively among informants. This question was intended as a preamble for informants to subsequent questions related to water reuse; therefore, some informants referred to treated wastewater as septic tank effluent prior to being presented with terminology.

The answers were varied across key informants:

"I don’t see [an advantage]. From what I am told, wastewater that has been treated can be stored if you have storage space that can be used for a period of drought and things like that...but in a rural area like this it is just not talked about... in this area [water] is a one-time resource."

"Most definitely, if it is done properly."

- Water reuse terminology

In general, two key informants were familiar with terminology used in the wastewater management sector possibly due to their past and/or current positions in water and
wastewater management facilities. However, there were still a few general terms not clearly identified or described and further explanation was given to assure the integrity of the interview was kept and that all participants understood the terminology in the same context.

Most community informants were not familiar with the terms used by the water reuse industry such as water reclamation. There was general knowledge about water recycling and it seemed to be a term most informants were familiar with expressing experiences of water reuse related to collection of rain water to be later used for other purposes such as laundry or dish washing. The concept of a cluster wastewater system was known as other communities were either considering them or already have them in place. The most confusing terms for informants appear to be ‘water reclamation’ and ‘onsite wastewater systems’. At the end of the question related to defining the terminology, all informants were given an explanation of the meaning of each term and given examples that they could relate to. Informants stated that unless there was an external effort such as a presentation or educational formats that they, as well as community members, would not be familiar with terminology.

- Knowledge about constructed wetlands as an alternative system

No informant was familiar with the term ‘constructed wetland’ and much less as an alternate wastewater treatment until after the information was provided during or prior to the interview. Since it was not expected for all informants to be familiar with constructed wetlands, a visual aid was added to the interview to explain what they consist of and how they fit into the wastewater management picture (see Appendix A). Informants then asked the following questions about constructed wetlands:
o Is this an alternative system for individual homes?

o How is it being cleaned?

o How far would that need to be from my house?

o Would the wetland plants then give me another problem...that I don't want to have to deal with on a regular basis, you know, such as snakes, raccoons, any of these animals that might live in wetlands?

o Are cattails the only thing that can grow in there?

o How much land does it take?

o How expensive is the system?

Other comments made were:

o "I'm thinking could this be installed for residence instead of putting in a traditional septic system for property that does not percolate. The water goes into plants and it's being cleaned"

o "This could also sell if the wetlands is able to produce something that might be income generating....I can use this to help me generate some money...we are talking about people who are living in very, that are in poverty areas, if you're with me"

o "And then I would have to say and now I got this water clean, how am I supposed to get it out? And is it in a holding tank, now I have to buy a holding tank, now I have to buy another pump to move it out? I got to have a little
irrigation system to spread it wherever I want to go or can I just go and dip a bucket in it? “

- **Community support and potential interest to use constructed wetlands for wastewater treatment and water reuse.**

In general, most informants declared that acceptance of CWs are dependent on the level of understanding about the technology. Given that water reuse is not talked about in the communities, some were hesitant on community support for reuse purposes but expressed more likelihood of support for wastewater treatment. Some informants said that communities might have feelings of reluctance towards CWs or perceive them as a technology that will take some labor to maintain. All informants agreed that education on the possible uses of reclaimed water from a CW would be necessary. The following quotes relate to the need of education to increase understanding about water reuse infrastructure, in particular when asked about CWs:

  - “I don’t think that it would be a natural understanding”
  - “They need to see it and understand the process”

With regards to community interest in learning more about constructed wetlands, most informants agreed. Some thought that their community would ‘absolutely’ support it, while others said that the initial response would be ‘slow’ or ‘negative.’ Suggestions from the participants were to have community meetings, ensure its low cost, find a way to catch their attention to initiate dialogue and rely on community advocates, but an educational component was stressed. One informant referred to interest in learning about the technology in terms of
time, and communicated that the community was a ‘group of people running out of time...if I am not gonna need it, I don’t have the time to listen to you. I don’t have the space”

While some informants suggested that their community would be reluctant towards CWs for wastewater treatment and reuse, others said that they would support it but had very similar questions about installation, maintenance and share of responsibility. As one informant noted, ‘they would not accept it if they don’t understand it.’ Some informants said that some individual level homes might be interested in learning more but as a community for clusters, there was concern about the lack of land to do so and there was a need for an educational process. Others claimed having the land to implement such project and that it may overcome current barriers for septic system installation due to unmet land requirements.

•  **Water reuse using constructed wetlands at the household level**

Informants reported that water reuse options are not commonly discussed at their communities and tend to perceive it as unnecessary. Some informants expressed interest in a technology that would allow them to pay for water only once since it could be reused without having to pay much for sewer. Others saw no advantage to water reuse due to the perception of water as an abundant resource around the community. Again, cost was raised as a main concern.

  o  “At this point given the information I have about such thing...this community will not...won’t be able to have an intelligent conversation out of anybody about water reuse”
“the hold to any new technology is people understand what it is and give people something that we need”

- **Perceived benefits of water reuse in the community (general not including constructed wetlands)**

The perceived benefits were for watering flowers & vegetable gardens, and as a source of drinking water for pets. Other informants mentioned that the perception of reusing wastewater even when it is been cleaned holds a mental picture of sewage. All participants were probed to answer the questions that if the barriers they listed were removed what would be the perceived benefits of water reuse. The response was then more positive.

In one instance, two informants revealed that landscaping and gardening was an acceptable and beneficial use of reclaimed water but that those practices are not widely practiced in the community. Therefore, the informants raised questions about end use of reclaimed water and the cost associated with its storage. Benefits of water reuse were in most instances associated with cost, economic gain, social responsibility and protection of the environment.

- **Perceived benefits or gain of water reuse to individuals or groups to implement CW.**

Responses were not as uniform when it was placed in the context of individual gain for individual or clustered households, although generally all informants thought that there was some sort of benefit. Two informants perceived that a great benefit of reusing water would be to lower water bills. Others believed some individuals would be interested but not all given that septic systems are the accepted and promoted method of wastewater treatment by local
health officials. Cluster vs. individual household implementation of CWs were both seen as having a gain; however, cluster systems were more accepted in some instances. Only one informant spoke about the aesthetic aspect of constructed wetlands as a perceived value.

- “You have to sell it, and that this water is just as any water that you take from the earth anyway”
- “this is an African American rural community that has struggled all of its’ life to become “middle class” quote on quote by having a septic tank and septic system, not that this is a septic system but no one has ever talked to them about that so they only know about what the health department tells them they have to have”

One community informant in particular viewed several benefits of using CW for water treatment such as the ability to keep properties and build in their own land, have younger generations stay and also build, and economic development. This appears to be a result of the continuous struggle this particular community had with soil composition that did not enable construction of septic systems. However, when it came down to reuse of water this informant did not see any benefits due to the perception of having an abundant water supply available in the community.

- “I have to say no again, because in this location and in the rural areas, it’s just difficult to sell reuse. Because we got creeks, streams, you know if we really have to have water we could go to the creek...”
• Community trust on capability of water officials to keep treated wastewater safe

Over half of the informants reported that the community does not fully trust officials in general, which extrapolated to their perception related to keeping treated wastewater safe for reuse. The rest expressed that there is some level of trust explaining that if there are complaints or questions, community members can ask questions, while in other instances trust was associated with just accepting things the way they are or just trusting officials to do what’s best for the community. However, all informants were probed to judge trust in terms of reclaimed water and all reported no trust in water officials to provide safe treated wastewater for any reuse applications in their communities.

Some informants associated water reuse to a cultural change that will initially cause community members to not be trustworthy of it. However, informants consistently reported that with education and community involvement resistance to water reuse may change. In several instances informants referred to cultural history and other examples that have caused their communities to not be trusting of government officials. One informant stated that water departments have sent notices for public meetings where they inform the community of high levels of certain pollutants in their drinking water supply after the fact. Another informant indicated that representatives of local community organizations serving as liaisons and community advocates at meetings with representatives of official bodies are trusted better, when explaining the issues presented by the officials than if the officials were to speak to the community directly.
"I'll say, African American poor people anyway, have a tendency to trust the government to do the right thing more so than people who have become a little more knowledgeable and educated, our white counterparts don't trust the government period because they always feel like it is trying to take something from them"

"the issue that we are having down in Camp Legune and Fort Bragg that the government would allow people to drink poison water for 30 years, folks who are there to protect the country, you know so I think that following those kinds of stories is going to be a lot less trust in the government in taking care of us"

"Simply because we have built the trust of the community, that if something new comes from governments or county elected official, they will come to us and say explain to me why this is, why are they doing this...they don't understand what these people are saying but I need somebody to speak my language..."

Questions that the community would need answers to in order to make a decision to adopt onsite wastewater treatment and reuse

Numerous questions were raised by the informants. The first questions usually had to do with overall cost, economic feasibility and affordability, personal payback, water usage and level of quality. All the informants said that these questions would hold for onsite treatment or reuse, whether through constructed wetlands or not. The following is a detailed list of all the questions brought up by the participants:

- How much is it going to cost?
Participants were probed to think about not having sewer connections and whether or not the community would consider exploring alternatives for onsite wastewater treatment. As a response, all informants appeared to consider that their communities would be receptive to alternative systems. Some of the examples given were related to households and family groups' living near each other and having to construct separate septic systems but due to the
lack of knowledge about other alternatives for treatment would follow the conventional route. Some community informants reported that high septic failure rates and soil conditions have made the idea of alternative systems more attractive, given that previous studies have deemed sewer systems economically unfeasible. One informant described community members as being very hands on and interested in the way nature takes care of the environment. They would likely consider it and, if affordable, might perhaps build it themselves.

- *In terms of current uses of drinking water that can be replaced by reclaimed water outdoors and indoors in households*

In general, most mentioned reclaimed water for the following uses without much hesitation.

- **Outdoor**: car washing, commercial and industry use for processing, feeding livestock, irrigation of lawns, and gardens
- **Indoor**: Laundry, and toilet flushing

In terms of indoor uses of reclaimed water all informants agreed on use for laundry purposes. There was some disagreement regarding bathing and cooking; some thought one could be more accepted than the other or vice versa. The reasoning with cooking by some was due to the perception that boiling water will eliminate the bacteria in it while others were not comfortable with any type of consumption, cooking or drinking. Drinking of reclaimed water was definitely perceived as not acceptable. For outdoor uses, some perceived it would be accepted for crops but that even then communities might not be comfortable with the idea.
At the household level, more specific questions regarding community consideration about the use of reclaimed water for laundry, bathing, cooking and drinking were asked. Reclaimed water for laundry was accepted by some attributed to the large quantities of water needed but with hesitation as long as negative impacts were not seen. Others did not think it would be acceptable for laundry but perhaps for outside use. Yet another informant, although accepting of indoor water reuse, posed some questions about the need for additional infrastructure to support the use of reclaimed water based on hot water lines, and what to do with the outflowing water.

In terms of bathing, informants were hesitant but acceptance was generally better if there was no odor, the water was clean and clear, and could be heated. Rejection of this notion was attributed in one case to children developing rashes and skin problems.

Quotes referring to bathing with reclaimed water:

  o "I think, we would have a really hard time about the water that I flushed down the stool with waste then... now you want...now I can bathe in it? I think that would be a hard sell. That is a hard sell even to me, and I consider myself somewhat enlightened."

Cooking and drinking of reclaimed water were all initially rejected by all informants. They were then probed to see which of the four indoor uses of reclaimed water might change during a drought period. The results were that communities are mostly accepting of cooking given the
perception that boiling water improves the quality. Two informants revealed that during drought periods, it would probably change for all of them, from laundry to drinking.

- “We will have to be mighty desperate to cook with it, that’s all I know. I know that’s the next question. And as long as the government is sending in some plastic bottles you are not going to have to worry. I will not be cooking with it...I think it would be easier to do it during a dry spell, a real dry spell. And the government wasn’t sending in plastic bottles.”

- “Cooking, it could be...they probably boil it ...I just don’t see them accepting them for drinking.”

- “...most of the fears of it it’s knowing where it’s been before we got it, and that is being used before and now we are using it again... If there’s a drought they would reuse it; for all of them, laundry, cooking drinking, bathing.”

- Community thoughts on reuse of wastewater for the following:

  Environment friendly:

Almost all informants thought reuse of water was environmentally friendly, although one informant did not perceive it that way.

- “they’d be more receptive now because of the fact of having been working on some environmental issues...that is all connected.”

- “…water that has been through sewer systems is a no-no for most people at this point.”
Health concerns:

Concerns about how reclaimed water may affect the health of vulnerable populations such as the young and elderly were raised. Others expressed that given the history of environmental justice, they have the tools and resources to run their own water tests and read the results instead of trusting external groups that claim to provide safe drinking water. There was also concern about fear, need for education, and whether or not contact with irrigated crops would be safe for human health.

- "we drank bad water for so long...we don't have to take their word for it, because now we know how to run our own tests, we know how to give it to labs and send it in and read the results. You tell us that is good, fine, but we are not gonna take your word, we gonna test it ourselves, which is one of the things that we learned."

- "If I am using it in my garden, my vegetable garden, isn't some of that stuff going to stick to the vegetables when I cut it? Especially the cabbage leaf, or the collard leaf or the salad leaf."

- "Can I keep my kids from getting sick? Is this gonna [make them sick and how to protect them or my elderly parents...]"

Protection of water bodies:

In terms of acceptable use of reclaimed water for groundwater replenishment and edible crop irrigation, only two communities were asked this question. Both informants thought that their communities might be receptive to the idea. Informants seemed receptive to further
treatment of effluent water by natural cycle which is attributed to the general understanding groundwater is produced from surface water that goes through a continuous filtration process as it flows through the soil.

- *Overall feelings of community regarding water reuse*

Overall, most communities thought that both water reuse and reclamation may be beneficial or that is too early to say (see Appendix A). One informant stated that “within [American] Indian culture [it] is just the right thing to do,” while other informants perceived that benefits could be seen, but they hesitated to accept water reuse due to their perception that is not widely practiced elsewhere. One participant said it was too early for the community to make a decision due to the lack of information on the topic while another informant suggested that “if there was a good education program” then there may be a “very positive perception.” However, the same participant expressed concerns about whether the idea of reuse was also being presented to gated communities and followed up by raising this question; “you want us to have recycled water while they can still have good water?” This particular comment might relate to environmental justice paradigms described earlier, where groups might feel water reuse projects are placed at their communities over others of higher economic status. One participant thought it was not beneficial given the experience from community resistance to other wastewater related issues, but expressed that during droughts the reality might be very different.
- Sharing of information regarding wastewater issues and handling of past environmental concerns

Informants referred to neighbors and casual communal talks about septic systems but for the most part declared that no real programs about water and wastewater management are implemented. Individual communities all had different ways to receive information, as shown in Table 4.2. Regarding community strategies to handle past environmental issues, there were different ways ranging from passive (relying on pertaining entities) to more active involvement (including protests).

Table 4.2. Reported avenues for sharing information about wastewater and handling of environmental concerns.

<table>
<thead>
<tr>
<th>Community informant</th>
<th>Sharing of information regarding wastewater</th>
<th>Handling of past environmental issues (If any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community 1</td>
<td>Newsletter in the education section, community events</td>
<td>Rely on officials</td>
</tr>
<tr>
<td>Community 2</td>
<td>No real programs</td>
<td>Organizing to keep out large industries that pollute water.</td>
</tr>
<tr>
<td>Community 3</td>
<td>Local newspaper, or community newsletter</td>
<td>Tips on the newsletter, community meetings, reactionary or seasonal approaches</td>
</tr>
<tr>
<td>Community 4</td>
<td>Word of mouth, family connections</td>
<td>None reported</td>
</tr>
<tr>
<td>Community 5</td>
<td>Emails, flyers, talk among neighbors</td>
<td>Protests, council meetings, presentations, educational campaigns</td>
</tr>
</tbody>
</table>

- Connection to nature

From a tribal American Indian perspective, two key informants from these communities explained the inherent respect for nature, in which water should be protected for future
generations. One key informant in response to how their community would feel about nature doing the water treatment instead of infrastructure answered, “Yes, they are very fond of nature’s way of doing things. That would be an excellent idea... of mother earth doing it the correct way vs. man-made things; tearing up or destroying the land...just the natural cycle of God healing.” Another informant acknowledged the American Indian perspective by saying, “we have to protect it for future generations.” However, at the same time this particular informant expressed concerns about balancing environmental protection and land development identifying a need for a “happy medium between protecting the environment and developing your land areas...it’s sort of a catch 22. You need economic development because we are dealing with a 17% unemployment rate.”
References


Chapter 5

Conclusions and recommendations

5.1—Summary and conclusions

The overall objectives of this technical report were to provide a case study for the state of North Carolina regarding the use of constructed wetlands as a wastewater management and reuse tool for decentralized domestic households and providing a public perception assessment. Under these overarching objectives, the study aims were to 1) provide a review on constructed wetlands as a technology for decentralized domestic wastewater treatment and reuse in terms of design, components and pollutant removal, 2) discuss the current state of constructed wetlands for wastewater treatment and reuse in NC in terms of regulations and permitting as well as case study locations, and 3) assess community perception of wastewater management and reuse in decentralized poor communities in NC using key informant interviews.

The literature review on design and components of CWs showed the technology to provide adequate wastewater treatment but with significant benefits over conventional methods of decentralized wastewater disposal. The most noticeable benefits of CWs over conventional septic systems were found to be low O&M requirements, aesthetic features from emergent vegetation enabling the creation of green spaces, and the production of high quality effluent...
water suitable for water reuse applications or safer wastewater disposal protecting of groundwater. In addition, CWs can be integrated after septic tanks to act as an advanced pretreatment wastewater system (AWPS) unit which in turn decreases the amount of improvement permit denials. This enables the building of new developments and replacement of current malfunctioning infrastructure.

One of the main barriers for the implementation of CWs at decentralized households over septic systems is cost. Although CWs are promoted as a low cost alternative, this is not necessarily true for residential homes. The capital cost associated with the replacement or construction of septic tank infrastructure is much lower than it is for CWs. Another cost impediment to having CWs at homes is the need for an operator as stipulated by the NC state rules and which has to be subsidized by homeowners. Given these drawbacks, CWs are better suited for community level wastewater disposal projects such as sewer districts and cluster wastewater treatment systems.

Other barriers associated with the use of CWs for wastewater treatment at households and beyond in NC may be attributed to the lack of good communication between stakeholders in the sector such as between permitting agencies at the state and local levels and consumers. Although CWs are catalogued as an experimental AWPS, not much documentation is found at NC DHHS-On-Site Wastewater Protection Branch (OSWPB) about the technology. In addition, consulting engineers in the decentralized wastewater sector appear to be the most knowledgeable about CWs and are the main advocating agents for its expansion. Generally, the
permitting of decentralized systems was found non-comprehensive and disjointed across two of the NC agencies involved in the permitting process, namely DENR and NC DHHS. Although most of the permitting of wastewater treatment at decentralized households is by the NC DHHS, some homeowners are able to receive permits from NC DENR (e.g. single family residence, SFR) if the treated effluent is disposed of by surface land application. SFR permits do not require routine maintenance and operation by a certified operator and general effluent limits are different from systems permitted by NC DHHS.

The CW site locations in NC demonstrate the different avenues (industrial, municipal and domestic) for which the technology is being utilized at the state. Some of the problems pertaining to CW operation were traced to design specifications (Raleigh stormwater wetland), or inability to keep pH within parameter limits (City of Goldsboro wetlands). Other sites reported optimal functioning and pollutant removals. The case study locations also demonstrated that CW can treat wastewater to secondary and tertiary levels, and in some instances serve as a pre-treatment technology for water reuse applications. CWs in NC have also alleviated water pollution from stormwater runoff or industrial waste reaching nearby water bodies. Successful projects for the treatment of domestic water and reuse applications utilizing CWs continue to serve as prime examples for the technology to move forward. Regarding public acceptance at sites using CWs, public input at the planning stages on the projects seemed to be minimal or non-existent; however, no negative press was found on the CWs showcased. In some instances, the early involvement of the public increased the
knowledge about CWs as a natural treatment system and as an educational tool (i.e. Boone Greenway Wetlands and Northern Guilford Middle School).

In terms of water reuse, the literature review indicated that NC compared to other Southern states has significantly fewer projects related to reclaimed water applications. In the 2012 EPA Water Reuse Guidelines (U.S. EPA, 2012), details about the state of water reuse in NC were presented showing applications related to agricultural (Type 1 and Type 2), and environmental reuse. The most updated reclaimed water rules in the state show irrigation of food crops is allowed along with wetland augmentation. Other beneficial water reuse applications (with no direct human contact) are to comply with effluent limitations and design specifications such as conjunctive vs. non-conjunctive systems.

The scientific evidence on water reuse shows that there is a growing need to address major barriers in the sector. One of the barriers to expansion and acceptability of water reuse projects is public perception. This has been recognized by the EPA Water Reuse Guidelines with a dedicated section to public outreach and participation. Concurrently, this same section also sets the ground for interfacing public perception and environmental justice issues related to water reuse at decentralized locations to inform other stakeholders in the sector and provide useful and effective educational materials to such communities. The key informant interviews from five communities in NC that were decentralized, resource poor, minority and/or facing environmental justice issues suggested several overarching take away points (listed below) regarding community perception on wastewater management and water reuse acceptability.
- Alternative options for wastewater disposal at homes were welcome due to recurring problems with septic system permitting and maintenance,
- Water reuse terminology used by industry and permitting agencies is not recognized by communities,
- Effective educational and outreach programs are essential when introducing new wastewater treatment or water reuse ideas in order to:
  - address community questions related to overall cost, economic feasibility and affordability, personal payback, water usage and level of quality, and
  - overcome foreseen barriers such as those associated with lack of trust on officials from previous experiences associated with environmental justice issues.
- Constructed wetlands were perceived somewhat positively in terms of attractive features for community wastewater management and reuse capabilities,
- Perception towards acceptance of water reuse is varied at the communities interviewed and dependent on the following factors; trust in water officials, water availability, cost, economic gain and proposed endpoint use of reclaimed water,
- During drought periods, community residents might be more receptive to domestic water reuse applications outdoors (car washing, watering lawns and gardening) and indoors if necessary (toilet flushing and laundry).
5.2—Recommendations

The large proportion of the population of North Carolina is practices on-site treatment of their wastewater; therefore, as wastewater infrastructure evolves water reuse enabling technologies are expected to expand to those areas. In the past 10 years, NC has faced severe droughts which have shifted the notion of water as a one-time commodity to a recycling resource. This has been supported by legislation of water reclamation at the state level to save potable water sources for human consumption and utilize reclaimed water for nonpotable uses. Many decentralized communities in NC are impoverished but clustered in groups enabling the use of community wastewater treatment and wider applications for water reuse. However, support and leadership from regulatory agencies is needed to advocate and promote for alternative clustered wastewater systems.

This study informs the water reuse sector about perception of wastewater treatment and water reuse, and serves as a starting point for using qualitative tools to assess community level perception. The findings from this study can help frame a more culturally competent and structured data collection tool for evaluating community or individual perception on decentralized wastewater related questions.
Appendix A—Key Informant Interview Guide Document

- Wastewater as a safe resource: water reuse and reclamation
- Adoption of alternative technologies for water reclamation and reuse

Objectives:

1. Assess the perceptions about wastewater management in minority communities that are decentralized and low-income facing environmental justice issues.
2. Obtain information about previous options explored by communities regarding wastewater management and viewing domestic waste as a resource.
3. Get opinion on their perceived benefits and limitations of decentralization
4. Introduce the topic and/or terminology of water reuse and reclamation and get information on level of knowledge about it and whether or not alternative treatment technologies such as green infrastructure (constructed wetlands) would be considered.

Thank you for your time today. We are conducting a study about onsite and domestic wastewater systems in un-sewered or unincorporated communities in NC; particularly those currently facing some kind of environmental justice issues. One of the most important aspects of the study concerns the perceptions and attitudes of people in your community regarding wastewater management, and your input is highly valuable.

The study has been approved by the University of North Carolina under IRB # 13-1319 under the title, Assessment of constructed wetlands as an alternative for wastewater management in decentralized communities.

Before starting, I would like your permission to tape record the interview. The interview has a number of discussion questions which are difficult to record by handwriting. Of course, the recording, like the questionnaire, will be treated in strictest confidence. May I record our session? I will listen to the recording to obtain the answers to the questions and will discard the recording.

I will like to notify you that the interview will take approximately 45 minutes to an hour. Is this okay with you? As you answer the following questions, please keep in mind that we will not disclose any personally identifying data or data that would easily be linked to the individual being interviewed. However, data gathered may be used in reports and published as research. Feel free to interrupt me at any point if you have a question and keep in mind that there are no rights or wrong answers. Of course, you are not required to participate, or answer any questions you do not wish to respond to.

Thank you for agreeing to participate!
Again, the purpose of this interview is to understand what the community perceptions about wastewater management and processes related to its reuse are as well as assess an innovative technology for wastewater treatment and its likelihood of adoption.

To start off the interview, I would like to ask a few general questions about your relationship with this community [name the community]:

- How many years have you been a resident of the [_________ community]
- What is your present position or active role in the community?
  1. And, how many years have you served in that role? (How long have you been in that position?)

**Water services, protection and conservation**

1. **What's happening with drinking water** in your community?
   a. What are the **primary issues** with drinking water?

2. What are the primary sources of drinking water for the community?
   a. Are most people connected to municipal water? If so, since when?

3. Are there members of the community that rely on well water for drinking purposes and/or other purposes (not just drinking)?
   a. Can you describe for me what, if any, issue with well water there are or have been in the community?
      i. What about contamination?
      ii. Can you tell me more about this?
      iii. What is the extent of water resources pollution in the community
      iv. [maybe] What are the major uses of drinking water in the community besides at households
         1. Industries, farming, agriculture?
         [ME] Whatever that means to you, I'd be happy to hear about...

4. How was your community (or other organization) involved in the decisions with the development (formation/construction/building) of water infrastructure (water connections/sanitary sewers/onsite wastewater infrastructure)?
   a. Tell me how that affected you and/or residents in the community.

5. What do people in your community do to conserve (preserve/keep/save/protect) water?
   a. Can you share with me what types of educational campaigns you have seen on the conservation of water?
      i. How have the campaigns shaped how people conserve water?
1. What types of water saving/conservation do you know of? If yes, do people tend to save water in rain barrels or any other way?

6. In the past years (1998-2002 and 2007-2008), NC has gone through drought periods. How has the community been affected during this time? several
   a. Earlier you mentioned the drought, how was the community affected?”[DON'T ASK] What about the lack of water? How did the community handle that?
      i. What about the alterations on water supply and waste management? How did the community handle those?

Waste disposal and issues

1. What's happening with wastewater management in your community?

2. What do you feel are the issues with wastewater at the homes?
   a. In terms wastewater management at the homes, how is the wastewater/sewage from households disposed of in the community?

3. Are there any issues with up keeping or repairs (maintenance) of water wells? What are the issues?
   a. What about septic tanks?
   b. What about drain fields?
   c. What about any other kind of sewage disposal? If any?

4. In your opinion, is the community satisfied with these ways of disposal (septic tanks and any other they may mention)?
   a. If no, can you talk more about this?
   b. What are their concerns?

5. Have the community ever considered other options for (alternative) waste disposal (dumping/removal) or treatment technologies or tools for their homes:
   i. For example, other types of soil absorption, community clusters to treat wastewater collectively, natural systems
   ii. What about other locations around the community, beyond the houses?
      1. Such as at public locations (such as community centers/churches), for stormwater run-off
      2. Probe on the time delay of public utilities to provide basic services
6. Do you see **any benefits or advantages** on recycling (another word) wastewater as a resource?
   a. What about waste?
   b. Should they be a one-time use?
   c. Can you tell me more about that?

**Water reuse questions**

1. When I say **water reuse**, what comes to mind? Have you heard the term before?
   a. What about **water reclamation**? Does anything come to mind?
   b. What about **Recycled water**?
   c. What about **reclaimed water**?
   d. **Onsite wastewater treatment (WWT)**?
   e. **Cluster WWT**

2. Would you say the community is **familiar with these terms**?

**Explain terms:**

[ME] I hear water reuse being talked about as the use of wastewater that is treated to later be used for things such as irrigation, car washing, toilet flushing, among other applications; and save our drinking water for human consumption only.

And water reclamation is the actual process or treatment that the sewage/wastewater goes through to ensure it is treated to a level that allows for its use or reuse, I should say, without being a public health hazard/threat/concern.

Recycle water or reclaimed are essentially the same meaning water that was wastewater but has now been treated and can be used for a beneficial purpose.

**Onsite WWT** is the treatment of sewage close to where it’s generated. For example, a septic tank and a drainfield are onsite WWT because it’s right on a house’s yard, or the back of a business.

**Cluster WWT** consists of a group of homes or business that has their sewage treated collectively. For example a few homes connected to one septic tank or other type of treatment.

3. Are you and/or the community **familiar with any other methods of onsite** (closer to location/not sent to wastewater treatment plant [on your backyard sewage disposal]) wastewater treatment besides septic tanks and drain fields?
   a. Have you heard of the term **constructed wetlands**?
      i. Could I show you an example of what I mean when I say constructed wetlands (CW)?
1. Explain what they useful for, benefits and limitations are. Where is it being done in the U.S.? Focus on their water reuse capabilities and how it works.
2. Treatment process- Benefits/limitations-used by who/who can you water reuse/level of cleanliness
4. Given the information, on water reuse and the use of CW I just shared with you:
   a. How would the public in the community support the use of CW as a technology to
      i. Treat sewage?
      ii. For water reuse?
      iii. Can you tell me more about that?
5. Do you think the community would be interested in learning more about this technology?
6. Can you share with me how the community may think there are any benefits to the public from water reuse or use of reclaimed water?
   a. What would the community think are the gains to individuals or groups (such as clusters) to implement constructed wetlands and then reuse water at the household level?
   b. Does the community trust the capability of water officials (wastewater treatment plants and local health officials) to keep treated wastewater quality or reclaimed water that protects human health?
      i. To provide reclaimed water for other purposes other than human consumption?
   c. What kind of questions the community would need answers to, in order to make a decision to adopt/accept
      i. Any kind of onsite water reuse?
      ii. Constructed wetlands for wastewater treatment and discharge?
      iii. Constructed wetlands for wastewater treatment and reuse?
7. If having sewer connections was not a possibility, would the community be interested in exploring additional alternatives to wastewater treatment such as constructed wetlands

Trust and perceptions (Opinions regarding reuse of treated wastewater)

8. If there was not enough drinking water to meet the community needs, what are current uses of drinking water that can be replaced by a reclaimed water/treated wastewater that is free of bacteria?
   (Doesn't have any disease causing bugs/microorganism/bacteria)
   a. Probe about indoor and outdoor uses
9. Based on our conversation, what do you think would be the community thoughts on the reuse of wastewater?
   a. Probe (what about their thoughts on...)
      i. Would they think is environmentally friendly?
      ii. Or that it causes health concerns?
      iii. Protection of water bodies (such as wells) from contamination/pollution?

10. What do you think would be the community’s reaction to using reclaimed water...for:
(Can you say more about why you feel that way?)
   a. Water edible crops?
   b. Replenish (refill) groundwater?
   c. Household toilets?
   d. Water parks and schools?
   e. Water lawns?

11. At the households in the community, how would the community consider using reclaimed water (again microbe free) for...[and why]
   a. Laundry
   b. Bathing
   c. Cooking
   d. Drinking

12. What about during a dry period when water is less available?

13. Considering everything we have discussed up to this point, what would be the overall feelings of the community with regards to water reuse?
   a. That water reuse and reclamation may be beneficial for the community, that is too early to say or that is not beneficial?
   b. Can you tell me more about that or give me an example?

Community participation –Information

1. How is information concerning waste issues shared with the community at large?

2. What has been done in the past to address the water related environmental concerns of the community?
   a. Can you tell me more about this?

3. How has your community engaged with other people or groups with topics concerning water?
   a. What about working with local health departments, environmental groups, environmental engineers, etc.?
b. Can you describe the level of involvement?
c. Could you say the community has had positive or negative experiences with these groups?

4. Based on our interview, would the community see any benefit or advantages on the reuse of reclaimed water?
   a. What would be their thoughts about viewing water as one-time use resource?

Visual aid