Bren School
of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

ASSESSING DECENTRALIZED WASTEWATER TREATMENT OPTIONS IN SANTA BARBARA COUNTY

2012 Group Project

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Peikert Group Architects and The Sustainability Project

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Assessing Decentralized Wastewater Treatment

Options in Santa Barbara County

As authors of this Group Project report, we are proud to archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Arturo A. Keller, Ph.D.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS

BOD: Biochemical Oxygen Demand, 5 day.
CDPH: California Department of Public Health
CWA: Clean Water Act
CEQA: California Environmental Quality Act
CSO: Combined Sewer Overflow
CUP: Conditional Use Permit
CWNS: Clean Watersheds Needs Survey
DAU: Designated Analysis Unit
DWR: Department of Water Resources
EHS: Environmental Health Services
ET: Evapotranspiration
GHG: Greenhouse Gas
GWP: Global Warming Potential
HSSF: Horizontal Subsurface Flow
LCA: Life Cycle Assessment
MBR: Membrane Bioreactor
MOU: Memorandum of Understanding
NPDES: National Pollutant Discharge Elimination System
OWTS: Onsite Wastewater Treatment System
POTW: Publicly Owned Treatment Work
RF: Recirculating Filter
RWQCB: Regional Water Quality Control Board
SBC: Santa Barbara County
SWRCB: State Water Resources Control Board
SWIS: Subsurface Wastewater Infiltration System
TSP: The Sustainability Project
VF: Vertical Flow
WHO: World Health Organization

DEFINITIONS

Aerobic: biological processes which require oxygen to perform.

Anaerobic: biological processes that occur in the absence of oxygen.

Activated sludge: highly concentrated mass of live organisms in a suspended environment with aeration and mixing.

Alternative onsite wastewater treatment system: onsite wastewater treatment system that is not a conventional system as described by local regulatory code.

Bacteria: prokaryotic microorganisms that perform specific ecosystem functions and in some cases act as disease causing agents.

Biochemical Oxygen Demand (BOD): the amount of dissolved oxygen required by aerobic organisms to break down organic compounds present within a volume of water for a specific temperature and time interval.

Coliforms, fecal: common indicator bacteria that is cultured in standard tests to indicate either contamination from sewage or the level of disinfection; generally measured as number of colonies/100 mL or most probable number (MPN).

Coliforms, total: measurement of water quality expressed as the number of colony-forming units (cfu) of coliform bacteria per unit volume.

Colony-forming units: term used to report the estimated number of live non-photosynthetic bacteria in a water sample.

Denitrification: biochemical reduction of nitrate (NO_3-) or nitrite (NO_2-) to gaseous molecular nitrogen (N_2) or an oxide of nitrogen.

Disinfection: process used to destroy or inactivate pathogenic microorganisms in wastewater to render them non-infectious.

Dissolved Oxygen: amount of molecular oxygen (O_2) dissolved in water, wastewater, or other liquid; commonly expressed as a concentration in milligrams per liter (mg/L), parts per million (ppm), or percent of saturation.

Escherichia coli (E. coli): member of the coliform bacteria group normally present in human and animal intestines; indicator organism for fecal contamination in water.

Eutrophication: nutrient enrichment of a water body typically characterized by increased growth of planktonic algae and rooted plants, which can be accelerated by wastewater discharges and polluted runoff.

FOG: acronym for Fats, Oils, and Grease compounds that can interfere with wastewater treatment processes if not removed prior to entering a wastewater treatment train.

Helminths: parasitic worms that can infect humans when brought into contact with infected water.

Most probable Number (MPN): estimate of the density of microorganisms in a sample based on certain growth rates and statistical formulas, commonly used for coliform bacteria.

Mound: above-grade soil treatment area designed and installed with at least 12 inches of clean sand between the bottom of the infiltrative surface and the original ground elevation.

Nitrification: biological oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-), or a biologically induced increase in the oxidation state of nitrogen.

Nitrogen, nitrate (NO3-): stable oxidized form of nitrogen; nitrifying bacteria can convert nitrite (NO2-) to nitrate (NO3-) in the nitrogen cycle.

Nitrogen, total: measure of the complete nitrogen content in wastewater including nitrate, nitrite, ammonia (NH_3), ammonium and organic nitrogen, expressed as mg/L of N.

Package plant: term commonly used to describe a modular aerobic treatment system unit serving multiple dwellings or establishments with relatively large flows (greater than 1,500 gallons per day).

Pathogens: organisms that cause infectious disease; examples in wastewater include Salmonella, Vibrio cholera, Entamoeba histolytica, and Cryptosporidium.

Phosphorus, total (TP): sum of all forms of phosphorus in effluent.

Protozoa: single celled eukaryotic organisms with specific members able to cause human diseases, most notably Giardiasis and Cryptosporidiosis.

Sludge: accumulated solids and associated entrained water within a pretreatment component, generated during the biological, physical, or chemical treatment; coagulation; or clarification of wastewater.

Solids, settleable: suspended solids that will settle out of suspension within a specified period of time, expressed in milliliters per liter (mL/L).

Solids, suspended: that portion of total solids that is retained on a filter of 2.0 μm (or smaller) nominal pore sized under specified conditions.

Solids, total (TS): includes total suspended solids (TSS) and total dissolved solids (TDS); typically expressed in mg/L.

Solids, total dissolved (TDS): material that passes through a filter of 2.0 μm (or smaller) nominal pore size, evaporated to dryness in a weighed dish and subsequently dried to constant weight at 180 degrees C; typically expressed in mg/L.

Solids, total suspended (TSS): a conventional pollutant, defined by the measure of all suspended solids in a liquid, typically expressed in mg/L.

Suspended-growth process: configuration wherein the microorganisms responsible for treatment are maintained in suspension within a liquid.

Treatment train: site-specific combination of components that make up a wastewater treatment system; a simple example of a treatment train is a septic tank and a soil treatment area.

Turbidity: relative clarity of effluent as a result of the presence of varying amounts of suspended organic and inorganic materials or color.

Unit Process: an engineered system to effect a given change in wastewater. Examples include screening, gravity settling, coagulation, flocculation, filtration, membrane separation, biological treatment, disinfection, and chemical precipitation.

Virus: small parasitic microbes that reproduce by invading a host cell and redirecting its reproductive process to manufacture more viruses. In domestic wastewater, rotaviruses and noroviruses may be found.

Wastewater, residential strength: effluent from a septic tank or other treatment device with a BOD_5 less than or equal to 170 mg/L; TSS less than or equal to 60 mg/L; and fats, oils, and grease less than or equal to 25 mg/L.

Wastewater treatment system, cluster: wastewater treatment systems designed to serve two or more sewage-generating dwellings or facilities with multiple ownership; typically includes a comprehensive, sequential land-use planning component and private ownership.

Wastewater treatment system, decentralized: wastewater treatment system for collection, treatment, and dispersal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, at or near the point of waste generation.

Wastewater treatment system, onsite (OWTS): wastewater treatment system relying on natural processes and/or mechanical components to collect and treat sewage from one or more dwellings, buildings, or structures and disperse the resulting effluent on property owned by the individual or entity.

ABSTRACT

Freshwater resources are critical for meeting human needs, but California's water supply is currently threatened due to increased demand and a growing population. One potential solution to address this water shortage is reducing demand through recycling water. Decentralized wastewater treatment can provide high quality, recycled water on site, but these technologies are scarce in Santa Barbara County due to a lack of familiarity. We partnered with The Sustainability Project, a Santa Barbara based non-profit, to develop a decision support tool for architects and builders to learn about and compare systems, and to assist them in identifying appropriate wastewater treatment systems for their projects. We then applied our tool to a project for Peikert Group Architects that faced strict wastewater restrictions. Additionally, we analyzed the life cycle global warming impacts of centralized and decentralized systems, including sewage collection, to comprehensively evaluate their impacts. Lastly, we created a decentralized wastewater treatment permitting flowchart to guide stakeholders through the complex regulatory process. Our project provides a thorough analysis of the strengths and weaknesses of various decentralized wastewater systems from an environmental, economic, and social perspective. Our analysis shows that there is no perfect technology since tradeoffs exist between different criteria, and that obtaining a permit for advanced decentralized wastewater treatment systems is difficult. Information is presented in an accessible manner to stakeholders, preparing them to meet the sustainable design challenges of the future.

EXECUTIVE SUMMARY

Millions of gallons of domestic wastewater are generated everyday from sinks, showers, and toilets. This wastewater contains pathogens that are dangerous to human health, and thus properly treating and managing it is crucial for human safety. Wastewater has traditionally been managed through large centralized treatment facilities in urban areas and septic tanks in rural areas. Today, there is an array of innovative decentralized wastewater systems that collect and treat domestic wastewater onsite. These systems sometimes offer benefits over conventional treatment because they reduce the need for energy and large infrastructure, provide recycled water for use onsite, and can expand to meet increasing demand.
Our clients, The Sustainability Project (TSP) and Peikert Group Architects (PGA), are interested in innovative decentralized systems for Santa Barbara County. In particular, TSP, a non-profit that works with the architecture community, requested a Guidance Document for its members and stakeholders, to provide easily accessible information about the systems. PGA asked for a recommendation on a decentralized wastewater system for one of their developments to meet strict water restrictions.

To address our clients' needs, we researched decentralized systems through a comprehensive literature research, interviews in the field, and a community workshop. We focused on 11 wastewater systems from 3 broad treatment categories: subsurface, constructed wetlands, and prefabricated and modular systems. We evaluated them based on 21 different criteria, including environmental, economic, and social parameters. We created a scoring system to compare systems, and integrated our results into a decision support matrix. The matrix serves as an educational tool to help architects and builders understand the relative advantages and disadvantages of the 11 technologies, and is included in the Guidance Document.

Through creating the Guidance Document, we found a number of interesting results. First, no single technology received a high scoring across all criteria, since a tradeoff often exists between valuation criteria because if a system performs well in one criterion, its ability to meet another criterion may be compromised. An example of this tradeoff is the increased amount of energy required to produce a high quality effluent.

When comparing decentralized technologies, we found that constructed wetlands offer a passive, low-energy and low-cost treatment option that contributes to an increased social benefit. However, constructed wetlands may not consistently produce high quality effluent and are therefore comparatively less reliable.

On the other hand, prefabricated and modular systems achieve high quality effluent more consistently, but they typically face increased costs in the areas of construction, energy consumption, and maintenance and labor.

Similar to constructed wetlands, subsurface treatment systems offer cost-effective, low-tech treatment capabilities. Yet these systems are subject to high geographical restrictions due to the soil-based treatment process.

We also found that permitting a decentralized system can be challenging. The regulatory framework for decentralized systems was designed for conventional septic systems, meaning that other systems must be reviewed on a case-by-case basis. This process can be time-consuming, costly, unpredictable, and may serve as a barrier to the adoption of these systems locally. To address this challenge, we created a permitting flowchart to help users determine which permit is required for their project, their costs, and approximate timelines. We incorporated the flowchart into the Guidance Document for TSP.

The last section of the Guidance Document is the PGA case study. PGA is designing the site plan for a project called The Children's Project Academy (CPA). The CPA will be a residential boarding school for foster children. Located in northern Santa Barbara County, the CPA needs to meet strict wastewater restrictions in order to receive its permit. We applied the guidance document tool to make a recommendation about which innovative wastewater systems would meet the project's restrictions. We found that, based on the project's constraints of cost, land availability, water reuse, and education, the most appropriate systems would be the Living Machine® or a vertical flow wetland. We included this case study in the Guidance Document.

In addition to creating the Guidance Document, we addressed an often overlooked issue, the life cycle global warming impacts from both centralized and decentralized wastewater treatment. We collected environmental impact data on the construction and installation of both wastewater treatment plants and sewage collection systems. We also examined emissions from operation and maintenance, and system disposal. We found that decentralized systems may offer environmental benefits in sparsely populated areas because there are larger per capita global warming impacts for centralized treatment systems located in small towns (under 800 people) than in large cities. This relationship holds true for sewage collection systems as well; that is, a sewer system for a small town incurs larger per capita environmental impacts compared to a large city. Based on these findings, we recommend that decentralized systems be considered in small town and rural settings.

We also determined that the global warming potential for modular and prefabricated systems, such as activated sludge and membrane bioreactors, have the highest impacts during the operational stage due to the electricity required to run these systems. These impacts depend largely on the electricity grid mix, and could be decreased with increased use of renewable energy.

Lastly, we found that constructed wetlands can sequester carbon dioxide because they have plants, which absorb this gas. However, if the wetlands use an anaerobic treatment process, they may release methane, a greenhouse gas 20–25 times more potent than carbon dioxide. Therefore, it is important that constructed wetlands be properly maintained to maximize their ability to sequester greenhouse gases.

We also discovered several challenges in evaluating wastewater technologies that should be addressed in order to improve their assessment. First, there is a lack of standardized, audited information about treatment systems, particularly pertaining to cost. We found data was either missing, or was released by the owners of proprietary systems without undergoing a third party verification. This lack of consistency and transparency is problematic for comprehensively evaluating the systems.

To address these challenges, we recommend the creation of a publically accessible centralized database containing performance information from system installers. Another recommendation is to address the antiquated regulatory system that makes permitting a system so cumbersome. We suggest streamlining the permitting process and facilitating communication amongst agencies. Lastly, for determining the life cycle impacts of wastewater systems, there is a need for uniform research that includes the same system boundaries and impacts for all studies. In particular, many life cycle studies omitted the treatment and disposal of sludge, which has a significant environmental impact.

Our project provides a comparative analysis of the strengths and weaknesses of decentralized wastewater systems for Santa Barbara County. We included environmental, economic, and social criteria to provide a comprehensive analysis, addressing the many aspects of wastewater treatment. We presented our results to our client in the form of a Guidance Document. This document will distribute system information to local architects, builders, and policymakers, helping them to meet the sustainable design challenges of the future.

CHAPTER 1: PROJECT SCOPE

Introduction

Properly managing wastewater is an issue of increasing importance in sustainable development and design due to growing populations and recent scarcity of freshwater resources. In urban areas, wastewater has traditionally been collected and transported to a centralized municipal treatment facility where it is treated and discharged into a water body. In rural areas, septic systems that collect and treat wastewater onsite have been the conventional method. However, large centralized systems are expensive to maintain and often face funding shortages.

Additionally, because centralized plants treat water that has been transported to a single site, the recycled water from these plants is not used in the location from which it was collected. Septic systems also face challenges, such as improper operation and maintenance, which can cause contamination of surface and groundwater. To fill this void, innovative onsite technologies can provide state-of-the-art treatment and avoid pumping water long distances, all while offering significant savings in water and energy. Additionally, by treating water on site, decentralized systems take the strain off of aging centralized treatment plants and their infrastructure. The treated water may be reused for landscape irrigation or toilet-flushing in order to maximize water savings. Furthermore, innovative decentralized systems are more effective than traditional septic systems in their ability to reduce nutrient load in treated effluent.

Project Significance

Recent years have seen a spike in the number of available decentralized technologies. However, several obstacles exist which have hampered their implementation. One such barrier is the lack of guidance in choosing which system to use. To better understand when and where to install a system, and thus facilitate the use of decentralized wastewater treatment, we have created a document for guidance through these technologies. This document highlights the different benefits and disadvantages to each system, their geographical and physical limitations, and their associated permitting requirements. The guidance document developed from our research is designed to help permitters, installers, users, and in particular one of our clients, The Sustainability Project, understand when and where each system can be installed as well as the pros and cons associated with each technology. To create this document, we developed a matrix to qualify the relative advantages and disadvantages of the surveyed systems. We then organized them based on treatment methods, and evaluated them. Valuation categories considered within the matrix' framework include cost, energy use, water savings, nutrient recycling, land use, and health and safety.

Another barrier is the lack of clarity regarding the permitting process for onsite treatment systems in Santa Barbara County. Through our research we also provide relevant information to planners, installers and users, to clarify the steps that need to be taken in order to permit an onsite system.

Project Objectives

We have explored a variety of issues related to wastewater treatment and recycling. This section outlines the specific objectives associated with our project.

- From a life cycle perspective, establish the benefits and disadvantages of centralized treatment systems compared to selected onsite technologies. Determine under which circumstances it is advantageous to use centralized over decentralized, and vice versa.
- Understand how current policies regarding decentralized wastewater treatment in Santa Barbara County relate to each technology as well as develop recommendations on how to improve the permitting process.
- Quantify and categorize the important characteristics of potential technologies for small residential community clusters and onsite treatment, based on a Multi Criteria Decision Analysis and life cycle operational energy use.
- Develop a guidance document for The Sustainability Project, designers, and policy makers to assist them in choosing an appropriate system for their projects.
- Make recommendations for the Peikert Group Architects on the most appropriate technology to use for water conservation and recycling at the Children's Project Academy.

Our Clients

Peikert Group Architects: The Children's Project Academy

In May 2010 the Santa Barbara County Board of Education approved the creation of the Children's Project Academy (CPA). CPA, designed by Peikert Group Architects, will encompass 114 acres within Los Alamos, California serving a student population of 120. Before the permitting process can continue and construction can begin, the Peikert group must show that it can provide a minimum reduction of wastewater entering the sanitary sewer. This reduction is needed due to the zoning constraints of the building site, which is zoned as agricultural land but will be producing a waste load comparable to an urban zone classification. As such, the Peikert group needs to reduce the water consumption by a minimum of 20% to meet the necessary criteria for a permit to be issued. The Peikert group would like to go beyond this requirement, and achieve a 50% reduction.

The Sustainability Project

The Sustainability Project (TSP) is interested in finding resources that delve into leading edge technologies and methods for sustainable building projects, since these would help fulfill their mission, which is to deliver inspiration to the Santa Barbara community through the promulgation of lasting structure in the built environment. TSP is interested in using the information that our research has uncovered in ways that can influence building practices for a sustainable future.

CHAPTER 2: BACKGROUND

Many factors need to be considered when choosing and installing a wastewater treatment system. These include the type of system to install; wastewater characteristics and extent of treatment; human health considerations; level of management and oversight that will be required; and the standards to be met. Additionally, there is an ongoing discussion regarding centralized and decentralized systems, touching upon the potential benefits and shortcomings from both options. In this chapter we provide background information on wastewater treatment and motivate the comparison between centralized and decentralized systems. The following definitions have been adopted:

- **Centralized Wastewater Treatment System:** A managed system that consists of collection sewers and a single treatment plant, which is used to collect and treat wastewater from an entire service area. Traditionally, these systems are referred to as publicly owned treatment works (U.S. EPA Water, 2012), although not all of these systems will be publicly owned.
- **Decentralized Wastewater Treatment System:** A wastewater treatment system for collection, treatment, and dispersal or reuse of wastewater from individual homes, clusters of homes, or isolated communities at or near the point of generation (National Decentralized Water Resources Capacity Development Project, 2012).

Our research is limited to treatment of residential or domestic wastewater for Santa Barbara County. Relevant background information on the county is presented, with emphasis on climate and topography, water supply and demand, current state of wastewater infrastructure and policies, and barriers for the adoption of decentralized wastewater treatment systems.

2.1 Wastewater Composition and Extent of Treatment

In order to assess different options for the treatment of domestic wastewater, the characteristics of wastewater, as well as the level of treatment that may be achieved through different processes, need to be understood and considered.

Wastewater Composition

Wastewater is water that contains undesirable and potentially unsafe chemical and biological contaminants generated from specific processes in residential, commercial, and industrial processes. While introduced contaminants make up a relatively small fraction of the total wastewater composition, they can still be present in amounts large enough to endanger public health and environmental integrity (Trotta et al., 2002). Domestic wastewater typically has lower pollutant loads than commercial and industrial wastewater. Regardless, many potential pollutants can be present in domestic wastewater due to a wide variety of domestically available chemicals that can easily be disposed of down a toilet, drain, or sewer.

Despite the large number of potential pollutants that can be present in domestic wastewater, its general chemical and biological composition has been well characterized (Metcalf & Eddy, 2002; Burks & Minnis, 1994). Domestic wastewater is made up of two components: graywater and blackwater. These are defined by the source of wastewater generation and definitions vary from state to state. The following definitions for these components are taken from the California Code of Regulations, title 24, part 5.

Graywater

Graywater is defined as untreated wastewater that has not come into contact with human waste. Sources of graywater include wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, and laundry tubs (California Plumbing Code, 2010). Total flow of graywater is typically 30–50% of total wastewater flow generated in indoor residential use (O'Connor et al. 2008; Roesner et al., 2006). Clothes washers generate the largest contribution to graywater flow, which makes up 21.6% of total indoor water use and approximately 39% of graywater (Mayer et al., 1999).

The chemical composition of graywater in domestic and institutional settings varies greatly due to a number of factors including: original water quality delivered to the building, personal water use habits, and the preferences of consumer products that are utilized. It is estimated that 2,500 chemicals in 5,000 consumer products are used within domestic households, and these could potentially be disposed of in graywater fixtures (National Institute of Health, 2004). The most common of these consumer products are soaps used in personal hygiene, domestic cleaning chemicals, laundry detergent, medication, and other waste products disposed of in sinks (Eriksson et al., 2002). Chemicals habitually disposed of in graywater fixtures contribute to the contaminant load within graywater, specifically to the water quality parameters of Biochemical Oxygen Demand (BOD), Phosphorous, Nitrogen, Total Suspended Solids (TSS), and Total Dissolved Solids (TDS) (NAPHCC, 1992). Additionally, intermittent releases of toxic chemicals such as oils, paints, and solvents can also contribute to waste loads within graywater (Christova-Boal et al., 1996). Details of graywater composition may be found in Table B.1, Appendix B.

Blackwater

Blackwater is defined as any wastewater that has come into contact with human waste. In California, wastewater generated from toilet fixtures and laundry water from soiled cloth diapers is considered blackwater under this definition. Additionally, wastewater from kitchen sinks, dishwashers, and home photo lab sinks is considered blackwater due to its potential of carrying human pathogens, its high organic content, and/or presence of other chemical constituents of concern (California Plumbing Code, 2010). The main pollutants of interest within blackwater are nitrogen and phosphorous containing compounds from feces and urine, organic compounds measured in BOD, and potential human pathogens. Details of blackwater composition may be found in Table B.2, Appendix B.

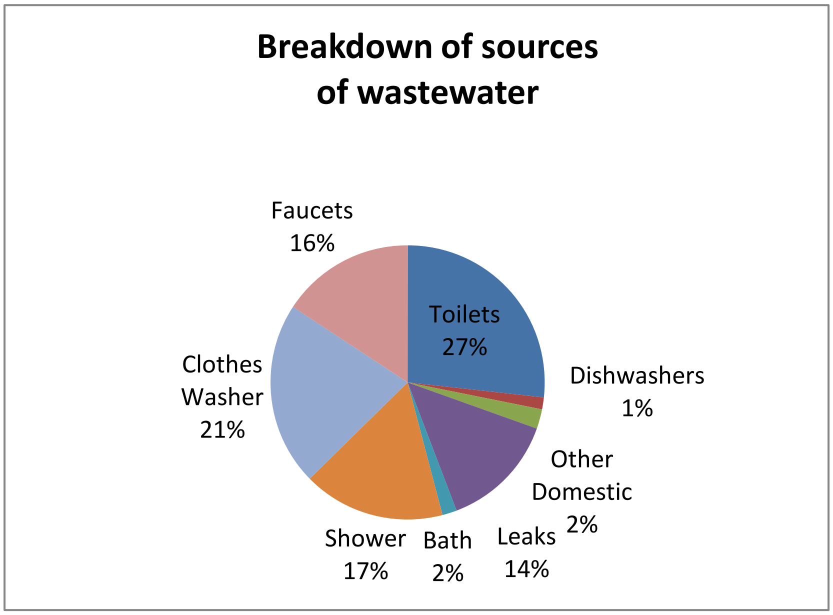
Nitrogen containing compounds and TSS are typically much higher in blackwater when compared to graywater. Food scraps from dishwashers and sink grinders, feces, urine, and toilet paper all contribute to high nitrogen loads and TSS within this waste stream. Conversely, phosphorous containing compounds are in higher concentration within graywater due to domestic surfactants and detergents.

Combined Wastewater Composition and Flows

Graywater and blackwater generated within a domestic or institutional setting typically are combined within a single wastewater piping system. This piping system ultimately delivers the combined waste stream to a sewer system to be treated at a centralized wastewater treatment facility or directly at an onsite or decentralized system. Typically, combined flows will contain more graywater than blackwater in volume, as can be seen from Figure 2.1.1. Relative amounts will vary depending on the extent of water efficient fixtures and appliances installed, as well as the personal habits of the inhabitants.

Like its graywater and blackwater components, the composition of combined wastewater is highly variable. Table B.3 in Appendix B details potential ranges of chemical and biological constituents as well as typical values for each component. Compounds contributing to BOD loading within graywater are typically much more soluble than BOD generating compounds in blackwater, such as toilet paper and human excreta, which makes them easier to biodegrade when compared to combined sewage (NAPHCP, 1992).

Figure 2.1.1: Residential Sources of Wastewater



Source: Adapted from Mayer et al., 1999

Extent of Treatment

Historically, wastewater treatment facilities have been designed to treat and remove suspended solids, biodegradable organics, and pathogenic organisms (Metcalf & Eddy, 2003). Extent of treatment is classified by the treatment levels which utilize different technologies, known as unit processes or unit operations, to remove specific pollutants of interest. Typical wastewater treatment trains follow a system of primary, secondary, tertiary, and disinfection depending on the strength and the final fate of the treated wastewater. Each level of treatment beyond the first offers an increasingly higher quality of finished effluent. Higher effluent quality is achieved by linking unit processes in sequence so that finished effluent from one unit process flows into the next. Consequently, higher effluent quality requires systems of increased complexity, higher capital costs, and increased operation and maintenance by qualified operators and wastewater managers.

Preliminary treatment involves processes designed to remove large objects, grit, oil, and grease compounds that can potentially clog pumps, damage equipment, or disrupt unit processes downstream in the treatment train (Tchobanoglous, 2003). Preliminary treatment also serves to buffer and equalize high and peak flow events that occur throughout the day. Not equalizing flow can cause surge events, which overwhelm the capacity of the system to effectively treat wastewater flows (known as short circuiting). This can cause a sharp decrease in effluent water quality.

Primary treatment systems utilize physical processes that remove settleable solids and organic matter within the wastewater stream. Like grease traps and screening grates, solids removed in primary treatment processes periodically have to be pumped and emptied from the primary unit process. Rates of solid accumulation differ from technology to technology and must be accounted for in management plans. Primary treatment processes are thought to be the most important treatment process, with ineffective primary treatment systems being responsible for a large amount of problems downstream (Metcalf & Eddy, 2003).

Secondary treatment processes utilize chemical and biological mechanisms to remove the majority of suspended solids remaining after primary treatment and dissolved organic matter within the wastewater stream. There are many secondary treatment options, which can be performed under anaerobic or aerobic conditions. Secondary treatment that produces an effluent with a BOD_5 and TSS of <30 mg/L is the minimum level of treatment required of municipal systems before discharge into surface water bodies (Kadlec, 2009). Secondary treatment can also include processes that transform and remove nitrogen and phosphorous containing compounds that can cause eutrophication in surface water bodies if not removed prior to discharge.

Tertiary treatment processes remove residual suspended solids that may remain after secondary treatment. These processes are also known as “polishing steps” and are typically performed through a filtration process (Metcalf & Eddy, 2003). Tertiary processes can also include nutrient removal, which is often achieved through specialized media that can adsorb constituents of interest, typically phosphate. Once the materials have been saturated with the constituent of interest, they must be replaced or regenerated (Tchobanoglous, 2002).

Disinfection is the unit process that involves inactivation of pathogenic organisms or prevention of their reproduction. This process is a critical step in reducing the number of disease-causing organisms and protecting the public from acquiring waterborne illnesses. Common pathogenic organisms found in domestic wastewater streams include enteric bacteria, viruses, helminthes, and protozoan cysts (Water Environment Resource Foundation, 2010).

Disinfection is often confused with sterilization, which is the complete removal of all organisms present within water. Sterilization is not the goal of disinfection, rather the objective is to reduce the risk of disease and disease transmission to an acceptable level set by the regulatory agency in a cost-effective manner.

Since there are several wastewater components that could create environmental and human health impacts, different policies have been established to regulate wastewater treatment and discharge into the environment, as outlined in the following section.

2.2 Overview of Wastewater Treatment Policies

Wastewater is addressed in several policies at the national, state and/or local level. This section outlines the policies surrounding wastewater treatment and associated regulating agencies to provide an understanding of the regulatory framework.

The Clean Water Act

The Federal Water Pollution Control Act, enacted in 1948, was the basis for the significantly reorganized and expanded Clean Water Act (CWA) of 1972. The CWA was passed in order to establish water quality standards and help protect the integrity of the nations waters, which in many cases were in poor environmental condition. The CWA initiated a mandate requiring municipal sewer systems for all residences across the nation. This also included funding for large municipal wastewater treatment systems to help address water pollution issues. The forefront of the CWA's authority made the discharge of any pollutant from a point source into navigable waters illegal, unless a permit was obtained prior to that discharge.

Discharge permits are controlled by the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) permit program, and include discrete conveyances of water flow, such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have surface discharge, are exempt from an NPDES permit. Industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters (U.S. EPA, 2012).

Under the CWA, the states are required to meet a minimum level of compliance but can choose to set their own standards, as long as they are as or more stringent. In California this has led to the Porter Cologne Water Quality Control Act, to monitor and enforce water quality standards.

Porter- Cologne Water Quality Control Act

In 1969, California enacted the Porter-Cologne Water Quality Control Act to protect California's waters. The Porter-Cologne Act establishes the California Water Code and grants authority to the State Water Resources Control Board and the nine Regional Water Quality Control Boards (RWQCB) (California EPA, 2009).

The California Water Code has important implications for permitting onsite systems, including the requirement of a discharge permit. The RWQCB sets the requirements for these permits, and determines whether or not to issue a permit. The RWQCB bases its requirements on the conditions in the disposal area or receiving waters (SWRQCB, 2011)[a].

It is important to notice that the ability to discharge, even when made in accordance with waste discharge requirements, is a privilege, not a right (Section 13263(g)). If a discharge has the potential to cause water quality impairments or affect beneficial uses, the RWQCB may refuse to issue a permit (SWRQCB, 2011)[a].

Through the Porter-Cologne Water Quality Control Act, the RWQCB determines whether an onsite system can receive a discharge permit or not. Systems considering water reuse must comply with additional regulation included in Title 22 of the California Code of Regulations.

Title 22: Recycled Water-related Statutes and Regulation

An advanced onsite treatment system can potentially use effluent directly onsite for irrigation and other purposes. Using recycled water eliminates the costs of purchasing water from the local water supplier. Additionally, recycled water faces less stringent water quality standards than drinking water. Using recycled water instead of transferring water over far distances can result in cost savings, such as reduced energy consumption, pumping, treatment, and pipeline costs. Furthermore, using recycled water can reduce the water footprint of a building. However, for these benefits to be realized, a recycled water treatment system must comply with California's regulations.

Title 22 is the State of California's regulatory policy governing the reuse of recycled water. The policy allows the reuse of recycled water for irrigation and other reuse applications. Authority for recycled water is under the California Department of Public Health (CDPH). However, the CDPH has a memorandum of understanding with the RWQCB for the permitting approval of wastewater discharge for irrigation purposes. The RWQCB issues the permit under the waste discharge requirements with input from the CDPH (CDPH, 1996). The use of recycled water is subject to a number of water quality standards and restrictions as detailed below. The California Water Code describes four levels of treatment for recycled water.

The highest level of treatment is disinfected tertiary recycled, which is defined under section 60301.230 of the California Water Code. The goal of this level of treatment is to ensure that 99.999 percent of viruses are destroyed. For bacteria, the effluent cannot exceed a most probable number (MPN) of 2.2 per 100 milliliters. Recycled water that meets this criterion can be used for unrestricted uses. Some of these uses include landscaping for school, parks, golf courses, and food crops. Additionally, this water may be used in places where the human body can come into contact with the water, such as recreational or non-potable uses. Disinfected tertiary recycled water can also be used in flushing toilets and urinals. The main concern is direct consumption of the recycled water, and the use must be at least 50 feet away from domestic water wells (CDPH, 2009).

The next level of treatment is disinfected secondary-2.2 recycled water, which is defined under section 60301.220 of the California Water Code. The recycled water must be oxidized and the effluent cannot exceed an MPN of 2.2 per 100 milliliters. The use of this water is limited because it cannot be utilized for irrigation on surfaces that come into direct contact with humans. The water may be used for agricultural irrigation as long as it does not come into contact with edible crops. The disinfected secondary-2.2 recycled water must be at least 100 feet away from domestic water wells (CDPH, 2009).

The next level of treatment is disinfected secondary-23 recycled water, which is defined under section 60301.225 of the California Water Code. The recycled water must be oxidized and the effluent cannot exceed an MPN of 23 per 100 milliliters. This level of recycled water can be used for irrigation that does not come into direct contact with humans. However it cannot be used to irrigate food crops and must be at least 100 feet away from domestic water wells (CDPH, 2009).

The lowest level of treatment is undisinfected secondary, which is defined under section 60301.900. The level of treatment is oxidation and there are no standards for the bacteria levels. This recycled water has the lowest allowable uses, such as irrigation for plants and vegetation that do not come into contact with humans. Additionally, this water must be used at least 150 feet away from domestic water wells (CDPH, 2009).

The level of treatment necessary for recycled water is determined by the end use of that water. Food crops and unrestricted public access require a higher level of treatment, including a lower level of BOD and total coliforms. Restricted public access, so that there is limited contact with the recycled water, allows a lower quality water to be used. Relevant water quality standards for recycled water are included in Table 2.2.1.

The use of recycled water is limited within indoor residential units, and must be sourced from a recycled water agency into a dual plumbing facility. Currently, the use of recycled water for individual residential homes is not allowed, and therefore cannot be legally permitted (CDPH, 2009).

Under Section 7604, backflow protection devices must be installed in order to protect the water supply. This precaution is necessary to protect public health and ensures that no potential bacteria or contaminants enter the water supply. A dual piping system is needed to carry both drinking water and recycled water, and ensure these are not mixed. The back flow preventers ensure there is no potential for cross contamination (CDPH, 2009).

Table 2.2.1: Ranges of Water Quality for Water Reuse Applications in California

Type of Reuse	BOD (mg/L)	TSS (mg/L)	Turbidity NTU	Tot. coliforms, (No./100 mL)
Agricultural Irrigation				
Nonfood crop	≤ 30	≤ 30		< 23
Food crop	≤ 10		≤ 2	< 2.2
Landscape Irrigation				
Restricted Access	≤ 30	≤ 30		< 23
Unrestricted Access	≤ 10		≤ 2	< 2.2
Industrial				23
Groundwater recharged			≤ 2	≤ 2
Recreational/Environmental	≤ 10		≤ 2	< 2.2
Non-potable urban uses	≤ 10		≤ 2	< 2.2
Indirect Potable Uses			≤ 2	< 2.2

*Blanks denote no values are given

Source: Adapted from the California Code of Regulations, Title 22 (California Plumbing Code, 2010) & Metcalf and Eddy, 2003).

Current State of Policies

The State Water Resources Control Board (SWRCB) is currently in the process of adopting the first statewide onsite wastewater treatment policy. This policy will provide uniform requirements and conditions for the state, and potentially streamline some of the permitting process. The objectives are as follows:

- Adopt a statewide policy for Onsite Wastewater Treatment Systems (OWTS) consistent with the Porter-Cologne Water Quality Control Act and related state water quality control plans and policies adopted by the State Water Board.
- Help ensure that beneficial uses of the state's waters are protected from OWTS effluent discharges by meeting water quality objectives.
- Establish an effective implementation process that considers economic costs, practical considerations for regional and local implementation, and technological capabilities existing at the time of implementation.

The expectation is that this policy will be approved by the SWRCB in March of 2012. If approved, this policy will be implemented by the regional water boards and those local agencies given authority by the regional water boards (SWRCB, 2011)[b]. It is anticipated that Santa Barbara County will be given authority to implement this policy and be responsible for regulating onsite systems in the county.

The policies described thus far address human health and environmental concerns, and also aim to improve water infrastructure. The next section elaborates on these issues by explaining how they impact wastewater treatment.

2.3 Significance of Sanitation on Human Health

Municipal wastewater flows contain harmful bacteria and viruses and other health hazards, so they require treatment to limit the risks associated with many pathogens, and to protect public welfare. As health and safety are paramount in wastewater management, the critical role of any management plan, permitting agency, or treatment technology is to offer protection from dangerous contaminants.

The management of a sanitation system may include regular operation and maintenance and oversight by a third party, typically a governmental agency such as the Environmental Protection Agency (U.S. EPA) or Environmental Health and Safety (EHS). For example, septic systems require periodic inspections, and large centralized facilities require constant operation by a systems engineer to ensure human safety. For systems that require regular operation and maintenance, chemical and biological loading measurements of the influent and effluent must be quantified, especially in regards to total coliforms, BOD, TSS, nitrogen, and phosphorous (U.S. EPA, 2002)[a]. Government agencies that regulate safe practices and technology direct the oversight of permitting and monitoring requirements.

Threats to Public Health

Today, our wastewater treatment systems and management plans protect human health from cholera, ciardiasis, escherichia coli, salmonella, and many other waterborne and vector borne diseases. The World Health Organization's Environmental Health in Emergencies and Disasters (2002) explains that the most effective way of preventing the spread of diseases is through sanitation (WHO, 2002).

Research and application has proven that both centralized and decentralized wastewater treatment technologies offer human health protection at comparable standards. The U.S. EPA explicitly identifies that "regardless of whether a community selects more advanced decentralized systems, centralized systems, or some combination of the two, a comprehensive management program is essential" (U.S. EPA, 2002)[a]. Thus, creativity within wastewater management must be promoted to provide acceptable treatment, which fits local and regional constraints.

The WHO document also shows that current funding gaps for maintenance of wastewater treatment systems are exacerbated by an aging infrastructure (WHO, 2002).

2.4 Infrastructure and Water Quality Needs

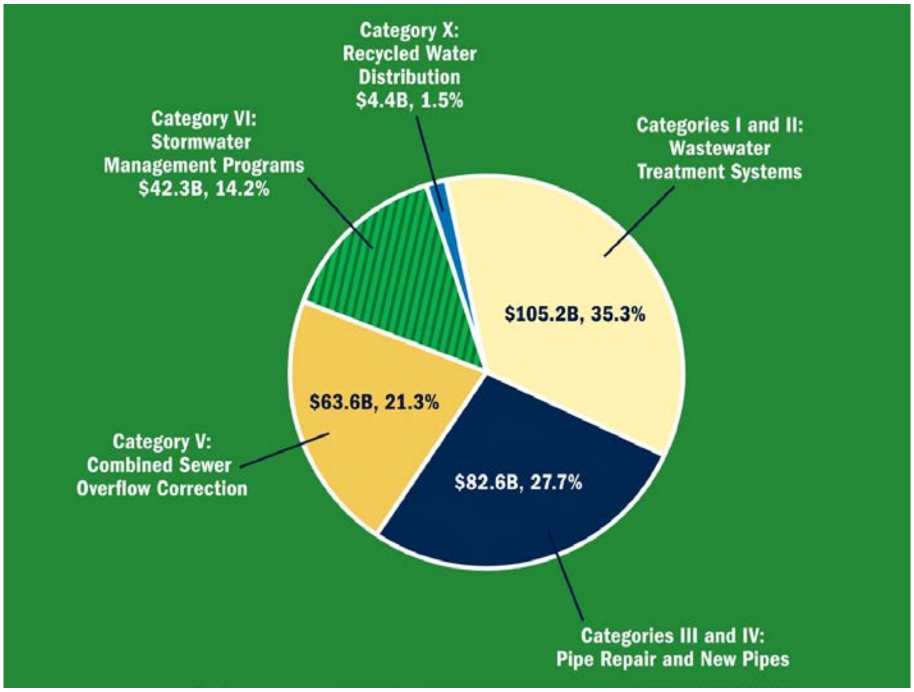
Since the passing of the Clean Water Act in 1972, Congress has invested over $77 billion in the construction and maintenance of publicly owned wastewater treatment systems. State and local governments have also invested heavily on these systems, spending $841 billion between 1991 and 2005 (ASCE, 2009). In spite of these investments, many of the nation's wastewater treatment facilities are in poor physical condition as funds have not been sufficient to properly maintain them.

The majority of publicly owned wastewater treatment systems were built in the 1070's and, as such, may show evidence of wear and also be prone to failures if their capacity is met or exceeded. This is particularly noticeable during peak flow events, where the systems overflow and raw sewage is discharged into the nation's waters as combined sewer overflows (CSO) (ASCE, 2009).

Given these failures, measures have been taken to assess the condition of centralized wastewater systems. In particular, infrastructure replacement needs were evaluated and documented in 2002 in the Clean Water and Drinking Water Infrastructure Gap Analysis report by the U.S. EPA, also referred to as the "gap analysis." This analysis estimated that the United States must spend nearly $390 billion over the next two decades to replace existing wastewater infrastructure systems and build new ones (U.S. EPA, 2002)[b]. The analysis found that a significant gap could develop if current spending and operations practices continued.

In addition to the gap analysis, a number of Clean Watershed Needs Surveys have been performed. These surveys, carried out by the U.S. EPA, recorded investment needs for publicly owned treatment works. The total water quality needs for the nation reported in 2008 were $298.1 billion, distributed as shown in Figure 2.4.1. The highest investment corresponds to wastewater treatment systems (105.3 billion), followed by pipe repairs and new pipes (82.7 billion) (U.S. EPA, 2008).

Figure 2.4.1: CWNS 2008 Total Documented Needs (Jan 2008 dollars in billions)



Source: Figure ES-1. CWNS 2008 total documented needs from U.S. EPA, 2008.

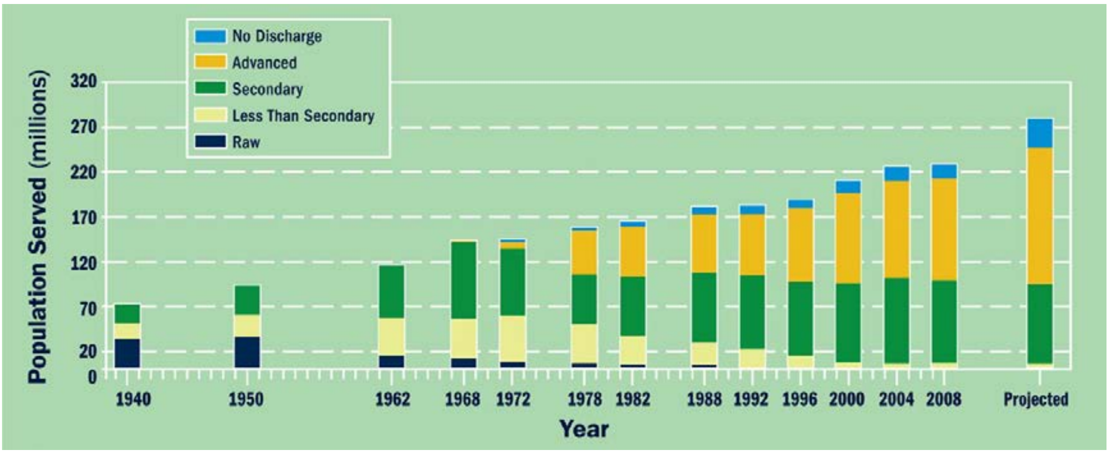
General Trends in Infrastructure Needs

The needs for wastewater treatment, pipe repairs, and new pipes are $187.9 billion, an 18% increase since 2004. These increased funds are intended to rehabilitate aging infrastructure, to meet more protective water quality standards, and to respond to present and future population growth (U.S. EPA, 2008).

Trends in Nation's Ability to Provide Wastewater Treatment

Although both current and previous CWNS reports show increases in investment needs for publicly owned treatment works, there have been many improvements. Figure 2.4.2 shows that the population served with advanced wastewater treatment has dramatically increased since 1972 (from 7.8 million to 113.0 million in 2008). Additionally, the population that had less-than-secondary treatment has also decreased significantly (U.S. EPA, 2008).

Figure 2.4.2: Population Served by Publicly Owned Treatment Works Nationwide between 1940 and 2008 and Projected



Source: Figure ES-2, from Executive Summary CWNS 2008.

Since funding for centralized systems is not sufficient to keep up with infrastructure needs, there is potential for contamination due to system failure, leakage from pipes and CSO. Additionally, traditional decentralized systems in the form of septic systems also have their problems.

Problems with Septic Systems

The Clean Water Act has achieved considerable success in addressing water quality issues, in particular for point sources. However, nonpoint sources are the largest remaining cause of water quality impairment. Amongst these nonpoint sources, failing septic systems are major contributors.

According to state and tribal agencies reports, failing onsite septic systems are the third most common source of ground water contamination. The source of failure is inappropriate site selection and design, or inadequate long-term maintenance (U.S. EPA, 2002[a]). Echoing this finding, the U.S. Housing Survey of 2009 states that a significant number of onsite systems have problems. The survey estimated that 252,000 homes experienced septic system breakdowns within a 3-month period (U.S. Census Bureau, 2011).

These problems may be due to a lack of management, monitoring and standardization. With proper maintenance, septic systems can offer adequate treatment of wastewater while recharging groundwater. However, septic tanks are only viable in climatic and geographic areas with appropriate soil composition and landscape characteristics to allow soils to properly filter wastewater. For instance, if the groundwater level is elevated, wastewater may bubble to surface level, exposing potentially harmful pathogens before treatment is possible. Additionally, if soil composition is characterized by dense compaction (e.g. limited porosity) wastewater will have difficulty percolating into the soil for treatment (Lesikar, 1999). Furthermore, when population density becomes too high, the load born by these systems will exceed capacity, and again overflow becomes a potentially hazardous problem.

Consequently, there has been a recent declining trend in septic systems for the United States. According to the U.S. Census Bureau (1999), approximately 23% of the estimated 115 million occupied homes in the United States was served by onsite systems (U.S. EPA, 2002)[a]. The American Housing Survey completed by the U.S. Census Bureau in 2005 suggests the percentage of homes on septic systems fell to 20% in 2005 (Coalition for Alternative Wastewater Treatment, 2009). The housing survey of 2009 indicates that this percentage was maintained, with an estimated 112 million occupied homes on septic systems (U.S. Census Bureau, 2011).

Innovative decentralized wastewater treatment systems, which may be viable in a wider range of geographic areas, provide an opportunity to lessen the impacts both from failing centralized infrastructure and faulty septic tanks. There may also be other benefits associated with decentralized wastewater treatment, as outlined in the following section.

2.5 Centralized v. Decentralized Wastewater Treatment

Under certain conditions, decentralized technologies may offer benefits over centralized technologies, but an array of different factors needs to be considered. The following section outlines and compares these two options, and also provides considerations regarding wastewater treatment infrastructure and planning options.

Background

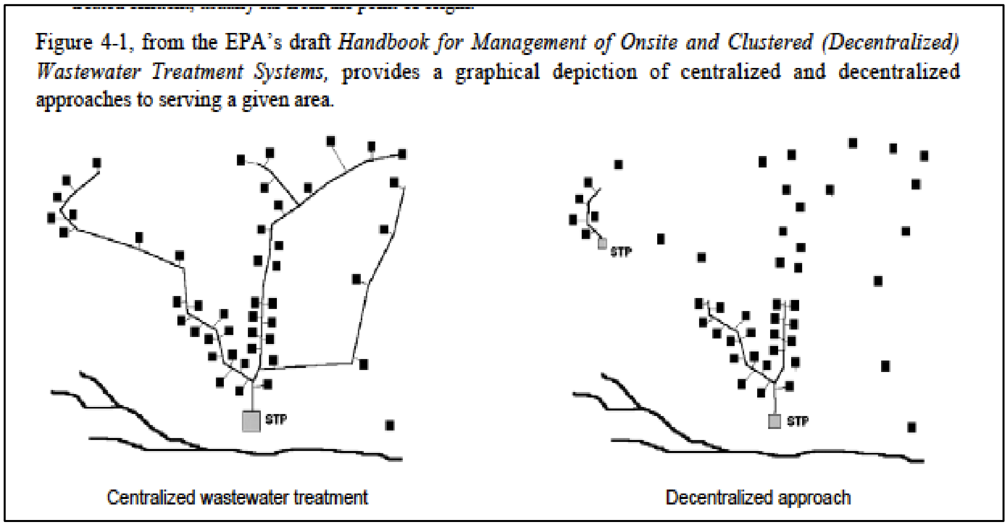
To meet standards set forth by the Clean Water Act, centralized treatment plants capitalized on economies of scale in treating large quantities of wastewater. With public opinion in the 20th century favoring centralized systems, funding from federal construction grants, and later subsidized loans, connected municipal technologies became the conventional option (Burian et al., 2000).

Over the years, Onsite Wastewater Treatment Systems (OWTSs) have evolved from primitive pits to installations capable of producing a disinfected effluent that is fit for human use and consumption. In the modern era, the typical onsite system has consisted primarily of a septic tank and a soil absorption field, also known as a subsurface wastewater infiltration system (SWIS). These are known as conventional onsite systems. While these conventional systems have traditionally consisted of subsurface soil treatment, many alternatives today involve advanced chemical treatments that enable high quality effluent, comparable to centralized municipal systems (U.S. EPA, 2002)[a].

Comparing Centralized and Decentralized Technologies

Decentralized wastewater technologies differ from conventional centralized systems in that they “treat and reuse or dispose of wastewater at or near its source of generation” (Magliaro and Lovins, 2004). This difference is shown in Figure 2.5.1, which includes a centralized system (left) and a decentralized approach (right).

Figure 2.5.1: Centralized v. Decentralized System Visual Aid



Source: Magliaro and Lovins, 2004

Note: STP indicates a centralized or cluster sewage treatment plant

Magliaro and Lovins (2004) further articulate the distinction between decentralized and centralized systems using the following categories:

- **Volume.** Decentralized systems treat relatively small volumes of water
- **Sewer type.** Centralized systems typically use conventional gravity sewers, while cluster (decentralized) systems typically use alternatives such as small-diameter pressurized pipes, small-diameter gravity, and vacuum sewers, often employing on-lot settling tanks and/or grinder pumps before wastewater flows from a lot into the sewer system.
- **Treatment type.** Centralized systems usually use activated-sludge processes, while decentralized systems typically use alternatives such as sand filters, trickling filters, etc.
- **Discharge method.** Centralized systems typically discharge treated wastewater to a surface water body. Decentralized systems typically discharge treated wastewater by infiltration into soil.

- **Ownership.** Centralized systems are typically publicly owned, while decentralized systems are usually owned by a developer, homeowners' association, or another private entity.
- **Relative scale.** Centralized systems are intended to serve entire communities or substantial areas of large communities. Decentralized systems serve only a portion of a community (p. 4-5).

Today there is a wide variety of decentralized systems, and more are being developed for residential, industrial, and commercial use. They can be scaled to meet the needs of individual homes, or for clustered treatment to meet the needs of several residential housing units or commercial facilities. Figure 2.5.2 represents the scaling of decentralized and centralized capacities.

Figure 2.5.2: The Wastewater Scale

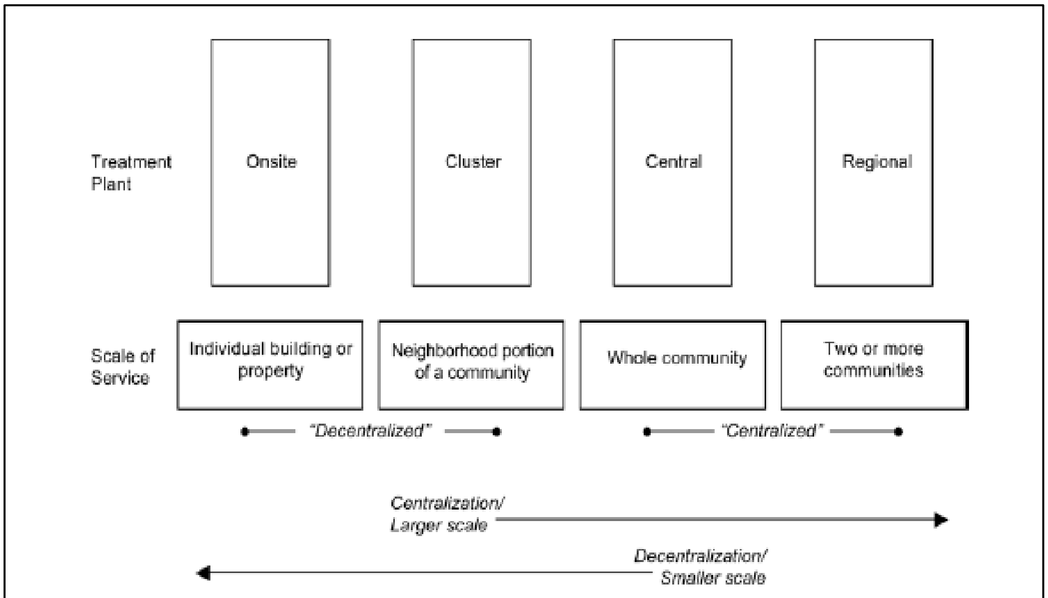


Figure 4-2: The Wastewater Scale Continuum

Source: Magliaro & Lovins, 2004

Innovative systems may be desired for several purposes, including cost-reduction, flexibility in site constraints, and lowered environmental impact. These systems may also appeal to their users for aesthetic reasons, a sense of environmentalism, or specific required treatment. These potential benefits are explained in further detail in the section below.

Water Reuse Potential

The potentials for lowered water consumption and water reuse are particularly appealing features of innovative decentralized systems. The U.S. EPA defines water recycling as “reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge)” (U.S. EPA, 2011)[b]. The use of recycled water on site lessens demand for energy (to pump water), total water demand on a centralized system, and the need for water storage.

Just-in-time Management of Decentralized

A major value of innovative decentralized technologies when compared with standard centralized systems is their ability to deliver ‘just in time’ capacity for wastewater treatment. Figure 2.5.3, provided by the Rocky Mountain Institute, displays the financial benefits of slow growth capacity development offered by decentralized systems. This figure shows that building additional small modules of capacity may save on several kinds of costs, such as increased lead time to build central resources and the costs of overbuilt capacity that remains idle for a significant period of time (2004). Essentially, the opportunity cost of building or expanding a centralized system capacity may be exceeded by the benefits of building on site, ‘just in time’ capacity through decentralized systems. This is echoed by Paul O’Callaghan, who said “the smaller unit size of the decentralized system allows closer matching of capacity to actual growth in demand” (O’Callaghan, 2008).

Figure 2.5.3: Flow v. Capacity for Centralized and Decentralized Systems

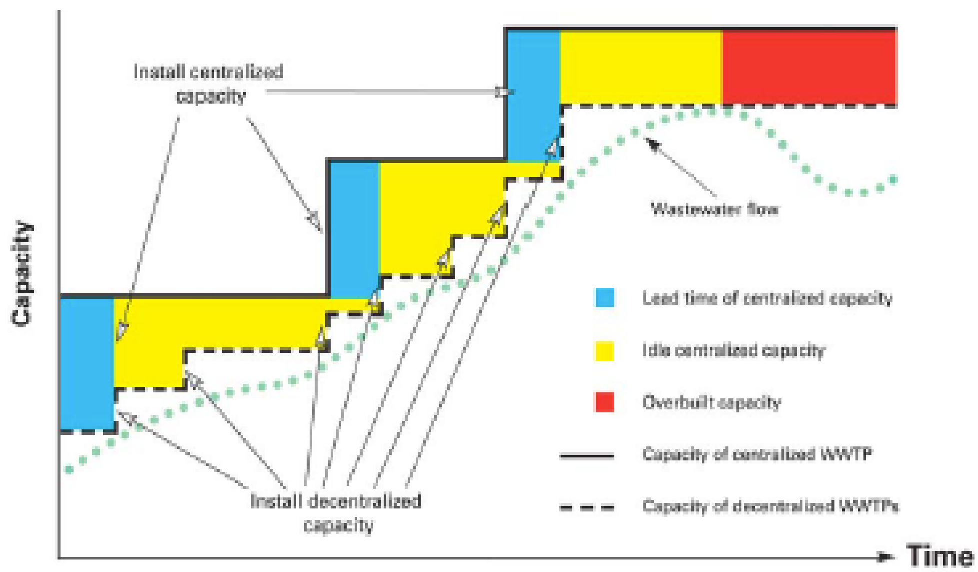


Figure 8-1: Flow Versus Capacity for Centralized and Decentralized Wastewater Systems. WWTP stands for Wastewater Treatment Plant.

Source: Magliaro and Lovins, 2004

Capital Costs and Running Costs

As a result of its smaller size, decentralized systems have lower capital costs, minimizing reliance on risky loans for systems that are highly dependent on speculations of increased population and treatment demand. These savings can be realized instantly through the reduction of conveyance and piping costs. O’Callaghan states, “Given that collection system costs can be 80 percent or more of total systems costs, collection diseconomies of scale can overwhelm treatment economies of scale, resulting in decentralized systems being the more economical choice” (O’Callaghan, 2008).

Moreover, costs associated with system failure are minimized in smaller decentralized technologies when compared to large centralized systems. Due to the smaller nature of decentralized systems, the water flows are lower in relation to central treatment plants, require less sewer piping, and are typically designed to reuse water onsite. These localized systems minimize reliance on leaky pipes, joints, exchanges, and pumps, and can capture additional savings both immediately and continually through built in efficiency.

Reduced size and increased efficiency can translate into a less energy intensive option, as wastewater does not have to be pumped over large distances, gradients, and between multiple points, thus reducing the embedded energy requirements (Cohen et al., 2004; Garrison et al., 2009). If we consider the existing nexus between energy and water, a decentralized system might be appealing not only at the local or regional scale, but also at the state and national level.

Need for Infrastructure Replacement

Since treatment capacities either remain constant or increase, wastewater systems must respond to that demand. Rather than replacing heavy and corroding iron pipes, municipalities and communities may find opportunities through a just-in-time approach; that is, customizing treatment capacity as it arises rather than over-building a large treatment capacity.

Furthermore, in many cases, decentralized systems can increase local water reuse and decrease impacts on natural hydrologic integrity. This can create direct environmental benefits while offering economic and social opportunities (Magliaro, J., Lovins, A., 2004). If managed properly, both on the technical side and the regulatory side, decentralized wastewater systems offer a potentially sustainable alternative.

Social Component

An additional awareness to natural water cycles and environmental systems has been observed in cases where decentralized technologies are adopted for onsite wastewater treatment. The Rocky Mountain Institute (2004) highlights potential educational and social benefits associated with decentralized systems, such as habitat creation, aesthetic appeal, and educational opportunities.

The social and aesthetic appeal of alternative onsite systems such as constructed wetlands, aquatic ecological systems, and even prefabricated systems offer an element of community connection to the filtration and treatment process (Leverenz et al., 2002). The localized nature of decentralized infrastructure encourages public awareness and participation. With appropriate management, this can offer awareness to consumption rates, which is increasingly important as western states seek to conserve water consumption (Garrison et al., 2009).

These considerations and regulatory framework thus outlined will influence decisions regarding the use of decentralized systems. The final factors to consider are specific characteristics pertinent to Santa Barbara County, as outlined in the following section.

2.6 Background Information on Santa Barbara County

When looking at decentralized wastewater treatment within Santa Barbara County, one must consider characteristics that are specific to the area, such as climate and topography, local water supply and demand, expected population growth, current wastewater infrastructure (municipal and onsite) and the regulatory environment.

Climate and Topography

Some technologies may be suited for a certain type of climate and topography, but not for others. This has been well established for evapotranspiration beds, which are dependent on the rate of evaporation in relation to precipitation, temperature, soils, and slope gradients. Constructed wetlands may respond differently according to temperature and season (Sovik et al., 2006). Technologies may also be limited by available land, as well as topographical constraints.

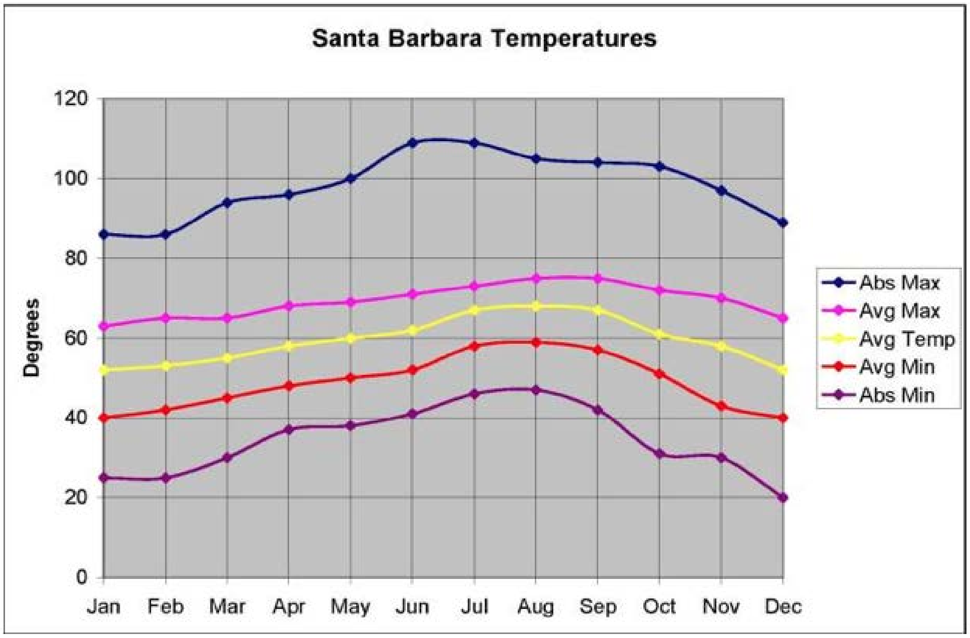
Santa Barbara County's climate is typically warm and dry in summer and cool and wet in winter, very similar to a Mediterranean-type climate. The Pacific Ocean exerts a moderating effect on Santa Barbara's climate and temperatures near the coast. Steep mountain ranges that run parallel to the coast also cause an orographic effect in which the storms coming from the Pacific Ocean are forced to move upwards, resulting in precipitation release on the western slopes of the mountains (Santa Barbara County, 2011)[a]. As a result, very little precipitation occurs on the land lying eastwards of these slopes.

Precipitation within the county has pronounced seasonal variation, and also varies with location. Average annual precipitation ranges from a minimum of about 8 inches in the Cuyama Valley to over 36 inches in the Santa Ynez Mountains. At the county's highest elevations snow is also common. Drought periods are regular occurrences, lasting sometimes as long as a decade (Santa Barbara County, 2011)[a]. Rainfall within the county is usually moderate, but occasionally short duration rainfall of very high intensity occurs.

Average temperatures in Santa Barbara tend to be moderate as is illustrated by Figure 2.6.1, with a range between 50–65 degrees Fahrenheit. However, extreme highs and lows may occur (Santa Barbara County, 2011)[a].

Santa Barbara County occupies more than 2,700 square miles, and for the most part is sparsely populated and mountainous. Most developed areas in the county are located along the coastal plain and in the inter-mountain valleys (Santa Barbara County, 2011)[a].

Figure 2.6.1: Average Temperature in Santa Barbara County



Source: Extracted from County of Santa Barbara, Public Works Department

Based on this information, the moderate climate of Santa Barbara is expected to be suitable for most treatment technologies. Regarding topography, areas that are hilly in nature will not be as suitable for technologies involving land treatment or requiring great expanses of land, since the cost of preparing and leveling the ground for the installation of a system will be elevated, and so will be the environmental impacts. Before installing any system, the local climatic and geographic conditions at the proposed site must be evaluated.

Another factor to be considered is the water supply and demand situation. If there is water scarcity, then technologies that allow water reuse will reduce pressure on water districts. In order to evaluate if this would be a significant benefit for Santa Barbara, we consider the existing water supplies and water use for the county.

Water Supply and Demand Overview

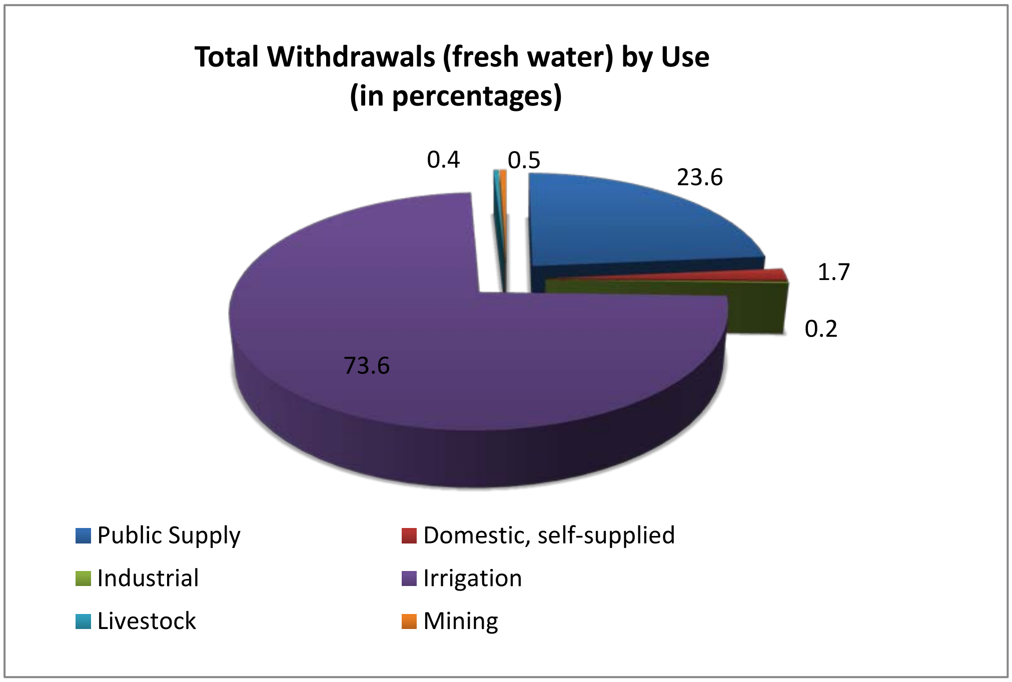
According to information from the Water Resources Division (Public Works, County of Santa Barbara), potable water for the county is obtained from several sources: groundwater withdrawal, storm runoff collected in reservoir systems, the State Water Project, recycled water and desalinated water resources. There are a variety of water purveyors, including incorporated cities, community service districts, water districts, private water companies, and conservation districts (Santa Barbara County, 2011)[b].

There are four major reservoirs in the County of Santa Barbara: Cachuma, Twitchell, Gibraltar and Jameson. The first two are federally owned, managed by the Water Resources Division, and operated by local water purveyors. The latter two are owned and operated by the City of Santa Barbara and the Montecito Water District respectively (Santa Barbara County, 2011)[b].

Groundwater is a primary source of potable water for many county residents. In order to avoid overdrafting, this withdrawal is closely monitored. Supply is complemented with state water and some surface water from rivers, in particular in the communities of Santa Ynez, Ballard and Los Olivos (Santa Barbara County, 2011)[a]. According to the 2005 USGS Water Use study, public supply from ground water sources serves approximately 51% of the County's population (202.7 thousand people), and roughly 47% (191 thousand people) is served through surface water sources. The remaining 2% is self-supplied, mostly through groundwater extraction (USGS, 2005).

Total withdrawals are 239.6 million GPD, with 97% coming from freshwater sources. Most withdrawals (87 %) are from ground water sources. Breaking down this information by use, most withdrawals (roughly 172 million GPD) are for irrigation, accounting for 73.6% of total fresh water withdrawals (Figure 2.6.2).

Figure 2.6.2: Total Withdrawals (Fresh Water) by Use



Source: Constructed from USGS Water Use Data, 2005

The single biggest use of water in the county is for agriculture; this demand comprises almost 75% of the current total water demand (Santa Barbara County, 2003).

In Santa Barbara County, water use in 2000 was 175 GPD per person, which is significantly lower than countywide water use in 1980 (County of Santa Barbara, 2003). According to the USGS study (2005), domestic per capita use is approximately 112 GPD per person; this represents a 36% reduction due mainly to stricter conservation measures. This is comparable to the national average, which is 100 GPD per person (Santa Barbara County, 2003).

Water Supply v. Demand

Water supply estimates show that countywide supply can meet demand today. However, projections for the year 2020 indicate that there will be a countywide deficit of approximately 6.79 million GPD. This gap will increase through 2040, with a shortfall of 8.14 million GPD by 2030 and a deficit of 9.56 million GPD by 2040. However, this gap only represents 3% of the total needs, and result on average in a 13–16 GPD water shortage per person. These forecasts should be considered as trends and not as exact forecasts (Santa Barbara County, 2003). They take into account population estimates because they provide valuable data for determining future water demand. Population in Santa Barbara County is expected to exceed 500,000 people by the year 2020, and reach approximately 520,000 (Census 2000 forecast) or 576,000 (NWSLTR 2030) by the year 2030.

Water availability varies in different designated analysis units (DAUs) within Santa Barbara County. In some, current supply meets demand, but shortages are projected for the future. In others, such as Cuyama, present demand already exceeds supply. Overall, the general trend is for the county to face water shortages before 2020.

Since the county has a strong water conservation program, and many conservation measures are already in place (City of Santa Barbara, 2012), water reuse emerges as an interesting possibility to address water scarcity issues. Decentralized wastewater treatment systems that can offer recycled water on site thus may be an appealing option. These systems may also complement existing wastewater infrastructure. To evaluate this further, we present the current conditions of municipal and onsite wastewater treatment in Santa Barbara County.

Current State of Municipal Wastewater Treatment in Santa Barbara County

The main municipal wastewater systems in Santa Barbara County are El Estero, located in Santa Barbara city; the wastewater treatment plant in Goleta; and Los Alamos Community Services District wastewater treatment system, providing sewer systems to the community of Los Alamos (Santa Barbara County Water Agency, 2003). Other wastewater treatment systems include those in the city of Santa Maria, the Carpinteria Sanitary District, Laguna County Sanitation District, Santa Ynez Community Services District, and the Lompoc regional wastewater treatment plant. The City of Buellton wastewater treatment plant and Montecito Sanitary District provide secondary treatment (Santa Barbara Water, 2012).

El Estero Wastewater Treatment Plant

El Estero is an 11 million GPD secondary treatment facility equipped with a 4.3 million GPD tertiary treatment system for recycled water. This plant is almost 30 years old, but several recent projects have been developed to upgrade the facility (Santa Barbara County IWRM, 2009). The completed work is expected to extend the plant's life for the next decade or more, also allowing the city to update equipment to more energy-efficient models (The City of Santa Barbara, 2011). Upgrades have included installation of an additional influent pump, equipment rehabilitation and replacement in primary and secondary clarifiers, a new thickened sludge pump station, redesign of aeration basins, and new sludge presses (The City of Santa Barbara, 2011). The level of treatment is secondary or tertiary.

Goleta Water and Goleta Sanitary District

Goleta Water District has a 3 million GPD wastewater reclamation plant, which was completed in 1995, located next to the Goleta Sanitary District wastewater treatment plant. The Goleta wastewater treatment plant services the unincorporated area of the Goleta Valley immediately west of the City of Santa Barbara, and a portion of the City of Goleta (Goleta Sanitary District, 2011). Over the years, structural and hydraulic deficiencies were observed in the collection system, which led to the implementation of a capital improvement program. Under this program, the sewer system was evaluated and priorities for repair were established (Goleta Sanitary District, 2011). There is an upgrade requirement for the Goleta Sanitary District to achieve full secondary effluent treatment by 2014 (Santa Barbara County, 2009).

Los Alamos Community Services District

The Los Alamos plant (Phase I) was constructed in 1988, and later expanded in 1994 (Phase II) to allow disposal of effluent of up to 1.76 million GPD. This expansion was done to ensure adequate service for the planned build out conditions for the community. The district currently operates and discharges at 63% of its capacity (Santa Barbara County Water Agency, 2003). In 2005, the Central Coast RWQCB set new waste discharge requirements for the Phase III expansion, increasing the allowed discharge to a maximum of 2.25 million GPD. Building for Phase III was completed in 2006 (Santa Barbara County, 2009). The wastewater treatment system includes aerated treatment ponds and an effluent disposal system. The level of treatment that is achieved is secondary (Dennis Bethel & Associates, 2006).

Carpinteria

The Carpinteria Sanitary District was formed in 1928. Its first wastewater treatment plant was operational by 1951, with a capacity of 0.5 million GPD. In 1961, the treatment plant was expanded and upgraded to a capacity of 2 million GPD and in 1993, another major upgrade was completed, involving the replacement of most of the process infrastructure. The plant currently includes preliminary screening and grit removal, primary clarification, extended aeration biological treatment, final clarification, chemical disinfection, aerobic digestion, and odor control systems (Santa Barbara County, 2009). The level of treatment is secondary (Santa Barbara Water, 2012).

Santa Ynez Community Services District and City of Solvang

This district, formed in 1971, provides wastewater collection for urban uses in the Santa Ynez Township. The district purchased capacity in the City of Solvang's wastewater treatment plant rather than building and maintaining its own, and is allowed by contract to send up to 0.2 million GPD to the City of Solvang 1.5 million GPD wastewater treatment plant. This plant uses a Sequential Batch Reactor process, which provides secondary treatment (City of Solvang, 2012). The Chumash Indians also have a wastewater treatment plant with a capacity of 0.2 million GPD, which has been operational since 2004. The discharge meets California Title 22, tertiary 2.2 standards (Santa Barbara County, 2009).

Santa Maria

The original facilities were expanded and in 1962 had a capacity of 5 million GPD. Due to population growth, design capacity was reached in 1975 so the plant was expanded. This upgrade was completed in 1982 (Santa Barbara County IRWM, 2009). The level of treatment achieved is secondary (Santa Barbara Water, 2012).

Laguna County Sanitation District

The Laguna County Sanitation District was formed in 1958, at a time when both Lompoc and Santa Maria were experiencing significant growth due to the activities at the Vandenberg Air Force Base. The plant has a current capacity of 3.7 million GPD. The plant has been recently upgraded, and now provides full tertiary treatment through the use of membranes including reverse osmosis for portions of flow that have high salt levels due to water softener discharges (Santa Barbara County, 2009).

City of Lompoc

The City of Lompoc owns the Lompoc Regional Wastewater Treatment Plant, which was first put in operation in 1975. It utilizes secondary treatment technology and has a design capacity of just over 5 million GPD. The plant has received upgrades since 2007 up till 2011 to improve reliability, meet more stringent discharge requirements, and increase treatment level from secondary to tertiary (Santa Barbara County, 2009).

Overall, it appears that municipal wastewater treatment plants in Santa Barbara County have invested sufficient funds to ensure that systems work properly and already take advantage of water reuse options through the water reclamation plant in

Goleta. However, it is uncertain if future investments will be enough to compensate for normal wear and ageing, and if the county will be able to meet increased wastewater treatment demands associated with population growth.

Present Onsite Systems Status in California and Santa Barbara County

In California, onsite systems serve 3.5 million people, representing 10% of the housing units in the state. This percentage has been maintained for new housing units since 1990. This trend is expected to continue in the future (Banathy, 2004).

California has approximately 1.3 million onsite systems. Additionally, about 5000–10,000 new systems are installed per year. Problems with septic systems occur mostly along the coast, on the steep slopes of the Coast Range and the Sierra Nevada, and in densely populated developments on the outskirts of cities. The type of failure varies, but is typically due to effluent surfacing. Reported causes of failure are hydraulic overloading, poor maintenance, poor soils, inadequate design or construction, and saturation of leachfields and age (Stone Environmental Inc., CAWT, 2009).

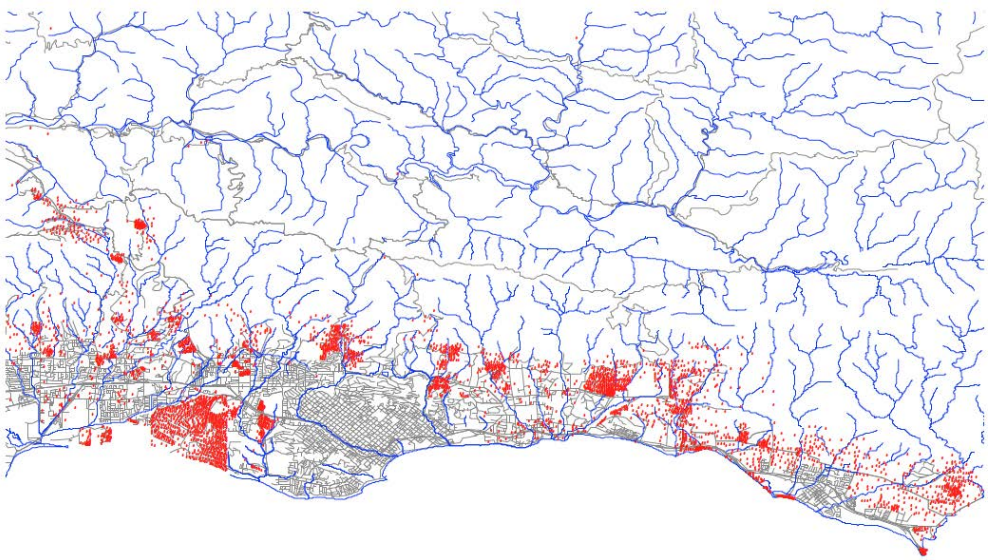
The main pollution concerns are nitrates in groundwater and fecal coliform contamination of surface waters. In order to minimize pollution threats, onsite system permits have been denied when sites presented shallow groundwater, slow percolation rates, steep slopes, poor thin soils and fractured rock (Stone Environmental Inc., CAWT, 2009).

Water Quality Impairment from Septic Systems in Santa Barbara County

Parts of Santa Barbara County are characterized with restrictive, expansive clays and shallow soils, which result in a large numbers of failures (Stone Environmental Inc., CAWT, 2009). Because of these failures, and in order to protect the valuable shoreline, there have been initiatives to prevent pollution. One such example is the prevention of pollution using Geographic Information Systems.

The Department of Environmental Health, with help from GeoDigital Mapping Inc., has begun to work on the creation of parcel maps of the county, projecting where water quality impairments might occur as a result of septic system failure. Through the use of maps of existing sewer lines they have identified the areas on septic systems. The integration of data with links to the maps facilitates access to information, also enabling the County to make informed decisions for sustainable and environmentally protective growth (Banathy, 2004). A map showing clusters of septic systems (shown in red) is included in Figure 2.6.4.

Figure 2.6.4: Septic System Map of Santa Barbara County, South Coast



Source: Heal the Ocean, 2012

Many of these systems are along coasts and creeks, and the big cluster on the bottom left of the map corresponds to Hope Ranch (Heal the Ocean, 2012). This type of research and activities might be very useful for planners and architects thinking about installing alternative onsite systems since critical areas, or areas with poor site conditions, may be easily identified.

CHAPTER 3: METHODOLOGIES AND RESULTS

Introduction

To address our research questions and the needs of our clients, we used a variety of methodologies and research approaches. Following a comprehensive literature review, we identified potential decentralized wastewater technologies to include in our research. We also considered criteria on which these systems could be evaluated.

We hosted a community workshop to gather input from important stakeholders and members of the local design community. The purpose of this workshop was to identify the barriers preventing the adoption of decentralized systems, as well as to understand critical aspects of selecting, permitting, and installing decentralized systems from in-the-field experts.

To evaluate the life cycle impacts of wastewater treatment, we compiled data from life cycle assessment studies and life cycle inventory databases. Based on this research, we determined the pros and cons of each system from a life cycle perspective, as well as compared onsite systems to centralized treatment, based on their life cycle global warming potential and environmental impacts from sewer connections.

In order to obtain a clear understanding of the permitting process, we analyzed the relevant regulatory requirements and interviewed policy makers in the field. We presented this information in the form of a permitting flowchart, indicating expected times and costs for permit approvals.

After extensive data collection and analysis, we created a decision making tool in the form of a matrix, which includes 11 selected technologies and 21 valuation criteria, covering economic, environmental, social and permitting considerations.

To create the decision matrix, we scored the different technologies on a relative scale, for each of the selected criteria. Each system received a high (green), medium (yellow) or low (red) score.

Further details of the methods and results are included in Section 3.1 Life cycle Assessment of Wastewater Treatment, Section 3.2 Matrix Decision Support Tool and Section 3.3 Policy Environment in Santa Barbara County.

The Community Workshop

As part of our methodology, we hosted a community workshop on November 30th, 2011 at the Built Green Resources Center in Santa Barbara. A host of professionals from the building design and regulatory community were in attendance (Table 3.1).

Table 3.1: List of Attendees to Community Workshop

Name	Professional Affiliation	Title
Willie Brummett	SB County of Public Health	Environmental Health Specialist
Paul Jenzen	SB County of Public Health	Sr. Environmental Health Specialist
Eric Lohela	City of SB Environmental Services	Environmental Specialist
Gene Talmadge	Talmadge Associates/ Association of Enironmental Professionals (AEP)	President of AEP; Owner of Talmadge Associates
Bob Wilkinson	Bren School	Professor of Water Policy
Paul Poirier	Poirier & Associates Architects	Architect
Adam Sharkey	Blackbird Architects	Architect
Larry Miller	US Geological Survey	Water Resource Manager
Jeff Moeller	Water Environment Research Foundation (WERF)	Research Director
David Lacaro	Regional Water Quality Control Board (RWQCB)	Environmental Scientist

Table 3.1 (Cont.): List of Attendees to Community Workshop

Name	Professional Affiliation	Title
Wendy Read	The Children's Project Academy	Founder
Elizabeth Janes	U.S. EPA Region 9 Ground Water Office (WTR9)	Underground Injection Control Program Officer
Detlev Peikert	Peikert Group Architects	Architect
Karen Feeney	Allen and Associates	Green Resources Manager
Lisa Plowman	Peikert Group Architects	Planning Manager
Arturo Keller	Bren School	Principal Project Advisor

Our focus was to facilitate conversation around the topic of onsite wastewater treatment, and in particular to understand the barriers inhibiting the adoption of decentralized systems. As such, we framed our discussion with the following questions:

1. Can you explain your familiarity with advanced systems beyond septic systems?
2. What do you see as some of the potential barriers?
3. What are some of your concerns with regards to permitting?
4. What do you see as the most viable purposes of recycled water from a wastewater treatment system?
5. What information would be most useful in a guidance document?

From discussing these questions at the workshop, we gathered valuable information and insight into decentralized systems. This input helped direct our research questions and was also included in our matrix decision support tool.

3.1 Life Cycle Assessment of Wastewater Treatment

Introduction

Wastewater treatment systems must be manufactured, installed, and operated. These steps often have environmental impacts, from use of chemical compounds and manufacturing emissions to land disturbances, sludge production and energy consumption. Therefore, in order to holistically assess the environmental impacts of a particular system, it is crucial to look at its full life cycle through an analysis called a life cycle assessment (LCA).

An LCA quantifies the environmental impacts of a product or system from its origins to its disposal. It often includes extraction of raw materials, processing, transportation, manufacture, use of product, and lastly disposal and end of life (Dixon et al., 2003). The International Organization for Standardization outlines the LCA methods (ISO 14040, 2006).

Applying the LCA approach to wastewater treatment provides insight into the overall environmental impacts of a system (Dixon et al., 2003). This approach is useful in water management because it emphasizes the entire life cycle of a system without focusing too much on particular steps in a process or certain aspects of a system. In fact, Emmerson et al. (1995) argue that life cycle analysis has potential for wider application within the water industry. Furthermore, because LCA assesses all impacts using a consistent framework, it minimizes the potential for problem shifting.

We have assessed both centralized and decentralized systems to offer a cradle-to-grave comparison. This section outlines our research and achieves the following objectives:

- Compares the environmental impacts of centralized systems to decentralized systems with a particular focus on sewer collection systems.

- Determines which stages in the wastewater treatment life cycle, such as manufacture, construction, operation, or disposal, have the highest impacts.
- Examines and compares the life cycle impacts of different decentralized technologies.
- Analyzes the energy required to run different technologies and their consequent emissions.
- Explores the tradeoff between higher effluent quality and energy use.

Methodology

In order to assess the life cycle impact of alternative wastewater treatment technologies, we performed an extensive literature review of existing studies, drawing conclusions from these when results were comparable. We also accessed the ecoinvent database, the world's leading supplier of consistent and transparent life cycle inventory data of known quality (ecoinvent, 2012) to locate more detailed information. In taking this approach, we have made several assumptions and addressed quite a few limitations. Since evaluating a long list of wastewater treatment options was beyond the scope of this project, we only considered a couple of technologies for centralized and decentralized treatment. These include activated sludge, constructed wetlands, membrane bioreactors and septic systems. Living machines were also considered, but only from an energy use perspective since there was limited information available for this proprietary technology.

Literature Review

The main environmental impacts that we focused on include greenhouse gas emissions (carbon dioxide, methane and nitrous oxide) and energy use (in kWh per volume of wastewater treated). We chose these impacts because of readily available data and the fact that some of the largest environmental damages associated with wastewater treatment result from greenhouse gas emissions and energy consumption (Lim et al, 2008). Furthermore, the production of energy is associated with several environmental concerns, such as the release of airborne pollutants that contribute to global warming, acidification and generation of low-level or tropospheric ozone (Emmerson et al., 1995).

Other impact categories that are important to wastewater treatment but were not included in this analysis are: abiotic depletion, caused mostly by the use of resources for the construction of these systems; eutrophication and human and ecosystem toxicity, which could result from the discharge of treated wastewater into the environment; and final sludge disposal, due to the presence of a certain amount of pollutants. We excluded these impact categories from our analysis because there was a lack of consistent data across all the technologies. However, general findings from the LCA studies that were reviewed have been noted.

Database Calculations

The ecoinvent database provided us with information on the environmental impacts associated with the sewer collection system and the centralized treatment process. We used the data from version 2.2 of 2010, and although the information was derived from a wastewater system in Switzerland, it is applicable to modern wastewater practices in North America, and therefore relevant to our study.

The sewer collection system: This system consists of the infrastructure materials for municipal sewer system, transports, and dismantling of an underground sewer system with pipes. The numbers used in the study represent an average of the impacts from five different sized systems.

Centralized treatment process: This process includes infrastructure materials for municipal wastewater treatment plant, transports, dismantling, and land use burdens. The technology consists of a three-stage wastewater treatment (mechanical, biological, chemical) including sludge digestion (fermentation) according to the average technology in Switzerland.

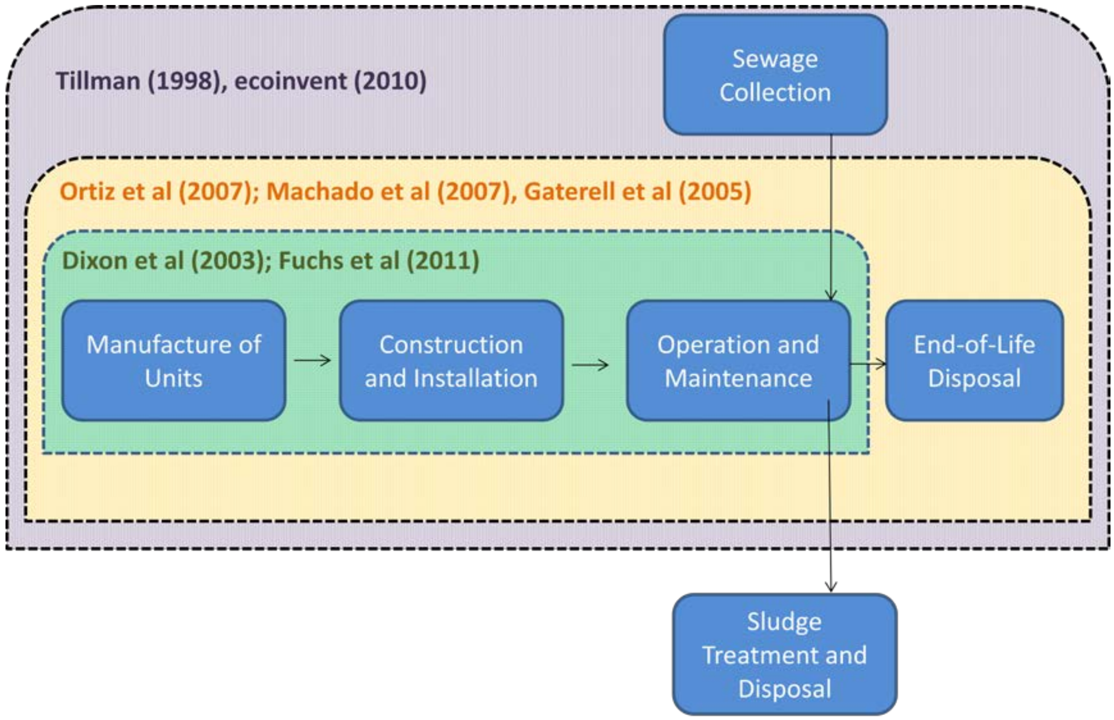
Assumptions and Limitations

The conclusions that may be drawn from an LCA literature review are limited by the quality of data available and how well results can be compared across studies or extended to other situations. Additionally, system boundaries usually vary considerably from study to study, since these are chosen based on the purpose of the LCA. For example, if the goal is to compare two treatment technologies with identical collection systems, then this individual phase could be excluded.

Available LCA literature covers different phases of the wastewater treatment process, and data and assumptions are not always transparent. Characterization methods also vary between studies, as do the impact categories that are analyzed or reported in detail. For example, some studies, such as Machado et al. 2007, only report on carbon dioxide emissions, while others report all greenhouse gas emissions in terms of carbon dioxide equivalents or overall global warming potential, such as Ortiz et al. 2007. These discrepancies are noted when reporting our findings.

The life cycle phases that are covered by each study also vary greatly. These boundary conditions are critical because they can have a significant effect on the LCA results (Dixon et al, 2003). A few studies include transport and collection of municipal waste (Tillman et al, 1998; Neumayr et al., 1997), as well as processes for final sludge disposal. The majority of the studies consider operation and maintenance, and a few also consider the construction phase. Most of the LCA studies exclude the end of life, or capital disposal phase, since this generally does not contribute significantly to the overall impact (Emmerson et al., 1995; Zhang and Wilson, 2000; Machado et al., 2007; Ortiz et al., 2007). It should be noted, however, that according to Machado et al., the end of life disposal of constructed wetlands contributes significantly to ozone layer depletion, and to a small extent to abiotic depletion and acidification. However, construction and operation combined still are the major contributors (2007). The following diagram (Figure 3.1.1) illustrates the system boundaries for the studies we have analyzed in detail.

Figure 3.1.1: System Boundaries Diagram



An ideal LCA study would include the impact of sewer systems, as well as the full life cycle impacts of the wastewater treatment plant, and solids handling and disposal. Regarding sewer systems, because this information was lacking from many of the studies, we extracted information from the ecoinvent database. We included sewers in our analysis of environmental impacts because of their potential significance for centralized systems, where sewers cover great expanses of land.

Solids handling and disposal have a significant environmental impact (Hospido et al., 2004; Gaterell et al., 2005), but are usually not included in studies that compare different wastewater technologies since focus is on operation and maintenance, and similar sludge disposal scenarios are assumed (incineration, land filling, or land application). There are, however, studies that consider different sewage sludge scenarios (Suh, Rousseaux, 2002; Houillon, Jolliet, 2005; Murray et al., 2008), showing that environmental impacts will vary depending on the final fate of these solids.

For the purpose of our analysis, we have assumed that the sludge generated by the different technologies will be removed and disposed off off-site, in accordance with California regulations. This places them outside our system boundaries. We assume similar impacts, although this is a simplification, as sludge will vary in composition and water content depending on the technology and extent of wastewater treatment. In light of this, we suggest that future studies should include this life cycle phase, as it has a significant impact. Impact will also depend to a great extent on the specific site characteristics, and the proximity of appropriate treatment facilities (Gaterell et al., 2005).

Another potential difficulty that arises from making comparisons across LCA studies is differing functional units. A functional unit is the measure used to quantify the impacts in a life cycle study. For wastewater treatment, common functional units include amount of emissions per person or per volume of treated water (in gallons or cubic meters). To make valid comparisons across studies, we converted the results into one functional unit: kg of emissions per person per year. We assumed that a person generated 150 gallons of wastewater per day. To put the studies into a per year basis, we first determined the time horizon on which the studies were based. A time horizon indicates for how much time the impacts are measured, and common time horizons include 10 years, 25 years, and 50 years. We then divided the results by the amount of years in the time horizon to find the emissions per person per year.

While this approach does ensure that the results are quantified in a similar metric, it does not guarantee that the results are applicable to Santa Barbara. Geographic variance is a challenge when comparing studies across regions. To address this, we gathered data from a variety of studies across different geographic locations.

This approach also helps address discrepancies in results due to the size of the treatment plant. Scale can play a factor in per capita emissions because the impacts are divided among the users. This often results in lower per capita emissions for large systems and higher per capita emissions for small systems. When comparing across decentralized systems, scale is less of an issue because these treatment options tend to be used for single households or small clusters of homes. However, when comparing centralized systems with decentralized systems, scale is a crucial factor.

A life cycle approach assesses the systems holistically; however LCAs may not be able to fully capture the environmental impacts or benefits known from each system since LCA results are very specific to the assumptions that are made, and therefore cannot always be generalized to represent a system's environmental performance under all conditions (Tangsubkul et al., 2005). LCA studies may also fail to account for non-physical impacts, such as biodiversity, habitat, and aesthetics (Dixon et al., 2003). For example, as Brix (1999) points out, constructed wetlands serve a variety of functions in addition to treating wastewater, such as creating habitat for biodiversity and open space for public use.

Another challenge with using the LCA approach to determine which system has a smaller impact on the environment is that the results depend entirely on which impact is being considered (Seymour, 1997). For example, systems that release large amounts of greenhouse gases may produce a high quality effluent, thus having a large impact on global warming and a small impact on eutrophication. Due to these limitations, the LCA approach represents one part of many in our analytical study of wastewater treatment systems.

Results

Our life cycle analysis reveals several important implications in understanding the environmental impacts of wastewater treatment systems from waste collection to the construction of treatment plants to the actual treatment of municipal waste.

1. A sewer system that serves a large number of people has lower per capita impacts than a system that serves a small number of people.

The per capita environmental impacts associated with the collection of sewage through the sewer system have an inverse relationship with the number of people served by the system. This finding is evident in the greenhouse gas emissions resulting from the collection and treatment of waste. According to the ecoinvent database, sewer systems cause the following global warming impacts (Table 3.1.1).

Table 3.1.1: Global Warming Impact from Sewer Systems

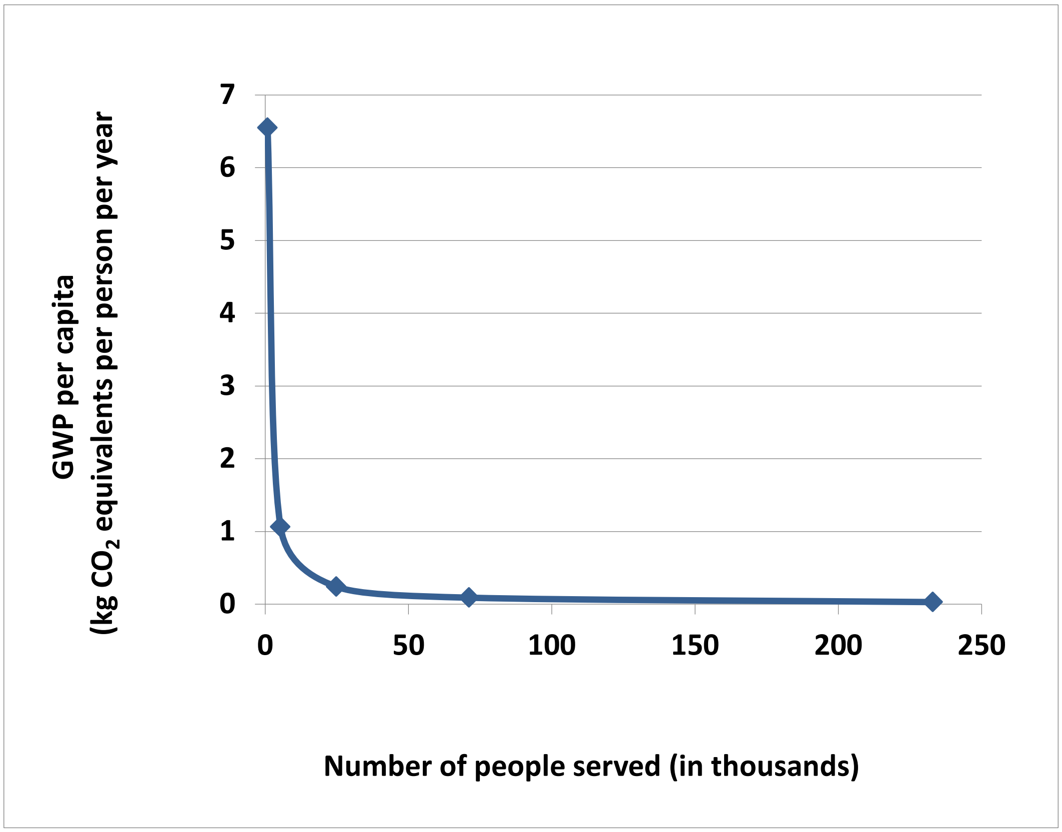
Class	1	2	3	4	5
Number of people served	233,000	71,113	24,864	5,321	806
Average length of sewer (km)	583	242	109.4	30.3	6.13
Global warming potential 100Y (kg CO_2e)	665,250	632,700	597,500	565,520	527,690
CO_2e per person per year	0.03	0.09	0.24	1.06	6.55

Source: ecoinvent database v 2.2, http://db.ecoinvent.org

Note: CO_2e refers to carbon dioxide equivalents, which include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. All emissions are expressed in terms of CO_2 by using the global warming potential of each gas to convert individual emissions to equivalent CO_2 emissions.

As shown in Table 3.1.1 above, the per capita impacts increase with smaller sewer systems. The sewer system that serves a large population of 233,000 people emits 0.03 kg of CO_2 equivalents per person each year while the sewer for 806 people emits 6.55 kg of CO_2 equivalents per person each year. This relationship is also portrayed in Figure 3.1.2 below.

Figure 3.1.2: Inverse Relationship between Sewer Size and Per Capita GWP



Source: ecoinvent database v 2.2, http://db.ecoinvent.org

In addition to the information from ecoinvent database, there are studies that suggest that sewer systems may have an impact in small conventional wastewater treatment plants. Lassaux et al. (2007) consider a small conventional activated sludge system and gravity flow sewers made of concrete, with pipelines with a diameter of 500 mm. According to their results, the second largest environmental impact is due to the sewer system (building phase), preceded only by the emissions from the operation of the plant, and followed by emissions from water discharge to the environment (since it may include some untreated water).

A second study, based in Europe, considers the life cycle impacts of an unplasticized polyvinyl chloride (PVC-U) solid wall sewer pipe system. A PVC-U solid wall pipe is commonly used in stormwater and sewer systems. According to the study results, the biggest impacts for greenhouse gas emissions stem from the production of raw materials for PVC pipes and polypropylene manholes, and to a lesser extent from the installation of the pipe system. Use, maintenance, and end of life stages are negligible. The carbon footprint of the sewer pipe system, expressed per 100 meters of pipe system (diameter 250 mm) for a 100-year lifespan, and calculated per year, is 25.787 kg CO_2 equivalents (for 12,500 persons). This number is similar to the results in ecoinvent for a medium-sized system (TEPPFA, 2010).

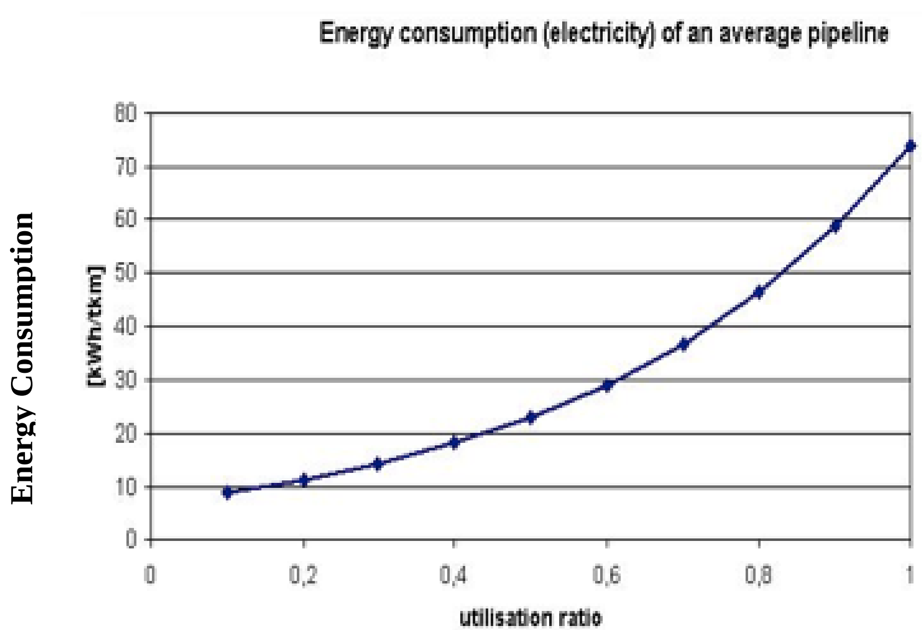
2. The impacts from sewage collection for decentralized systems may be lower than for centralized systems.

Sewage collection may also have an impact on decentralized systems, considering their need for pipes to convey the waste to the treatment system. In the case of septic tanks and other systems located adjacent to a home, conveyance of sewage is expected to have rather low environmental impacts. This expectation is due to the fact that the wastewater flows almost immediately from the household to the septic tank. In systems where the treatment facility is located further form the origin of the waste, such as cluster systems, there may be comparatively higher impacts, as they utilize more intricate collection systems. Expected emissions for cluster systems may mirror those for a small community sewer system, like those listed for Class 5 sewer systems in the ecoinvent database. These overall emissions are lower than for large, centralized systems because of their smaller collection system, both in pipe diameter and area of land covered. However, emissions per capita may be lower for larger collection systems as they serve a greater number of people. As Lundin et al. (2000), point out, “large economies of scales, in environmental terms, could be gained both for the operation and for the construction phase” of wastewater treatment plants.

3. For sewer systems that require pumping, energy use can be calculated based on energy consumption graphs.

All sewer systems have greenhouse gas emissions from the manufacture and installation of sewer pipes. Yet for those systems that require pumping as a supplement to gravity, there are additional greenhouse gas emissions associated with energy requirements. Energy consumption can be predicted using Figure 3.1.3 if the utilization ratio (used capacity divided by the maximum design capacity of the pipeline) and pipe diameter are known. Also, information regarding mass to be transported and distance of transport need to be known, as well as the gradient or slope of the land. Figure 3.1.3 shows the energy consumption for an average pipeline, extracted from GaBI Documentation Databases (2006).

Figure 3.1.3: Energy Consumption of an Average Pipeline



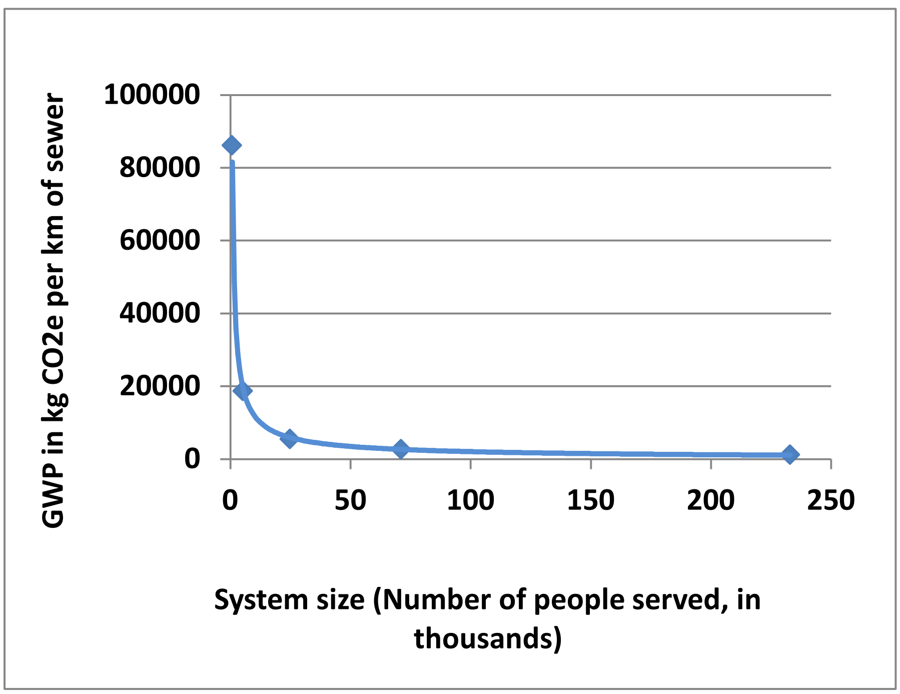
Source: GaBI database, 2006

If the utilization ratio is unknown, an average value of 28% may be used which, for the system shown in Figure 3.1.3, would result in an energy use of 15 kWh per kg of transported wastewater. For higher utilization ratios, more energy will be required to pump the wastewater, as shown by the ascending curve in the figure.

The amount of energy used to transport wastewater can have an effect on overall emissions, and must be considered when calculating life cycle impacts for an entire system.

4. The environmental impacts of a sewer system can be calculated based on the distance from the home to the centralized system and the centralized system size. This relationship depends on the size of the sewer system because the per capita impacts for large systems are lower than those for small systems (Figure 3.1.4).

Figure 3.1.4: Impacts by System Size and Sewer Length



Source: Constructed from ecoinvent database, http://db.ecoinvent.org

To determine the environmental impacts of connecting into the sewer system, the following equations, as shown in Table 3.1.2, can be used. These equations are based on data from the ecoinvent database and take the general form:

Total kg CO_2e = Multiplying Factor x Distance from Central Treatment (km) x People to Serve

Table 3.1.2: Equations to Calculate Global Warming Impact from Sewers

Centralized Treatment Facility Size (# of people served)	Equation
Under 806	Not applicable
Between 806 and 5,321 (Use Class 5 value)	= 1.07 * distance (km) * ppl served
Between 5,322 and 24,864 (Use Class 4 value)	= 3.51E-02 * distance (km) * ppl served
Between 24,865 and 71,113 (Use Class 3 value)	= 2.20E-03 * distance (km) * ppl served
Between 71,113 and 233,000 (Use Class 2 value)	= 3.68E-04 * distance (km) * ppl served
Over 233,000 (Use Class 1 value)	= 4.09E-05 * distance (km) * ppl served

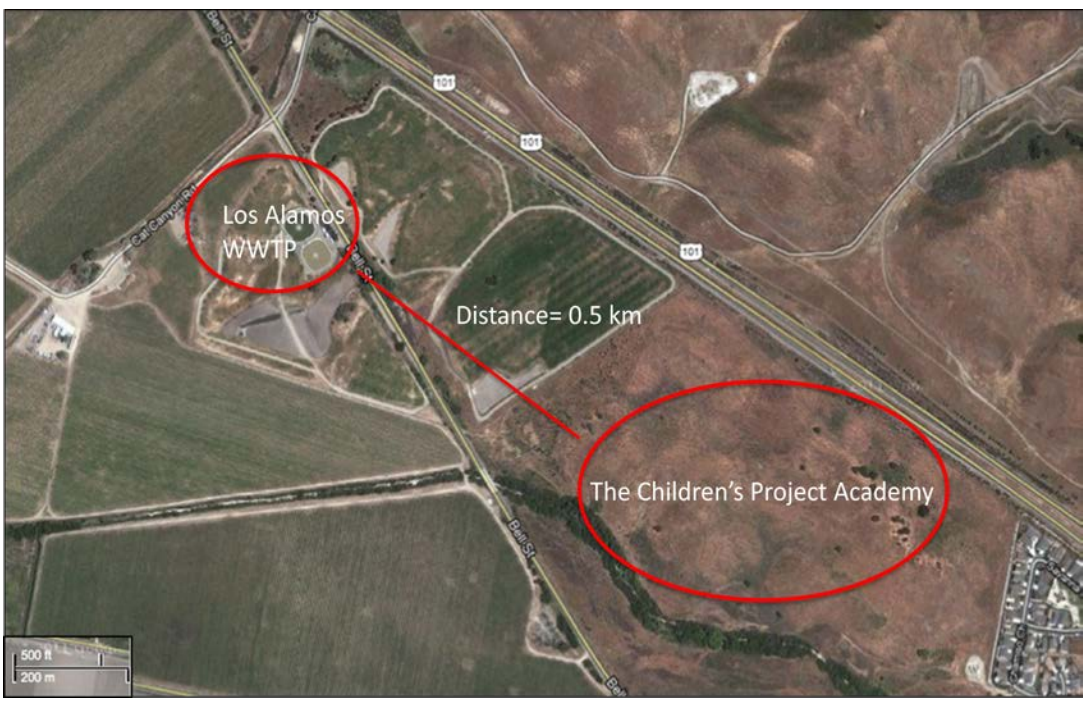
distance (km) is the distance from central facility; ppl = people

We obtained the multiplying factor for each system class as defined in the ecoinvent database by dividing the total impact by the number of people served and the kilometers of sewer system. Thus, the multiplying factor is expressed in kg CO_2e per km and per person. For example, for Class 5 (806 people served, 6.13 km), this corresponds to 1.07 kg CO_2e per km per person. For Class 4 (5,322 people served, 30.3 km) this impact is 3.51E-02 CO_2e per km per person. As the size of the system increases, the multiplying factors decrease.

For a system serving a number of people between 806 and 5,321 (sized between Class 4 and Class 5), we took a conservative approach and use the highest multiplying factor, which is the one corresponding to Class 5. We proceeded in a similar way for other population sizes. The end points in the categories shown on Table 3.1.2 were chosen based on the number of people for each class of sewer, according to the ecoinvent database (Class 1 corresponds to 233,000 people; Class 2 to 71,113; Class 3 to 24,865; Class 4 to 24,864; Class 5 to 806 people).

These equations provide an estimate of the impacts in kg of CO_2 equivalents per person per year. We illustrate these calculations by applying them to the Children's Project Academy Case Study. The centralized wastewater treatment plant in Los Alamos, CA treats waste for 1,649 people. Therefore, we use the equation ***1.07 * km * ppl***. The Children's Project Academy is located 0.5 kilometers from this treatment plant (Figure 3.1.5).

Figure 3.1.5: Aerial View of the Children's Project Academy



Source: Aerial photograph from Google Maps

Using this distance, we calculated ***0.535 kg CO_2 equivalents*** per person per year. Then we multiplied by 200, the estimated number of people at the Children's Project Academy. The resulting figure was ***107 kg*** CO_2 equivalents per year for all of the users of the Children's Project Academy from connecting into the sewer system. This number does not account for emissions from wastewater treatment.

5. Sewage collection represents a small portion of the overall impacts of centralized wastewater technologies, especially for larger treatment systems. While sewer collection does account for some life cycle greenhouse gas emissions, its impact is relatively small compared to other life cycle phases such as plant construction, wastewater treatment, and disposal, at least for small lengths of pipelines (1 km). This finding results from the comparison of emissions data on centralized treatment from the ecoinvent database. Table 3.1.3 summarizes these findings:

Table 3.1.3: Contribution of Sewers to Overall Global Warming Impact

Sewer System Class	**Collection** *kg CO2e p.e./ year*	**Sewage treatment** *kg CO2e p.e./ year*	**Total** *kg CO2e p.e./ year*	**Percent collection** *kg CO2e p.e./ year*	**Percent treatment** *kg CO2e p.e./ year*
1	0.03	20.35	20.38	0.14	99.86
2	0.09	27.14	27.23	0.33	99.67
3	0.24	29.10	29.34	0.82	99.18
4	1.06	29.95	31.02	3.43	96.57
5	6.55	30.16	36.71	17.84	82.16

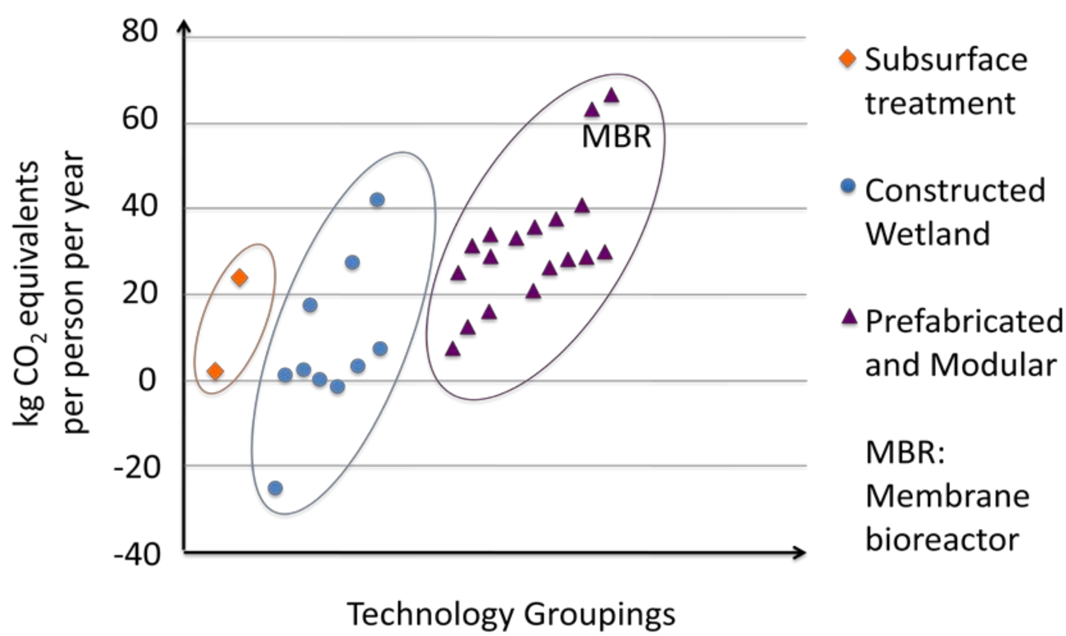
Source: ecoinvent database v 2.2, http://db.ecoinvent.org

For centralized wastewater systems that treat over 24,000 people, the impact from sewers is less than 1% of all environmental impacts. For the smaller systems under 24,000, the emissions from sewage collection are 3.43% and 17.84%.

6. When looking at the life cycle global warming potential of the systems, including construction, operations, and disposal, membrane bioreactors have the largest life cycle impact, followed by activated sludge plants, septic tanks, and then constructed wetlands.

Results from this analysis are represented in Figure 3.1.6. It should be noted that these values are to be taken as reference numbers, to observe the scatter and compare the GWP impacts of the different technologies.

Figure 3.1.6: Life Cycle Global Warming Potential per System



Source: Constructed from several LCA studies and ecoinvent database, details in Appendix D.

Prefabricated and Modular (Activated Sludge and MBR)

Activated sludge systems are energy intensive operations, and when combined with a membrane bioreactor, these systems are known to have heavy impacts on the environment (Machado et al., 2007). The majority of this impact occurs in the operational phase, as large amounts of energy are required to produce the high-quality, tertiary-treated effluent. This is particularly true with external bioreactors, the more energy intense membrane bioreactor (Dixon et al., 2003).

Conventional activated sludge without added treatment options emits the second highest amount of greenhouse gas emissions. This system requires energy consuming equipment, such as an anaerobic reactor, that contributes to the large life cycle footprint (Pasqualino et al., 2009). Data from the ecoinvent database shows that the average GWP per person per year of an activated sludge facility varies between 20 and 30 kg CO_2 equivalents depending on system size. Similar to the centralized collection system, the per capita impacts of activated sludge plants increase for smaller scaled systems.

Constructed Wetlands

Constructed wetlands, on the other hand, have a much lower life cycle impact because they do not require much energy and have the ability to absorb carbon dioxide. When comparing the use phase of constructed wetlands to activated sludge, it is estimated that a wetland treatment system uses 0.16 kg of fossil fuel carbon to every 3.7 kg for conventional wastewater treatment (Ogden, 1999). Similarly, Pan et al. 2010 find that the greenhouse gas emissions (including CO_2, CH_4 and N_2O) from the treatment stage of a conventional system are almost 7 times higher compared to those of a constructed wetland system. In fact, depending on season and location, constructed wetlands can sometimes be carbon neutral or even carbon sequesters (Machado et al., 2007). The only exception to this finding is the global warming potential from methane, which could be emitted from an anaerobic wetland. These emissions could be the largest contributor to global warming in constructed wetland systems, mostly from the sludge-handling phase (Pan et al., 2011). Because there is a worldwide increase in the development of constructed wetlands for wastewater treatment, it is important to fully understand their potential atmospheric impacts (Sovik et al., 2006).

Subsurface Treatment (Septic Tanks)

The life cycle global warming potential from septic tanks varies from study to study. After installation, these systems are gravity-fed waste and treat it using natural soil processes. The only major operation phase impacts would come from periodically hauling away sludge and from release of greenhouse gases into the atmosphere.

According to an LCA prepared for the National Precast Concrete Association by Morrison Hershfield, the Athena Institute, and Venta, Glaser & Associates (2010), the impacts from the construction, installation and end of life disposal of a 1,500-gallon concrete septic tank over a lifespan of 100 years are 1.87 kg CO_2 equivalents per year. If we assume a typical family of four (conservative estimate), then the septic tank contributes 0.47 kg CO_2 equivalents per person equivalent per year. This number is close to the emissions of a constructed wetland system (NPCA, 2010).

This study does not include the use phase of septic tanks, but it may be complemented with a study carried out by WERF, which includes an assessment of the GHGs associated with wastewater that originate from onsite septic tank systems (2010). This includes gases such as methane and nitrous oxide since there is concern that decentralized ‘natural’ treatment processes and septic tanks may emit relatively large amounts of these gases (Scheehle and Doorn, 2003).

Methane is a potent greenhouse gas (GHG), with a global warming potential 20–25 times that of carbon dioxide. Nitrous oxide has a global warming potential 298 times that of carbon dioxide over a time horizon of 100 years (Forster et al., 2007). The U.S. EPA has used the Intergovernmental Panel on Climate Change methodology and determined that methane emissions of wastewater from onsite septic systems are significant, both because there are many systems in place and because emission rates for methane are high (WERF, 2010)[a].

Results from the WERF study indicate that the primary GHG emissions in the septic tank were methane and carbon dioxide, and in the soil dispersal system were carbon dioxide and nitrous oxide. Results in terms of tons of CO_2 equivalents per capita per year are summarized in Figure 3.1.7, extracted from the study (WERF, 2010)[a].

Figure 3.1.7: Comparison of GHG Emission Rates as CO_2 equivalents

Table ES-2. Comparison of GHG Emission Rates as CO_2e from the Septic Tank and Vent Average Measurements.

	Geometric mean emission rate value (g/capita·d)			Carbon dioxide equivalent emissions (tonne CO_2e/capita·year)	
Compound	Septic tank	Septic system[b]	GWP[a]	Septic tank	Septic system[b]
Methane	11.0	10.7	21	0.084	0.082
Nitrous oxide	0.005	0.20	310	0.00057	0.023
Carbon dioxide	33.3	335	1	0.012	0.12
Total GHG emissions				0.096	0.23
Total anthropogenic emissions[c]				0.085	0.10

[a] GWP for a 100 year horizon IPCC (1996).
[b] As determined from vent system sampling.
[c] Biogenic carbon dioxide is not included in GHG inventories (U.S. EPA, 2009).

Source: WERF, 2010[a]

According to Figure 3.1.7, there are 96 kg CO_2 equivalents per person per year as measured in the septic tank vents, and 230 kg CO_2 equivalents for the combined emissions of the septic tank and soil dispersal system (septic system). These findings were higher than our results for all the other technologies (activated sludge, MBR, constructed wetland, etc). Because these findings were orders of magnitude different from the other research papers, we excluded them from our comparative analysis under the assumption that they included factors that were ignored in the other studies. However, this represents an important area of further research because of the wide use of septic tanks across the United States and the world.

Another important conclusion from this study is that the GWP impact from septic tanks is higher when levels of sludge in the tank are higher, since this promotes anaerobic conditions and therefore the formation of methane. As such, cleaning out the tank with a higher frequency might help reduce the amount of GHG that these systems vent into the atmosphere.

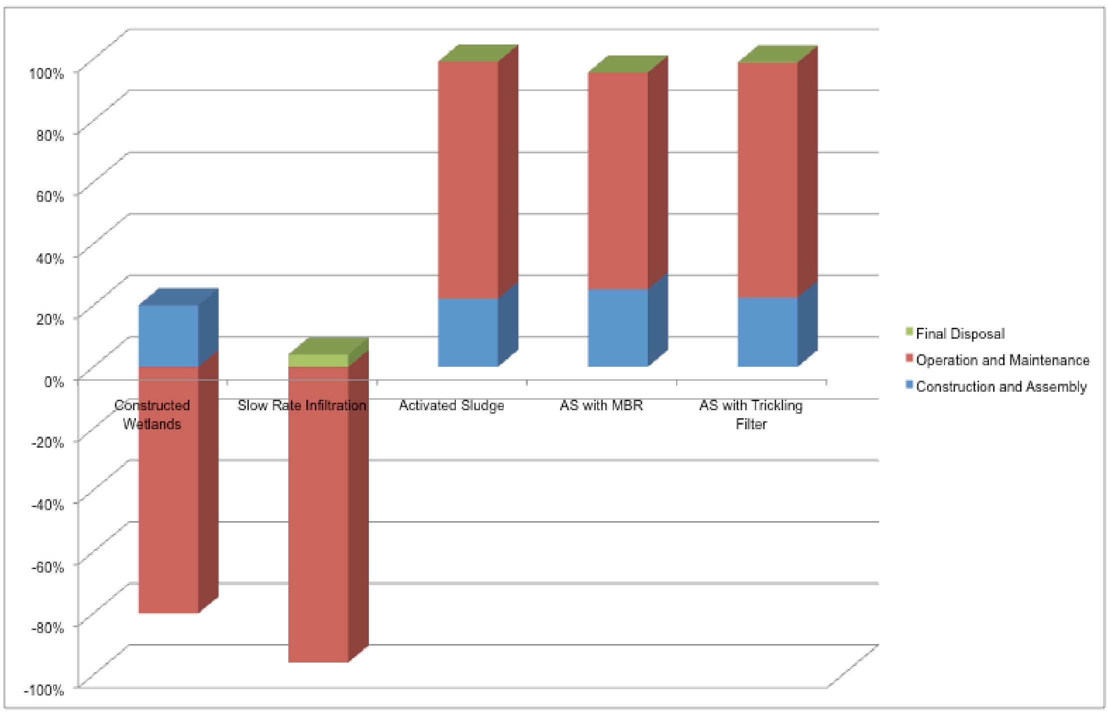
7. For most wastewater treatment systems, the life cycle phase with the greatest impact on the environment is the operation phase, followed by the manufacture/construction phase, and then by the end-of-life disposal.

In particular, for conventional activated sludge treatment systems, studies indicate that the life cycle impacts of the operation phase are much greater than the construction phase (Tillman et al., 1998; Lundin et al., 2000; Dixon et al., 2003; Emmerson et al., 1995; Ortiz et al., 2007; Renou et al., 2008). In fact, 95% of the energy consumption occurs during the operational phase for activated sludge (Emmerson et al., 1995).

However, for less energy intensive operations, such as constructed wetlands and septic systems, the environmental impacts originate mostly from the construction stage, as shown in Figure 3.1.8. This is due to the amount of materials that need to be transported to the site, and the low operational energy use (Dixon et al., 2003; Machado et al., 2007). In addition, many of the biological systems absorb atmospheric carbon dioxide during the use phase, giving them a negative value for operational global warming impact. Plants absorb carbon dioxide during photosynthesis, converting it into biomass. Bacteria or other microbial organisms in the soil may use carbon dioxide as their carbon source, and also uptake this gas.

In fact, for biological filter systems, around 50% of total life cycle energy is used during the construction phase (Emmerson et al., 1995). Gaterell et al. echo this finding by stating that there are few measurable impacts seen in the operations phase of biological systems (2005). Also, there are minimal impacts associated with the end-of-life disposal of wetland systems (Gaterell et al., 2005). In fact, the end-of-life, life cycle phase appears to have negligible impacts across most technologies.

Figure 3.1.8: Global Warming Impact for Different Technologies and Life Cycle Phases

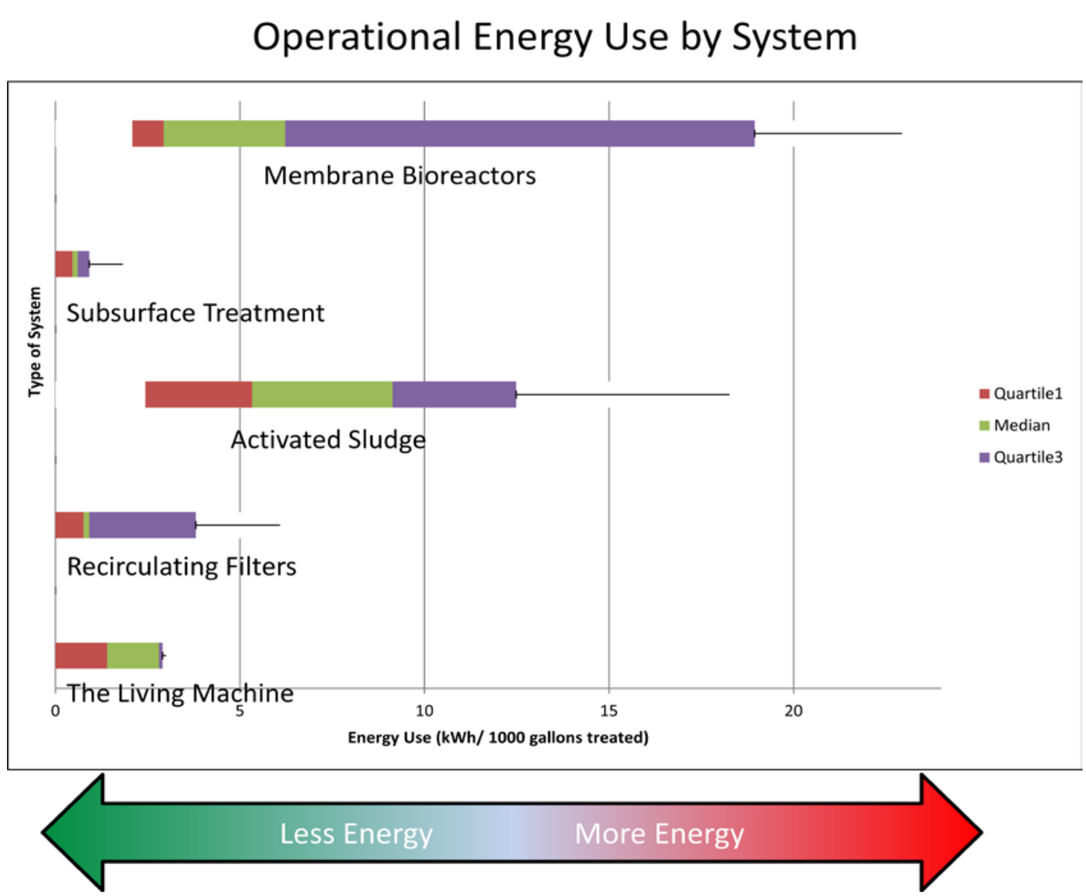


Source – Constructed from Machado et al., 2007 and Ortiz et al., 2007

8. Energy use is a key contributor to global warming potential in the operational life cycle phase, but each technology uses different amounts of energy, and their emissions are dependent on the local electricity grid mix.

We gathered data on energy use for a variety of technologies, and this information is presented in Figure 3.1.9. Each system had a wide range of values, and this is indicated in the whiskers and the interquartile range.

Figure 3.1.9: Operational Energy Use by System



Source: Constructed from literature data, available in Appendix D

As can be seen from Figure 3.1.9, Activated Sludge systems and Membrane Bioreactors have the highest energy use, although there is great variation in the data, and Subsurface Treatment is the least energy intensive.

Greater energy use is usually indicative of higher greenhouse gas emissions; however, this relationship depends entirely on the electricity grid mix of the local power company. Electricity that relies more heavily on fossil fuels has a higher global warming potential per kWh than a grid with a substantial mix of renewable energy and hydropower. In the United States alone, global warming potential varies from 0.23 in Alaska to 0.96 kg CO_2 per kWh for non-base load Midwest electricity (U.S. EPA, 2005)[b]. Table D.3 in Appendix D shows the values for each region of the United States.

9.Because more energy is required to produce higher quality effluent, there is a tradeoff between the environmental impacts associated with secondary and tertiary treatment.

Table 3.1.10 shows the average energy associated with several types of treatment, as established by Frank Burton.

Figure 3.1.10: Energy Requirements for Different Technologies

Type of Treatment	Energy Use (kWh/MGal)
Activated Sludge	1228
Advanced Treatment without Denitrification	1538
Advanced Treatment with Denitrification	1964

Source: Constructed from Burton, 1996

The increase in energy consumption required to produce high-quality effluent represents an important trade-off in the energy-water nexus. High-quality effluent can be environmentally beneficial as it prevents pollution and eutrophication, while providing clean water for recycling. In fact, in a big conventional wastewater treatment plant, the most significant impact categories are eutrophication and terrestrial ecotoxicity (Hospido et al., 2004; Gallego et al., 2008). In light of this, in order to reduce environmental impacts, the focus should be on reducing the pollutant loading from discharge of treated wastewater (in the form of nitrates, phosphates and chemical oxygen demand) and the emissions of pollutants to soil (such as chromium, mercury and zinc), when the final sludge is applied to land (Hospido et al., 2004). However, this achievement comes at the cost of increased energy demands. Hoibye et al. explored this trade-off more closely in a study called “Sustainability Assessment of Wastewater Technologies” in 2008.

Hoibye et al. examined the environmental impacts and benefits associated with five treatment technologies, and in particular, how improved effluent quality compared to the environmental damages incurred from achieving this improvement. Their results varied by technology, with sand filters as the most advantageous treatment, and ozone treatment and membrane biofilters as the least favorable in terms of environmental impacts. Yet more importantly, this study sheds light on the complex and challenging nexus between wastewater and energy, and shows how sustainable wastewater treatment, with a reduced carbon footprint, is now becoming a goal of technical exploration and experimentation (Hoibye et al., 2008).

Conclusions

This chapter has focused on the life cycle impacts associated with the collection and treatment of wastewater across all technologies. The environmental impacts were found to be substantial, especially considering the widespread use of wastewater treatment across the globe. This last section highlights our recommendations on how to decrease the life cycle impacts of wastewater treatment, and reviews areas where further research is needed.

Clean energy and energy efficiency are a vital part of decreasing the life cycle impacts of wastewater treatment plants. Since energy use is a big contributor to the overall environmental impact of wastewater treatment plants, measures that decrease energy use will reduce impacts. If more renewable energy were used, then the global warming potential of the electricity use would decrease, vastly reducing the environmental impacts of wastewater treatment. Similarly, wastewater treatment plants could implement renewable energy technologies, such as methane capture and fuel cells, to harness the energy inherent in wastewater and use it to reduce the energy requirements of the treatment facility. Municipal wastewater contains high amounts of energy in the form of stored energy from the chemical bonds of organic compounds within the wastewater. If this energy is captured in the treatment process, it can be converted into electricity and used to reduce energy requirements of facilities or be fed into the grid.

Recycling treated effluent offers several life cycle benefits. Recycled water is reliable even during drought years, which is especially important as the reliability of seasonal snowpack and rains is threatened by global climate change. Additionally, recycled water generally requires less energy than other supply-side sources, including desalination (Cohen et al., 2004).

Decreasing the amount of wastewater treated by maximizing water conservation would also reduce the life cycle impacts of wastewater treatment. Our research considered impacts in global warming potential per person under the assumption that the average person produces 150 gallons of wastewater per day. However, the true impacts are measured by the volume of wastewater that is treated (CO_2e per gallon of wastewater). Therefore, if the average person decreased the volume of wastewater produced per day, then the overall impacts would lessen as well. Some ways of achieving this are through water efficient toilets, showerheads, and sinks, as well as capturing graywater and recycling it onsite.

For small-scale developments located far away from a central treatment facility, it is probably best to consider an onsite treatment system. The environmental costs of connecting to the sewer increase with distance from the central system as well as number of people served. Therefore, if a development is located far away from a system, it is recommended to use an onsite treatment option. The equations in finding #4 can be used to determine the exact environmental payoffs.

More research is needed to determine the global warming potential of septic tanks, in particular regarding their fugitive emissions. ***Emissions from other technologies should also be studied further.*** As expressed in the WERF study on GHG emissions from septic systems, septic tank emissions have generally not received as much attention as those associated with large centralized wastewater treatment plants, and this holds particularly true for methane. In terms of relative contribution, according to this study, the methane fugitive emissions from septic tanks represent 0.47% of the average per capita GHG emissions. This study only considered septic systems, but there is a need to research and evaluate GHG emissions from alternative onsite wastewater treatment systems, such as constructed wetlands, packed bed filters, and other aerobic processes (2010)[a].

Future LCA research that includes sludge disposal can provide additional information on the impact of wastewater systems. Sludge disposal will have a considerable effect on the receiving environment; more so considering that in California about 54% of treated sludge (biosolids) is applied to land. The remaining 46% is broken down as follows: 16% is composted, 12% is used as cover in landfills, 6% is landfilled, 4% is surface disposed, and only 8% is incinerated (Government of California, 2012). To the extent that different technologies produce different volumes of final sludge, with varying composition, the environmental impacts will also vary, and therefore should be included in LCA studies.

It is hard to say which system is better from a life cycle perspective, as it depends on which impact category one is considering. To assess overall environmental impact, each impact category must be given a relative weight, based on what is most relevant. As a result, it is hard to establish which system provides similar treatment with less impact, since this relies on subjective valuations. For example, if the most important impact category is global climate change, centralized systems have a greater impact than decentralized options. If instead the main impact considered is eutrophication potential, then the system that removes the least nutrients from wastewater might have the greatest impacts.

3.2 Matrix Decision Support Tool

Methodology

We developed a Matrix Decision Support Tool ("the matrix"), incorporating feedback from a series of meetings with TSP and a stakeholder workshop held to gain insight from professionals in the community. The primary objective of this matrix is to provide non-technical information to decision makers when comparing decentralized technologies.

This matrix displays the technologies and their relative scores for criteria in three categories: economic, environmental, and social. When combined with the life cycle assessment comparison of system global warming potential, this matrix offers a holistic evaluation of decentralized technologies. Technologies and parameters incorporated into the matrix are described below.

Introduction of the Matrix

Traditionally in management science, a decision-support matrix is one of many approaches utilized in a multi-criteria decision analysis (MCDA) problem. MCDA problems are characterized by containing several alternative options that may conflict (Kiker et al., 2005). For example, when choosing a suitable decentralized system, cost may conflict with another criterion such as desired treatment level. In this case, the objective would be to optimize desired attributes with conflicting constraints. In economic terms, this describes the determination of an individual's preference for one good when alternatives are present, given a certain set of constraints.

We utilized an evidential reasoning approach in the decision matrix for the TSP. Evidential reasoning approaches are characterized by the use of both qualitative and quantitative methods to make decisions when uncertainty is inherent in valuation (Yang, 1999). An example of this type of valuation is demonstrated in how the decision matrix incorporates social considerations, including pernicious odors or altered aesthetic characteristics of a site; these are innately subjective concerns. Additionally, due to a lack of consistent estimates of technology costs, some relative approaches to economic valuation were selected.

Technology Categorization by Functional Process Utilized

There is a broad spectrum of existing technologies for onsite wastewater treatment. However, the matrix is not intended to be an exhaustive catalog of all available technologies. Treatment systems may use a variety of physical, chemical, and biological processes in order to effectively treat wastewater. Thus, to make the distinctions between system functions easier for the end user to comprehend, technologies have been grouped based on similarity of processes utilized.

Assessment Criteria

Valuation categories are listed along the vertical axis of the decision matrix, as shown below in Figure 3.2.1. We expanded individual parameters into broader categories of social, environmental, and economic considerations to meet a triple bottom line assessment. We determined the categories for the matrix by analyzing the criteria necessary to achieve effective wastewater treatment while incorporating other important considerations in implementing new wastewater infrastructure.

The considerations investigated in this matrix include: (a) typical final effluent quality produced by decentralized systems (Environmental), (b) the costs associated with meeting treatment criteria (Economics), and (c) social implications that could result from utilization of these systems from a community perspective (Social).

Figure 3.2.1: Example of Organization of Matrix and Valuation Categories to be Considered.

Valuation Category			Treatment Technology Group		
			Technology 1	Technology 2	Technology 3
Economic	Capital	Land Requirement			
		Construction			
	Operation & Maintenance	Materials			
		Energy Requirements			
		Operational Labor			
	Regulation	Permitting (Current and Future)			
Enviromental	Reliability				
	Performance	Total Suspended Solids (TSS)			
		Total Nitrogen Concentration*			
		BOD			
		Fecal Coliforms			
	Site Constraints	Soil			
		Slope			
	Natural Environment	Habitat Creation Potential			
Social	Aesthetic	Visual			
		Odor			
		Noise			
	Quality of Life	Educational Opportunity			
		Owner Supervision Requirements			
		Health - Risk of Vector Contact			

We obtained information important in designing matrix valuation categories from a variety of sources including:

- Vendor interviews and technical worksheets
- Technical reviews and guidelines from government reports,
- Scientific literature, and
- The decentralized wastewater treatment stakeholder workshop.

Through these methods we created scoring assessment criteria to provide an analysis of the technologies.

Scoring Assessment Criteria

The TSP decision matrix utilizes a 'stoplight' scoring approach, in which parameters are evaluated in a three-tier color-coding system (red, yellow, and green) (Figure 3.2.2). Boxes highlighted in green indicate the most optimal potential outcome, while yellow boxes indicate less desirable outcomes, and red boxes indicate least desirable outcomes. We chose this system for end user ease. Familiarity with 'stoplight' indicators allow the end user to adjust to reading the matrix quickly and easily, while additionally finding numerical scores of 1, 2, and 3 to correspond with colors.

Figure 3.2.2: Example of Matrix Valuation Category Rating based on Stoplight Approach

Valuation Category			Treatment Technology Group		
			Technology 1	Technology 2	Technology 3
Economic	Operation & Maintenance	Materials	1	2	1
		Energy Requirements	2	1	2
		Operational Labor	3	3	2

A description of valuation category parameters and associated scoring criteria are included below. This information is included in Appendix E Supplements 2 and 4.

Economics

The economic section of the matrix intends to describe specific considerations with regard to initial and long-term expected costs of onsite systems. The economic category is divided into three subcategories: Initial Capital, Operation and Maintenance, and Regulation. The subcategories are further divided into individual parameters, described below.

Initial Capital includes costs associated with land requirements and costs from building an onsite system.

Land Requirement

Parameter Description: Different systems require different amounts of land to treat wastewater. Depending on the process utilized to treat wastewater and the intended use, the amount of land required will vary.

Scoring Method: Systems requiring less than 0.25 square feet per GPD receive a high or green score. Systems requiring between 0.25 square feet and 0.75 square feet per GPD receive a medium or yellow score, and systems requiring more than 0.75 square feet per GPD receive a low or red score. These estimates were chosen in order to capture the land requirement spread for the systems reported in literature and by experts.

Construction Costs

Parameter Description: Construction costs include the costs to prepare a site for the construction of an onsite treatment system, as well as the construction process itself.

Scoring Method: We valuated this parameter relatively to others based on qualitative information collected through the literature review. A red scoring indicates an expensive system. Moderately priced systems receive a yellow scoring, and relatively inexpensive systems receive a green scoring.

Operation and Maintenance refers to annual costs associated with system maintenance. These include Materials, Energy Requirements, and Operational Labor requirements.

Materials

Parameter Description: This refers to all costs associated with maintaining system function including the cost of replacement parts, monitoring, biosolids removal, and the addition of chemicals or other products required for treatment.

Scoring Method: This parameter is valuated relatively with others based on qualitative information collected through the literature review. A red scoring indicates expected high operational expenses. Systems requiring moderately expensive operational supplies, such as recirculating filters, receive a yellow scoring, and systems with relatively inexpensive expected operational supply cost receive a green scoring, such as a leachfield. A membrane bioreactor is an example of a system that requires high material costs due to the nature of treatment.

Energy Requirements

Parameter Description: Different systems utilize different processes to treat wastewater. Generally, passive systems utilizing biological processes require less energy than active systems, which use some physical and chemical processes to treat wastewater.

Scoring Method: Systems with expected energy costs less than $0.25 per thousand gallons treated receive a green scoring. Systems with expected energy costs between $0.25-$1.00 per thousand gallons treated receive a yellow scoring, and systems with energy costs exceeding $1.00 per thousand gallons treated were assigned a red scoring. We chose these estimates to capture the spread of the data between systems requiring minimal energy input, such as mound systems to membrane bioreactors that have a high-energy requirement.

Operational Labor

Parameter Description: Operational labor refers to the costs required to employ an operator to maintain and ensure system function.

Scoring Method: Systems that do not require the employment of an operator achieve a green scoring. Systems requiring a part time operator achieve a yellow scoring, and systems requiring a full time operator receive a red scoring.

Regulation refers to the time associated with getting a permit from the responsible agencies for onsite treatment system in unincorporated areas of Santa Barbara County.

Current Permitting

Parameter Description: Current permitting refers to the time needed to get the required agencies to permit an onsite treatment system with the current regulatory process in unincorporated parts of Santa Barbara.

Scoring Method. Established onsite treatment systems that take approximately 1–2 weeks to receive a permit achieve a green scoring. This is equivalent to receiving a permit for a septic system with a flow rate less than 2,500 GPD, or the time required to permit a connection to an existing septic system. Onsite treatment systems that take approximately 6 weeks to obtain a permit receive a yellow scoring. This is equivalent to the time it takes to receive a general order permit from the RWQCB. Onsite treatment systems that take approximately 6 months to be permitted receive a red scoring. This is equivalent to an individual permit from the RWQCB or the Conditional Use permit from the Santa Barbara County Planning Department.

Predicted Future Permitting

Parameter Description: Future permitting refers to the anticipated time needed to get the required agencies to permit an onsite treatment system in unincorporated parts of Santa Barbara. The SWRCB is currently considering a policy change that would delegate the permitting of onsite systems to local agencies. If this is approved, Santa Barbara County Environmental Health Services is expected to publish guidance to assume this authority.

Scoring Method. Established onsite treatment systems that approximately take 1–2 weeks to obtain a permit receive a green scoring. This is equivalent to receiving a permit for a septic system with a flow rate under 2,500 GPD, or the time required for a permit to connect to an existing septic system. Onsite treatment systems that take approximately 6 weeks to obtain a permit receive a yellow scoring. This is equivalent to the time it takes to receive a general order permit from the RWQCB. Onsite treatment systems that take approximately 6 months to obtain a permit were assigned a red scoring. This is equivalent to an individual permit from the RWQCB or the Conditional Use permit from the Santa Barbara County Planning Department.

Environmental

The environmental portion of the matrix describes performance expectations in terms of desired treatment levels. This section is divided into four subcategories: Reliability, Performance, Site Constraints, and Natural Environment. The subcategories are further divided into individual parameters.

Reliability describes the likelihood of variation in a system's effluent quality.

Reliability

Parameter Description: Reliability refers to the level of variation possible in effluent. Scoring Method: Systems with consistent minimal variation in effluent receive a green score. Systems with seasonal variation in effluent receive a yellow score and systems with increased likelihood of variation in final effluent receive a red score.

Performance refers to a system's ability to remove nutrient and pathogen content from influent to meet Title 22 restricted and unrestricted reuse standards. Title 22 Requirements can be found in Chapter 2, Section 2.2. These performance indicators include total suspended solids, total nitrogen concentration, biochemical oxygen demand, and removal of potential pathogens. Turbidity is an important consideration for Title 22, but it is not included because it is only mandatory for unrestricted use, and frequently goes unreported by vendors and in academic literature.

Total Suspended Solids (TSS)

Parameter Description: TSS is a measurement of particulate matter content in a given water sample (one liter). In the matrix, TSS is described as the milligrams per liter of total suspended solids expected in final effluent.

Scoring Method: In order to receive a green scoring, a system must achieve less than 30 milligrams per liter of TSS in final effluent as required for Title 22 Restricted Reuse standards. TSS is not required for Title 22 Unrestricted Reuse. Therefore, no yellow scoring is assigned, and a red scoring indicates that Title 22 Restricted Reuse is not met.

Total Nitrogen Concentration

Parameter Description: Total nitrogen concentration refers to the amount of total nitrogen compounds in a given water sample (one liter). In the matrix, total nitrogen content is expressed in milligrams per liter of nitrogen content expected in final effluent.

Scoring Method: Total nitrogen content of less than 5mg/L receives a green scoring. Total nitrogen content above 5 mg/L and below or equal to 10 mg/L receives a yellow scoring, and total nitrogen content exceeding 10 mg/L was assigned a red scoring. These estimates were chosen in order to capture the spread of the data reported in literature and by experts. This information can be found in the Matrix Results section.

Biochemical Oxygen Demand (BOD)

Parameter Description: Biochemical oxygen demand measures the dissolved oxygen required for aerobic biological organisms in a body of water to break down organic material in the water. In the matrix, BOD is expressed in milligrams per liter of BOD expected in final effluent.

Scoring Method: In order to receive green scoring, a system must achieve less than 10 milligrams per liter of BOD in final effluent as required for Title 22 Unrestricted Access standards. For a system to receive yellow scoring less than 30 milligrams per liter of BOD must be achieved to meet Title 22 Restricted Access standards. Red scoring indicates that Title 22 requirements are not met.

Removal of Potential Pathogens

Parameter Description: Fecal coliform represents a bacterial indicator of pathogen content in a given water sample (100 milliliters). Specifically, coliform represents potentially harmful fecal content in water. Total coliform is expressed in the number of colonies present in 100 milliliters of water. Frequently, this is reported in log removal of pathogen content.

Scoring Method: In order to receive green scoring, a system must achieve greater than 3 log removal of fecal coliform, meaning that the effluent must contain a pathogen count that is 1,000 times less than the influent. Systems achieving 2 log removal of fecal coliform receive a yellow scoring, and systems achieving less than 2 log removal of fecal coliform receive a green scoring. These estimates were chosen in order to capture the spread of the data reported in literature and by experts. This information can be found in the Matrix Results section.

Site Constraints refers to physical characteristics of the site that must be considered in order for a properly installed system to function effectively.

Soil

Parameter Description: This refers to the degree to which soil characteristics are important for system function. For example, treatment processes that involve subsurface land treatment require specific soil types and porosity in order to function correctly. This results in a red scoring for systems that are dependent on good soil hydraulic conductivity, since many sites do not meet such a requirement.

Scoring Method: Systems with no soil requirements receive a green scoring. Systems with minimal soil requirements receive a yellow scoring, and systems with extensive soil requirements receive a red scoring. Therefore, a prefabricated modular system, which is independent from soil constraints, receives a green scoring, whereas a subsurface system, such as a leachfield requires specific soil characteristics. A yellow scoring reflects systems that can use various soil types based on the nature of their construction, such as an evapotranspiration system or free water surface wetland which can be constructed with bed liners.

Slope

Parameter Description: The slope parameter refers to the degree to which slope directly affects a systems ability to function properly. If a specific slope is required for a given technology, then management decisions must be made based on specific site constraints. For example, subsurface systems typically require slopes below 10 degrees.

Scoring Method: Systems with no slope requirement receive green scoring, which is reflected in the membrane bioreactor and tidal flow Living Machine®, systems that are constructed to fit a landscape. Systems with flexible slope requirement, such as a vertical flow wetland, receive a yellow scoring, and systems with extensive slope requirement receive a red scoring.

Natural Environment refers to the way a system interacts with the environment and subsequent effects on ecosystem function.

Habitat Creation Potential

Parameter Description: Habitat creation refers to the potential for a system to provide ecosystem services onsite. Ecosystem services are defined as the benefits that nature can provide to households, communities, and economies.

Scoring Method: A system receives green scoring if additional habitat for flora or fauna is generated. A system receives a yellow scoring if a neutral impact on habitat is generated, and a red scoring if habitat is impacted negatively.

Social

The social section describes potential outcomes associated with system implementation that could affect the surrounding community. The social category is divided into four subcategories: Aesthetic, Educational Opportunity, Ownership and Participation, and Quality of Life. The subcategories are further divided into individual parameters.

Aesthetic refers to the sensory impacts of systems, including visual aesthetic, odor, and noise generation.

Visual

Parameter Description: This refers to the ability of a system to affect the visual aesthetic of a site.

Scoring Method: A system receives a green scoring if it improves the visual aesthetic of a site. A system receives a yellow scoring if it has a neutral impact on the visual aesthetic of a site, where there is no visual impact caused by a system. Red scorings reflect systems that negatively impact a site's appearance.

Odor

Parameter Description: Some systems are characterized by having increased likelihood of odor associated with treatment. Depending on the process utilized, odor is minimal.

Scoring Method: Systems receive a green scoring if no odor is associated with treatment. Yellow scoring is assigned to systems that have the potential for seasonal odor generation, and red scoring is assigned to systems that have an increased potential for odor due to high organic loading.

Noise

Parameter Description: Some systems generate noise during the treatment process. Generally, passive systems do not generate as much noise as activated sludge systems, which utilize aeration, do.

Scoring Method: A system receives a green scoring if no noise is generated during treatment. A system receives a yellow scoring if minimal noise is generated during treatment, and a red scoring if treatment generates significant noise.

Educational Opportunity

Parameter Description: This refers to the ability of a system to provide community education opportunities. For example, wetland systems have been used to explain wastewater treatment processes to the general public, while other systems, like leachfields, whose primary treatment methods are subsurface, do not provide that opportunity.

Scoring Method: A system receives a green scoring if it generates education potential for community members and the general public and a red scoring if it does not. For this parameter, no yellow scoring is conferred.

Owner Supervision Requirements

Parameter Description: This refers to the amount of supervision required by owners of systems. As a system increases in complexity, ownership awareness increases.

Scoring Method: A green scoring reflects systems where minimal owner supervision is required, as is the case with a leachfield. As systems become more complex, such as mound systems, they receive a yellow scoring due to more frequent monitoring and maintenance is requirements. A system receives a red scoring if it requires extensive owner supervision as well as an external operator to ensure function.

Quality of life refers to the influence on the wellbeing of community members in terms of health, in particular by considering the risk of vector contact.

Risk of Vector Contact

Parameter Description: This refers to the chance for humans to come in contact with disease vectors associated with wastewater, such as mosquitoes. Generally, properly functioning subsurface treatment have no risk for vector contact, while systems utilizing above surface processes, like wetlands, may contain some risk for vector contact.

Scoring Method: Systems receive a green scoring if no risk of vector contact exists with the exception of system malfunction. Systems receive a yellow scoring if minimal risk of vector contact is associated with system function. Systems with an increased risk of vector contact receive a red scoring.

Scoring Assumptions

Scoring of technologies by assessment criteria is represented through the stoplight scoring system described in the methodologies. Some general assumptions within the matrix are listed below:

- Performance of evapotranspiration systems is similar to subsurface horizontal wetlands.
- Vertical flow wetlands fundamentally only differ from recirculating filters because of the addition of vegetation to the system (City and County of San Francisco, 2009). In the absence of sufficient data from literature, we assume these systems share similar attributes evaluated within the matrix.
- For permitting, all systems are assumed to have flows less than 20,000 GPD, which serve approximately 400 people or less.
- Biosolids generation and disposal frequency are similar for each system.
- Liability and Insurance are not considered in our analysis. However, this may be an important consideration for end users considering implementing these technologies. The burden of liability is frequently an issue of concern, especially in cluster systems that support multiple units.

Technology Categorization by Functional Process Utilized

We categorized onsite wastewater technologies incorporated into the matrix based on processes utilized for treatment (Figure 3.2.3). The category headings chosen include

Subsurface Treatment Systems, Constructed Wetlands, and Prefabricated and Modular Systems. The results for technology categorization by functional process utilized are presented below. For complete technology descriptions see Appendix C.

Systems were chosen to represent a broad spectrum of available and widely accepted technologies appropriate for the Santa Barbara region. This list is not meant to be exhaustive and is not representative of all available technologies. Systems not included in the matrix were eliminated based on a variety of factors. In particular, systems in embryonic stages of development were not included, as well as systems that are not widely available for use in Santa Barbara County.

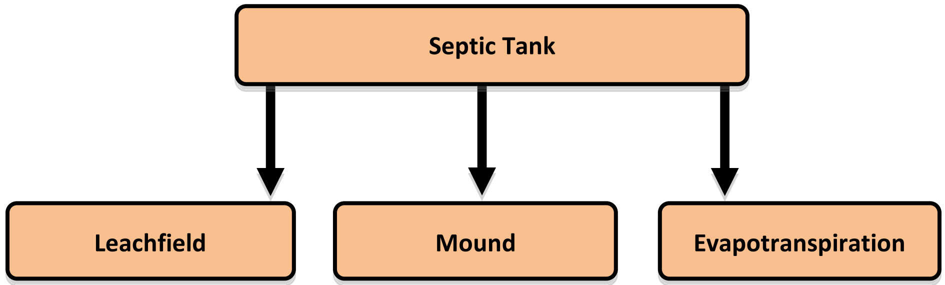
Figure 3.2.3: Technology Grouping by Functional Process Utilized

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Recirculating Filters		Membrane Bioreactors	Activated Sludge Systems
							Sand or gravel	Advanced Media		

Subsurface Treatment

Subsurface treatment is characterized by primary treated effluent that is discharged into a subsurface soil structure, where physical and biological treatment process occurs. This category is indicated by an orange color fill in the matrix. The treatment trains for the different subsurface treatment systems are shown in Figure 3.2.4. All technologies listed below are included in this categorization.

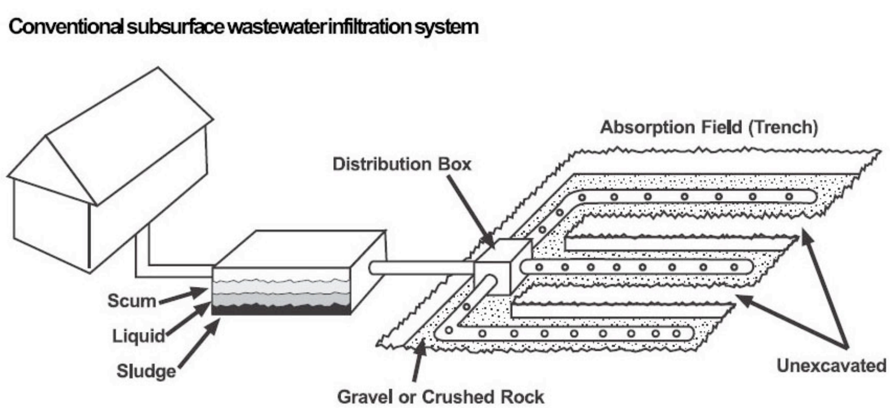
Figure 3.2.4: Treatment Trains of Subsurface Treatment Systems



Leachfield

This treatment utilizes slow rate infiltration into the subsurface zone where biological and physical filtration occurs via soil media (U.S. EPA, 2002[a]; Lesikar, 1999). Effluent from the septic tank is distributed through a drainage network of pipes into the soil where it percolates through a media (typically native soil or otherwise imported material) (Figure 3.2.5). Contaminants are transformed and assimilated before the water recharges the ground water; the rate of filtration is dependent on characteristic percolation rates of the media and soil (Tyler, 2001). This system is typically sought in situations where open space is not a limiting factor.

Figure 3.2.5: Leachfield System Diagram

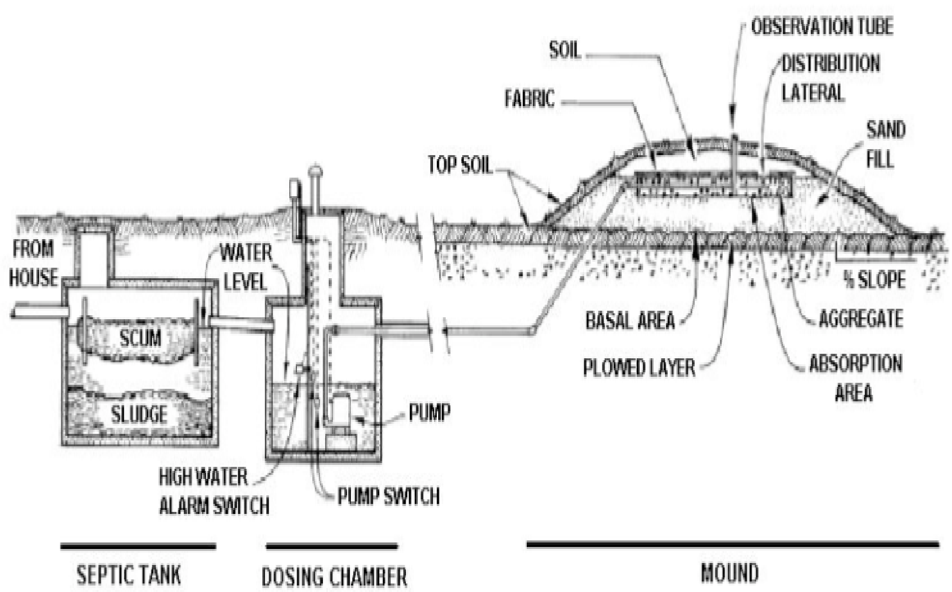


Source: Inspectapedia, 2012.

Mound System

This treatment utilizes slow rate infiltration into a constructed mound structure, typically composed of sand fill or excavated native soil (U.S. EPA, 2002[a]; Environmental Technology Initiative, 1998[b]; U.S. EPA 2000[d]). This treatment includes biological and physical filtration via the mound media. Effluent flows into a dosing chamber where the primary treated water is pumped to the mound system for dispersal and secondary treatment (Figure 3.2.6). Contaminants are reduced and eliminated before the water recharges the ground water; the rate of filtration is dependent on characteristic percolation rates of the media and soil (Tyler, 1998). This system is usually sought in situations of high ground water levels.

Figure 3.2.6: Mound System Diagram

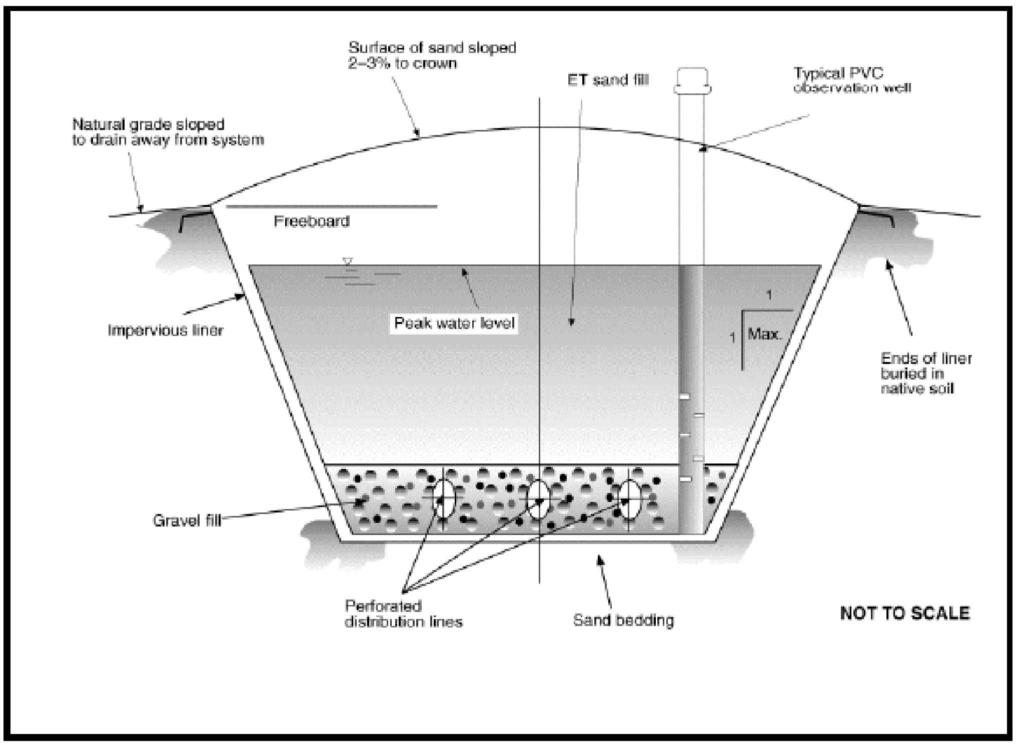


Source: Converse, J. C. and Tyler E. J., 1987

Evapotranspiration

This treatment utilizes the process of evaporation and plant transpiration in the treatment process, offering an alternative to conventional soil treatment (U.S. EPA, 2000[b]; U.S. EPA, 2002[a]). Effluent from primary treatment is distributed below surface in sand bedding, atop an impermeable surface (typically a liner) (Figure 3.2.7). Water levels within the evapotranspiration bed are maintained at a suitable level, with the use of an observation well to ensure satisfactory water levels. This is specifically sought in situations where native soil properties are inappropriate for infiltration or ground water levels are too high (U.S. EPA, 2000[b]).

Figure 3.2.7: Evapotranspiration System Diagram



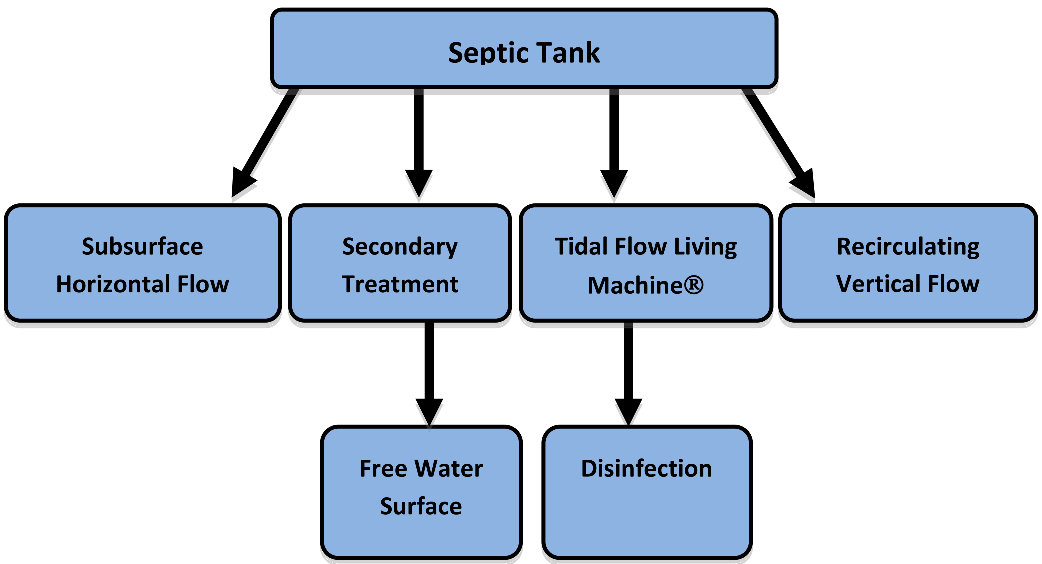
Source: copyright © Water Environment Federation, reprinted with permission, 1999.

Source: U.S. EPA, 2002[a]

Constructed Wetlands

Constructed wetland treatment is characterized by utilizing passive physical and biological treatment processes carried out by natural processes. A blue color fill indicates this category in the matrix. The treatment trains for the different subsurface treatment systems are shown in Figure 3.2.8. All technologies listed below are included in this categorization.

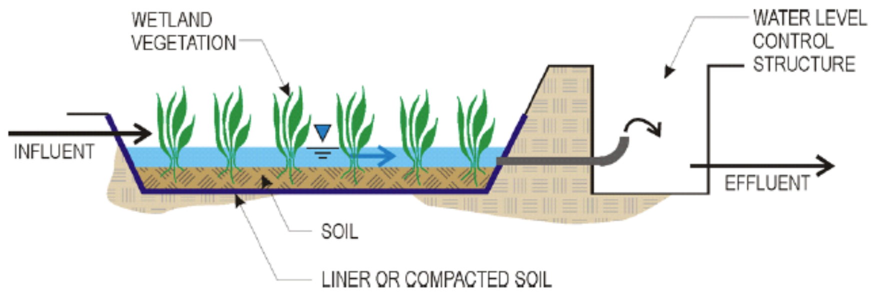
Figure 3.2.8: Treatment Trains of Constructed Wetland Treatment Systems



Free Water Surface Wetlands

Free water surface (FWS) wetlands are natural wastewater treatment systems designed such that the water surface is exposed to the atmosphere (U.S. EPA, 2000)[c]. Wastewater in these systems flows over a soil surface with wetland plant species that encourages high levels microbiological activity, which allows for effective biological treatment (Figure 3.2.9).

Figure 3.2.9: FWS Wetlands System Diagram

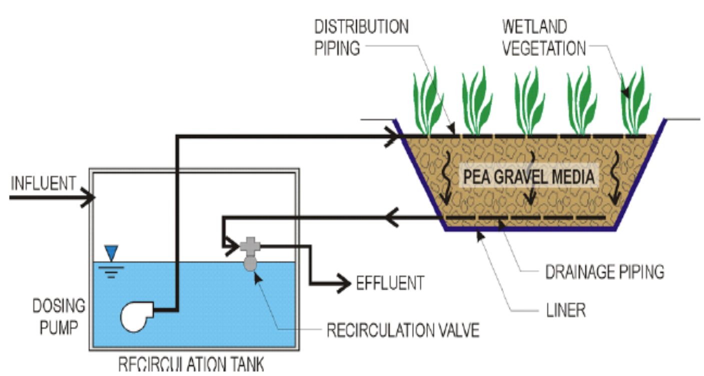


Source: City and County of San Francisco, 2009

Recirculating Vertical Flow Wetlands

Recirculating vertical flow (VF) wetlands are natural wastewater treatment systems that combine the functionality of pre-fabricated sand and gravel filters with microbiologically active soil surface and wetland plant species (Figure 3.2.10). These systems encourage high levels of physical and biological treatment of wastewater through multiple rounds of physical vertical filtration, combined with high rates of biological activity (City and County of San Francisco, 2009).

Figure 3.2.10: Recirculating VF Wetlands System Diagram

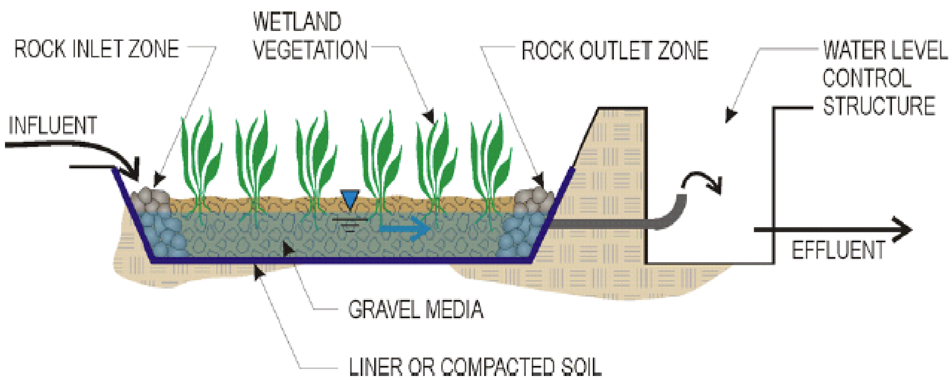


Source: City and County of San Francisco, 2009

Horizontal Subsurface Flow

Horizontal subsurface flow (HSSF) wetlands are a natural wastewater treatment system where wastewater flows horizontally through a microbiologically active soil with wetland plant species (Figure 3.2.11). These systems physically and biologically treat wastewater through a single round of horizontal filtration combined with metabolic activity of microbiological organisms (U.S. EPA. 2000)[e].

Figure 3.2.11: HSSF Wetlands System Diagram

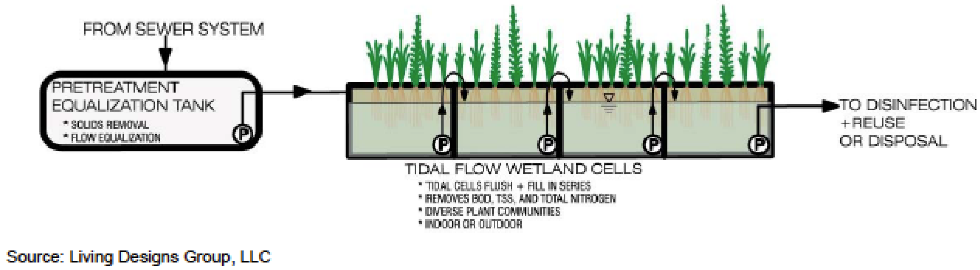


Source: City and County of San Francisco, 2009

Tidal Flow Living Machine®

The tidal flow Living Machine® is a proprietary natural treatment system developed by Worrell Water technologies. These systems treat wastewater by manipulating various biological processes through multiple wetland cells that emulate natural tidal flows. Tidal flows are simulated through multiple fill and drain cycles of cells that promote biological treatment through wetland plant species and metabolism of microbiological organisms (Worrel Water, 2007). Because these systems incorporate drain and fill cycles, they use both aerobic and anaerobic conditions, thus promoting preliminary nitrification, followed by denitrification. A schematic of this system is shown in Figure 3.2.12.

Figure 3.2.12: Tidal Flow Wetlands System Diagram

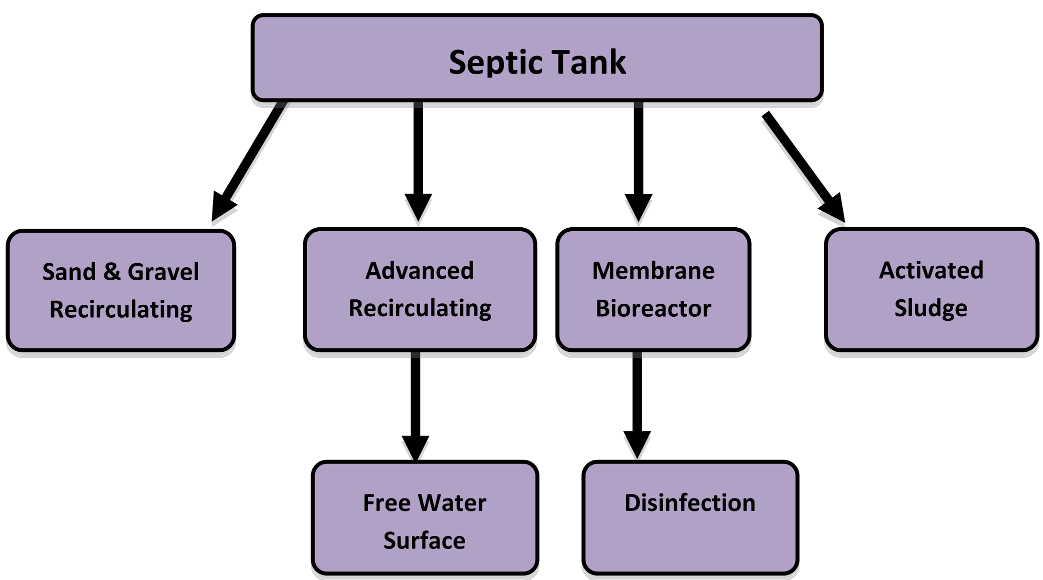


Source: City and County of San Francisco, 2009

Prefabricated and Modular Systems

Prefabricated and modular systems include engineered box systems, which perform treatment through biological, physical, and chemical processes in a tightly controlled environment. This category is indicated in the matrix by a purple color fill. The treatment trains for the different subsurface treatment systems are shown in Figure 3.2.13. All technologies listed below are included in this categorization.

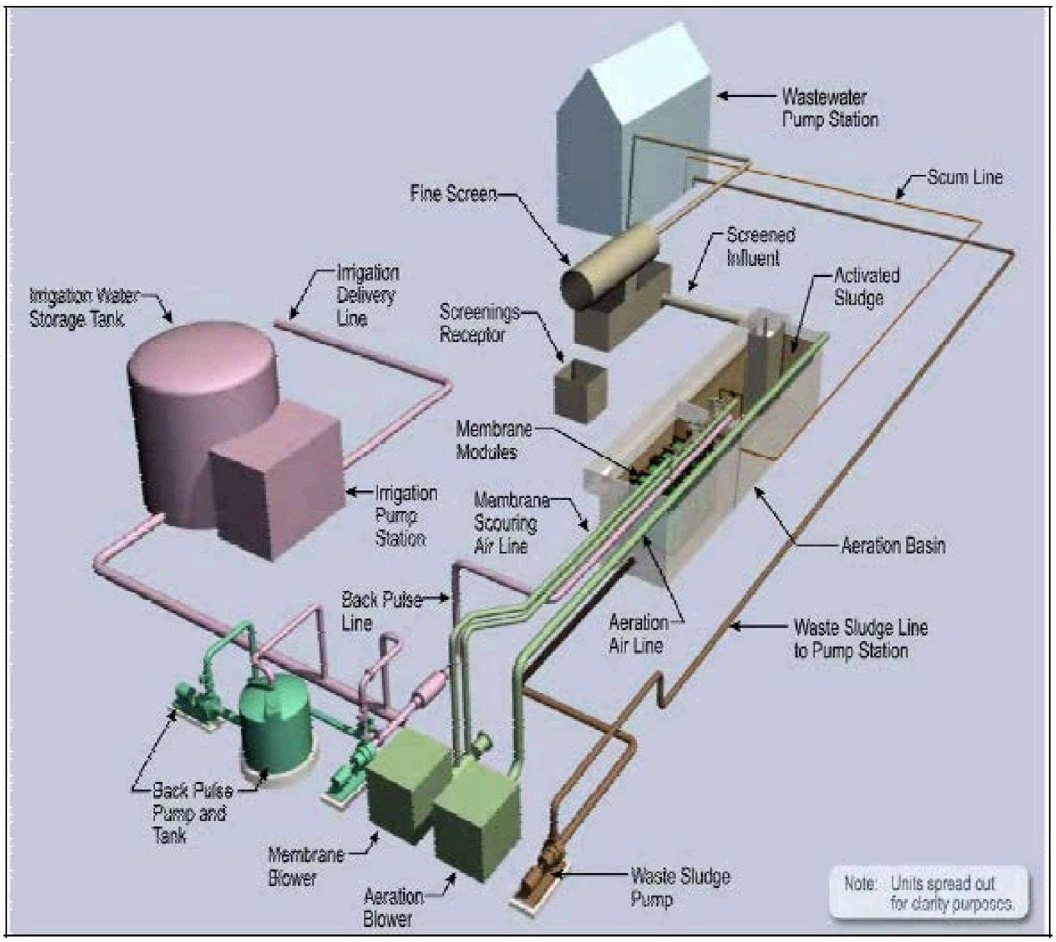
Figure 3.2.13: Treatment Trains of Prefabricated and Modular Systems



Membrane Bioreactor

Membrane bioreactors (MBR) are characterized by a suspended growth activated sludge process similar to conventional activated sludge systems, with the addition of a membrane filter to separate and confine solid particles as water flows through. The MBR system uses a cross-flow process that prevents accumulation of solid particles on the membrane, and allows for them to be collected for recovery or disposal (U.S. EPA, 2007)[a]. Through this highly mechanized process, reliably high quality effluent is produced. An example is shown in Figure 3.2.14.

Figure 3.2.14: MBR System Diagram

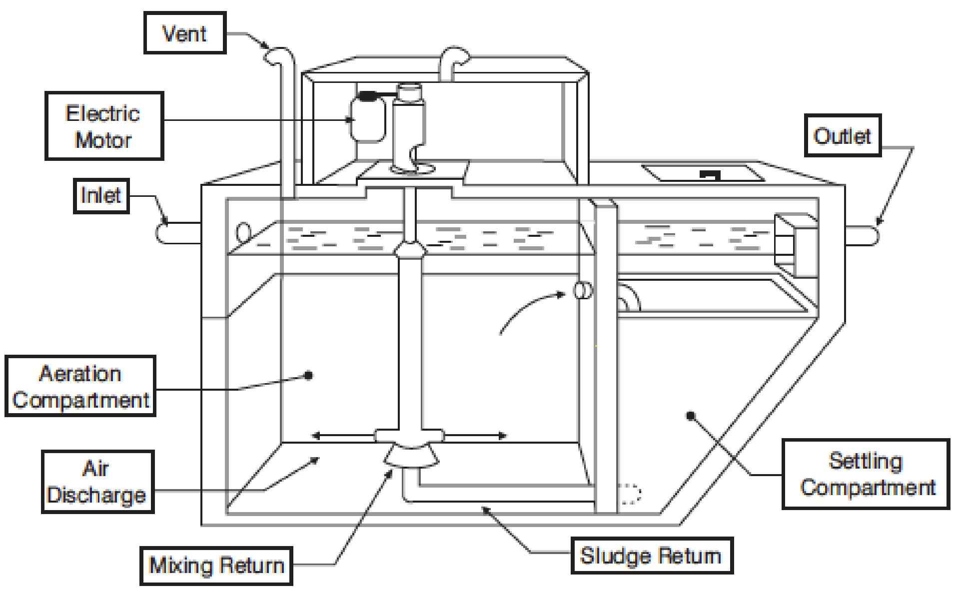


Source: City and County of San Francisco, 2009

Activated Sludge

Activated sludge systems utilize an aerobic suspended-growth microbial process to degrade organic matters as well as some inorganic compounds (U.S. EPA, 2002)[a]. Biomass generated through this process is settled out through a secondary clarifying process. A basic activated sludge system consists of an aeration tank and a clarifier, although some systems incorporate modifications to enhance treatment (U.S. EPA, 2002)[a]. An example is shown in Figure 3.2.15.

Figure 3.2.15: Activated Sludge System Diagram



Source: U.S. EPA, 2002[a]

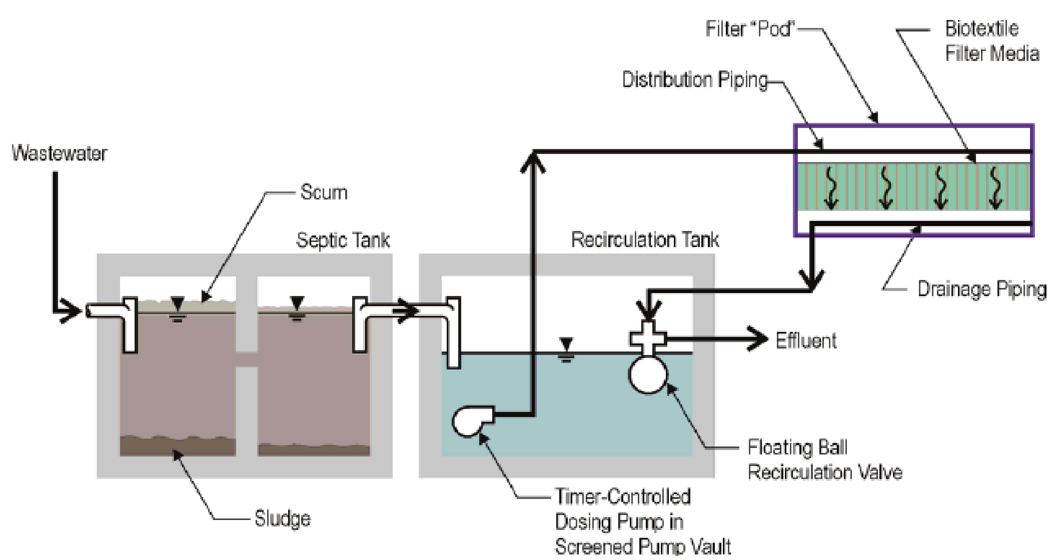
Sand and Gravel Recirculating Filter

Sand and gravel recirculating filters "are essentially aerobic fixed film bioreactors" similar to activated sludge or MBR systems (U.S. EPA, 2002)[a]. These systems contain a sand or gravel filter medium, typically 2 feet in depth, which is dosed with septic tank effluent (National Small Flows Clearinghouse, 1998)[b]. Dissolved pollutants sorb to media while suspended solids are removed via sedimentation and straining processes (U.S. EPA, 2002)[a]. Generally, the dosing process is managed via automated timers and control panels. Filtrate is then collected into "underdrains" where effluent may be disinfected further or discharged following requisite guidelines (National Small Flows Clearinghouse, 1998). An example is shown in Figure 3.2.16.

Advanced Media Recirculating Filter

Advanced media filters use essentially the same processes as sand and gravel recirculating filters. The main benefit of advanced media filters exists in the form of increased hydraulic loading capabilities and improved treatment potential of specific pollutants (City and County of San Francisco, 2009). This translates to a reduced footprint in terms of system size. Advanced medias may include biotextiles, peat, shale, glass, crushed brick or other engineered materials (Tchobanoglous et al., 2002).

Figure 3.2.16: Recirculating Filter System Diagram



Source: City and County of San Francisco, 2009

Results

In this section we present the results for each technology scoring based on the 21 criteria within the economic, environmental, and social valuation categories.

Economics

The details of the results of the Economics section of the matrix are presented below, as well as specific valuation subcategories and individual parameters. This section of the matrix values cost considerations, which are important for planners and architects in their determination of appropriate systems given financial constraints.

Initial Capital

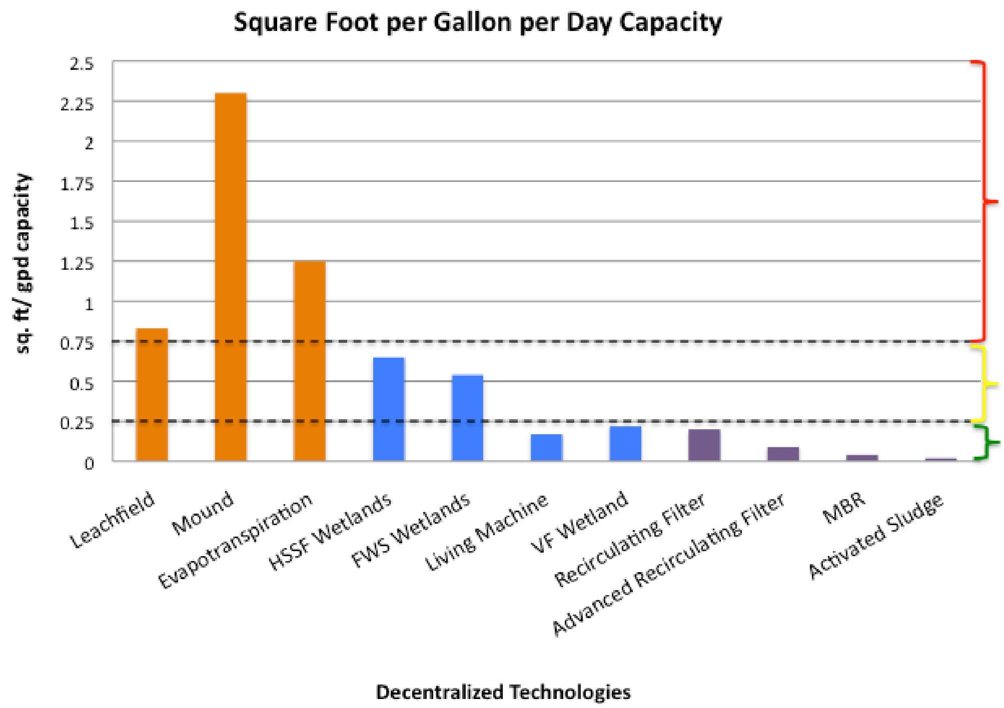
This includes results for land requirements and construction costs.

Land Requirement

We calculated the Land Requirement parameter by determining the square foot per GPD utilized by each system. These estimates were extrapolated from information found in literature. Results for land use estimations are summarized above in Figure 3.2.17.

All of the Prefabricated and Modular systems received a green scoring due to their small land use footprints of less than 0.25 square feet per GPD treatment capacity. Living Machine® and VF Wetlands also received a green scoring due to small land use footprint. HSSF an FWS Wetlands received a yellow scoring due to their intermediate land use footprint of greater than 0.25 square feet per GPD and smaller than 0.75 square feet per GPD. Not surprisingly, all Subsurface Treatment systems received a red scoring due to their high land use footprint. Subsurface treatment requires effluent to be infiltrated into soil for biological and physical treatment, which requires extensive land to ensure that hydraulic overloading does not occur.

Figure 3.2.17: Square ft. per GPD Treatment Capacity by System



Note: The colored brackets on the right-hand side of the figure show the scoring that was awarded, in accordance with the stoplight method.

Construction Costs

Scorings for Construction Costs are summarized in Figure 3.2.18.

Leachfield systems were the only systems to receive a green scoring. This is due to minimal costs associated with constructing absorption field trenches (Tchobanoglous, et al., 2002). The Living Machine® and MBR systems received a red scoring due to expected increased construction cost associated with proprietary pricing systems and increased cost for engineered box systems (U.S. EPA, 2007[a]; U.S. EPA 2002[d]). Although these systems may be competitive with conventional centralized systems, their costs are typically higher than other decentralized treatment options utilizing similar processes (U.S. EPA, 2002)[d]. All other systems received a yellow scoring due to intermediate associated costs.

Figure 3.2.18: Construction Cost Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	2	2	2	2	1	2	2	2	1	2

Systems were scored relatively to one another based on quantitative and qualitative information found in literature and through expert opinion. Capturing exact cost information was problematic due to issues with economies of scale, a lack of comprehensive academic and professional literature and continuity within literature regarding decentralized systems, as well as regional factors and fluctuations in markets for construction materials. Attempts to quantify cost using data from a variety of sources were unsuccessful and produced results that were inconsistent with reality. Results from this analysis can be found in Appendix E. Due to the inability to quantify costs, we used an evidential reasoning approach to compare systems to one another in order to include qualitative understandings of system cost expectations.

Operation and Maintenance

This includes materials, energy requirements and operational labor.

Materials

Scorings for Materials cost are summarized in Figure 3.2.19 below.

Figure 3.2.19: Materials Cost Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	3	3	3	3	1	2	2	2	1	2

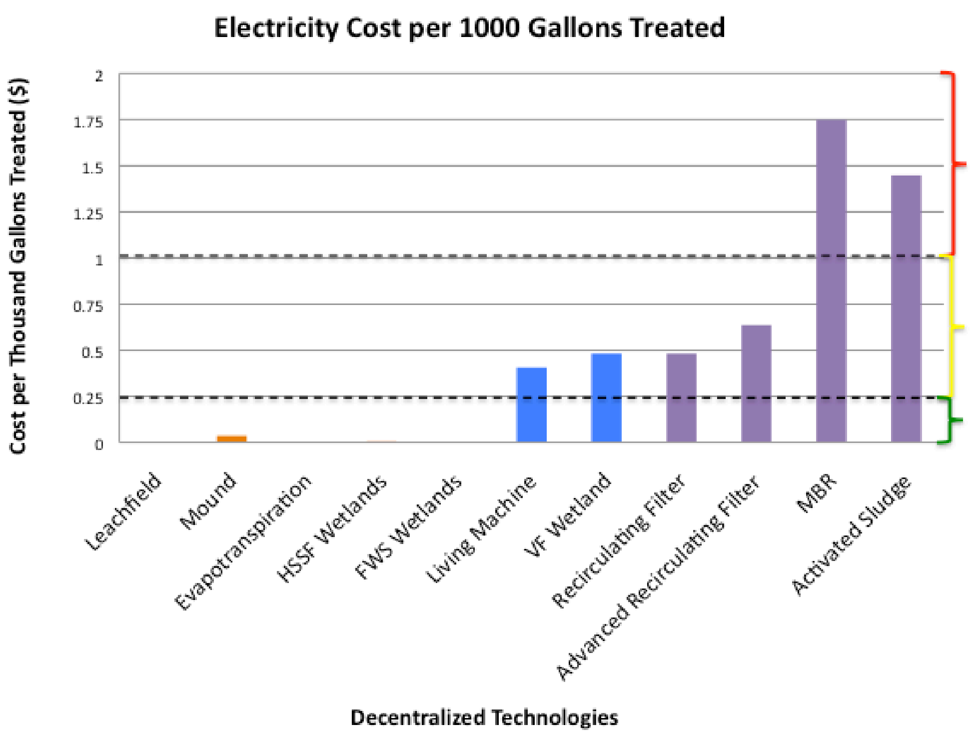
Subsurface Treatment systems as well as HSSF Wetlands and FWS Wetlands received a green scoring due to requiring minimal materials for maintenance of systems. However, it is important to note that wetlands systems may periodically require maintenance of vegetation to ensure adequate function (Wallace, 2006). Recirculating filters require some routine maintenance to be performed to ensure proper functioning, including "monitoring influent and effluent, inspecting dosing equipment and maintenance of filter surfaces" as well as maintaining the vegetation in the case of VF Wetlands (National Small Flows Clearinghouse, 1998). Activated Sludge systems require monitoring of blowers and pumps, maintenance of mechanical equipment controlling aeration and sludge return, and periodic inspection of the clarifier and removal of biosolids (U.S. EPA, 2000)[a]. These systems received a yellow scoring. The Living Machine® and MBR systems received a red scoring due to increased expected materials cost associated with high costs for membrane replacement in MBR systems and filter media and chemicals for disinfection for the Living Machine® (U.S. EPA 2007[a]; U.S. EPA, 2002[b]).

Scorings for material costs were generated using a similar process to construction costs. Attempts to calculate exact material costs could not produce statistically significant results. Similar trends in the existence and types of data available influenced the choice to use an evidential reasoning approach to score systems relative to one another using available qualitative and quantitative data.

Energy Requirements

We calculated energy requirements by determining the cost per 1000 gallons treated. These estimates were generated from information found in literature. Results for energy requirements by system are summarized in Figure 3.2.20.

Figure 3.2.20: Electricity Required per Thousand Gallons Treated by System



All of the subsurface and wetland systems, except for the Living Machine® received green scoring due to their low energy use. MBR and Activated Sludge systems received a red scoring due to increased energy costs associated with aeration processes (U.S. EPA, 2002)[a]. The Living Machine®, VF Wetlands and Recirculating Filters received a yellow scoring due to intermediate energy. These systems have increased energy requirements compared to other subsurface and wetland treatment systems likely due to mechanical processes associated with piping water through these systems.

Operational Labor

Scorings for Operational Labor are summarized in Figure 3.2.21 below.

Figure 3.2.21: Operational Labor Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	2	3	3	3	1	1	1	1	1	1

Prefabricated and Modular systems, as well as the Living Machine® and VF Wetlands received a red scoring because they require licensed operators to manage systems, due to their increased mechanical complexity and maintenance requirements (U.S. EPA, 2002)[a]. The employment of a licensed operator will increase the operational labor costs associated with maintaining proper system function. Mound systems require increase knowledge and participation by owners, and therefore received a yellow scoring (U.S. EPA, 2002[a]). Leachfield and Evapotranspiration systems, FWS Wetlands, and HSSF Wetlands received a green scoring due to limited owner participation and knowledge required to ensure adequate system function.

Scorings for operational labor costs were generated using a similar process to construction costs. Attempts to calculate exact operational labor costs did not produce statistically significant results and could not capture the breadth of information provided in qualitative assessments of these systems throughout literature. Thus we used an evidential reasoning approach to valuate scorings for the Operational Labor parameter of the matrix.

Regulation

This includes results for current permitting and predicted future permitting

Current Permitting

Scoring for current permitting is based on the permits needed to legally approve the onsite technology. The following assumptions were made for the technologies: the system is allowable under the basin plan; the system is installed within Santa Barbara County unincorporated area; there are no coastal issues involved; the system meets all effluent criteria; and the system is under 20,000 GPD. The Leachfield is an established technology and a system with a flow rate under 2,500 GPD takes approximately 1-2 weeks to be approved by the EHS (P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012). A system that is larger may take up to 6 weeks for approval, involving the RWQCB and SBC EHS (P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012). A Mound system and Evapotranspiration system received a red scoring because a Conditional Use Permit is needed. These systems are defined as alternative technologies (Santa Barbara County Code, 2011). It takes approximately 6 months to receive a permit for these technologies (B. Banks, personal communication, January 3, 2012 and Eric Graham, personal communication, January 4, 2012). The remaining technologies received a red scoring because an individual permit from the RWQCB is required. These scorings are shown in Figure 3.2.22.

Figure 3.2.22: Current Permitting Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	1	1	1	1	1	1	1	1	1	1

These systems are considered experimental and need to be approved on a case-by-case basis. The RQWCB individual permit needs to be approved by the board, thus requiring extra time (D. Lacaro, personal communication, January 24, 2012).

The process on acquiring permits is found in Chapter 3, Section 3.3 Policy Environment in Santa Barbara County.

Predicted Future Permitting

Scoring for predicted future permitting is based on the assumption that the RWQCB will adopt a policy that allows Santa Barbara County to assume authority to regulate and issue permits for onsite treatment systems. The policy is currently being reviewed by the SWRQCB and approval is expected by March 2012. If approved, Santa Barbara County Environmental Health Services will publish guidance to assume this authority. Santa Barbara County Environmental Health Service has a non-public draft to assume authority. The prediction is that the levels of regulation will be the same as those currently in place for alternative technologies as defined by Santa Barbara County. This new process would enable non-alternative technologies to be permitted in approximately 6 weeks. The following assumptions are still in effect: the system is allowable under the basin plan; the system is installed within Santa

Barbara County unincorporated areas; there are no coastal issues involved; the system meets all effluent criteria; and the system is under 20,000 GPD. New scorings, based on these predictions, are shown in Figure 3.2.23.

Figure 3.2.23: Predicted Future Permitting Scoring by System

Subsurface Treatment			**Constructed Wetlands**				**Prefabricated and Modular**			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	1	1	2	2	2	2	2	2	2	2

These predicted changes do not affect the scoring for Leachfield, Mound and Evapotranspiration systems. On the other hand, Constructed Wetland systems and Prefabricated and Modular systems may now receive a yellow scoring, since approval could occur in a 6-week timeframe.

Environmental

Details of the results of the environmental section of the matrix as well as the specific valuation subcategories and individual parameters are outlined below. The purpose of this section is to determine the reliability and quality of typical final effluents of the surveyed treatment technologies given specific site constraints. An additional objective is to assess whether a system's installation will enhance, augment, or remove habitat.

Reliability

We assessed the reliability of systems based on literature ascertaining the ability of the surveyed systems to provide a consistent final effluent of a specified quality. This scoring is shown in Figure 3.2.24.

Figure 3.2.24: Reliability Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Recirculating Filters		Membrane Bioreactors	Activated Sludge Systems
							Sand or gravel	Advanced Media		
1	1	1	2	2	3	3	3	3	3	3

All Prefabricated and Modular systems received a green scoring. These systems are tightly regulated and controlled due to their overall design complexity and are thus able to handle and respond to a large range of flow volumes and wastewater strength without compromising final effluent quality (U.S. EPA.2002)[a]. The Living Machine® and Recirculating Vertical Flow filters also received a green scoring due to their similarly highly controlled treatment processes. In some cases a greenhouse is added to Living Machine® systems in order to ensure adequate functioning in varying weather conditions (U.S. EPA, 2002)[d]. Although the climate in Santa Barbara is very stable and mild, periodic intense rainfall could impact the performance of these systems, in which case greenhouse additions should be considered.

HSSF Wetlands and FWS Wetlands received a yellow scoring. This scoring was based on the highly passive nature of the systems and their exposure to the outdoor environment. HSSF and FWS wetlands are often subject to daily, seasonal, and climatic variations in final effluent quality due to the lack of control on temperature dependent processes (Wallace, 2006). As such, these systems should not be utilized when strict discharge limits are required, unless additional unit processes are used to ensure a specific final effluent quality is achieved.

All the technologies represented in the subsurface category received a red scoring. These systems may be highly sensitive to volume and strength of wastewater due to factors such as system design and average number of residents (Kaplan, 1991). However, it is important to note that these systems can increase their reliability if larger septic tanks and discharge zones are installed. In these cases, there might be a higher upfront construction cost as well as excess capacity that may be underused. The recommendation is that a professional installer be advised in helping to overcome these limitations to ensure system reliability is maximized.

Performance

This includes results for total suspended solids, total nitrogen concentration, biochemical oxygen demand and removal of potential pathogens.

Performance data for all systems was evaluated based on averaging estimates found in literature. These estimates indicate measurements taken at the outfall of the named unit process. Due to the system designs of Leachfield and Mound systems, final effluent concentrations could not be measured traditionally; therefore, water quality assessments for these systems were based on ground water sampling at a distance of five feet below the level at which primary treated effluent was applied to the soil (Crites, 2000).

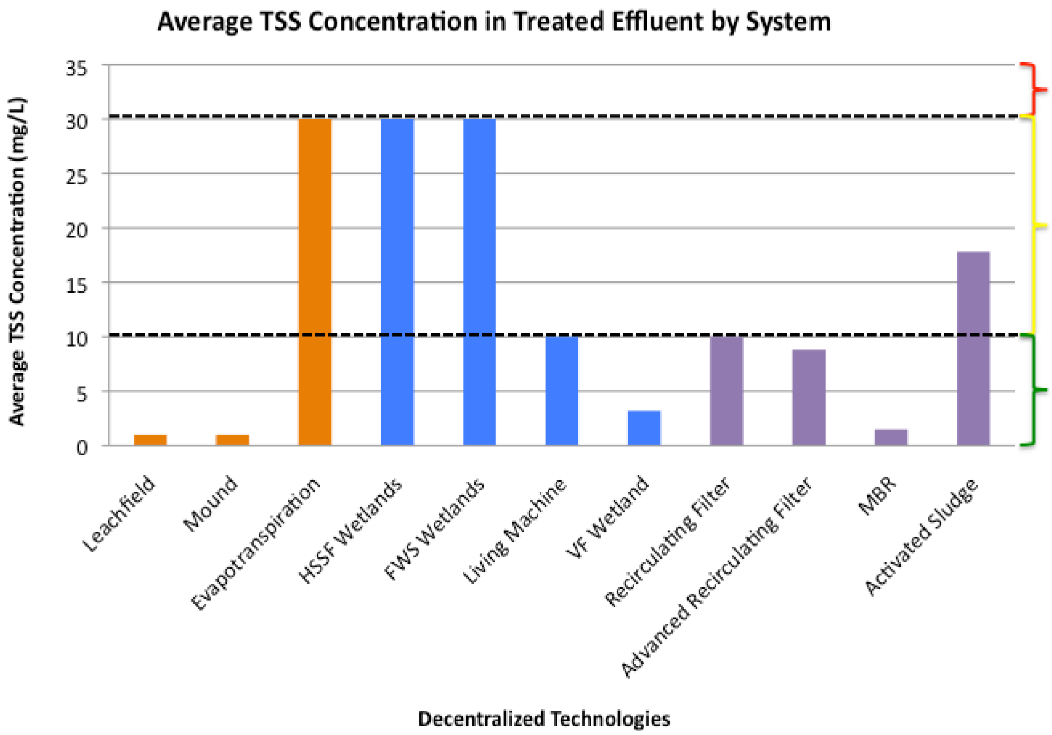
Additionally, log-removal of fecal coliforms was extrapolated from the log difference of influent and effluent MPN/100mL if data was not reported in log-removal. In the case of influent concentrations not being available in a source, an average value of

10^7 MPN/100mL was assumed for influent concentrations of fecal coliform based upon typical wastewater characteristics (Metcalf & Eddy, 2003).

Total Suspended Solids (TSS)

Results for TSS concentration in the treated effluent are shown in Figure 3.2.25.

Figure 3.2.25: TSS Concentration in Treated Effluent by System



Leachfield, Mound, Living Machine®, VF Wetlands, Recirculating Filters, and MBR systems all received a green scoring in the decision matrix for TSS. These systems met or exceeded the 10mg/L criteria established to gain this scoring. It is important to note that unlike other water quality parameters, meeting the established 10 mg/L standard does not qualify these systems for “unrestricted” irrigation reuse under Title 22. Reuse standards for this specific reuse are based on turbidity measured in Nephelometric Turbidity Units (NTU) rather than TSS. Due to varying levels of turbidity for every stream, there is no mechanism to convert TSS to NTU (Metcalf & Eddy, 2003).

Evapotranspiration, HSSF Wetlands, FWS Wetlands, and Advanced Sludge systems were awarded a yellow scoring. These systems were able to consistently meet or exceed the less than or equal to 30mg/L concentration limits under Title 22 reuse standards for restricted irrigation. As mentioned previously in the reliability category, passive wetland systems demonstrate variations in the quality of their final effluent and therefore require additional unit processes to ensure that BOD meets the monitoring requirements outlined under Title 22.

None of the technologies surveyed exceeded the 30mg/L standard established for the TSS valuation category; therefore no systems received a red score.

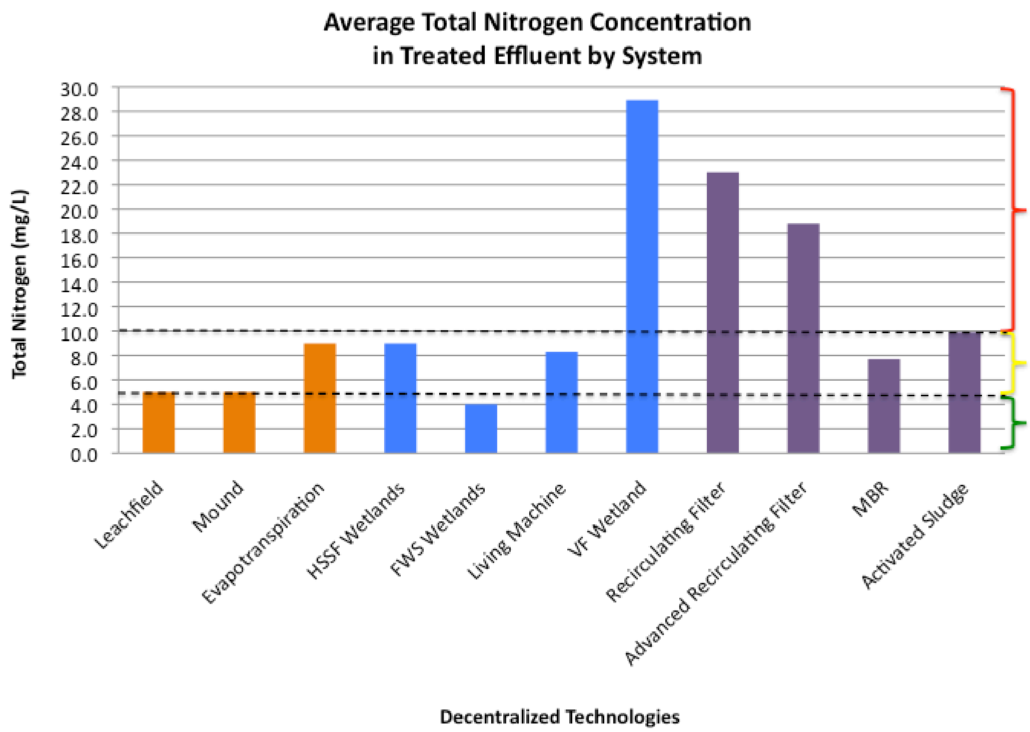
Total Nitrogen Concentration

Results for Total Nitrogen Concentration are summarized in Figure 3.2.26.

Leachfield, Mound, and FWS Wetlands systems received a green scoring, with average final nitrogen concentrations equal to or below the criteria of 5mg/L. Evapotranspiration, HSSF Wetlands, Living Machine®, MBR, and Activated Sludge systems received a yellow scoring, with their treated effluent average falling in the 5-10 mg/L range.

VF Wetlands, Recirculating Filter, and Advanced Media Recirculating filters all received a red scoring, with their average final effluents demonstrating total nitrogen concentrations higher than 10mg/L. The poor results for these systems are not surprising however, as recirculating vertical flow filters promote nitrification through increased oxygen transfer. This increases the amount of nitrate within their final effluent and contributes to the high total nitrogen load (Vymazal, 2010).

Figure 3.2.26: Total Nitrogen Concentration in Treated Effluent by System



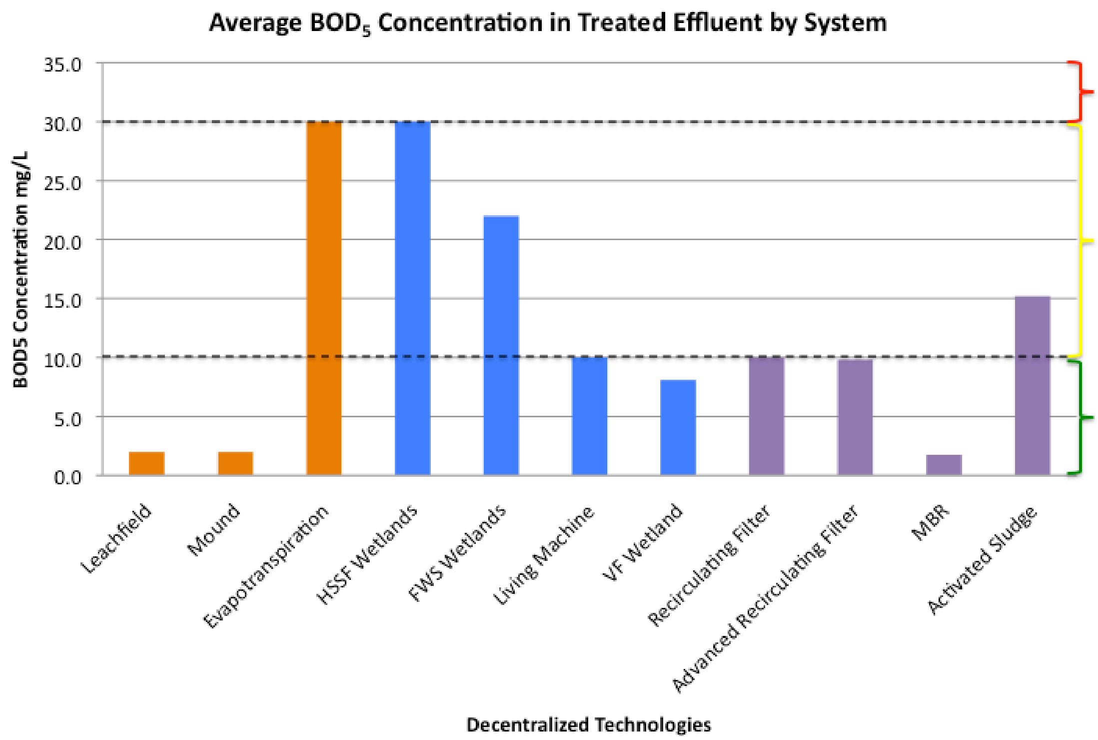
High concentrations of nitrates can be of particular concern in the case of high water tables because of health risks associated with aquifers used as potable water sources. Due to this risk, it is advised that system designers consider additional treatment processes prior to discharge of the final effluent to ensure compliance with local basin plans (Mohr, 1994).

Biochemical Oxygen Demand (BOD)

Results for total BOD are shown in Figure 3.2.27.

Leachfield, Mound, Living Machine®, VF Wetlands, Recirculating and Advanced Recirculating Filters, and MBR systems all received a green scoring in the decision matrix for biochemical oxygen demand measured in BOD_5. These systems would meet the effluent standards of less than or equal to 10mg/L under Title 22 "Unrestricted" reuse standards for irrigation.

Figure 3.2.27: BOD Concentration in Treated Effluent by System



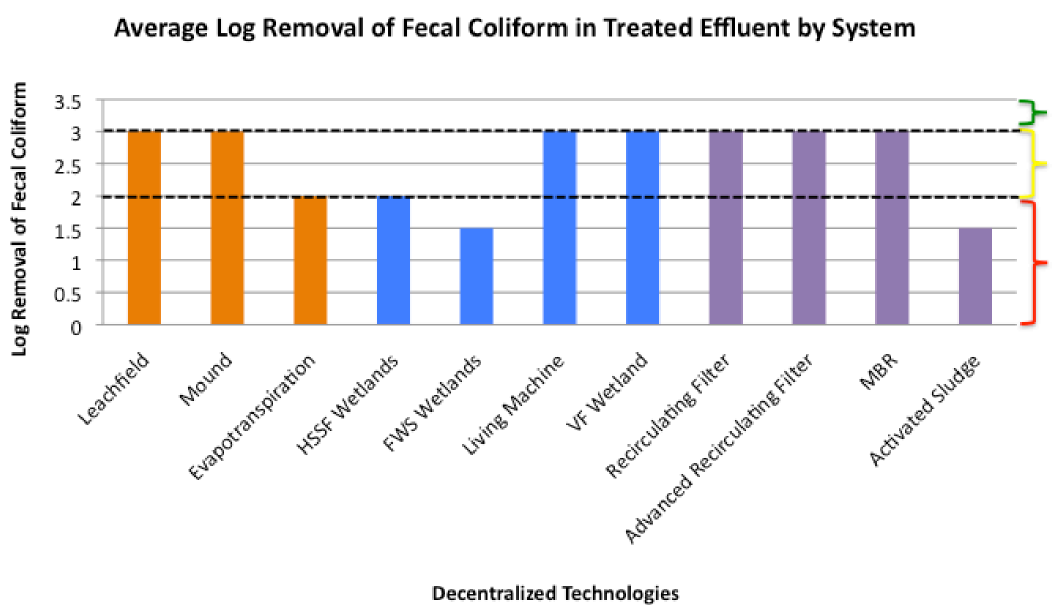
Evapotranspiration, HSSF Wetlands, FWS Wetlands, and Advanced Sludge systems received a yellow scoring. These systems were able to consistently meet or exceed the 30mg/L concentration limits under Title 22 for "Restricted" reuse category. As mentioned previously in the reliability category, passive wetland systems demonstrate variations in the quality of their final effluent and therefore would require additional unit processes to ensure that BOD would meet the monitoring requirements outlined under Title 22.

None of the technologies surveyed exceeded the 30mg/L standard established for the BOD valuation category thus no systems received a red scoring.

Removal of Potential Pathogens

Results for removal of pathogens are shown in Figure 3.2.28.

Figure 3.2.28: Log Removal of Fecal Coliform in Treated Effluent by System



Leachfield, Mound, Living Machine®, VF Wetlands, Recirculating and Advanced Recirculating Filters, and MBR systems all received a green score by achieving at least a 3-log removal of fecal coliform bacteria. In the case of MBR and Living Machine® systems, a greater than 3-log removal was achieved; however, this is not reflected in Figure 3.2.28. For ease of presentation of data, an assumption was made that only that the minimum, 3-log removal, was achieved.

Evapotranspiration systems and HSSF Wetlands averaged a 2-log removal of fecal coliform indicator bacteria so they received a yellow scoring. FWS Wetlands and

Activated sludge systems demonstrated less than average 2-log removal and were given a red scoring.

Removal of potential pathogens can be improved in all systems by utilizing a disinfection unit process such as ultraviolet light or chlorine contactors. When attempting to meet strict discharge or reuse guidelines it is strongly recommended to include these additional processes as part of the final treatment train.

Site Constraints

This includes results for soil and slope requirements.

Soil

Prefabricated and Modular systems as well as Living Machine® systems all received a green score within the matrix for the soil valuation category (Figure 3.2.29).

Figure 3.2.29: Soil Requirement Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
1	1	2	2	2	3	2	3	3	3	3

These systems' self-contained modular characteristics do not depend on soil as part of their treatment process and therefore can be installed on a variety of soil types after appropriate grading has been performed.

Evapotranspiration, HSSF Wetlands, FWS Wetlands, and VF Wetlands all have specific soil requirements. These systems need relatively impermeable soils (high clay) or soil compaction in order to prevent infiltration of wastewater into the subsurface. However, the installation of synthetic liners allows for these systems to circumvent this requirement through a higher upfront construction cost (Kadlec, 2009). They therefore received a yellow scoring.

Leachfield and Mound systems received a red scoring when compared to the other systems surveyed. These systems require soil as part of their treatment process as physical filtration and biological treatment is accomplished when the primary treated wastewater passes through naturally present soil. Soils for these installed systems must demonstrate specific percolation rates in order to allow for effective treatment and prevent surface pooling if percolation rates are exceeded (Crites, 2000).

Slope

Living Machine® and Prefabricated and Modular systems all received the highest or green scoring for slope, as shown in Figure 3.2.30. These systems do not demonstrate any specific grading requirements beyond ensuring a site is level before installation.

Figure 3.2.30: Slope Requirement Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
1	1	1	1	1	3	2	3	3	3	3

VF Wetlands received a yellow scoring for slope. This score was awarded due to the fact that wetland systems are constructed with a specific slope in order to ensure proper flow. Other wetland systems did not receive this score however, because those system types are typically much larger than VF wetlands and therefore require more grading of a site (Kadlec, 2009).

All Subsurface Treatment systems, Horizontal Subsurface Flow and Free Water Surface Wetlands received a red score because they have high grading requirements.

Natural Environment

This includes the results of Habitat Creation Potential.

Habitat Creation Potential

FWS and HSSF Wetlands received a green score (Figure 3.2.31). These systems are able to provide habitat for a wide variety of animals and plants based upon their emulation of natural systems, particularly if these systems are large in size (Kadlec, 2009).

Figure 3.2.31: Habitat Creation Potential Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
2	2	2	3	3	2	2	1	1	1	1

VF Wetlands, Living Machine® and all Subsurface Treatment systems received a yellow score. In the case of VF wetlands and the Living Machine®, these systems are much smaller than other wetland systems, which limits the extent of recruitment that these engineered ecosystems are able to achieve. Evapotranspiration systems are also limited in the amount of habitat potential they are able to generate. While not subject to the issues of size as VF Wetlands and the Living Machine®, evapotranspiration systems do not encourage the same level of biodiversity that other wetland systems provide, even though they do provide habitat for introduced plant communities (North Arizona University, 1999; U.S. EPA, 2002[a]).

Social

This section details the results of the social section of the matrix as well as the specific valuation subcategories and individual parameters.

Aesthetic

This includes results from Visual, Odor and Noise parameters.

Visual

The scorings for expected impacts on visual aesthetic are displayed in Figure 3.2.32.

Figure 3.2.32: Visual Impact Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
2	1	3	3	3	3	3	2	2	1	1

The determinations of these values is based on the assumption that systems featuring visible vegetation will positively impact visual aesthetics, while above grade box systems will have negative impacts. Systems without above ground components are assumed to have no effect on visual aesthetic. Using the scoring parameters in Appendix E Supplement 2, we determined a system's impact on the appearance of the landscape.

Constructed Wetlands as well as Evapotranspiration systems received a green scoring due to the incorporation of above grade vegetation components. Activated Sludge and MBR systems received a red scoring due to their closed-box structure. Although these systems may be placed below grade, when they are placed above ground they create a visual obstruction to the natural landscape. Yellow scorings represent systems that offer neither an enhancement nor obstruction to the view of the natural landscape; this valuation includes Leachfield systems and Recirculating Filters, which operate below the surface.

Odor

The scorings for odor are displayed in Figure 3.2.33.

Figure 3.2.33: Potential Odor Generation Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	3	2	3	2	3	3	3	3	3	1

Incorporating the scoring parameters in Appendix E Supplement 2, our results factor in the potential for odor in each systems process.

Systems with no associated odors received a green scoring. Yellow scoring reflects a seasonal potential for the emission of offensive odors due to changes in temperature, resulting in lowered biological treatment processes. Evapotranspiration and FWS Wetland systems, which are sensitive to high loading rates and temperature fluctuations, received this scoring (WERF, 2010)[b]. A red scoring reflects a high chance of odor due to periods of high organic loading. Activated Sludge may produce unwanted odors in time of high organic loading (U.S. EPA, 2002) [a].

Noise

The scorings for noise are displayed in Figure 3.2.34. This evaluation assumes that passive systems, requiring minimal or no energy, do not generate unwanted noise.

Figure 3.2.34: Potential Noise Generation Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	3	3	3	3	3	3	3	3	3	1

A green scoring was awarded to systems that are not expected to generate noise. Membrane Bioreactors, requiring high amounts of energy, received a green scoring because of their sound eliminating packaging structure (Chapman et al., 2001 pp. 3).

Red scorings reflect systems that have the potential to generate high noise levels. Activated Sludge systems are the only system receiving this scoring because of the increased noise production associated with use of compressors and blowers for aeration (WERF, 2010)[b]. Noise generation is an important consideration when determining appropriate systems for onsite or small community treatment options.

Quality of life

This includes results of the Education, Owner Supervision Requirements, and Risk of Vector Contact parameters.

Education

The scorings for education potential are displayed in Figure 3.2.35.

Figure 3.2.35: Education Generation Potential Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
1	1	3	3	3	3	3	1	1	1	1

While education can be accomplished for any system with an appropriate outreach program, this valuation assumes that natural systems will offer increased educational opportunities because of ease of accessibility (Rocky Mountain Institute, 2004).

Green scoring was awarded to technologies that offer educational opportunities, and red scoring for systems that do not. Treatments that function below surface, or within a contained unit do not allow easy access to view system operation. This resulted in red scorings for Leachfield, Mound, and all Prefabricated and Modular systems. Evapotranspiration systems and Constructed Wetlands offer increased educational benefits due to visible components and ease of access for community members. The potential for community education offers increased awareness to the various treatment processes utilized to clean wastewater.

Owner Supervision Requirements

The scoring for ownership supervision requirements are displayed Figure 3.2.36.

Figure 3.2.36: Ownership Supervision Requirements Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	2	3	3	3	1	1	1	1	1	1

The valuations of this category are dependent upon the amount of owner participation and awareness that is required for each system. In some cases a licensed operator is required to monitor and maintain systems to ensure adequate function.

Systems that require minimal supervision received a green score. For example, Leachfield systems only require periodic pumping every three to five years, and minimal oversight otherwise (U.S. EPA, 2002)[a]. A red score has been awarded to systems that require a licensed operator to function properly. More mechanically complex systems, such as the Prefabricated and Modular systems will require this.

The Living Machine® and VF Wetlands also contain increased mechanical components, which require maintenance by a licensed operator. These technologies also received a red score. A yellow score, which was given only to the Mound system, requires that an owner be informed, and perform increased monitoring and maintenance activities (U.S. EPA, 2002)[a]. Wetland systems that include minimal operational controls, i.e. the HSSF and FWS systems, only require periodic visits and maintenance of the plant habitat (WERF, 2010[b]; Garcia-Perez et al., 2008).

Risk of Vector Contact

The scorings for vector contact risk are displayed in Figure 3.2.37.

Figure 3.2.37: Risk of Vector Contact Scoring by System

Subsurface Treatment			Constructed Wetlands				Prefabricated and Modular			
							Recirculating Filters			
Leach field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow (VF)	Sand or gravel	Advanced Media	Membrane Bioreactors	Activated Sludge Systems
3	3	2	3	2	3	2	2	2	3	2

As an important safety component to public health, this category refers to the chance for humans to come in contact with disease vectors associated with wastewater. Generally, properly functioning subsurface treatment will have no risk for vector contact, while systems utilizing above surface processes, like wetlands, may contain some risk (Tchobanoglous, 2002; U.S. EPA, 2002[a]; WERF, 2010[c]).

A green score indicates that there is no chance of vector contact. Systems that utilize subsurface flow or that keep water from contact with the air received this score. MBR systems for example, which are self contained, do not expose water to the air. A yellow score indicates a minimal risk of vector contact in cases of high flow rates, or prolonged exposure of surface water to the air. Evapotranspiration systems create a risk of vector contact if the vegetation is not regularly maintained by increasing the likelihood of pests such as mosquitoes, which may carry disease vectors (WERF, 2010)[b]. Similarly, FWS Wetlands and other systems that expose water to the surface in their treatment were awarded a yellow score. As a large social concern, systems that pose any risk of vector contact must be installed appropriately to minimize potential human contact with disease vectors.

Conclusions

This section has focused on the findings of the Matrix Decision Support Tool generation process. Some general trends about systems were discerned.

Constructed Wetlands offer a passive low-energy and low-cost treatment system but are subject to increased fluctuations in treatment capabilities. Natural characteristics inherent in wetland systems contribute to an increased social benefit. However, passive systems utilizing natural processes are less tightly controlled, and are subject to more variation in treatment performance due to variations in climate and organic loading.

Prefabricated and Modular systems typically face increased costs in the areas of construction, energy consumption, and operational maintenance and labor. However, these systems achieve consistent high quality effluent. In general, we discerned that more energy intensive systems tend to be more reliable due to tightly controlled unit processes.

Subsurface treatment systems offer cost-effective, low-tech treatment options. However, these systems are subject to high biogeographical constraints, including high land requirements, and specific grading and soil requirements.

Further Research should be conducted to increase the amount of accessible information about decentralized systems. The lack of a comprehensive large-scale database, which incorporates information for smaller systems, increases the difficulty of finding accurate, reliable data about small-scale decentralized systems. Additionally, there is a lack of targeted information for architects, planners, and end users. Furthermore, methods used to analyze various system components and processes should be standardized in order to more effectively cross-reference information about decentralized systems.

3.3 Policy Environment in Santa Barbara County

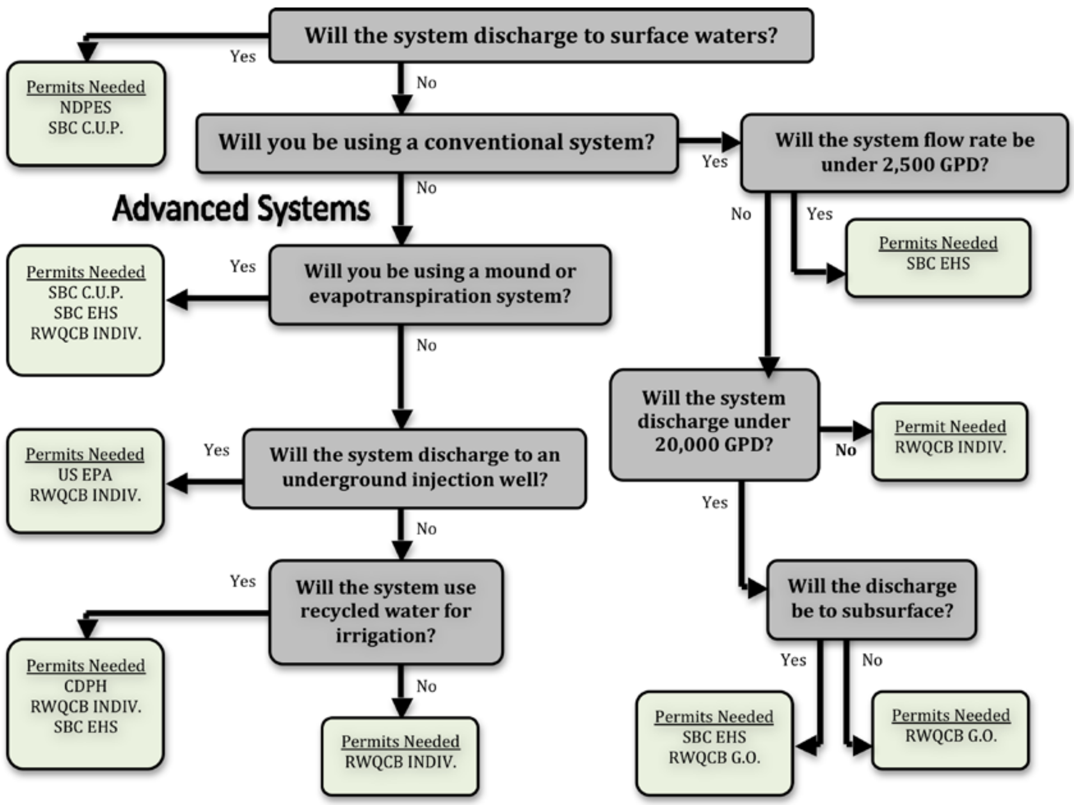
In this section we present the permitting and monitoring requirements for decentralized wastewater treatment systems by outlining the process and the types of permits that may be required. For systems wishing to implement graywater systems, relevant graywater regulations will also have to be followed.

Permitting & Monitoring of Decentralized Systems in Santa Barbara County

The permitting process in Santa Barbara County is not well understood by those seeking a permit (P. Amato, personal communication, November 30, 2011). An onsite wastewater treatment system might need several permits from different agencies or just one agency. For a first time discharger, the process is cumbersome and requires significant time to understand what permits are needed. The flow chart is the first comprehensive mechanism for determining which agency and what type of permits are needed, as outlined in Figure 3.3.1 (Flowchart for the Permitting Process in Santa Barbara County). While this flowchart describes the administrative process for receiving a permit, we recommend discussing the proposed system with RWQCB and Santa Barbara County EHS under the discretionary process (P. Jenzen, personal communication, December 14, 2011). The discretionary process can identify major issues and concerns about the system. This can prevent a discharger from completing the necessary permitting forms, only to have the system rejected. The purpose behind using an advanced system, defined as any system that is not a conventional septic system, is to enable the use of treated water for irrigation. Information on the application process and required forms may be found in Appendix A.

Permits and approval agencies are based on the type of system that is used, the location of the discharge of treated waters, and volume of wastewater that will be treated by the system. All onsite systems are allowable under the basin plan. The systems must comply with basin plan requirements, meet all standards, and not degrade the environment. The flow chart (Figure 3.3.1) is only for unincorporated areas of Santa Barbara County and assumes that no coastal issues are involved.

Figure 3.3.1: Permit Process in Santa Barbara County Unincorporated Areas



Cost and approval times for these permits:

Depending on the type of permit and the agency involved, costs and approval times will vary. These are outlined in Table 3.3.1, which applies to unincorporated areas of Santa Barbara County.

Table 3.3.1: Permit costs and approval times for unincorporated areas of Santa Barbara

	Leach Field	Mound System	Evapotranspiration
Disposal	Sub Surface	Mound System	Evapotranspiration
Agency	SBC EHS	SBC EHS	SBC EHS
Approximate Cost	$544*	$544*	$544*
Approximate Time	1-2 weeks	1-2 weeks	1-2 weeks
Agency	RWQCB General Order Permit	RWQCB Individual Permit	RWQCB Individual Permit
Approximate Cost	$1,389 - $7,447**	$1,389 - $7,447**	$1,389 - $7,447**
Approximate Time	6 weeks	6 months	6 months
Agency	SBC Planning	SBC Planning CUP	SBC Planning CUP
Approximate Cost	$1,677 - $7,034***	Up to $4785	Up to $4785
Approximate Time	30 days	6 months	6 months
Agency	N/A	SBC Planning	SBC Planning
Approximate Cost		$1,677 - $7,034***	$1,677 - $7,034***
Approximate Time		30 days	30 days

	Membrane Bioreactors (MBR)	Activated Sludge Systems	Recirculating Filter (Sand, Gravel or Other)
Disposal	Sub Surface	Sub Surface	Sub Surface
Agency	RWQCB Individual Permit	RWQCB Individual Permit	RWQCB Individual Permit
Approximate Cost	$1,389 - $7,447**	$1,389 - $7,447**	$1,389 - $7,447**
Approximate Time	6 months	6 months	6 months
Agency	SBC Planning	SBC Planning	SBC Planning
Approximate Cost	$1,677 - $7,034***	$1,677 - $7,034***	$1,677 - $7,034***
Approximate Time	30 days	30 days	30 days

Table 3.3.1 (Cont.): Permit costs and approval times for unincorporated areas of Santa Barbara

	Constructed Wetland Free Water Surface (FWS)	**Constructed Wetland Vertical Flow Wetlands (VF)**	**Constructed Wetland Subsurface Horizontal Flow**
Disposal	Land	Land	Sub Surface
Agency Approximate Cost Approximate Time	RWQCB Individual Permit $1,389 - $7,447** 6 months	RWQCB Individual Permit $1,389 - $7,447** 6 months	RWQCB Individual Permit $1,389 - $7,447** 6 months
Agency Approximate Cost Approximate Time	SBC Planning $1,677 - $7,034*** 30 days	SBC Planning $1,677 - $7,034*** 30 days	SBC Planning $1,677 - $7,034*** 30 days

	Tidal Flow Living Machine	**Recycled Water Add this cost and permitting time to technology**
Disposal	Land	Sub Surface
Agency Approximate Cost Approximate Time	RWQCB Individual Permit $1,389 - $7,447** 6 months	CDPH review ~$2,520**** 1 month
Agency Approximate Cost Approximate Time	SBC Planning $1,677 - $7,034*** 30 days	SBC EHS $544* 1-2 weeks

Source:

** Santa Barbara County, 2012*

*** SWRCB, 2011[c]*

****Santa Barbara County, 2011[b]*

***** CDPH, 2011*

Additional information on the approval process for a variety of applicable permits is outlined below.

NPDES Permit

A National Pollutant Discharge Elimination System (NDPES) permit is required for the discharge of pollutants from point sources into surface waters of the United States (U.S. EPA 2007[b]). In California, the U.S. EPA has delegated authority to the RWQCB, who is responsible for issuing a permit (U.S. EPA, 2012)[b]. However, depending on other dischargers to surface waters, a permit may not be available. Decentralized systems should avoid discharging into surface waters if possible to exempt them from the NPDES requirement.

Regional Water Quality Control Board (RWQCB) General Order

The RWQCB is the agency that has primary responsibilities for permitting onsite treatment systems. This permit was created for conventional septic tanks, although other technologies can qualify, and is for discharge to land, including subsurface. The RWQCB will determine if the wastewater disposal will qualify for this type of permit to comply with the Waste Discharge Requirements as outlined in the SWRCB Quality Order No. 97-10-DWQ, which is included in Appendix A-1. This permit takes approximately six weeks for completion. We recommend discussing projects with the RWQCB in the early stages of proposal to determine if the project would fit a general order permit. The estimated annual cost for this permit in 2012 values is between $1,389 and $7,447. The fee is based on the complexity of the system and the threat to water quality. A system that qualifies for a general order permit will fall on the low end of this fee schedule (SWRCB, 2011 and D. Lacaro, personal communication January 24, 2012). Appendices A-2 and A-3 contain the information to complete the application to receive the permit. If systems do not qualify for this general order permit, then a RWQCB permit will be required, which will involve longer approval times.

RWQCB Individual Permit

The approval for this permit is done on a case-by-case basis. The discharger provides data to show that the system is safe and reliable. To receive an individual permit it takes approximately six months because the Board of the RWQCB needs to be involved in the approval. It is estimated that this permit will have an annual cost between $1,389 and $7,447. The fee is based on the complexity of the system and the threat to water quality. A system that qualifies for a general order permit will fall on the high end of this fee schedule (SRWCB, 2011 and D. Lacaro, personal communication January 24, 2012). The individual permit uses the same forms as the general order permit, which are included in Appendices A-2 and A-3. The requirements outlined for a general order permit and an individual permit comply with waste discharge requirements, as outlined below.

Waste Discharge Requirements (WDR)

The State Water Resources Control Board developed the Water Quality Order 97-10 to address waste discharge requirements (WDR) and comply with the California Water Code (CWC) section 13260(a). To qualify, the treatment system must comply with the basin plan and prevent pollution, contamination, or discharge of hazardous waste. The WDR also prohibit unpermitted discharges of waste (SWRCB, 1997).

The potential discharger must provide information about the treatment system including but not limited to the location, facility description, flow, quality of the discharge, soil profile, disposal location, and depth to groundwater to the RWQCB. Also required is approval from other agencies and complete CEQA/NEPA documentation (RWQCB, 1996).

Santa Barbara County (SBC) Planning Permit

The Santa Barbara County (SBC) Planning Department is responsible for approving the construction of the building. The Planning Department will verify if the building has a method to dispose of its wastewater. It takes approximately thirty days to receive a permit and the cost is approximately $1,677 to $7,034. Additionally, the RWQCB and SBC EHS require a completed CEQA document before a permit may be issued (B. Banks, personal communication, January 3, 2011; E. Graham, personal communication, January 4, 2011; Santa Barbara County, 2012). CEQA requirements are outlined below.

California Environmental Quality Act (CEQA)

CEQA evaluates the environmental impacts of a project and is triggered when constructing a new building that may include an onsite treatment system. The Santa Barbara County Environmental Health Service and the Regional Water Quality Control Board review the CEQA document for impacts related to the onsite system.

In order to receive the necessary permits for the construction of an onsite system, CEQA must be fully completed, including the 30-day public comment period (California Code of Regulations, 2007). The lead agency for CEQA for building projects in Santa Barbara County is the Santa Barbara County Planning Department and private projects are subject to County approval. The building planners will be in consultation with the Santa Barbara County Planning Commission throughout the project, who will review the application and determine the appropriate level of CEQA needed. Once determined, the planners will develop the CEQA document (Santa Barbara County, 2008).

Generally, the impacts from an onsite treatment system are consistent with an Initial Study / Negative Declaration. A negative declaration is assigned to projects that may have potential impacts on the environment, but that have proposed revisions or plans that would mitigate or avoid the impacts to a point where there would be no significant effect on the environment (California Code of Regulations, 2007).

However, the environmental effects from the construction and ongoing use of a new building are the overriding concern. These environmental effects are usually larger than those from the onsite system and an initial study/ mitigated negative declaration is consistent for this level of impact. When awarding a mitigated Negative Declaration classification, the premise is that there will be no significant effects from the project (California Code of Regulations, 2007).

Once the planner completes the draft CEQA document, the Santa Barbara County Planning Department will review the document for accuracy. The notice of preparation will be completed and the CEQA document will be placed on public notice for 30 days. Following this, comments will be incorporated and the final CEQA document will be signed if no major deficiencies are commented on. If there are major comments, another public notice period will be required.

If additionally, federal funding is involved, then the project also has to comply with the National Environmental Policy Act (NEPA) documentation. It is unlikely that an onsite septic system would qualify for federal funding.

Santa Barbara County Environmental Health Services (EHS) Permit

The approval of EHS is required for permitting certain onsite systems. The RWQCB has a memorandum of understanding with the EHS to delegate responsibility for the permitting of a septic system with a flow rate of 2,500 GPD or less. For conventional septic systems under 20,000 GPD discharging to sub surface, the EHS needs to be involved in the permitting. It is recommended to discuss any proposed project with the EHS, regardless of the level of the project. A permit from EHS will cost approximately $544 and take one to two months to complete (Santa Barbara County, 2011; P. Jenzen, personal communication, December 14, 2011).

To receive a permit from EHS, the discharger must submit a completed application for individual sewage disposal. The application must include a copy of the soil report. The onsite system must not exceed a 30% slope and drywells may only be used if leach lines are not feasible. The system must also comply with the RWQCB prohibitions. The discharger must supply the designs for the system, executed by a registered engineer, and all building plans. The discharger is also required to pay an hourly fee for the review time of the permit (Santa Barbara County EHS, 2006). Appendices A-4 and A-5 reference the required forms to receive a permit.

SBC Conditional Use Permit (C.U.P.)

The Santa Barbara County Planning Department will require a Minor Conditional Use Permit if the disposal system is considered an "alternative system". Currently only mound and evapotranspiration systems are considered alternative (Santa Barbara County Code, 2011). The C.U.P. is determined on a case-by-case basis. Submittal application information and the forms for a minor C.U.P are referenced in Appendix A.6. The C.U.P. costs up to $4785 and takes around 6 months to complete. It is not recommended to pursue this type of permit (E. Graham, personal communication, January 4, 2011; Santa Barbara County, 2012).

California Department of Public Health (CDPH) Permit

For the use of recycled water for irrigation the CDPH must provide a recommendation to allow this use. Technically this is not a permit, but is part of the WDR requirements outlined by the RWQCB. It takes approximately one month for the CDPH to complete the review and the cost of the permit is approximately $2,520 (CDPH, 1996; CDPH, 2011; K. Souza, personal communication, February, 7, 2012).

U.S. EPA Underground Injection Permit

The U.S. EPA issues a permit for underground injection for the purposes of groundwater recharge. It is unlikely that small domestic onsite treatment system will be used for groundwater recharge and therefore it is unlikely this permit will be required (U.S. EPA, 2007)[b].

The above-mentioned permits apply only to unincorporated parts of Santa Barbara County, where the County has jurisdiction. Within the City, the Cities are primarily responsible for treating wastewater through the existing wastewater treatment plants. Onsite wastewater treatment systems are limited because the California Plumbing Code Section 713.5 mandates that new buildings must hook into a sewer system if such a system is available (California Plumbing Code, 2010). Under section 13281(b)(3) a sewer system is available if the sub-division is within 200 feet of the existing or proposed building (SWRQCB, 2011).

City of Santa Barbara

Most of the City of Santa Barbara is connected to the El Estero Wastewater treatment plant, and only properties located in the hills are not connected to the sewer system. The Building and Safety Department is responsible for the permitting of an onsite wastewater treatment system. The department will examine the soil report and the California Building and Plumbing Code Regulations to determine if the system is allowable. The Department will also verify if the system meets applicable standards, and is responsible for inspections and ensuring that the system is installed correctly. It is estimated that the cost to permit a system by itself will be $600 to $1,000. The described process is for a conventional septic system in the hills of Santa Barbara. No advanced onsite wastewater treatment system was identified for the City of Santa Barbara. It is not cost prohibitive to use an onsite system when a sewer line is directly available. The Planning Department is responsible for the design review of the building structure (S. Routher, personal communication, January 18, 2012).

City of Goleta

The City of Goleta is connected to the Goleta Wastewater Treatment Plant, and the general plan requires a connection to the Goleta Sanitation District. Due to the layout of the City, it is extremely unlikely that an onsite wastewater treatment system will be permitted. The responsible agency is the Building and Safety Department.

No onsite treatment system has been identified within the City limits. If a discharger sought to receive a permit, the Building and Safety Department would use the criteria set forth by the Santa Barbara EHS for guidance. Final approval would fall on the Planning Department. The Building and Safety Department building approval process takes between 6-12 months and costs around $2,000 to $4,000. However, because an onsite wastewater system would be a new process for the City, the time and costs are expected to be greater (V. Johnson personal communication January 16, 2012 and C. Moore, personal communication January 17, 2012).

City of Carpinteria

New onsite treatment systems are essentially not allowed in the City of Carpinteria. Section 16.32.020 of the Carpinteria Municipal Code states that “service to lots by individual sewage system, septic tanks, cesspools or drywells in any subdivision for which a tentative map is required to be filed shall be prohibited. In all such cases, sewage disposal shall be by the Carpinteria Sanitary District” (Carpinteria, 2011). Section 16.45.040 of the Municipal Code requires a tentative map for all new construction (Carpinteria, 2011). If a discharger sought to get a system approved, both the City and the Sanitation District would have to review the proposal. However, this process is extremely unlikely (S. Farley, personal communication, January 30, 2012).

This section has shown the complexity involved in the regulatory framework for decentralized system. The permitting flowchart (Figure 3.3.1) was designed to provide guidance for local designers, architects, and builders when considering an onsite system. The case study in the following chapter highlights an example of when the flowchart and other project deliverables can be used to solve real world challenges.

CHAPTER 4: CASE STUDY – THE CHILDREN'S PROJECT ACADEMY

Decentralized technologies can be an attractive option for architects and designers who face unique design challenges. These challenges may include projects in remote locations, projects with rigid water restrictions, or projects for clients who want to demonstrate their commitment to sustainability. One such example in Santa Barbara County is The Children's Project Academy (CPA), a residential charter school currently in the design phase, that will be located about 50 miles north of Santa Barbara.

Due to the project's need for irrigation water and imposed limits on wastewater discharge, the CPA design team is considering an onsite wastewater treatment system. The CPA provides a relevant case study to demonstrate the functionality of the matrix decision-support tool. The section below summarizes the CPA project details and provides an example of how the guidance document can fill the knowledge gap for architects, builders, and designers.

Project Details

The CPA will encompass 114 acres within Los Alamos, California. Located north of the city of Santa Barbara, along the 101 freeway, the school will reside on hilly terrain between the small town of Los Alamos and agricultural land (see Figure 4.1 below). The yellow line on the map below indicates the property lines of the project, and the meandering green belt is the San Antonio Creek, which runs through the back of the property.

Figure 4.1: Location of the CPA

Source: The Children's Project Academy, 2011

The CPA will consist of a school for 120 students; housing for the students, their families, and the teachers; recreational fields for sports; and a swimming pool. Figure 4.2 shows a preliminary design of the site plan.

Figure 4.2: Site Plan for the CPA

Source: The Children's Project Academy, 2011

The project is expected to demand more water than a typical school because the students and teachers will be living onsite. Therefore, the water demands will include both academic and residential use. Also, the arid climate of the Los Alamos region means that the athletic fields will require irrigation year round to maintain green turf grass.

Similarly, the CPA is expected to generate large amounts of wastewater from the school facilities and residences. We used estimates from the Los Alamos Community Plan to calculate expected wastewater generation. For residential wastewater, there is an estimated 178 gallons per day (GPD) per unit, with a 10% decrease for multi-family units. For the non-residential wastewater from the school, we used an average of 10 GPD per student. By multiplying these estimates by the number of students and homes, we estimated that the facility will generate 11,613 GPD (see Table 4.1 for detailed calculation).

These wastewater estimates are important because the CPA faces strict wastewater generation limits. The development will be built on agriculturally zoned land, and therefore must meet the agricultural water restraints in order to receive its permit. In particular, the design teams needs to find a solution to reduce the development's wastewater generation by a minimum of 20%, or a total of 9,290 GPD. However, because the Peikert Group is committed to sustainability of their projects, the team wishes to go beyond this requirement and achieve a 5,800 GPD or 50% reduction.

Table 4.1: Wastewater Generation for the CPA

Use	Number	Generation Rate 178 GPD/Unit 21.67 GPD/1000 S.F.	Attached Housing Factor	Total Estimated Demand
Residential	65	178	0.9	10413
Students	120	10	N/A	1200
Pool	N/A	N/A	N/A	0
Total Wastewater (gallons)				**11,613**

Source: Peikert Group Architects

CPA's property consists of a variety of soil types, but the most prevalent are chamise sandy loam, in 45.8% of the site, and botella loam, in 37.7% of the site (NCRS Soil Report, n.d.). Table 4.2 below contains a detailed list of each soil type, its description, and the percentage.

The type of soil present on the property is important because the soil qualities affect some of the types of treatment systems that can be installed. For example, systems with subsurface wastewater infiltration are particularly sensitive to soil type.

Table 4.2: Soil Types within the Property

Soil Type	Description	% of Land
ArD	Arnold sand, 5 to 15 percent slopes	4.7%
BsA	Botella loam, slightly wet, 0 to 2 percent slopes	37.7%
BtA	Botella clay loam, 0 to 2 percent slopes	8.1%
ChF	Chamise shally loam, 15 to 45 percent slopes	45.8%
CuC	Corralitos loamy sand, 2 to 9 percent slopes	2.7%
EdC2	Elder sandy loam, 2 to 9 percent slopes, eroded	0.6%
Sk	Sandy alluvial land, wet	0.2%
TrE3	Tierra loam, 5 to 30 percent slopes, severely eroded	0.1%

Source: NRCS Soil Report p.21, n.d.

In order to meet their permit requirements and offset potable water use in irrigation, PGA is considering a water recycling system that takes the water generated in the school and homes and reuses it onsite for irrigation. Because wastewater treatment and recycling systems can be complex and expensive, as well as subject to stringent guidelines under Title 22, PGA requested assistance in choosing an adequate system that would meet all of their constrains. The matrix decision support tool was developed to help facilitate the selection of an onsite wastewater system. The following section shows how this tool can be applied to the CPA development.

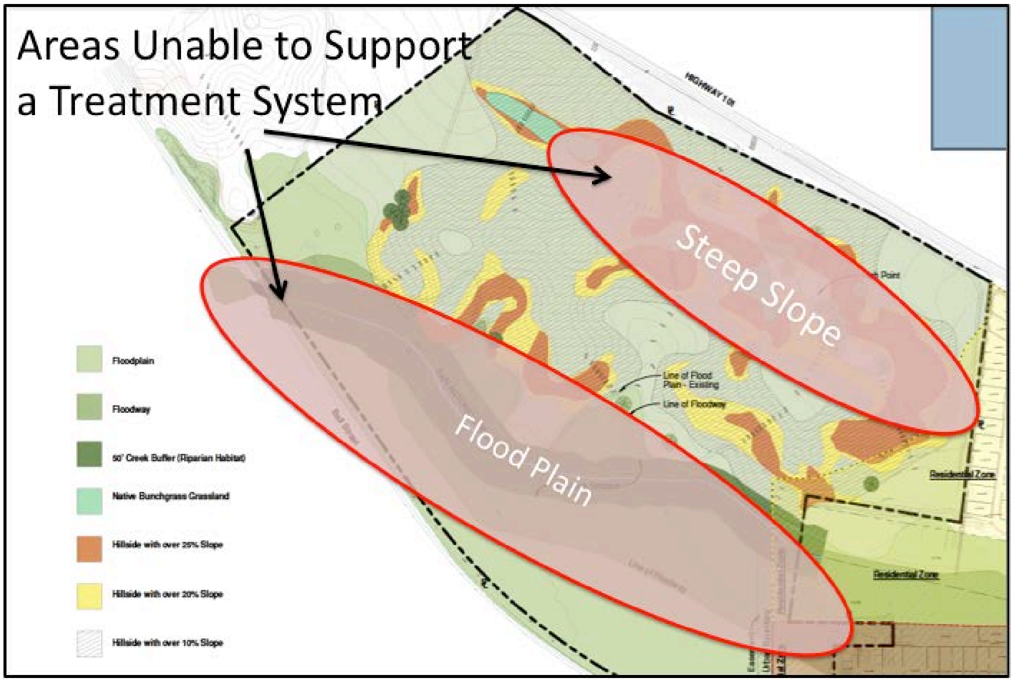
Using the Matrix to Select a System

The first step toward selecting an appropriate wastewater system is to identify the project constraints. For the CPA, the constraints were:

1. Economic Limits: The CPA is a non-profit organization that relies on donations and government grants for funding. Therefore, the project has a limited budget of $1 million for its wastewater treatment plant.
2. Land Availability: The development has a limited amount of land available to dedicate to a wastewater treatment system. Some areas of the property itself,

including those with a steep slope and those in floodplain areas, are physically unable to support a treatment system. Figure 4.3 shows these areas.

Figure 4.3: The CPA – Areas Unable to Support a Treatment System



Built structures will cover the majority of the remaining land, leaving a somewhat limited space for a treatment system.

3. Reuse Requirements: One main objective in using an alternative treatment system is to recycle the treated effluent onsite for irrigation of landscape and recreational fields. As such, the system must perform well by meeting strict effluent quality requirements.
4. Education: Because the treatment plant will be located at a school, there is a preference for a system that can engage students and residents in its operational stages, fostering environmental education and stewardship.

Based on these constraints, we used the matrix to eliminate treatment options that would not be appropriate for this project.

1. Economic Limits: Membrane bioreactors were eliminated as a possible option because they have a red scoring for four of the five cells indicating cost.

			Membrane Bioreactors (MBR)
Economic	Initial Investment	Land Requirement	3
		Construction	1
	Operation & Maintenance	Materials	1
		Energy Requirements	1
		Operational Labor	1

2. Land Availability: The three subsurface treatment options, Leachfield, Mound System, and Evapotranspiration, were eliminated due to their high land requirements (as indicated by the red colored cells).

Valuation Category			Subsurface Treatment		
			Leachfield	Mound System	Evapotranspiration
Economic	Initial Investment	Land Requirement	1	1	1
		Construction	3	2	2
	Operation & Maintenance	Materials	3	3	3
		Energy Requirements	3	3	3
		Operational Labor	3	2	3

3. Reuse Requirements: The CPA has a strong preference for a system that is reliable and capable of meeting stringent effluent requirements. However, the remaining systems all have similar performance standards and therefore no systems could be were eliminated based on this criterion.

4. Education: Both the Activated Sludge systems and Recirculating Filters receive a low ranking for this category, and were therefore eliminated.

		Activated Sludge Systems	Recirculating Filters	
			Sand or Gravel	Advanced Media
Education		1	1	1
Ownership and Participation		1	1	1
Quality of Life	Health/Risk of Vector Contact	2	2	2

After narrowing down the choices based on constraints, the only remaining systems were the four Constructed Wetlands. Upon closer inspection, the Free Water Surface system and the Subsurface Horizontal Flow were eliminated because of their poor scoring under soil and slope restraints.

	Free Water Surface
Removal of Potential Pathogens	1
Soil	2
Slope	1

The two remaining technologies that meet most of the requirements for the CPA are: Recirculating Vertical Flow Wetlands and the Tidal Flow Living Machine®. The Guidance Document would then provide more detailed information on the benefits and disadvantages of each system, as well as a description of how they work. It is important to note that the matrix can assist in eliminating technologies that do not fit the criteria for a project so that the user can then pursue further information on possible systems; its purpose is not to choose the perfect wastewater system, nor is it capable of doing this. The matrix user is expected to seek out the advice of an expert, who can perform a site visit and a financial quote, before choosing to implement a system.

Recommendations

The two potential onsite combined wastewater treatment systems that may meet CPA project requirements of cost, land availability, water reuse, and education are:

1.Recirculating Vertical Flow Wetlands

2. Tidal Flow Living Machine®

Therefore, we recommend that Peikert Group Architects pursue more information on these systems, including a site evaluation and a cost estimate. However, the matrix does not review all possible technologies, meaning there could be a treatment system which better meets the CPA project objectives but that was excluded from this analysis. Also, these recommendations are based on an academic exercise, and the CPA would first consult their neighbors and the Los Alamos Community Services District before implementing a decentralized system.

Similarly, another option for the design team would be to use an onsite wastewater system for treating and recycling graywater only. CPA could then connect to the nearby sewer to dispose of the blackwater from toilets. Graywater is typically 30-50% of the total wastewater generated from indoor residential use (O'Connor et al. 2008) (Roesner et al. 2006). By capturing and recycling graywater directly from sinks, showers, and clothes washers, the CPA could reduce its wastewater generation by 30-50%. While a graywater recycling system would still require treatment and disinfection, it would avoid the added expense of sludge removal.

Other Considerations

We also considered water efficiency as a potential solution for the CPA to meet its 20% wastewater reduction goal. Water efficient fixtures, such as faucets and showerheads, decrease the flow of water, reducing the amount of wastewater generated. Similarly, water efficient dishwashers and washing machines have lower water demands and also reduce total wastewater generated.

To determine if water efficiency alone could achieve the 20% wastewater reduction goal, we examined the CPA wastewater generation estimates more closely. According to the Los Alamos Community Plan (LACP), household wastewater generation is estimated to be 178 GPD (refer to table 4.1). A 10% decrease was applied to this value for the CPA because of its multi-family housing, resulting in an estimated 160 GPD per unit. Since LACP uses an average of 2.82 persons per household, the per person estimate is about 56 GPD. To achieve a 20% reduction, this number would have to decrease to 45 GPD per person.

We then compared this wastewater generation to the estimated water demands from the same community plan, as shown in Figure 4.4.

Figure 4.4: Water Consumption Estimates (Los Alamos Community Plan)

Groundwater Thresholds Manual for Environmental Review of Water Resources in Santa Barbara County

Table 8a - Water Demand Estimations Based on Individual Indoor Uses For Santa Barbara County Including Limitations of Ordinance 2948 (Applies to all areas of Santa Barbara County)

Indoor Use Per Person	gal/yr. w/5.5 gal. Toilet* 3.9 gpm shwr.	gal/yr. w/3.5 gal. Toilet* 3 gpm shwr	gal/yr. w/1.6 gal. toilet* 2 gpm shwr
Toilet 4 flushes/day - gallons/flush 5.5/3.5/1.6	8030	5110	2336
Shower .7/day - 3.9 gal/3 gal/2 gpm x 10 min.	9965	7665	5110
Tub bath .2/day tub 1/2 full = 24 gallons	1752	1752	1752
Brush teeth 1.3/day x 2.5 gal	1186	1186	1186
Shaving 1/day 25% of pop. X 4.5 gal.	411	411	411
Washing hands 5/day wet and rinse @ .2 gal/wash	365	365	365
Drinking and cooking x 1 gallon/day	365	365	365
Clothes washing .29 x 35 gallons/wash	3704	3704	3704
Dishwashing (calc. 1 person assume 2 person/household) auto wash .5 wash/day x 18 gallons inc. rinse	3285	3285	3285
Garbage disposal (calc. one person assume 2 person/ house .5 use/day x 1 gallon	183	183	183
Gallons/Year/Person	**29,246**	**24,026**	**18,697**
AFY/person	**0898 AFY**	**.0737 AFY**	**.0574 AFY**

* Pre-ordinance toilets have mostly 5.5 gal tanks, Larry Farwell GWD 4/15/88 and Pre-ordinance standard pipe output (showers and faucets) was 3.9 gpm Ed Justus, Co., Bldg. Dept. 4/15/88.

** Further reductions in these indoor uses can be achieved through the installation of higher efficiency plumbing fixtures, for example, changing a 3.5 gallon flush toilet to a 1.6 gallon flush toilet.

Source: Los Alamos Community Plan, 2010

This figure shows three different yearly estimates of water consumption per person. The column on the far left, which is based on outdated pre-ordinance fixtures, estimates 80 GPD per person. This would generate wastewater in excess of the 45 GPD per person that the CPA needs. Similarly, the middle column estimates 66 GPD, still higher than CPA's goal, but it also relies on outdated fixtures. The column on the right uses estimates for current plumbing fixtures, including 1.6 gallon per flush (gpf) toilets and 2.0 gallon per minute (gpm) showerheads. The per capita estimate for these fixtures is 51 GPD, on par with CPA's expected use but still larger than their allowed wastewater generation. If the residences implemented ultra low-flow fixtures, such as 1.28 gpf toilets and 1.5 gpm showerheads, the estimated water use would almost meet CPA's reduction goal, at 46 GPD per person (calculation in Table 4.3).

Table 4.3: Water Consumption Estimates With Ultra Low-Flow Fixtures

Fixture	**Flow rate**	**Uses**	**Total (yearly)**	**Total (daily)**
Low flow toilet	1.28	4	1869	5
Low flow showerhead	1.5	7	3833	11
Other estimates	N/A	N/A	11251* from Figure 4.4	31
Total	N/A	N/A	16544	**46**

This analysis shows that the CPA cannot rely solely on water efficiency to meet its wastewater reduction goal. However, one important element which was not considered in this analysis is the possibility of using low flow faucets and clothes washers. To estimate water demand, the LACP only allowed for variable toilets and showerheads while holding constant the faucet and clothes washer water demands. To more accurately estimate water consumption, the LACP should consider fluctuations in water use from more efficient sinks and clothes washers.

Regardless of this oversight, we still recommend the use of an onsite treatment system to meet wastewater generation goals for the CPA. To determine whether a blackwater or graywater system would be more beneficial, we performed an analysis of their anticipated environmental impacts.

Because a graywater system would require the CPA to connect to the sewer, we measured the environmental impacts associated with connecting to the sewer in terms of global warming potential (GWP). It is important to note that GWP is not the only impact associated with wastewater treatment, but we chose to focus on this metric because of the readily available data. Our findings are outlined below.

Impacts from Connecting to the Sewer: The centralized treatment facility in Los Alamos serves 1,649 people; therefore, we used the equation ***1.07 * km * ppl*** to estimate the GWP per person per kilometer (derived in Chapter 3, Section 3.1, Life Cycle Assessment of Wastewater Treatment). The school is located 0.5 km from the centralized plant, and the school will house around 200 students and residents. Using this information, the total life cycle impacts from the sewer are ***107 kg CO_2e per year***. However, this number does not account for emissions from wastewater treatment, which are estimated below.

Impacts from Centralized Treatment: We used data from the ecoinvent database to estimate the environmental impacts of a centralized wastewater treatment that uses activated sludge and serves between 806 and 5,321 people. The global warming potential per person per year is 30.16 kg CO_2e. Aggregating these impacts across all the users in the CPA, the total impacts are ***6,020 kg CO_2e per year.*** However, the centralized treatment facility closest to the CPA does not use the activated sludge, but facultative ponds, which are a very basic form of treatment. More research is needed to determine the life cycle impacts of this treatment.

Total Impacts from Connecting to the Sewer: By adding the impacts of the sewer and the treatment plant, total global warming potential is ***6,127 kg CO2e per year.***

We compared this result with the estimated impacts of a constructed wetland system since this is the system we recommended to the CPA.

Impacts for a Constructed Wetland System: The values for global warming potential from constructed wetland systems varied across studies, from a low of 0.1 to a high of 41.1 kg CO_2e per person per year. The average impact show in the studies was ***12.2 kg of CO_2e per person per year.*** Extrapolating this figure across the residents and students at the CPA, the resulting life cycle impacts are ***2,442 kg CO_2e per year***, a figure much lower than the projected 6,127 kg for connecting to the sewer. These findings seem to indicate that the global warming life cycle impacts of an onsite constructed wetland system are lower than those from connecting to the sewer. However, due to the wide range of values for constructed wetlands, we determined the full range of impact values.

Range of Values Analysis: We chose the lowest value of 0.1 kg and the highest value, 41.1 kg CO_2e per person, and calculated total impacts for the CPA. The table below summarizes our results:

Low Value	Average Value	High Value
20 kg CO_2e per year	2,442 kg CO_2e per year	8,220 kg CO_2e per year

These results show that there is a wide range of potential impacts from a constructed wetlands system. In the best-case scenario, the wetland would have a very small impact in terms of global warming potential. However, if the wetland were poorly functioning and became an anaerobic system, the global warming potential could be as high as 8,220 kg CO_2e per year, a value higher than the 6,127 kg from connecting to the sewer. Yet these figures only indicate greenhouse gas emissions and do not consider the impact of reduced water consumption. Recycling treated water from constructed wetlands could further reduce the environmental impacts of this system.

These mixed numbers portray the complexity of quantifying and analyzing the life cycle impacts of wastewater systems. For this particular case study, they show that life cycle global warming potential may not be the best criteria on which to base a decision. The Peikert Group may want to give more consideration to other aspects, such as system cost, land availability, or aesthetics, which are more easily comparable.

This exercise has demonstrated how the matrix can serve as a tool to identify potential systems for a development project. Stakeholders can use the matrix to eliminate potential technologies that do not meet the project constraints. They can also estimate life cycle impacts from connecting to the sewer. In this particular case study, the development project is located within 0.5 km of the centralized treatment facility, so that the environmental impacts of connecting to the sewer are relatively small. For more remote projects, these impacts would most likely be larger.

CHAPTER 5: FINDINGS AND RECOMMENDATIONS

In light of growing human populations, aging infrastructure, and higher demand for recycled water, an increased focus has been placed on advanced decentralized wastewater treatment options as an alternative or supplement to centralized facilities. We evaluated the benefits and disadvantages of using these systems from an environmental, economic, and social perspective. Based on the meta–analysis of treatment options, we have reached the following conclusions.

- Centralized facilities have lower life cycle global warming impacts per person than decentralized systems because their impacts are shared over a larger number of people. However, centralized facilities have larger overall life cycle global warming impacts than decentralized facilities due to their energy intensive operations and collection systems.

- It is not possible to conclude whether one system provides adequate treatment with less impact in regards to another because this is a subjective measure. Each impact category carries a different weight depending on what is most relevant for the individual. For example, if the most important factor is global climate change, centralized systems have a greater impact than decentralized options. If instead the main impact considered is ecotoxicity potential, then the system that removes the least pollutants from wastewater may have the greatest impacts.

- In order to fully evaluate the impact from wastewater treatment, future LCA studies should include sludge disposal, as this will have a significant environmental effect on the receiving environment. This is especially true in California where about 54% of treated sludge is applied to land. To the extent that different technologies produce different volumes of final sludge, with varying composition, the environmental impacts also vary, and therefore should be included in LCA studies.

- The regulatory framework for alternative decentralized systems is antiquated and cumbersome. This is especially true for the SWRCB, creating a barrier to the adoption of these systems in Santa Barbara County and the state of California in general. The permitting process should be streamlined, and permit approval should be based on effluent quality in addition to discharge location and flow rate.

- No wastewater system achieved a high score for all of the assessed criteria because of tradeoffs that exist between valuation categories. For example, a system that performs well and produces a high-quality effluent typically requires more electricity, resulting in a high score for performance and a low score for energy.

- When comparing decentralized technologies, we found that constructed wetlands offer a passive, low-energy and low-cost treatment option that contributes to an increased social benefit. However, constructed wetlands may not consistently produce high quality effluent and are therefore comparatively less reliable.

- Prefabricated and modular systems more consistently achieve high quality effluent, but they typically face increased costs in the areas of construction, energy consumption, and maintenance and labor.

- Similar to constructed wetlands; subsurface treatment systems offer cost-effective, low-tech treatment capabilities. Yet these systems are subject to high geographical restrictions due to the soil-based treatment process.

- Based on our application of the matrix decision support tool to the Peikert Group's project, the Children's Project Academy we found that, given the project's constraints of cost, land availability, reuse, and education, the most appropriate systems would be the Living Machine® or a vertical flow wetland.

- The viability of a decentralized system is dependent on the distance to the nearest sewer connection. Legally, if the nearest connection is within 200 feet, the development must connect to the main sewer line. If the project is far removed, a decentralized system will likely have a smaller environmental impact because the impacts of connecting to the main sewer increase with distance from the central system as well as number of people served. Therefore, if a development is located far away from a centralized wastewater treatment system, we recommend the use of an onsite treatment option.

- A decentralized wastewater treatment system may be used on site even if a project is legally required to connect to the central wastewater treatment system. Project planners may choose this option because it promotes sustainability, provides educational opportunities or gives status to a project. However, permitting such a system will be costly and time-consuming.

- There is a need for a statewide and nationwide database containing information on decentralized systems. This database could include information reported by installers as part of the permitting process, and it would allow for more quantitative assessments of system performance. It should also include monitoring of key parameters needed for decision making, such as cost, treatment performance, and specific land requirements. In particular, for system costs, we found a lack of standardization across industry reports.

- Finally, further research is needed to understand the ability of decentralized technologies in treating emerging pollutants.

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APPENDIX

Appendix A: Supplemental Policy Information

Appendix A.1: General Waste Discharge Requirements for Discharges to Land by Small Domestic Wastewater Treatment Systems.

Appendix A.2: Information Packet with Instructions on How to Complete a Report of Waste Discharge, Pursuant to California Water Code Section 13260.

Appendix A.3: Additional Information for Form 200 (SWRCB).

Appendix A.4: Application Procedures for Onsite Sewage Treatment Systems (new system) (EHS).

Appendix A.5: Onsite Sewage Treatment System Permit Application (EHS).

Appendix A.6: Information Packet on Minor Conditional Use Permit.

Appendix B: Supplemental Wastewater Composition Information

Table B.1: Average Chemical and Biological Composition of Graywater

Table B.2: Average Chemical Composition of Blackwater

Table B.3: Average Chemical Composition of Combined Wastewater

Appendix C: Supplemental Technology Descriptions

Supplement 1: Septic Tanks and Leachfields

Supplement 2: Mound Systems

Supplement 3: Evapotranspiration

Supplement 4: Horizontal Subsurface Wetlands

Supplement 5: Free Water Surface Wetlands

Supplement 6: Living Machine®

Supplement 7: Vertical Flow Wetlands

Supplement 8: Recirculating Filters

Supplement 9: Membrane Bioreactors

Supplement 10: Activated Sludge

Appendix D: Supplemental Information on LCA Analysis

Appendix E: Supplemental Information on Matrix Decision Support Tool

Appendix A: Supplemental Policy Information

Forms and application procedures for the permit processes described may be found through the following resources, available online.

Appendix A.1: General Waste Discharge Requirements for Discharges to Land by Small Domestic Wastewater Treatment Systems (Water Quality Order No. 97-1 0-DWQ)

Available at:
http://www.waterboards.ca.gov/board_decisions/adopted_orders/water_quality/1997/wq1997_10.pdf

Appendix A.2: Information Packet with Instructions on how to complete a Report of Waste Discharge (ROWD), pursuant to California Water Code Section 13260.

Available at:
http://www.swrcb.ca.gov/centralcoast/publications_forms/forms/docs/form_200.pdf

Appendix A.3: Additional information for Form 200 (SWRCB)

Available at:
http://www.swrcb.ca.gov/centralcoast/publications_forms/forms/docs/form_200_appendix.pdf

Appendix A.4: Santa Barbara Public Health Department, Environmental Health Services. Application Procedures for onsite sewage treatment systems (new system)

Available at:
http://www.countyofsb.org/uploadedFiles/phd/EHS/Onsite_NewSystemInstructions.pdf

Appendix A.5: Santa Barbara Public Health Department, Environmental Health Services. Onsite sewage Treatment System Permit Application

Available at: http://www.countyofsb.org/uploadedFiles/phd/EHS/42-1.pdf

Appendix A.6: Information Packet on Minor Conditional Use Permit

Available at: http://www.sbcountyplanning.org/PDF/C/MinorCupSubReqAPP.pdf

Appendix B: Additional Wastewater Composition Information

Table B.1: Average Chemical & Biological Composition of Graywater

Reference	**Erikson et al (2003)**	**Rose et al. (1991)**	**Cassanova et al. (2001)**
Temperature (°C)	21.6-28.2		
pH	7.6-8.6	6.54	7.47
COD (mg/L)	77-240		
BOD (mg/L)	26-130		64.85
TSS (mg/L)	7-207		35.09
Turbidity (NTU)		76.3	43
NH4-N (mg/L)	0.02-0.42	0.74	
NO3-N (mg/L)	<0.02-0.26	0.98	
Total-N (mg/L)	3.6-6.4	1.7	
PO4-P (mg/L)		9.3	
Total-P (mg/L)	0.28-0.779		
Sulfate (mg/L)		22.9	59.59
Chloride (mg/L)		9	20.54
Hardness (mg/L)		144	
Alkalinity (mg/L)		158	

Reference	**Erikson et al (2003)**	**Rose et al. (1991)**	**Cassanova et al. (2001)**
Ca (mg/L)	99–100		
K (mg/L)	5.9-7.4		
Mg (mg/L)	20.8-23		
Na (mg/L)	44.7-98.5		
Total Bacteria (CFU/100mL)	$4.0x10^7$-$1.5x10^8$	$6.1x10^8$	
Total Coliform (CFU/100mL)	$6.0x10^3$-$3.2x10^5$	$2.8x10^7$	$8.03x10^7$
Fecal Coliform (CFU/100mL)		$1.82x10^4$-$7.94x10^6$	$5.63x10^5$

Source: Adapted from Roesner L etal, (2006). Long-term Effects of Landscape Irrigation Using Household Graywater: blanks indicate no values given

Table B.2: Average chemical composition of blackwater

Table 2.1: Human excreta - per capita quantities and their resource value (Strauss, 1985)

	Faeces	Urine	Excreta
Quantity and consistency			
Gram/capita/day (wet)	250	1,200	1,450
Gram/capita/day (dry)	50	60	110
Chemical composition (% of dry solids)			
Organic matter	92	75	83
Carbon C	48	13	29
Nitrogen N	4-7	14-18	9-12
Phosphorus (as P_2O_5)	4	3.7	3.8
Potassium (as K_2O)	1.6	3.7	2.7
Comparison with other wastes (% of dry solids)	N	P_2O_5	K_2O
Human excreta	9-12	3.8	2.7
Plant matter	1-11	0.5-2.8	1.1-11
Pig manure	4-6	3-4	2.5-3
Cow manure	2.5	1.8	1.4

Source: Strauss, 1985

Table B.3: Average chemical composition of Combined Wastewater

Constituent	Unit	Range	Typical
Total Solids	mg/L	300-1200	700
Dissolved	mg/L	250-850	500
Fixed	mg/L	150-550	150
Volatile	mg/L	100-300	150
Suspended	mg/L	100-400	220
Fixed	mg/L	30-100	70
Volatile	mg/L	70-300	150
Settleable	mg/L	50-200	100
BOD_5	mg/L	100-400	250
TOC	mg/L	100-400	250
COD	mg/L	200-1,000	500
Total Nitrogen	mg/L	15-90	40
Organic	mg/L	5-40	25
Ammonia	mg/L	10-50	25
Nitrite	mg/L	0	0
Nitrate	mg/L	0	0
Total Phosphorous	mg/L	5-20	12
Organic	mg/L	1-5	2
Inorganic	mg/L	5-15	10
Chloride	mg/L	30-85	50
Sulfate	mg/L	20-60	15
Alkalinity	mg/L	50-200	100
Grease	mg/L	50-150	100
Total Coliform	CFU / 100mL	10^6-10^8	10^7
VOCs	µg/L	100-400	250

Source: Adapted from Burks and Minnis (1994) Onsite Wastewater Treatment Systems.

Appendix C. Supplement 1

Texas Agricultural Extension Service
The Texas A&M University System

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On-site wastewater treatment systems

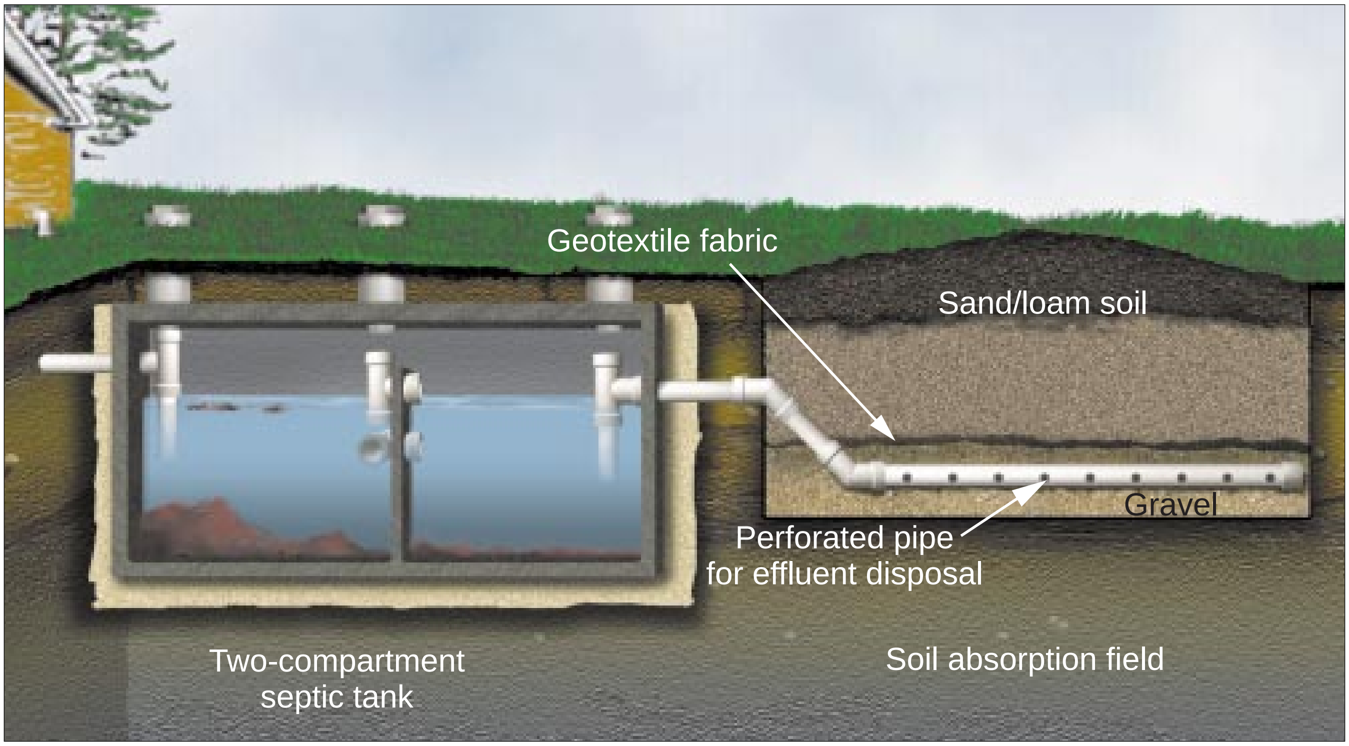

Figure 1: A septic tank and soil absorption field system.

Septic tank/soil absorption field

Bruce Lesikar
Extension Agricultural Engineering Specialist
The Texas A&M University System

The septic tank and soil absorption system is the most cost-efficient method available to treat residential wastewater. But for it to work properly, you need to choose the right kind of septic system for your household size and soil type, and you need to maintain it regularly.

This type of waste-treatment system has two components: a septic tank and a soil absorption system.

Septic tank

A septic tank is an enclosed watertight container that collects and provides primary treatment of wastewater by separating solids from the wastewater. It removes the solids by holding wastewater in the tank and allowing the settleable solids to settle to the bottom of the tank while the floatable solids (oil and greases) rise to the top. To provide time for the solids to settle, the tank should hold the wastewater for at least 24 hours.

Some of the solids are removed from the water, some are digested, and some are stored in the tank. Up to 50 percent of the solids retained in the tank decompose; the rest accumulate as sludge at the tank bottom and need to be removed periodically by pumping the tank.

There are three main types of septic tanks for on-site wastewater treatment:

- ✓ Concrete septic tanks, the most common;
- ✓ Fiberglass tanks, which are being used more often because they are easy to carry to “hard-to-get-to” locations; and

A watertight septic tank prevents rainwater from entering the tank and flooding the soil absorption field

- ✓ Polyethylene/plastic tanks, which come in many different sizes and shapes. Like fiberglass tanks, these are light, one-piece tanks that can be carried to "hard-to-get-to" locations.

All tanks must be watertight to prevent water from entering as well as leaving the system. Water entering the system can saturate the soil absorption field, resulting in a failed system.

From the septic tank, the wastewater passes through the outlet of the tank and enters the soil absorption field. The most common outlet is a tee fitting connected to the pipe going to the soil absorption field. However, an effluent filter can be placed in the outlet tee for additional filtering of the wastewater. The effluent filter removes additional solids from the wastewater and keeps them from clogging the absorption field and causing it to fail prematurely.

Soil absorption field

The soil absorption field provides final treatment and distribution of the wastewater. A conventional system consists of perforated pipes surrounded by such media as gravel and chipped tires, covered with geotextile fabric and loamy soil. To treat wastewater, this system relies heavily on the soil, where microorganisms help remove the organic matter, solids and nutrients left in the water.

As effluent continually flows into the soil, the microbes eating the components of the wastewater form a biological mat. The mat slows the water's movement through the soil and helps keep the area below the mat from becoming saturated. The water must travel into unsaturated soil so that microbes there and in the mat can feed on the waste and nutrients in the effluent. The grass covering the soil absorption system also uses the nutrients and water to grow.

Treatment

Used properly, the septic tank and soil absorption system works well. It reduces two ratios commonly used to measure pollution: biological oxygen demand, which is lowered by more than 65 percent; and total suspended solids, which are cut by more than 70 percent. Oil and grease are typically reduced by 70 to 80 percent.

Using a septic tank to pretreat sewage also makes other secondary treatment systems more effective. The effluent from the septic tank is mild, consistent, easy to convey and easily treated by either aerobic (with free oxygen) or anaerobic (without free oxygen) processes.

Design

For a septic tank to perform successfully, it must be the proper size and construction and have a watertight design and stable structure.

Tank size: The size of septic tank you need depends on the number of bedrooms in the home, number of people living there, the home's square footage and whether or not water-saving fixtures are used. For example, a three-bedroom house, assuming four people live there and it has no water-saving fixtures, would require a 1,000-gallon tank (see Table 1).

Tank construction: A key factor in the septic tank's design is the relationships between how much surface area it has, how much sewage the tank can store, how much wastewater is discharged and how fast it exits. All affect the tank's efficiency and the amount of sludge it retains.

The greater the liquid surface area, the more sewage the tank can collect. As more solids collect in the tank, the water there becomes shallower, which requires that the discharge be slower to allow more time to separate the sludge and scum.

A key to maintaining a septic tank is placing risers on the tank openings.

If a septic tank is buried more than 12 inches below the soil surface, a riser must be used on the openings to bring the lid to within 6 inches of the soil surface. Generally, the riser can be extended to the ground surface and protected with a good lid. These risers really make it easy to perform maintenance on the tank.

Soil texture: There are three textures of soil: sand, silt and clay. Soil texture affects how fast the wastewater filters into the soil (called hydraulic conductivity) and how big an absorption field you need. Sand transmits water faster than silt, which is faster than clay. Texas regulations divide these three soil textures into five soil types (Ia, Ib, II, III, IV). Sandy soils are in soil type I and clay soils are in soil type IV. A standard drain field cannot be used in a clay soil.

Hydraulic loading: Also important to the design is the hydraulic loading, which is the amount of effluent applied per square foot of trench surface. Because water filters through clay soils more slowly than through sand or silt, the hydraulic loading rate is lower for clay than for silt, and lower for silt than for sand. Because clay soils have a very low conductivity, only nonstandard drain fields can be used in clay.

Absorption field size: The size of the absorption field needed is also determined by how much wastewater goes into the system each day. Divide the wastewater flow by the hydraulic loading for the soil type in which the field will be built.

How to keep it working

To keep your septic system treating sewage efficiently, you need to have the tank pumped periodically. As the septic system is used, sludge accumulates in the bottom of the septic tank.

As the sludge level increases, wastewater spends less time in the tank, and solids are more likely to escape into the absorption area. If sludge accumulates too long, no settling occurs, the sewage goes directly to the soil absorption area, and little is treated.

Table 1. Minimum septic tank capacities for residential houses.

Bedrooms (number)	House size (square feet)	Tank capacity [without water-saving devices] (gallons)	Tank capacity [with water-saving devices] (gallons)
1 or 2	less than 1,500	750	750
3	less than 2,500	1,000	750
4	less than 3,500	1,250	1,000
5	less than 4,500	1,250	1,250
6	less than 5,500	1,315	1,250

Properly sized tanks generally have enough space to accumulate sludge for at least 3 years.

How often you need to pump it out depends on:

- ✓ The septic tank's capacity;
- ✓ The amount of wastewater flowing into the tank (related to size of household); and
- ✓ The amount of solids in the wastewater (for example, it has more solids if you use a garbage disposal).

In Texas, a 1,000-gallon septic tank is used for a home with three-bedrooms without water saving devices. If four people live in that three-bedroom house, the tank should be pumped every 2.6 years (see Table 2). If the same system serves a family of two in a three-bedroom house, the tank should be pumped every 5.9 years.

It is important to know that the soil absorption field will not fail immediately if you don't pump your tank. However, the septic tank is no longer protecting the soil absorption

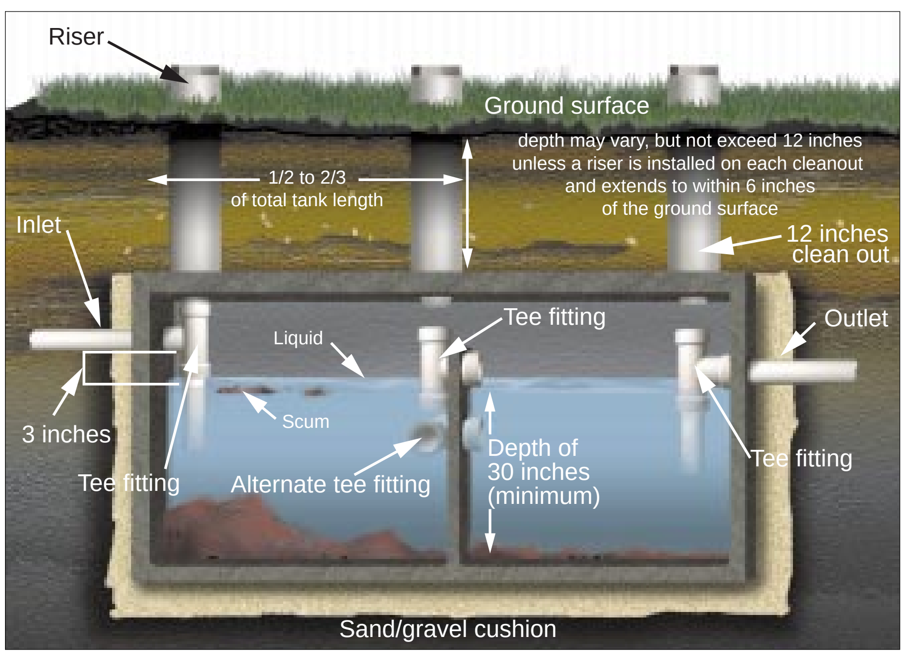

Figure 2. A two-compartment septic tank.

Table 2. Recommended number of years between pumpings of septic tanks according to size of tank and household.

Tank Size (gals)	Household Size (Number of People) 1	2	3	4	5	6	7	8	9	10
500	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1	—
750	9.1	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4	0.3
1000	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
1250		7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
1500		9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
1750			6.9	5.0	3.9	3.1	2.6	2.2	1.9	1.6
2000			8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
2250				6.7	5.2	4.2	3.5	3.0	2.6	2.3
2500					5.9	4.8	4.0	4.0	3.0	2.6

Note: More frequent pumping needed if a garbage disposal is used.

Soil absorption fields need to be protected from solids and rain

field from solids. If you neglect the tank for long, you may have to replace the soil absorption field.

Another maintenance task you need to do periodically to keep the system from backing up is to clean the effluent filter. Clean it periodically by spraying it with a hose directly into the septic tank, or have your maintenance provider clean the filter.

Soil absorption fields need to be protected from solids and rainfall. If you don't pump the tank, solids can enter the field. Rainfall running off roofs or concrete areas should be drained around the soil absorption field to prevent the field from filling with water. Fields that are saturated with rainwater are unable to accept wastewater. Planting cool-season grasses over the soil absorption field in winter can help remove water from the soil and help keep the system working properly.

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Office of Water Washington, D.C.
EPA 832-F 99-074 September 1999

Decentralized Systems Technology Fact Sheet
Mound Systems

DESCRIPTION

The mound system was originally developed in North Dakota in the late 1940s and called the NODAK disposal system. Some soil types are unsuitable for conventional septic tank soil absorption systems. As a result, alternative systems such as the mound system can be used to overcome certain soil and site conditions.

The mound design in predominate use today was modified from the NODAK design by the University of Wisconsin-Madison in the early 1970s. Although there are now many different mound designs in use, this fact sheet will focus on the Wisconsin design. The Wisconsin mound has been widely accepted and incorporated into many state regulations.

The three principle components of a mound system are a pretreatment unit(s), dosing chamber and the elevated mound. Figure 1 illustrates a Wisconsin mound system.

APPLICABILITY

Mounds are pressure-dosed sand filters that discharge directly to natural soil. They lie above the soil surface and are designed to overcome site restrictions such as:

- Slow or fast permeability soils.
- Shallow soil cover over creviced or porous bedrock.
- A high water table.

The main purpose of a mound system is to provide sufficient treatment to the natural environment to produce an effluent equivalent to, or better than, a conventional onsite disposal system.

ADVANTAGES AND DISADVANTAGES

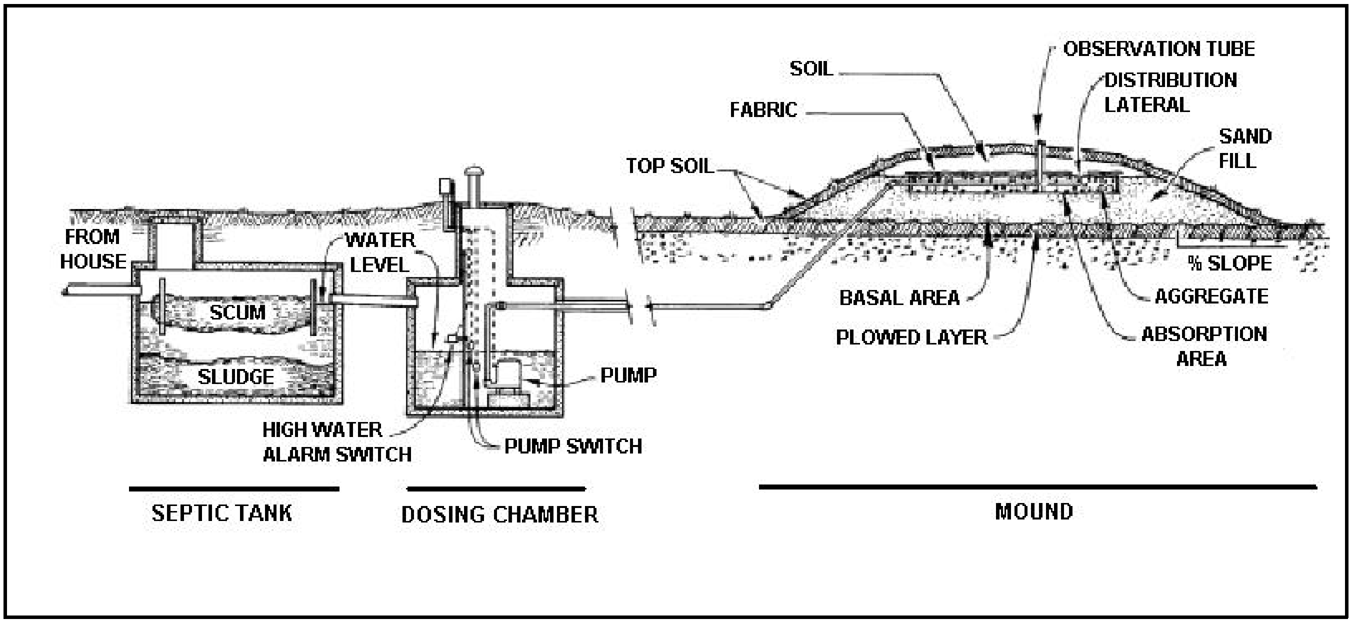
Listed below are some advantages and disadvantages of mound systems when compared to other alternative onsite systems.

Advantages

- The mound system enables use of some sites that would otherwise be unsuitable for in-ground or at-grade onsite systems.
- The natural soil utilized in a mound system is the upper most horizon, which is typically the most permeable.
- A mound system does not have a direct discharge to a ditch, stream, or other body of water.
- Construction damage is minimized since there is little excavation required in the mound area.
- Mounds can be utilized in most climates.

Disadvantages

- Construction costs are typically much higher than conventional systems.



Source: Converse and Tyler, Copyright © by the American Society of Agricultural Engineers, reprinted with permission, 1987.

FIGURE 1 SCHEMATIC OF A WISCONSIN MOUND SYSTEM

- Since there is usually limited permeable topsoil available at mound system sites. Extreme care must be taken not to damage this layer with construction equipment.
- The location of the mound may affect drainage patterns and limit land use options.
- The mound may have to be partially rebuilt if seepage or leakage occurs.
- All systems require pumps or siphons.
- Mounds may not be aesthetically pleasing in unless properly landscaped.

DESIGN CRITERIA

Two factors that determine the size and configuration of a mound are; how the effluent moves away and the rate at which it moves away from the system. The prediction of the movement and rate of movement is done from studies of the soil and site information obtained. To ensure proper performance of the mound system, the following concepts must be included in the design and construction process:

- 1) Leaving the topsoil in place but plowing it before placement of the fill.
- 2) Using a coarse sand fill meeting grain size distribution specifications.
- 3) Using pressure to uniformly distribute the effluent over the seepage area.

Soil Depth

A suitable depth of soil is required to treat the effluent before it reaches the limiting condition, such as bedrock, a high water table, or a slowly permeable soil layer. Although the separation distance varies, it is usually between 1 and 4 feet.

Site and Design

To date, siting and design experience at sites suitable for mound systems indicates that absorption systems should be long and narrow and should follow the contour (i.e., level). The more restrictive the site, the narrower and longer the system. Table 1 gives the soil criteria for a Wisconsin mound based on research and field experience.

TABLE 1 RECOMMENDED SOIL AND SITE CRITERIA FOR THE WISCONSIN MOUND SYSTEM BASED ON RESEARCH AND FIELD EXPERIENCE

Parameter	Value
Depth of high water table (permanent or seasonal)	10 in.
Depth to crevice bedrock	2 ft.
Depth to non-crevice bedrock	1 ft.
Permeability of top 10 in.	Moderately low
Site slope	25%
Filled site	Yes[a]
Over old system	Yes[b]
Flood plains	No

a Suitable according to soil criteria (texture, structure, consistence).
b The area and backfill must be treated as fill because it is a disturbed site.

Source: Converse and Tyler, 1990.

High Water

The high water table is determined by direct observation (soil boring), interpretation of soil mottling, or other criteria. The bedrock should be classified as crevice, non-crevice semi-permeable, or non-crevice impermeable. This will determine the depth of sand media required.

Percolation and Loading

Percolation tests are used in some jurisdictions to estimate the soil permeability because they are empirically related to the loading rate. Loading rates should be based on the soil texture, structure, and consistence, using the percolation test only to confirm morphological interpretations.

Mounds

Mounds can be constructed on sites with slopes up to 25%. The slope limitation is primarily for construction safety, because it is difficult to operate equipment on steep slopes, and they pose a construction hazard. From a hydraulic perspective, mounds can be positioned on steep slopes.

Sites

In the case of filled sites, fill material is placed on top of the natural soil and may consist of soil textures ranging from sand to clay. Sufficient time must be allowed for the soil structure to stabilize before constructing a system. Many more observations are required for filled areas.

When evaluating the soil loading rate for a mound over an old or failing in-ground system, the soil over the system must be considered to be disturbed, and thus, treated as a filled site. If a mound is to be placed over a large in-ground system, a detailed evaluation of the effluent movement should be done.

Mounds should not be installed in flood plains, drainage ways, or depressions unless flood protection is provided. Another siting consideration is maintaining the horizontal separation distances from water supply wells, surface waters, springs, escarpments, cuts, the boundary of the property, and the building foundation. Sites with trees and large boulders can make it difficult in preparing the site. Trees should be cut to the ground surface with tilling around stumps. The size of the mound should be increased to provide sufficient soil to accept the effluent when trees and boulders occupy a significant amount of the surface area.

The actual size of a mound system is determined by estimating the sand fill loading rate, soil (basal) loading rate, and the linear loading rate. Once these values are established, the mound can be sized for the site. The final step is to design the effluent distribution network and the pumping system.

PERFORMANCE

One factor that determines good performance is the type of sand fill material. A suitable sand is one that can adequately treat the wastewater. Suitable sand should contain 20% or less material greater than 2.0 mm and 5% or less finer than 0.053 mm. It should also have a size distribution that meets certain sieve analysis specifications, ASTMC-33 specifications, or meets limits for effective diameter and coefficient of uniformity.

For design of residential mounds, the daily wastewater volume is determined by the number of bedrooms in a house. Typical design flow requirements for individual homes are up to 150 gallons per day (gpd) per bedroom. Design specifications for mound systems are usually the same for both large and small flows for typical domestic septic tank effluent. Higher strength wastes must be pretreated to the levels of domestic septic tank effluent, or lower hydraulic loading rates may be applied.

IMPLEMENTATION

In Wisconsin, the success rate of the mound system is over 95%, which is due to their emphasis on siting, design, construction and maintenance.

Years of monitoring the performance of mound systems have shown that mounds can consistently and effectively treat and dispose of wastewater. Studies have shown evidence that some nitrogen removal does occur in mound systems when approximately 2 feet of natural unsaturated soil is below the fill material.

Mound Systems in Wisconsin (State-Wide)

Using relatively conservative soil criteria, many states have accepted the Wisconsin mound system as an alternative when conventional in-ground trenches and beds are not suitable. The Wisconsin mound system has evolved into a viable onsite system for the treatment of wastewater from individual, commercial, and community systems by overcoming some of the site limitations and meeting code requirements and guidelines.

In 1978, an experimental study was initiated to evaluate soil/site limitations for the Wisconsin mound (see Converse and Tyler, 1987a). The objectives of this research study were to determine whether the existing soil/site limitations on mounds were too restrictive and to determine the minimum soil/site limitations under which the mounds would perform without affecting public health and the environment. The experimental approach was to design, construct, and evaluate sites with mound systems that currently did not meet code requirements due to failing systems.

The sites selected for this study had to fit the objectives of the research and generate a reasonable amount of wastewater to be mound treated. The sites selected had to have:

1. Fill soil placed over natural soil.

2. A high water table where the seasonal high water table level was less than 60 cm below the ground surface.

3. Slowly permeable soils that were rated slower than moderately permeable soils.

4. Steep slopes greater than 12%.

5. Mounds over existing failing systems.

6. A combination of the above.

Over 40 experimental mounds were constructed between 1979 and 1983 on sites that did not meet the code requirements; 11 of these mounds are described in detail in this study. Site evaluations were done by certified soil scientists, plans prepared by designers were reviewed and approved by the state, and licensed contractors installed the systems with inspections by county sanitarians during construction.

The study concluded that the overall performance of the mounds was very good. The systems functioned satisfactory on filled sites, on sites with a high water table (seasonal water table 25 to 30 cm from the ground surface), on steep slope sites (up to 20 to 25%), on sites with slowly permeable soil, and on top of failing systems. Leakage occurred at the base of the mound on some sites during extremely wet conditions, but the effluent quality was good, with fecal counts generally less than 10 colonies per 100 ml in saturated toe effluent. It was found that Wisconsin mound systems can be constructed on difficult sites if the system is designed using linear loading rates, which are established based on the horizontal and vertical acceptance rates of the soil for each system.

Failure of Mound System in Wisconsin

Expansion of a Wisconsin firm's mound system in 1978, resulted in a clogging and seepage problem. The system was originally built to handle 65 employees at 750 gpd and was now serving a staff of 165. This expansion created a failure of the mound system due to hydraulic overload. To solve this problem, the mound system was expanded and a water conservation program was initiated. The expansion of the mound increased the hydraulic capacity to 2,600 gpd (Otis, 1981.)

In November 1979, the mound system failed again—this time due to a biological clogging mat. The clogging mat was removed by using 450 gallons of a 10% solution of hydrogen peroxide. The mound system was operating successfully within 2 days. However, further research indicates that for structured natural soils other than sand, hydrogen peroxide may reduce the soil infiltration rate, and thus, may not be an effective procedure to eliminate soil clogging.

A third failure occurred in January 1980, again due to hydraulic overload. The firm had expanded its employee base to 215 employees, with an average daily flow of 3,000 gpd. There was no room available to expand the mound system itself, so the firm redesigned the pumping chamber to avoid large peak flows, allowing the mound system to receive optimum dosing without failure.

OPERATION AND MAINTENANCE

The septic tank and dosing chamber should be checked for sludge and scum buildup and pumped as needed to avoid carryover of solids into the mound. Screens or filters can be used to prevent large solids from escaping the septic tank. The dosing chamber, pump, and floats should be checked annually and replaced or repaired as necessary. It is critical that the septic tank and dosing chamber be watertight. In addition, electrical parts and conduits must be checked for corrosion. Flushing of the laterals annually is recommended.

When a mound system is properly installed and maintained, it should last for a long period of time. In general, the maintenance required for mounds is minimal. However, as with any system, poor maintenance could lead to early system failure. Possible problems that can occur in an improperly designed or constructed mound system include:

- Ponding in the absorption area of the mound.
- Seepage out of the side or toe of the mound.
- Spongy areas developing on the side, top, or toe of the mound
- Clogging of the distribution system.

Practices that can be used to reduce the possibility of failure in a mound system include:

- Installing water-saving devices to reduce the hydraulic overload to the system.
- Calibrating pumps and utilizing event counters and running time meters.
- Timed dosing to dose equally sized doses on regular intervals throughout the day.
- Diverting surface water and roof drainage away from the mound.
- Preventing traffic on the mound area.
- Installing inspection tubes in the mound to check for ponding.
- Keeping deep-rooted plants (shrubs and trees) off the mound.
- Planting and maintaining grass or other vegetative cover on the mound surface to prevent erosion and to maximize water uptake.
- Stand-by power for the pump.

Follow all instructions recommended by the manufacturer. All equipment must be tested and calibrated as recommended by the equipment manufacturer. A routine operation and maintenance (O&M) schedule should be developed and followed for any mound system in addition to checking local codes.

COSTS

The cost of a mound system is dependent on design costs, energy costs, the contractor used, the manufacturers, land, and the characteristics of the wastewater. Table 2 lists some typical capital and O&M costs for a mound system serving a three-bedroom single home at a flow rate of 450 gpd (150 gallons per bedroom). Septic tank costs were estimated at $1 per treated gallon. It should be noted however, that costs will vary from site to site. To keep construction costs to a minimum, use good quality and local materials, when available.

TABLE 2 TYPICAL COST ESTIMATE FOR A MOUND SYSTEM (SINGLE HOME)

Item	Cost ($)
Capital Costs	
Construction Costs	
Septic tank (1000 gallon concrete tank)	1,000
Dosing chamber (includes pump and controls)	2,000
Mound structure	6,000
Total Construction Costs	**9.000**
Non-Component Costs	
Site evaluation	500
Permits	250
Total Costs	**9,750**
Annual O&M Costs	
Labor @$20/hr.	20 per year
Power @8 cents/kWh	35 per year
Septic tank pumping	75 to 150 every 3 years

Source: Ayres Associates, Inc., 1997.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-00-033 September 2000

Decentralized Systems Technology Fact Sheet
Evapotranspiration

DESCRIPTION

Evapotranspiration (ET) is a method of onsite wastewater treatment and disposal that offers an alternative to conventional soil absorption systems for sites where protection of the surface water and groundwater is essential. An ET system disposes of wastewater into the atmosphere through evaporation from the soil surface and/or transpiration by plants, without discharging wastewater to the surface water or groundwater reservoir. ET can offer flexibility by combining seepage with evaporation when absolute protection of the groundwater or surface water is not required.

An ET system is a feasible option in semi-arid climates where the annual evaporation rate exceeds the annual rate of precipitation. The amount that evaporation exceeds precipitation is the wastewater application capacity. The different design configurations of ET are discussed in more detail in the sections that follow.

Process

Evapotranspiration is the net water loss caused by evaporation of moisture from the soil surface and transpiration by vegetation. Three conditions must be met for continuous evaporation. First, it requires latent heat of approximately 590 cal/g of water evaporated at 15 °C. Second, a vapor pressure gradient between the evaporative surface and the atmosphere must exist to remove vapor by diffusion, convection, or a combination of the two. Third, there must be a continuous supply of water to the evaporative surface.

Evapotranspiration is also influenced by vegetation on the disposal field. Theoretically, ET can remove high volumes of effluent in the late spring, summer, and early fall, especially if large silhouette and good transpiring bushes are present.

There are three main types of evapotranspiration systems; ET, evapotranspiration/absorption (ETA), and mechanical.

The first type, an ET system, is the most common. The main components are a pretreatment unit (usually a septic tank or an aerobic unit) used to remove settleable and floatable solids and an ET sand bed with wastewater distribution piping, a bed liner, fill material, monitoring wells, overflow protection, and a surface cover. Vegetation must be planted on the surface of the bed to enhance the transpiration process.

The septic tank effluent flows into the lower portion of a sealed ET bed equipped with continuous impermeable liners and carefully selected sands. Capillary action in the sand causes the wastewater to rise to the surface and escape through evaporation as water vapor. In addition, vegetation transports the wastewater from the root zone to the leaves, where it is transpired as a relatively clean condensate. This design allows for complete wastewater evaporation and transpiration with no discharge to nearby soil.

Figure 1 shows a cross-sectional view of a typical ET bed. Although this design may be acceptable in certain sites, local and state regulations should be checked to ensure approval.

The second type of evapotranspiration system is known as ETA. In addition to evaporation and transpiration, percolation also occurs through an unsealed bed. This design provides discharge to both the atmosphere and to the subsurface.

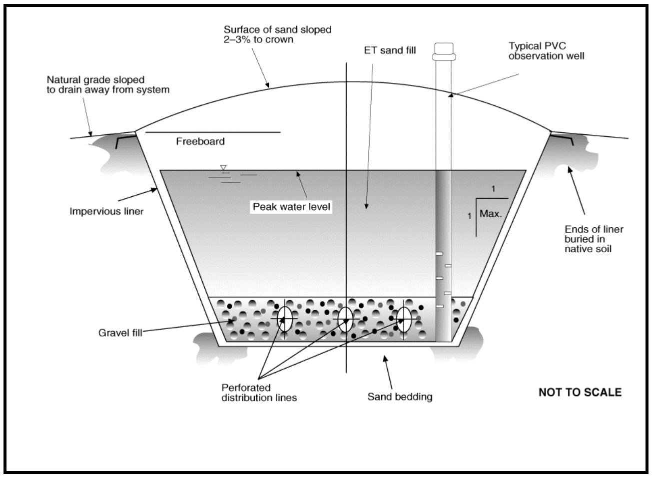

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FIGURE 1 CROSS SECTIONAL VIEW OF A TYPICAL EVAPOTRANSPIRATION BED

The third type of evapotranspiration system, which involves the use of mechanical devices, is still under development. There are two types of mechanical evaporation systems, both of which require a septic tank for pretreatment and storage tank. The first type consists of a rotating disk unit, in which the disks rotate slowly, providing a large surface area for the wastewater to evaporate.

The second type of mechanical ET system is a concentric cylinder unit, where forced air enters the center of the cylinder, moves outward through wetted cloth wraps, and is discharged as vapor.

Mechanical systems use little electricity and require minimal maintenance, which makes them attractive options for individual home wastewater disposal in regions where evaporation exceeds precipitation.

APPLICABILITY

Onsite systems with ET disposal are appropriate in locations with a shallow soil mantle, high groundwater, relatively impermeable soils, absence of fractured bedrock, or other conditions that put the groundwater at risk. ET systems perform well in semi-arid and arid locations. In certain parts of the United States, ET systems are feasible for homes, outdoor recreation areas, and highway rest areas. It is important to note that assessment of the reliability of the system requires micro-climatic data.

Boyd County Demonstration Project

A demonstration site was set up about five miles from the Huntington Airport in Kentucky, in an area with low population density and rough topography. Approximately 60 families live in the sanitary district. The demonstration project serves 47 families, with 36 individual home aeration treatment plants and two multi-family aeration plants which serve 11 families. Six manufacturers provided 16 stream discharge units, two spray irrigation units, one ET unit, and 19 subsurface field discharge units. Four recycle units serving five homes produced clear, odorless water.

The ET unit is 2,000 square feet (two 1,000 square foot beds) designed for disposing effluent from a Cromaglass model C-5 aeration plant. The beds are sealed with plastic to keep the high ground water at the site from flooding them. They contain 8 inches of gravel, 18 inches of sand, and are covered with topsoil and planted with grass and junipers. They are crowned to shed rainwater.

The Kentucky test provided valuable data on how the system handles variations in loading rates. Although the ET beds were designed for a family of four, seven people lived at the site which increased water usage, yet the ET system continued to perform well with only one small modification to the distribution box. Before installation of the ET beds, raw sewage pooled in the yard of this house from a nonfunctioning septic tank and soil absorption field. Despite high rainfall, the ET system continues to perform satisfactorily.

Leigh Marine Laboratory, University of Auckland, New Zealand

Leigh Marine Laboratory, a research institution on the New Zealand coastline about 62 miles north of Auckland, has an ETA system which was installed in 1982. It has a design load to support 35 persons (including residents and day visitors) at 4,565 L/d (1,180 gallons per day) total flow. Three septic tanks feed a sump pump that discharges through a 400 m rising force main, to an ETA bed system on an exposed grass ridge 70 m above the laboratory complex.

There is a loading factor of 1.0, an ETA loading rate of 10 mm per day for beds, and an areal rate (including spaces between beds) of 3.75 mm per day. This system includes extensive groundwater and surface water drainage controls. The total bed area is 450 m^2 divided into 20 beds, each 15 m by 1.5 m, arranged in four groups of five beds, with each group dose loaded for one week and rested for three.

Since their commissioning, the ETA beds have performed as predicted: in the summer, capillary action in the sand draws effluent to support vigorous grass growth; in the winter, the effluent gradually accumulates for storage and disposal during drier weather. The system is currently loaded between 80 and 90 percent of its capacity and is performing successfully.

ADVANTAGES AND DISADVANTAGES

Listed below are some advantages and disadvantages of ET systems.

Advantages

- ET systems may overcome site, soil, and geological limitations or physical constraints of land that prevent the use of subsurface wastewater disposal methods.
- The risk of groundwater contamination is reduced with ET systems that have impermeable liners.
- Costs are competitive with other onsite systems.
- ET systems can be used to supplement soil absorption for sites with slowly permeable shallow soils with high water tables.
- ET systems can be used for seasonal application, especially for summer homes or recreational parks in areas with high evaporation and transpiration rates, such as in the southwestern United States.
- Landscaping enhances the aesthetics of an ET system as well as beautifies the area.

Disadvantages

- ET systems are governed by climatic conditions such as precipitation, wind speed, humidity, solar radiation, and temperature.
- ET systems are not suitable in areas where the land is limited or where the surface is irregular.
- ET systems have a limited storage capacity and thus cannot store much winter wastewater for evaporation in the summer.
- There is a potential for overloading from infiltration of precipitation.
- The bed liner must be watertight to prevent groundwater contamination.
- ET systems are generally limited to sites where evaporation exceeds annual rainfall by at least 24 inches (i.e., arid zones).
- Transpiration and evaporation can be reduced when the vegetation is dormant (i.e., winter months).
- Salt accumulation and other elements may eventually eliminate vegetation and thus transpiration.

DESIGN CRITERIA

There are several variables that determine the size requirement of an ET system. The flow rate of domestic wastewater is site-specific. Accurate estimates (daily, weekly, or monthly) of flow rates must be calculated as part of the design process to prevent overloading associated with undersizing or the excessive cost of oversizing a system. The design flow rate should also include a safety factor to account for peak flows or increased site use in the future.

Like other disposal methods that require area-intensive construction, the use of ET systems can be constrained by limited land availability and site topography. For year-round, single-family homes, ET systems generally require about 4,000 to 6,000 square feet of available land. However, the use of water conservation plumbing devices could reduce the bed area requirements.

The maximum slope that an ET system can be used on has not yet been determined, although a slope greater than 15 percent could be used if terracing, serial distribution, and other necessary design features are incorporated.

PERFORMANCE

By far the most important performance consideration of any ET system is the rate of evaporation. This is largely affected by climatic conditions such as precipitation, wind speed, humidity, solar radiation, and temperature. Since these factors are variables, evaporation rates can vary significantly, a factor which must be considered in the design of an ET system.

Although most precipitation will be absorbed into the ET bed, hydraulic overloading could occur if more water enters the system than is evaporated. Provisions for long-term storage of excess water can be expensive. Thus, the evaporation rate must exceed the precipitation rate. This makes an ET system suitable for areas with relatively low rainfall, such as the western and southwestern parts of the United States. Climate requirements are not as well defined for ETA systems, although the soils must be able to accept all of the influent wastewater if net evaporation is zero for a long period of time.

In addition to the climate, other factors influence the performance of an ET system. These are discussed below.

Hydraulic Loading

If the hydraulic loading is too high, wastewater could seep out from the system. However, if a loading rate is too low, it can result in a lower gravity (standing) water level in the bed and insufficient evaporation. This situation can be solved by sectional construction in level areas to maximize the water level in a particular section of the bed.

Sand Capillary Rise Characteristics

The sand must be fine enough to draw the water up from the saturated zone to the surface by capillary action. The potential for capillary rising must be slightly more than the depth of the bed. However, if the sand is too fine, the bed can be clogged by solids from the wastewater.

Cover Soil and Vegetation

The vegetation used in an ET system must be able to handle the varying depths of free water surface in the bed. Grasses, alfalfa, broad-leaf trees, and evergreens are types of vegetation used in ET beds. They have been known to increase the average annual evaporation rate from an ET bed to a rate higher than that for bare soil. However, grasses and alfalfa also result in nearly identical or reduced evaporation rates as compared to bare soil during winter and spring, when evaporation rates are normally at a minimum. Similarly, topsoil has been shown to reduce evaporation rates. Some evergreen shrubs have resulted in slightly higher evaporation rates than bare soil throughout the year. Water seekers with hair roots, such as berries, are not recommended because they may clog the distribution pipes.

Construction Techniques

Although ET system performance is generally affected less by construction techniques than most subsurface disposal methods, some aspects of ET construction can affect performance. For ET systems, main considerations are to ensure that the impermeable liner is watertight and that the sand has sufficient potential for capillary rise.

Salt Accumulation (for ET only)

As wastewater is evaporated during dry weather, salt and other elements build up at the surface of the ET bed. Precipitation distributes the salt throughout the bed. For nonvegetated ET systems, salt accumulation is generally not a problem, but systems with vegetation may experience negative effects over time.

Soil Permeability (for ETA only)

Soil permeability affects the performance of ETA beds that use seepage into the soil in addition to evaporation. A portion of pretreated wastewater is absorbed and treated by the soil. As a general rule, the wastewater must travel through two to four feet of unsaturated soil for adequate treatment before reaching the groundwater.

OPERATION AND MAINTENANCE

Regular operation and maintenance (O&M) of ET and ETA systems is usually minimal, involving typical yard maintenance such as trimming the vegetation. If a septic tank is used for pretreatment, it should be checked for sludge and scum buildup and periodically pumped to avoid carryover of solids into the bed. Recommended maintenance practices include:

- Ensuring that all stormwater drainage paths/pipes are not blocked and that stormwater drains away from the system.
- Using high transpiration plants suitable for the wetness at ground level.
- If there is more than one bed, alternating the bed loading as necessary.
- Installing additional beds as required.

If an ET or ETA system is properly installed on a suitable site, maintenance is rarely needed.

COSTS

The cost of an ET system depends on the type of system, site, and wastewater characteristics. The construction cost of an ET bed is determined by its surface area, which is a function of the design loading rate. (For non-discharging, permanent home ET units located in suitable areas, the loading rate ranges from approximately 1.0 mm per day to 3.0 mm per day.) Other cost considerations include the availability of suitable sand, the type and thickness of the liner, use of a retaining wall (if needed), and vegetation (usually native to the area).

Typical costs for a three-bedroom residence with a septic tank and ET system run about $10,000 (minimum) yet may be higher depending on site conditions.

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Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:

http://www.epa.gov/owmitnet/mtbfact.htm

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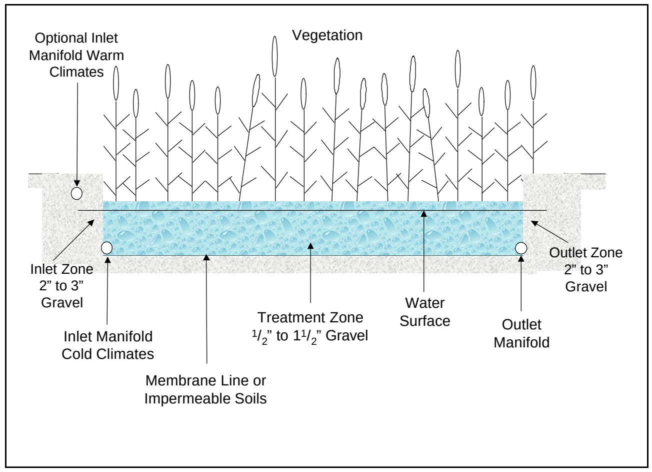
Wastewater Technology Fact Sheet
Wetlands: Subsurface Flow

DESCRIPTION

Wetland systems are typically described in terms of the position of the water surface and/or the type of vegetation grown. Most natural wetlands are free water surface systems where the water surface is exposed to the atmosphere; these include bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes). A subsurface flow (SF) wetland is specifically designed for the treatment or polishing of some type of wastewater and are typically constructed as a bed or channel containing appropriate media. An example of a SF wetland is shown in Figure 1. Coarse rock, gravel, sand and other soils have all been used, but a gravel medium is most common in the U.S. and Europe. The medium is typically planted with the same types of emergent vegetation present in marshes, and the water surface is designed to remain below the top surface of the medium. The main advantages of this subsurface water level are prevention of mosquitoes and odors, and elimination of the risk of public contact with the partially treated wastewater. In contrast, the water surface in natural marshes and free water surface (FWS) constructed wetlands is exposed to the atmosphere with the attendant risk of mosquitoes and public access.

The water quality improvements in natural wetlands had been observed by scientists and engineers for many years and this led to the development of constructed wetlands as an attempt to replicate the water quality and the habitat benefits of the natural wetland in a constructed ecosystem. Physical, chemical, and biochemical reactions all contribute to water quality improvement in these wetland



Source: Adapted from drawing by S.C. Reed, 2000.

FIGURE 1 SUBSURFACE FLOW WETLAND

systems. The biological reactions are believed due to the activity of microorganisms attached to the available submerged substrate surfaces. In the case of FWS wetlands these substrates are the submerged portion of the living plants, the plant litter, and the benthic soil layer. In SF wetlands the available submerged substrate includes the plant roots growing in the media, and the surfaces of the media themselves. Since the media surface area in a SF wetland can far exceed the available substrate in a FWS wetland, the microbial reaction rates in a SF wetland can be higher than a FWS wetland for most contaminants. As a result, a SF wetland can be smaller than the FWS type for the same flow rate and most effluent water quality goals.

The design goals for SF constructed wetlands are typically an exclusive commitment to treatment functions because wildlife habitat and public recreational opportunities are more limited than FWS wetlands. The size of these systems ranges from small on-site units designed to treat septic tank effluents to a $1.5x10^7$ liters per day (4 MGD) system in Louisiana treating municipal wastewater. There are approximately 100 systems in the U.S. treating municipal wastewater, with the majority of these treating less than $3.8x10^3$ m^3/day (1 MGD). Most of the municipal systems are preceded by facultative or aerated treatment ponds. There are approximately 1,000 small scale on-site type systems in the U.S. treating waste waters from individual homes, schools, apartment complexes, commercial establishments, parks, and other recreational facilities. The flow from these smaller systems ranges from a few hundred gallons per day to 151,400 liters per day (40,000 gallons per day), with septic tanks being the dominant preliminary treatment provided. SF wetlands are not now typically selected for larger flow municipal systems. The higher cost of the rock or gravel media makes a large SF wetland uneconomical compared to a FWS wetland in spite of the smaller SF wetland area required. Cost comparisons have shown that at flow rates above 227,100 liters per day (60,000 gallons per day) it will usually be cheaper to construct a FWS wetland system. However, there are exceptions where public access, mosquito, or wildlife issues justify selection of a SF wetland. One recent example is a SF wetland designed to treat the runoff from the Edmonton Airport in Alberta, Canada. The snow melt runoff is contaminated with glycol de-icing fluid and a SF wetland treating 1,264,190 liters per day (334,000 gallons per day) was selected to minimize habitat values and bird problems adjacent to the airport runways.

SF wetlands typically include one or more shallow basins or channels with a barrier to prevent seepage to sensitive groundwaters. The type of barrier will depend on local conditions. In some cases compaction of the local soils will serve adequately, in other cases clay has been imported or plastic membrane (PVC or HDPE) liners used. Appropriate inlet and outlet structures are employed to insure uniform distribution and collection of the applied wastewater. A perforated manifold pipe is most commonly used in the smaller systems. The depth of the media in these SF wetlands has ranged from 0.3 to 0.9 meters (1 to 3 feet) with 0.6 meters (2 feet) being most common. The size of the media in use in the U.S. ranges from fine gravel (≥0.6 centimeters or ≥ 0.25 in.) to large crushed rock (≥15.2 centimeters or ≥6 in.); A combination of sizes from 1.3 centimeters to 3.8 centimeters (0.5 to 1.5 inches) are most typically used. This gravel medium should be clean, hard, durable stone capable of retaining it's shape and the permeability of the wetland bed over the long term.

The most commonly used emergent vegetation in SF wetlands include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In Europe, *Phragmites* are the preferred plants for these systems. *Phragmites* have several advantages since it is a fast growing hardy plant and is not a food source for animals or birds. However, in some parts of the U.S. the use of *Phragmites* is not permitted because it is an aggressive plant and there are concerns that it might infest natural wetlands. In these cases cattails or bulrush can be used. In areas where muskrat or nutria are found, experience has shown that these animals, using the plants for food and nesting material, can completely destroy a stand of cattails or bulrush planted in a constructed wetland. Many of the smaller on-site systems serving individual homes use water tolerant decorative plants. The vegetation on a SF wetland bed is not a major factor in nutrient removal by the system and does not require harvesting. In cold climates, the accumulating plant litter on top of the gravel bed provides useful thermal insulation during the winter months. The submerged plant roots do provide substrate for microbial processes and since most emergent macrophytes can transmit oxygen from the leaves to their roots there are aerobic microsites on the rhizome and root surfaces. The remainder of the submerged environment in the SF wetland tends to be devoid of oxygen. This general lack of available oxygen limits the biological removal of ammonia nitrogen (NH_3/NH_4 - N) via nitrification in these SF wetlands, but the system is still very effective for removal of BOD, TSS, metals, and some priority pollutant organics since their treatment can occur under either aerobic or anoxic conditions. Nitrate removal via biological denitrification can also be very effective since the necessary anoxic conditions are always present and sufficient carbon sources are usually available.

The limited availability of oxygen in these SF systems reduces the capability for ammonia removal via biological nitrification. As a result, a long detention time in a very large wetland area is required to produce low levels of effluent nitrogen with typical municipal wastewater influents unless some system modification is adopted. These modifications have included installation of aeration tubing at the bottom of the bed for mechanical aeration, the use of an integrated gravel trickling filter for nitrification of the wastewater ammonia, and vertical flow wetland beds. These vertical flow beds usually contain gravel or coarse sand and are loaded intermittently at the top surface. The intermittent application and vertical drainage restores aerobic conditions in the bed permitting aerobic reactions to proceed rapidly. Cyclic filling and draining of a horizontal flow system has been successfully demonstrated at the 130,000 gallons per day SF wetland system in Minoa, NY. The reaction rates for BOD_5 and ammonia removal during these cyclic operations were double the rates observed during normal continuously saturated flow.

The phosphorus removal mechanisms available in all types of constructed wetlands also require long detention times to produce low effluent levels of phosphorus with typical municipal wastewater. If significant phosphorus removal is a project requirement then a FWS wetland will probably be the most cost effective type of constructed wetland. Phosphorus removal is also possible with final chemical addition and mixing prior to a final deep settling pond.

The minimal acceptable level of preliminary treatment prior to a SF wetland system is the equivalent of primary treatment. This can be accomplished with septic tanks or Imhoff tanks for smaller systems or deep ponds with a short detention time for larger systems. The majority of existing SF wetland systems treating municipal waste waters are preceded by either facultative or aerated ponds. Such ponds are not necessarily the preferred type of preliminary treatment. At most of these existing systems the SF wetland was selected to improve the water quality of the pond effluent. Since the SF wetland can provide very effective removal for both BOD_5 and TSS, there is no need to provide for high levels of removal of these constituents in preliminary treatments.

The SF wetland does not provide the same level of habitat value as the FWS wetland because the water in the system is not exposed and accessible to birds and animals. However, wildlife will still be present, primarily in the form of nesting animals, birds, and reptiles. If provision of more significant habitat values is a project goal it can be accomplished with deep ponds interspersed between the SF wetland cells. The first pond in such a system would be located after the point where water quality is approaching at least the secondary level

APPLICABILITY

SF wetland systems are best suited for small to moderate sized applications (≤ 227,100 liters/day or ≤60,000 gallons per day) and at larger systems where the risk of public contact, mosquitoes, or potential odors are major concerns. Their use for on-site systems provides a high quality effluent for in-ground disposal, and in some States a significant reduction in the final disposal field area is allowed. SF wetlands will reliably remove BOD, COD, and TSS, and with sufficiently long detention times can also produce low levels of nitrogen and phosphorus. Metals are removed effectively and about a one log reduction in fecal coliforms can be expected in systems designed to produce secondary or advanced secondary effluents.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of subsurface flow wetlands are listed below.

Advantages

- SF wetlands provide effective treatment in a passive manner and minimize mechanical equipment, energy, and skilled operator attention.

- SF wetlands can be less expensive to construct and are usually less expensive to operate and maintain as compared to mechanical treatment processes designed to produce the same effluent quality.

- Year-round operation for secondary treatment is possible in all but the coldest climates.

- Year-round operation for advanced or tertiary treatment is possible in warm to moderately temperate climates. The SF wetland configuration provides more thermal protection than the FWS wetland type.

- SF wetland systems produce no residual biosolids or sludges requiring subsequent treatment and disposal.

- The SF wetland is very effective and reliable for removal of BOD, COD, TSS, metals, and some persistant organics in municipal wastewaters. The removal of nitrogen and phosphorus to low levels is also possible but requires a much longer detention time.

- Mosquitoes and similar insect vectors are not a problem with SF wetlands as long as the system is properly operated and a subsurface water level maintained. The risk of contact by children and pets with partially treated wastewater is also eliminated.

Disadvantages

- A SF wetland will require a large land area compared to conventional mechanical treatment processes.

- The removal of BOD, COD, and nitrogen in SF wetlands are continuously renewable processes. The phosphorus, metals, and some persistent organics removed in the system are bound in the wetland sediments and accumulate over time.

- In cold climates the low winter water temperatures reduce the rate of removal for BOD, NH_3, and NO_3. An increased detention time can compensate for these reduced rates but the increased wetland size in extremely cold climates may not be cost effective or technically possible.

- Most of the water contained in the SF wetland is anoxic and this limits the potential for nitrification of wastewater ammonia. Increasing the wetland size and detention time will compensate, but this may not be cost effective. Alternative methods for nitrification in combination with a SF wetland have been successful. SF wetlands cannot be designed for complete removal of organic compounds, TSS, nitrogen, and coliforms. The natural ecological cycles in these wetlands produce "background" concentrations of these substances in the system effluent.

- SF wetland systems can typically remove fecal coliforms by at least one log. This is not always sufficient to meet discharge limits in all locations and post disinfection may be required. UV disinfection has been successfully used in a number of applications.

- Although SF wetlands can be smaller than FWS wetlands for the removal of most constituents, the high cost of the gravel media in the SF wetland can result in higher construction costs for SF systems larger than about 227,100 liters per day (60,000 gallons per day).

DESIGN CRITERIA

Published models for the design of SF wetland systems have been available since the late 1980's. More recent efforts in the mid to late 1990's have produced three text books containing design models for SF wetlands (Reed, et al 1995, Kadlec & Knight 1996, Crites & Tchobanoglous, 1998). In all three cases, the models are based on first order plug flow kinetics, but results do not always agree due to the author's developmental choices and because the same databases were not used for derivation of the models. The Water Environment Federation (WEF) presents a comparison of the three approaches in their Manual of Practice on Natural Systems (WEF, 2000) as does the US EPA design manual on wetland systems (EPA, 2000). The designer of a SF wetland system should consult these references and select the method best suited for the project under consideration. A preliminary estimate of the land area required for a SF wetland can be obtained from Table 1 of typical areal loading rates. These values can also be used to check the results from the previously cited references.

The SF wetland size is determined by the pollutant which requires the largest land area for it's removal. This is the bottom surface area of the wetland cells and, for that area to be 100 percent effective, the wastewater flow must be uniformly distributed over the entire surface. This is possible with constructed wetlands by careful grading of the bottom surface and use of appropriate inlet and outlet structures. The total treatment area should be divided into at least two cells for all but the smallest systems. Larger systems should have at least two parallel trains of cells to provide flexibility for management and maintenance.

These wetland systems are living ecosystems and the life and death cycles of the biota produce residuals which can be measured as BOD, TSS, nitrogen, phosphorus and fecal coliforms. As a result, regardless of the size of the wetland or the characteristics of the influent, in these systems there will always be a residual background concentration of these materials. Table 2 summarizes these background concentrations.

It is necessary for the designer to determine the water temperature in the wetland because the removal of BOD, and the various nitrogen forms are temperature dependent. The water temperature in large systems with a long HRT (>10 days) will approach the average air temperature except during subfreezing weather in the winter. Methods for estimating the water temperature for wetlands with a shorter HRT (<10 days) can be found in the published references mentioned previously.

It is also necessary to consider the hydraulic aspects of system design because there is significant frictional resistance to flow through the wetland caused by the presence of the gravel media and the plant roots and other detritus. The major impact of this flow resistance is on the configuration selected for the wetland cell. The longer the flow path the higher the resistance will be. To avoid these hydraulic problems an aspect ratio (L:W) of 4:1 or less is recommended. Darcy's law is generally accepted as the model for the flow of water through SF wetlands and descriptive information can again be found in the published references mentioned previously. The flow of water through the wetland cell depends on the hydraulic gradient in the cell and on the hydraulic conductivity (k_s), size, and porosity (n) of the media used. Table 3 presents typical characteristics for potential SF wetland media. These values can be used for a preliminary estimate and for design of very small systems. For large scale systems the proposed media should be tested to determine these values.

TABLE 1 TYPICAL AREAL LOADING RATES FOR SF CONSTRUCTED WETLANDS

Constituent	Typical Influent Concentration mg/L	Target Effluent Concentration mg/L	Mass Loading Rate lb/ac/d*
Hydraulic Load (in./d)	3 to 12**		
BOD	30 to175	10 to 30	60 to 140
TSS	30 to150	10 to 30	40 to 150
NH_3/NH_4 as N	2 to 35	1 to 10	1 to 10
NO_3 as N	2 to 10	1 to 10	3 to 12
TN	2 to 40	1 to 10	3 to 11
TP	1 to 10	0.5 to 3	1 to 4

Note: Wetland water temperature » 20°C.

TABLE 2 "BACKGROUND" SF WETLAND CONCENTRATIONS

Constituent	Units	Concentration Range
BOD_5	mg/L	1 to 10
TSS	mg/L	1 to 6
TN	mg/L	1 to 3
NH_3/NH_4 as N	mg/L	less than 0.1
NO_3 as N	mg/L	less than 0.1
TP	mg/L	less than 0.2
Fecal Coliforms	MPN/100ml	50 to 500

Source: Reed et al., 1995 and U.S. EPA, 1993.

PERFORMANCE

A lightly loaded SF wetland can achieve the "background" effluent levels given in Table 2. In the general case, the SF constructed wetland is typically designed to produce a specified effluent quality and Table 1 can be used for a preliminary estimate of the size of the wetland necessary to produce the desired effluent quality. The design models in the referenced publications will provide a more precise estimate of treatment area required. Table 4 summarizes actual performance data for 14 SF wetland systems included in a US EPA Technology Assessment (EPA, 1993).

In theory, the performance of a SF wetland system can be influenced by hydrological factors. High evapotranspiration (ET) rates may increase effluent concentrations, but this also increases the HRT in the wetland. High precipitation rates dilute the pollutant concentrations but also shorten the HRT in the wetland. In most temperate areas with a moderate climate these influences are not critical for performance. These hydrological aspects need only be considered for extreme values of ET and precipitation.

OPERATION AND MAINTENANCE

The routine operation and maintenance (O&M) requirements for SF wetlands are similar to those for facultative lagoons, and include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing on berms, inspection of berm integrity, wetland vegetation management, and routine monitoring.

The water depth in the wetland may need periodic adjustment on a seasonal basis or in response to increased resistance over a very long term from the accumulating detritus in the media pore spaces. Mosquito control should not be required for a SF wetland system as long as the water level is maintained below the top of the media surface. Vegetation management in these SF wetlands does not include a routine harvest and removal of the

TABLE 3 TYPICAL MEDIA CHARACTERISTICS FOR SF WETLANDS

Media Type	Effective Size D_{10} (mm)*	Porosity, n (%)	Hydraulic Conductivity k_s ($ft^3/ft^2/d$)*
Coarse Sand	2	28 to 32	300 to 3,000
Gravelly Sand	8	30 to 35	1,600 to 16,000
Fine Gravel	16	35 to 38	3,000 to 32,000
Medium Gravel	32	36 to 40	32,000 to 160,000
Coarse Rock	128	38 to 45	16×10^4 to 82×10^4

* mm x 0.03937 = inches
** $ft^3/ft^2/d \times 0.3047 = m^3/m^2/d$, or x 7.48 = $gal/ft^2/d$

Source: Reed et al., 1995.

TABLE 4 SUMMARY OF PERFORMANCE FOR 14 SF WETLAND SYSTEMS*

Constituent	Mean Influent mg/L	Mean Effluent mg/L
BOD_5	28** (5-51)***	8** (1-15)***
TSS	60 (23-118)	10 (3-23)
TKN as N	15 (5-22)	9 (2-18)
NH_3/NH_4 as N	5 (1-10)	5 (2-10)
NO_3 as N	9 (1-18)	3 (0.1-13)
TN	20 (9-48)	9 (7-12)
TP	4 (2-6)	2 (0.2-3)
Fecal Coliforms (#/100ml)	270,000 (1,200-1,380,000)	57,000 (10-330,000)

* Mean detention time 3 d (range 1 to 5 d).
** Mean value.
*** Range of values.

Source: U.S. EPA, 1993.

harvested material. Plant uptake of pollutants represents a relatively minor pathway so harvest and removal on a routine basis does not provide a significant treatment benefit. Removal of accumulated litter is unnecessary, and in cold climates it serves as thermal insulation to prevent freezing in the wetland bed. Vegetation management may also require wildlife management, depending on the type of vegetation selected for the system, and the position of the water. Animals such as nutria and muskrats have been known to consume all of the emergent vegetation in constructed wetlands. These animals should not be attracted to a SF wetland as long as the water level is properly maintained. Routine water quality monitoring will be required for all SF systems with an NPDES permit, and the permit will specify the pollutants and frequency. Sampling for NPDES monitoring is usually limited to the untreated wastewater and the final system effluent. Since the wetland component is usually preceded by some form of preliminary treatment, the NPDES monitoring program does not document wetland influent characteristics. It is recommended, in all but the smallest systems that periodic samples of the wetland influent be obtained and tested for operational purposes in addition to the NPDES requirements. This will allow the operator a better understanding of wetland performance and provide a basis for adjustments if necessary.

COSTS

The major items included in the capital costs for SF wetlands are similar to many of those required for lagoon systems. These include land costs, site investigation, site clearing, earthwork, liner, gravel media, plants, inlet and outlet structures, fencing, miscellaneous piping, etc., engineering, legal, contingencies , and contractor's overhead and profit. The gravel media and the liner can be the most expensive items from this list. In the Gulf States where clay soils often eliminate the need for a liner the cost of imported gravel can often represent 50 percent of the construction costs. In other locations where local gravel is available but a membrane liner is required the liner costs can approach 40 percent of the construction costs. In many cases compaction of the in-situ native soils provides a sufficient barrier for groundwater contamination. Table 5 provides a summary of capital and O & M costs for a hypothetical 378,500 liters/day (100,000 gallons per day) SF constructed wetland, required to achieve a 2 mg/L ammonia concentration in the effluent. Other calculation assumptions are as follows: influent NH_3= 25 mg/L, water temperature 20°C (68°F), media depth = 0.6 meters (2 ft), porosity = 0.4, treatment area = 1.3 hectares (3.2 ac), land cost =$12,355/hectare ($5,000/ac).

TABLE 5 CAPITAL AND O&M COSTS FOR 100,000 GALLONS PER DAY SF WETLAND

Item	Cost $*	
	Native Soil Liner	Plastic Membrane Liner
Land Cost	$16,000	16,000
Site Investigation	3,600	3,600
Site Clearing	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Gravel Media**	142,100	142,100
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	$229,500	$295,500
Engineering, legal, etc.	$133,000	$171,200
Total Capital Cost	**$362,500**	**$466,700**
O & M Costs, $/yr	$6,000/yr	$6,000/yr

* June 1999 costs, ENR CCI = 6039
**12,000 cy of 0.75 in. gravel

TABLE 6 COST COMPARISON SF WETLAND AND CONVENTIONAL WASTEWATER TREATMENT

Cost Item	Process	
	Wetland	SBR
Capital Cost	$466,700	$1,104,500
O &M Cost	$6,000/yr	$106,600/yr
Total Present Worth Costs*	$530,300	$2,233,400
Cost per 1000 gallons treated**	$0.73	$3.06

*Present worth factor 10.594 based on 20 years at 7 percent interest (June 1999 costs, ENR CCI = 6039).
**Daily flow rate for 365 d/yr, for 20 yr, divided by 1000 gallons

Source: WEF, 2000.

Table 6 compares the life cycle costs for this wetland to the cost for a conventional treatment system designed for the same flow and effluent water quality. The conventional process is a sequencing batch reactor (SBR).

REFERENCES

Other Related Fact Sheets

Free Water Surface Wetlands
EPA 832-F-00-024
September, 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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4. U.S. EPA (1999) *Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment*, US EPA, OWM, Washington, DC. (in press.)

5. U.S. EPA (2000) *Design Manual Constructed Wetlands for Municipal Wastewater Treatment*, US EPA CERI, Cincinnati, Ohio (in press.)

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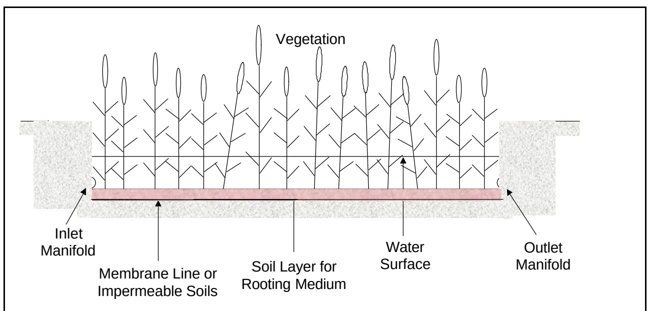
Wastewater Technology Fact Sheet

Free Water Surface Wetlands

DESCRIPTION

Free water surface (FWS) wetlands are defined as wetland systems where the water surface is exposed to the atmosphere. Most natural wetlands are FWS systems, including bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes.) The observation of water quality improvements in these natural wetlands for many years led to the development of constructed wetlands in an effort to replicate the water quality and habitat benefits of natural wetlands in a constructed ecosystem. The majority of FWS constructed wetlands designed for wastewater treatment are marshes, but a few operating examples of bogs and swamps exist. In FWS treatment wetlands, water flows over a vegetated soil surface from an inlet point to an outlet point. In some cases, water is completely lost to evapotranspiration and seepage within the wetland. A diagram of FWS wetland is shown in Figure 1.



Source: Adapted from drawing by S.C. Reed, 2000.

FIGURE 1 FREE WATER SURFACE WETLAND

There are relatively few examples of the use of natural wetlands for wastewater treatment in the United States. Because any discharge to a natural wetland must satisfy National Pollutant Discharge Elimination System (NPDES) limits, these wetlands are typically used for advanced wastewater treatment (AWT) or tertiary polishing. The design goals for constructed wetlands range from an exclusive commitment for basic treatment functions to systems which provide advanced treatment and/or combine with enhanced wildlife habitat and public recreational opportunities. The size of the FWS wetland systems ranges from small on-site units designed to treat septic tank effluents to large units with more than 16,188 hectares (40,000 acres). A large system is being used to treat phosphorus from agricultural storm water drainage in south Florida. Operational FWS wetlands designed for municipal wastewater treatment in the United States range from less than 3785 liters per day (1,000 gallons per day) to more than 75,708 m^3/day (20 million gallons per day).

Constructed FWS wetlands typically consist of one or more shallow basins or channels with a barrier to prevent seepage to sensitive ground waters and a submerged soil layer to support the roots of the selected emergent macrophyte vegetation. Each system has appropriate inlet and outlet structures to ensure uniform distribution and collection of the applied wastewater. The most commonly used emergent vegetations in constructed FWS wetlands include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In systems designed primarily for treatment, it is common to select only one or two species for planting. The plant canopy formed by the emergent vegetation shades the water surface, preventing growth and persistence of algae, and reduces wind-induced turbulence in the water flowing through the system. Perhaps most important are the submerged portions of the living plants, the standing dead plants, and the litter accumulated from previous growth. These submerged surfaces provide the physical substrate for the periphytic-attached growth organisms responsible for much of the biological treatment in the system. The water depth in the vegetated portions of these systems ranges from a few inches to two feet or more.

The influent to these wetlands spreads over a large area of shallow water and emergent vegetation. The subsequent low velocity and essentially laminar flow provides for very effective particulate removal in the front part of the system. This particulate material, characterized as total suspended solids (TSS), contains Biochemical Oxygen Demand (BOD) components, fixed forms of total nitrogen (TN) and total phosphorus (TP), and trace levels of metals and more complex organics. The oxidation or reduction of these particulates releases soluble forms of BOD, TN, and TP to the wetland environment, which are available for adsorption by the soils and removal by the active microbial and plant populations throughout the wetland. Oxygen is available at the water surface, microsites on living plant surfaces, and on root and rhizome surfaces, allowing some aerobic activity the wetland. It is, however, prudent to assume that the bulk of the liquid in the FWS wetland is anoxic or anaerobic. The lack of oxygen can limit the biological removal of ammonia nitrogen (NH_3/NH_4 - N) via nitrification, but the FWS wetland is still effective for removal of BOD, TSS, trace metals, and some complex organics because the treatment of these occurs under both aerobic and anoxic conditions.

If nitrogen removal and/or enhancement of wildlife habitat is a project goal, consideration should be given to alternating shallow water emergent vegetated zones with deeper (greater than 1.83 meters or six feet) water zones containing selected submerged vegetation. Deeper water zones provide a completely exposed water surface for atmospheric re-aeration and submerged vegetation provides an additional source of oxygen for nitrification. The deeper water zones will also attract and retain a large variety of wildlife, particularly ducks and other water birds. This concept, in use at Arcata, California, and Minot, North Dakota, can provide excellent treatment on a year-round basis in warm climates and on a seasonal basis in colder climates where low temperatures and ice formation occur. The hydraulic residence time (HRT) in each of the open water zones should be limited to about three days at design flow to prevent the re-emergence of algae. Such systems should always start and end with shallow emergent vegetation zones to ensure retention and treatment of particulate matter and to minimize wildlife toxicity in the open water zones. The use of FWS constructed wetlands has increased significantly since the late 1980's. The systems are widely distributed in the United States and are found in about 32 states.

Common Modifications

In the United States, it is routine to provide some preliminary treatment prior to a FWS wetland. The minimal acceptable level is the equivalent of primary treatment which can be achieved with septic tanks, with Imhoff tanks for smaller systems, or with deep ponds with a short HRT. About 45 percent of operational FWS wetland systems use facultative lagoons for preliminary treatment, but these systems have also been used behind other treatment systems. For example, some of the largest FWS systems, in Florida and Nevada, were designed for tertiary effluent polishing and receive effluent from mechanical AWT plants.

Non-discharging, total retention FWS systems have been used in arid parts of the United States where the water is completely lost through a combination of seepage and evapotranspiration. These systems require that attention be paid to the long term accumulation of salts and other substances which might become toxic to wildlife or plants in the system. While it is impossible to exclude wildlife from FWS wetlands, it is prudent to minimize their presence until the water quality approaches secondary levels of treatment. This can be accomplished by limiting open water zones to the latter part of the system and using dense stands of emergent vegetation in the front part of the wetland. Selecting vegetation with little food value for animals or birds may also help. In colder climates or where large land areas are not available for wetland removal of nitrogen, a smaller wetland system can be designed for BOD/TSS removal. Nitrogen removal can be achieved with a separate process. Wetland systems in Kentucky and Louisiana successfully use an integrated gravel trickling filter for nitrification of wastewater ammonia. Seasonally operated FWS wetlands are also used in very cold climates, in which the wastewater is retained in a lagoon during the winter months and discharged to the wetland at a controlled rate during the warm summer months.

APPLICABILITY

FWS wetlands require a relatively large land area, especially if nitrogen or phosphorus removal is required. The treatment is effective and requires little in the way of mechanical equipment, energy, and skilled operator attention. Wetland systems can be a most cost effective treatment alternative where suitable land is available at reasonable cost. They also provide enhanced habitat and recreational values. Land requirements and costs tend to favor application of FWS technology in rural areas.

FWS wetland systems reliably remove BOD, Chemical Oxygen Demand (COD), and TSS. With a sufficiently long HRT, they can also produce low levels of nitrogen and phosphorus. Metals are also removed and a reduction in fecal coliforms of about a one log can be expected. In addition to municipal wastewaters, FWS systems are used to treat mine drainage, urban storm water, combined sewer overflows, agricultural runoff, livestock and poultry wastes, landfill leachates, and for mitigation purposes. Because the water is exposed and accessible to humans and animals, the FWS concept of receiving partially treated wastewater may not be suited for use in individual homes, parks, playgrounds, or similar public facilities. A gravel bed subsurface flow (SF) wetland is a choice for these applications.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of FWS wetlands are listed below:

Advantages

- FWS wetlands offer effective treatment in a passive manner, minimizing mechanical equipment, energy, and skilled operator requirements.
- FWS wetlands may be less expensive to construct, and are less costly to operate and maintain than conventional mechanical treatment systems.
- Year-round operation for secondary treatment is possible in all but the coldest climates. Year-round operation for advanced or tertiary treatment is possible in warm to moderately temperate climates.
- Wetland systems provide a valuable addition to the “green space” in a community, and include the incorporation of wildlife habitat and public recreational opportunities.
- Wetland systems produce no residual biosolids or sludges requiring subsequent treatment and disposal.
- The removal of BOD, TSS, COD, metals, and persistent organics in municipal wastewaters can be very effective with a reasonable detention time. The removal of nitrogen and phosphorus can also be effective with a significantly longer detention time.

Disadvantages

- The land area required for FWS wetlands can be large, especially if nitrogen or phosphorus removal are required.
- The removal of BOD, COD, and nitrogen are biological processes and essentially continuously renewable. The phosphorus, metals, and some persistent organics removed by the system are bound in the wetland sediments and accumulate over time.

- In cold climates low winter temperatures reduce the rate of removal for BOD and the biological reactions responsible for nitrification and denitrification. An increased detention time can compensate for this, but the increased wetland size required in extremely cold climates may not be cost effective or technically feasible.

- The bulk water in most constructed FWS wetland systems is essentially anoxic, limiting the potential for rapid biological nitrification of ammonia. Increasing the wetland size and, therefore, the detention time, may compensate for this, but may not be cost effective. Alternate methods for nitrification in combination with a FWS wetland have performed successfully.

- Mosquitoes and other insect vectors can be a problem.

- The bird population in a FWS wetland can have adverse impacts if an airport is nearby.

- FWS constructed wetlands can remove fecal coliforms by at least one log from typical municipal wastewaters. This may not be sufficient to meet discharge limits in all locations and supplemental disinfection may be required. The situation is further complicated because birds and other wildlife in the wetland produce fecal coliforms.

DESIGN CRITERIA

Published models for the pollutant removal design of FWS wetland systems have been available since the late 1980's. More recent efforts have produced three textbooks containing design models for FWS wetlands (Reed, et al., 1995; Kadlec & Knight, 1996; Crites & Tchobanoglous, 1998) All three models are based on first order plug flow kinetics but provide different results based on the use of different databases. The Water Environment Federation (WEF) presents a comparison of the three approaches in the Manual of Practice on Natural Systems (WEF, 2000.) Another comparison is found in the U.S. EPA design manual on wetland systems (U.S. EPA, 2000.) This manual also includes design models developed by Gearheart and Finney. The designer of a FWS wetland system should consult these references and select the method best suited for the project under consideration. A preliminary estimate of the land area required for an FWS wetland can be obtained from Table 1 of typical areal loading rates presented below. These values can also be used to check the results from other references.

The pollutant requiring the largest land area for removal determines the necessary treatment area for the wetland, which is the bottom surface area of the wetland cells. The wastewater flow must be uniformly distributed over the entire surface for that area to be 100 percent effective. This is possible with constructed wetlands by careful grading of the bottom surface and the use of appropriate inlet and outlet structures. Uniform distribution of wastewater is more difficult when natural wetlands are used for treatment or polishing. The existing configuration and topography are typically retained in these natural wetlands, which can result in significant short circuiting of flow. Dye tracer studies in such wetlands have shown that the effective treatment area can be as little as 10 percent of the total wetland area. The total treatment area should be divided into at least two cells for all but the smallest systems. Larger systems should have at

TABLE 1 TYPICAL AREAL LOADING RATES

Constituent	Typical Influent Conc. (mg/L)	Target Effluent Conc. (mg/L)	Mass Loading Rate (lb/ac/d)*
Hydraulic Load (in/d)	0.4 - 4**		
BOD	5 - 100	5 - 30	9 - 89
TSS	5 - 100	5 - 30	9 - 100
NH_3/NH_4 as N	2 - 20	1 - 10	1 - 4
NO_3 as N	2 - 10	1 - 10	2 - 9
TN	2 - 20	1 - 10	2 - 9
TP	1 - 10	0.5 - 3	1 - 4

least two parallel trains of cells to provide flexibility for management and maintenance.

Wetland systems are living ecosystems. The life and death cycles of the biota produce residuals which can be measured as BOD, TSS, nitrogen, phosphorus, and fecal coliforms. As a result, regardless of the size of the wetland or the characteristics of the influent, there will always be a residual background concentration of these materials in wetland systems. Table 2 summarizes these background concentrations.

Because removal of BOD and various nitrogen forms is temperature dependent, the temperature of the wetland must be known for proper design. The water temperature in large systems with a long HRT (greater than 10 days) will approach the average air temperature except during subfreezing weather in the winter. Methods to estimate the water temperature for wetlands with a shorter HRT (less than 10 days) can be found in the references cited.

TABLE 2 "BACKGROUND" FWS WETLAND CONCENTRATIONS

Constituent	Concentration Range
BOD_5 (mg/L)	1 - 10
TSS (mg/L)	1 - 6
TN (mg/L)	1 - 3
NH_3/NH_4 as N (mg/L)	< 0.1
NO_3 as N (mg/L)	< 0.1
TP (mg/L)	< 0.2
Fecal Coliforms (MPN/100mL)	50 - 500

Because living plants and litter provide significant frictional resistance to flow through the wetland , it is necessary to consider the hydraulic aspects of system design. Manning's equation is generally accepted as the model for the flow of water through FWS wetlands. Descriptive information is found in the references cited. Flow resistance impacts the configuration selected for the wetland cell: the longer the flow path, the higher the resistance. To avoid hydraulic problems, an aspect ratio (L:W) of 4:1 or less is recommended.

PERFORMANCE

A lightly loaded FWS wetland can achieve the "background" effluent levels shown in Table 2. In general, an FWS constructed wetland is designed to produce a specified effluent quality. Table 1 can be used to estimate the size of the wetland necessary to produce the desired effluent quality. The design models in the referenced publications provide a more precise estimate of required treatment area. Table 3 summarizes actual performance data for 27 FWS systems from a recent Technology Assessment (U.S. EPA, 2000).

In theory, the performance of a wetland system can be influenced by hydrological factors. High evapotranspiration (ET) rates may increase effluent concentrations, but may also increase the HRT in the wetland. High precipitation rates dilute the pollutant concentrations but also shorten the HRT in the wetland. In most temperate areas with a moderate climate, these influences are not critical for performance. Hydrological aspects only need to

TABLE 3 SUMMARY OF PERFORMANCE FOR 27 FWS WETLAND SYSTEMS

Constituent	Mean Influent (mg/L)	Mean Effluent (mg/L)
BOD_5	70	15
TSS	69	15
TKN as N	18	11
NH_3/NH_4 as N	9	7
NO_3 as N	3	1
TN	12	4
TP	4	2
Dissolved P	3	2
Fecal Coliforms (#/100mL)	73,000	1320

Source: U.S. EPA, 2000.

be considered for extreme values of ET and precipitation.

OPERATION AND MAINTENANCE

The routine operation and maintenance (O&M) requirements for FWS wetlands are similar to those for facultative lagoons. They include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing on berms, inspection of berm integrity, wetland vegetation management, mosquito and vector control (if necessary), and routine monitoring.

The water depth in the wetland may need adjustment on a seasonal basis or in response to increased resistance from the accumulating plant litter in the wetland channel. Mosquitoes may require control, depending on local conditions and requirements. The mosquito population in the treatment wetland should be no greater than in adjacent natural wetlands.

Vegetation management in FWS wetlands does not include the routine harvest and removal of the harvested material. Plant uptake of pollutants represents a relatively minor pathway, so harvest and removal on a routine basis does not provide a significant treatment benefit. Removal of accumulated litter may become necessary if there are severe restrictions to flow. Generally, this will only occur if the wetland channels have been constructed with very high aspect ratios (L:W > 10:1). Vegetation management may also include wildlife management, depending on the type of vegetation selected for the system. Animals such as nutria and muskrats have been known to consume all emergent vegetation in FWS constructed wetlands.

Routine water quality monitoring is required for all FWS systems with an NPDES permit. The permit specifies the monitoring requirements and frequency of monitoring. Sampling for NPDES monitoring is usually limited to untreated wastewater and the final system effluent. Since the wetland component is usually preceded by some form of preliminary treatment, the routine monitoring program does not document wetland influent characteristics. Periodic samples of the wetland influent should be obtained and tested for all but the smallest systems to provide the operator with an understanding of wetland performance and a basis for adjustments, if necessary.

COSTS

The major items included in the capital costs for FWS wetlands are similar to those for lagoon systems, including land, site investigation, site clearing, earthwork, liner, rooting media, plants, inlet and outlet structures, fencing, miscellaneous piping, engineering, legal, contingencies, and contractor's overhead and profit. The liner can be the most expensive item. For example, a plastic membrane liner can approach 40 percent of construction costs. In many cases, compaction of the in-situ native soils provides a sufficient barrier for groundwater contamination. Table 4

TABLE 4 CAPITAL AND O&M COSTS FOR 100,000 GAL/D FWS WETLAND

Item	Cost ($)*	
	Native Soil Liner	Plastic Membrane Liner
Land Cost	16,000	16,000
Site Investigation	3,600	3,600
Site Cleaning	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Soil Planting Media	10,600	10,600
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	98,000	164,000
Engineering, legal, etc.	56,800	95,100
Total Capital Cost	154,800	259,100
O&M Costs ($/year)	6,000	6,000

* June 1999 Costs, ENR CCI = 6039

Source: Water Environment Federation, 2000.

summarizes capital and O&M costs for a hypothetical 378,500 liters per day (100,000 gallon per day) FWS constructed wetland, required to achieve a 2 mg/L ammonia concentration in the effluent. Other calculation assumptions include the following: influent NH_3 = 25 mg/L; water temperature = 20°C (68°F); water depth = 0.46 meters (1.5 ft); porosity = 0.75; treatment area = 1.3 hectares (3.2 ac); and land cost = $12,355/hectare ($5,000/ac).

Table 5 compares the life cycle costs for this wetland to the cost of a conventional sequencing batch reactor (SBR) treatment system designed for the same flow and effluent water quality.

TABLE 5 COST COMPARISON FOR FWS WETLAND AND CONVENTIONAL WASTEWATER TREATMENT

Cost Item	Process	
	Wetland	SBR
Capital Cost ($)	259,000	1,104,500
O&M Cost ($)	6,000/yr	106,600/yr
Total Present Worth Costs* ($)	322,700	2,233,400
Cost per 1000 gal treated ** ($)	0.44	3.06

*Present worth factor 10.594 based on 20 years at 7 percent interest

**Daily flow rate for 365 d/yr for 20 yr, divided by 1000 gal.

Source: Water Environment Federation, 2000.

REFERENCES

Other Related Fact Sheets

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http://www.epa.gov/owmitnet/mtbfact.htm

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Wastewater Technology Fact Sheet

The Living Machine®

DESCRIPTION

The Living Machine® is an emerging wastewater treatment technology that utilizes a series of tanks, which support vegetation and a variety of other organisms. The Living Machine® was conceived by Dr. John Todd, President of the non-profit organization Ocean Arks International, and gets its name from the ecologically-based components that are incorporated within its treatment processes (microorganisms, protozoa, higher animals such as snails, and plants). The Living Machine® has sometimes been referred to as the "*Advanced Ecologically Engineered System*" or AEES. The Living Machine® is now designed and marketed by Living Machines, Inc. of Taos, New Mexico.

The Living Machine® is a second generation design. Dr. Todd developed the Living Machine™ design concept after working on a number of similar small pilot-scale facilities, now referred to as Solar Aquatics™ and marketed by Ecological Engineering Associates of Marion, Massachusetts.

The Living Machine® incorporates many of the same basic processes (e.g., sedimentation, filtration, clarification, adsorption, nitrification and

Source: U.S. EPA., 2001.

FIGURE 1 THE OPEN AEROBIC TANKS OF THE LIVING MACHINE® IN SOUTH BURLINGTON, VT

denitrification, volatilization, and anaerobic and aerobic decomposition) that are used in conventional biological treatment systems. What makes the Living Machine® different from other systems is its use of plants and animals in its treatment process, and its unique aesthetic appearance. While these systems are aesthetic appealing, the extent to which the plants and animals contribute to the treatment process in current Living Machine® designs is still being verified (U.S. EPA, 2001). In temperate climates, the process is typically housed within a large greenhouse, which protects the process from colder temperatures.

Living Machines, Inc. describes the Living Machine® as being a wastewater treatment system that:

- Is capable of achieving tertiary treatment;
- Costs less to operate than conventional systems when used to achieve a tertiary level of treatment; and
- Doesn't typically require chemicals that are harmful to the environment" as a part of its treatment process (Living Machines, Inc., 2001).

Several federally-funded Living Machine® demonstration systems have been constructed, the largest of which handled design flows of up to 80,000 gpd. As configured for these demonstrations, these systems treated municipal wastewaters at various strengths, and reliably produced effluents with five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L (U.S. EPA, 2001 and see Table 1). With regard to phosphorus removal, the Living Machine® process is capable of about 50 percent removal with influents within the 5-11 mg/L range (U.S. EPA, 2001). In addition to the demonstration projects, the Living Machine® technology is being used by a variety of municipal and industrial clients, where similar performance has been reported.

Treatment Process

A typical Living Machine® comprises six principle treatment components, after influent screening. In process order (see Figure 1), these are (1) an anaerobic reactor, (2) an anoxic tank, (3) a closed aerobic reactor, (4) aerobic reactors, (5) a clarifier, and (6) "ecological fluidized beds" (EFBs). While the open aerobic reactors and EFBs are found in almost all Living Machines®, the other components are not always utilized in the treatment process. The specific components used are selected by the designers depending upon the characteristics of the wastewater to be treated and the treatment objectives. Sometimes additional process components may be added if considered necessary by the designers. For example, the demonstration system in Frederick, Maryland utilized a "Final Clarifier" and a high-rate subsurface flow (SF) wetland as the last two components of its treatment train.

Anaerobic Reactor (Step 1)

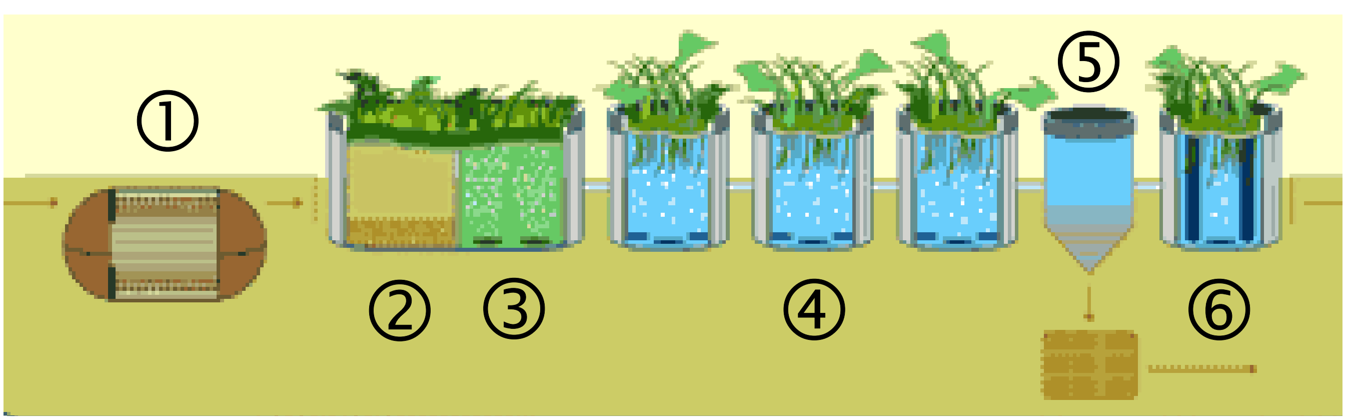
When it is employed, the anaerobic reactor serves as the initial step of the process. The reactor is similar in appearance and operation to a septic tank, and it is usually covered and buried below grade. The main purpose of the anaerobic reactor is to reduce the concentrations of BOD_5 and solids in the wastewater prior to treatment by the other components of the process. When necessary, gases are passed through an activated carbon filter to control odor.

Raw influent enters the reactor, which acts as a primary sedimentation basin. Some of the anaerobic reactors used have an initial sludge blanket zone, followed by a second zone for clarification. Additionally, strips of plastic mesh netting are sometimes used in the clarification zone to assist with the trapping and settling of solids, and to provide surface area for the colonization of anaerobic bacteria, which help to digest the solids. Sludge is typically removed periodically via perforated pipes on the bottom of the reactor, and wasted to a reed bed or other biosolids treatment processes. Gasses produced are passed through an activated carbon filter or biofilter for odor control.

Anoxic Reactor (Step 2)

The anoxic reactor is mixed and has controlled aeration to prevent anaerobic conditions, and to encourage floc-forming and denitrifying microorganisms. The primary purpose of the anoxic reactor is to promote growth of floc-forming microorganisms, which will remove a significant portion of the incoming BOD_5.

Mixing is accomplished through aeration by a coarse bubble diffuser. These diffusers are typically operated so that dissolved oxygen is maintained



Source: Living Machines Inc., 2001.

FIGURE 1 THE COMPONENTS OF THE LIVING MACHINE®: (1) ANAEROBIC REACTOR, (2) ANOXIC REACTOR, (3) CLOSED AEROBIC REACTOR, (4) OPEN AEROBIC REACTORS, (5) CLARIFIER, AND (6) "ECOLOGICAL FLUID BED"

below 0.4 mg/L. The space over the reactor is vented through an odor control device, which is usually a planted biofilter. Additionally, an attached growth medium can be placed in the compartment to facilitate growth of bacteria and microorganisms.

Settled biosolids from the clarifier (Step 5), and nitrified process water from the final open aerobic reactor (Step 4) are recycled back into this reactor. The purpose of these recycles is to provide sufficient carbon sources to the anoxic reactor to support denitrification without using supplemental chemicals, such as methanol.

Closed Aerobic Reactor (Step 3)

The purpose of the closed aerobic reactor is to reduce the dissolved wastewater BOD_5 to low levels, to remove further odorous gases, and to stimulate nitrification.

Aeration and mixing in this reactor are provided by fine bubble diffusers. Odor control is again achieved by using a planted biofilter. This biofilter typically sits directly over the reactor and is planted with vegetation intended to control moisture levels in the filter material.

Open Aerobic Reactors (Step 4)

Next in the process train are the open aerobic reactors, or aerated tanks. They are similar to the closed aerobic reactor in design and mechanics (i.e., aeration is provided by fine bubble diffusers); however, instead of being covered with a biofilter, the surfaces of these reactors are covered with vegetation supported by racks. These plants serve to provide surface area for microbial growth, perform nutrient uptake, and can serve as a habitat for beneficial insects and microorganisms. To what extent the plants enhance the performance treatment process in the Living Machine® is still being verified (U.S. EPA, 2001). However, with the variety of vegetation present in these reactors, these units (along with the Ecological Fluidized Beds - Step 6) set the Living Machine® apart from other treatment systems in terms of their unique appearance and aesthetic appeal.

The aerobic reactors are designed to reduce BOD_5 to better than secondary levels and to complete the process of nitrification. The size and number of these reactors used in a Living Machine® design are determined by influent characteristics, effluent requirements, flow conditions, and the design water and air temperatures.

Clarifier (Step 5)

The clarifier is basically a settling tank that allows remaining solids to separate from the treated wastewater. The settled solids are pumped back to the closed aerobic reactor (Step 3), or they are transferred to a holding tank, and then removed for disposal. The surface of the clarifier is often covered with duckweed, which prevents algae from growing in the reactor.

Ecological Fluidized Beds (Step 6)

The final step in the typical Living Machine® process are the "ecological fluidized beds" (EFBs). These are polishing filters that perform final treatment of the wastewater, and one to three are used in series to reduce BOD_5, TSS and nutrients meet final effluent requirements.

An EFB consists of both an inner and outer tank. The inner tank contains an attached growth medium, such as crushed rock, lava rock, or shaped plastic pieces. The wastewater flows into the EFB in the annular space between the inner and outer tanks and is raised by air lift pipes to the top of the inner ring that contains the media. The bottom of the inner tank is not sealed, so the wastewater percolates through the gravel media and returns to the outer annular space, from where it is again moved back to the top of the gravel bed. The air lifts also serve to aerate the water and maintain aerobic conditions.

The unit serves as a fixed bed, downflow, granular media filter and separates particulate matter from the water. Additionally, the microorganisms that occupy the granular media surfaces provide any final nitrification reactions.

As sludge collects on the EFB, it reduces its ability to filter. This would eventually clog the bed completely. Therefore, additional aeration diffusers beneath the gravel bed are periodically turned on to create an upflow airlift, reversing the flow direction. This aeration is intended to “fluidize” the bed and release the trapped sludge (hence the name of this unit). This sludge is washed over and accumulated at the bottom of the outer annular space where it can be collected manually, and wasted along with the biosolids from the anaerobic reactor. Consequently, the name “ecological fluidized bed” is somewhat misleading for this unit since, in its treatment mode, it acts like a typical, conventional, downflow coarse media contact filter unit. Only during backwash cleaning does the bed become partially fluidized.

After this last step, the wastewater should be suitable for discharge to surface waters or a subsurface disposal system, or reused for landscape irrigation, toilet flushing, vehicle washing, etc. (Living Machines, Inc., 2001).

APPLICABILITY

The Living Machine® is well suited for treating both municipal and some industrial wastewaters. As with most treatment systems using plants, it can require a larger footprint than more conventional systems, and its requirement for a greenhouse in more temperate climates can impact costs. However, its unique and aesthetically pleasing appearance make it an ideal system in areas that oppose traditional treatment operations based on aesthetics (i.e., smell and appearance). The designers also stress the educational benefits of the Living Machine® (http://www.livingmachines.com/htm/planet2.htm) in raising awareness of wastewater treatment methods and benefits.

ADVANTAGES/DISADVANTAGES

Advantages

- Capable of treating wastewaters to BOD_5, TSS, and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L.

- Offers a unique, aesthetically pleasing environment for treating and recycling wastewater. This may be helpful when attempting to locate the treatment system in areas where the public opposes traditional wastewater treatment operations for aesthetic reasons.

Disadvantages

- The Living Machine® has only been shown to remove about 50 percent of influent phosphorous (with influents in the range of 5-11 mg/L). The removed phosphorus appears to be primarily associated with the incoming solids.

- The process requires a greenhouse for reliable operation in the cold weather of more temperate climates, adding to system costs.

DESIGN CRITERIA

Every Living Machine® system is designed by Living Machines, Inc. based upon the expected wastewater volume and content, as well as the treatment requirements and local climate. Once these factors are known, the designers then determine whether a greenhouse is necessary, what types of reactors are needed, how many of each type of reactor are required, and what capacity is required to achieve the suitable residence times.

PERFORMANCE

The Living Machine® has reliably achieved treatment goals of BOD_5, TSS, and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L. Table 1 shows the results of independent evaluations of two demonstration systems. The Living Machine® demonstration project in Frederick, Maryland was designed to treat 40,000 gpd of screened and degritted wastewater. It employed a single anaerobic reactor for primary solids digestion, then three parallel treatment trains, each comprised of two open aerobic reactors, a clarifier, three “ecological fluidized beds,” a final clarifier, and a small, high-rate subsurface flow wetland. The demonstration project located in South Burlington, Vermont was designed to treat 80,000 gpd of screened and degritted wastewater,

TABLE 1 PERFORMANCE OF THE FREDERICK AND BURLINGTON LIVING MACHINES®

Parameter	FREDERICK Influent mg/L	GH Influent mg/L[a]	Effluent mg/L	% Removal	BURLINGTON Influent mg/L	Effluent mg/L	% Removal	Effluent Goal
BOD_5	230	156	4	97	227	5.9	97	<10
COD	944	378	21	94	556	35.9	94	--
TSS	381	70	2	97	213	5.3	98	<10
NH_3	-	22	1.2	94	16.3	0.4	98	<1
NO_3	-	20.8	10	52	15.9[b]	4.9	69	<5
TN (total nitrogen)	-	44	11	75	29.3	5.6	81	<10
TP (total phos-phorus)	11	7.7	6	45	6.0	2.0	67	<3

a Effluent from the anaerobic reactor at Frederick into the reactors contained within the greenhouse.
b Assumes that all removed ammonia is converted to nitrate.

Source: U.S. EPA, 2001.

and employed five open aerobic reactors (though one of these was later converted to an anoxic reactor), a clarifier, and three "ecological fluidized beds."

In these instances, the Living Machine® was capable of BOD_5 and TSS removal in excess of 95 percent. While the Frederick system did not consistently achieve its goal of < 5 mg/L for Nitrate, the Burlington Living Machine® did. The Living Machine® reliably demonstrated about 50 percent removal of Total Phosphorous (TP), although the Burlington system had a low influent TP concentration (U.S. EPA, 2001).

While the Frederick Living Machine® achieved quite good coliform removal (< 200 MPN/100mL), the Burlington system's effluent was above 1,000 MPN/100mL. Consequently, disinfection may be required as an additional step depending upon system configuration and effluent requirements.

OPERATION AND MAINTENANCE

Routine Activities

The routine operation and maintenance (O&M) requirements for Living Machines® are similar to the requirements for a conventional wastewater treatment plant, with a few additional requirements. These additional requirements include cleaning the inlet/outlet structure; cleaning the screen and tank; removing and disposing sludge; and maintaining and repairing machinery. Other requirements are vegetation management, including routine harvesting to promote plant growth, and removal of accumulated plant litter. Additionally, it may be necessary to manage fish and snail populations, and control mosquitoes and flies (if applicable).

Residuals Management

The Living Machine® produces residuals comparable in quantity to conventional treatment systems. However, some of these residuals are biosolids, while others are in the form of plant

TABLE 2 PRESENT WORTH COMPARISON OF "LIVING MACHINES®" AND CONVENTIONAL SYSTEMS

Process	40,000 gpd	80,000 gpd	1 million gpd
"Living Machine" with greenhouse	$1,077,777[1]	$1,710,280[1]	$10,457,542[2]
"Living Machine" without greenhouse	$985,391	$1,570,246	$9,232,257
Conventional System	$1,207,036[1]	$1,903,751[1]	$8,579,978[2]

(1) Cost difference is less than 20 percent
(2) Cost difference is greater than 20 percent

Source: U.S. EPA, 2001.

material. Analyses at the Frederick demonstration system showed that plant residuals could be composted and used for many agricultural or horticultural purposes. The biosolids would likely require stabilization and treatment to reduce pathogens and indicator organisms before they would meet Part 503 limits for sewage sludge (U.S. EPA, 2001).

COSTS

Since the Living Machine® is designed, marketed and trademarked by Living Machines, Inc., precise cost data are proprietary. However, a cost comparison with "conventional" treatment systems was performed as a part of an independent U.S. EPA evaluation of the Living Machines® (U.S. EPA, 2001). Table 2 summarizes the results of this cost comparison.

This analysis concluded that Living Machines® are typically cost competitive with more conventional wastewater treatment systems at flow volumes up to 1,000,000 gpd, if they are located in a warm climate where a greenhouse is not necessary. However, if the climate cannot support the plants year-round and a greenhouse must be constructed, construction costs will increase. Addition of a greenhouse structure makes the Living Machine® cost competitive with more conventional systems up to flow rates of around 600,000 gpd.

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Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owm/mtb/mtbfact.htm

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Rural Wastewater

EXPERT REVIEWED

Recirculating Vertical Flow Constructed Wetlands for Treating Residential Wastewater

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William Grant, LaGrange County Health Department • Mark Harrison, Bernardin-Lochmueller

In parts of the United States where soils are very permeable, conventional septic tank and absorption field systems are considered the largest contributor to waterborne disease and pollution of water bodies. However, an economical, recirculating vertical flow (RVF) constructed wetland, used as a pretreatment system, can significantly improve the performance of conventional onsite wastewater treatment systems while requiring relatively little space.

RVFs have been used in the United States for many years, but their use as a treatment for residential wastewater is relatively new. The first RVF was installed in Indiana in LaGrange County in 2001. Five were in place in the state, and all were performing well in 2007.

Residential Use

Homeowners faced with space limitations (such as around lakes), located in subdivisions without sanitary sewers, or confronted by replacement or recovery of failing septic systems should benefit from RVF constructed wetlands. They should place the RVF wetland after the septic tank and before final soil treatment and dispersal (conventional leach field, mound system, drip irrigation, or other approved soil absorption system). An RVF wetland's relatively small footprint and high degree of treatment should improve the performance of the soil absorption system by minimizing the amount of solids and nutrients entering the soil infiltration system. In some cases, county and state codes may even permit a smaller soil infiltration area because of the high level of treatment.

Design

The size of the RVF constructed wetland (Figure 1a and 1b) should be based on the expected gallons per day (GPD) of sewage produced, as determined by Indiana State Department of Health (ISDH) rules. The recommended design parameters for individual residences are in Table 1.

Table 1. *Sizing recommended for RVF in Indiana.*

Residence	Wastewater	Septic Tank	RVF Constructed Wetland
Bedrooms (#)	Daily Flow (Gallons Per Day)	Size Volume (Gallons)	Cell Size (Feet)
1	150	1000	8.5 x 8.5
2	300	1000	12 x 12
3	450	1000	15 x 15
4	600	1250	17 x 17
5	750	1500	19 x 19

As a general guideline, the minimum cell size of the RVF constructed wetland is based on 0.48 ft^2 of surface area per gallon of sewage treated daily. The constructed wetland cell is from 42–48 in deep, and it is square (Figure 1a and 1b, see page 2).

Construction

As in a conventional septic system, a home's wastewater should first collect in a septic tank with a solids retention-time of at least 48 hours and with an effluent filter installed at the tank outlet (Figure 2, see page 3). The septic tank overflow should direct effluent to the inlet at the bottom gravel layer of the RVF constructed wetland. Across the bottom of the wetland, place a 4-in diameter, two-row PVC perforated pipe with holes in the 4 and 8 o'clock positions or a three-row pipe with holes at the 4, 8, and 12 o'clock positions. In early designs, a PVC perforated pipe was also placed at both the inlet and outlet ends of the gravel to distribute and then collect the effluent after it traveled through the gravel layer at the bottom of the wetland. More recently, plastic soil absorption chambers (often used in place of septic stone in absorption trenches) have been used as an inlet

Figure 1a. *Cross sectional view of a Recirculating Vertical Flow (RVF) Constructed Wetland.*

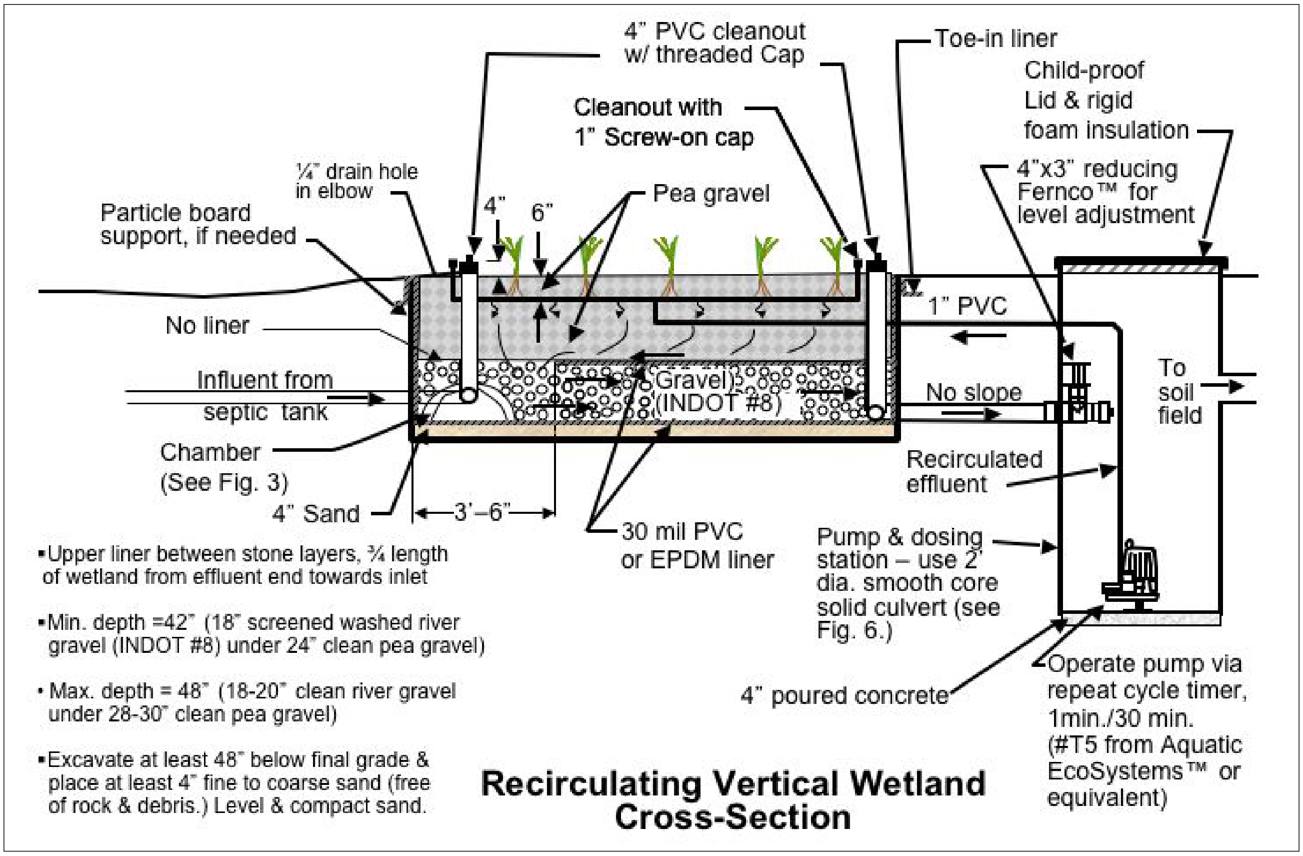


Figure 1b. *Top sectional plan view of a RVF Constructed Wetland.*

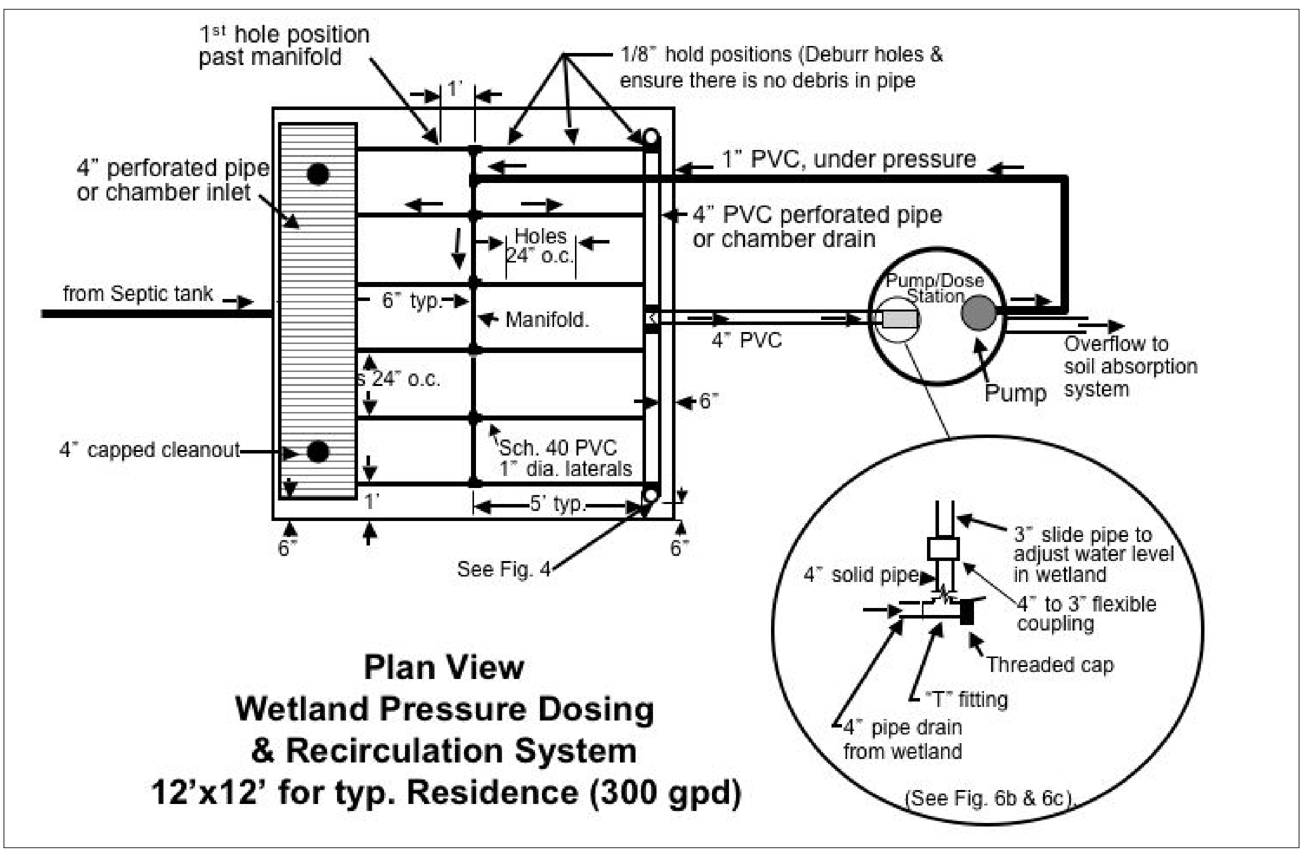


Figure 2. *Effluent filter in place at the septic tank outlet.*

manifold to distribute effluent across the width of the RVF and have been found to work as well as or better than perforated pipe (Figure 3). Chambers can hold more than traditional 4-in diameter manifold pipes and their innovative design facilitates periodic cleanout. In Indiana, the Indiana State Department of Health currently approves plastic chambers from several providers. The outlet manifold uses regular perforated 4-in sewer pipe (Figure 4).

Figure 3. *Wetland cell using a plastic chamber as an inlet-end manifold and 4" PVC pipe as an outlet-end manifold with clean-outs.*

To begin construction, line an appropriately sized, excavated area with a 30-mil geomembrane PVC liner or comparable impermeable material such as a 45-mil EPDM (Ethylene Propylene Diene Monomer) rubber sheet. Cover the impermeable liner and inlet/outlet manifolds with a layer of 13–25 mm (1/2–1 in) diameter gravel. Then, place a second layer of impermeable material (PVC or EPDM) over most of the top area of the gravel to separate the aerobic from the anaerobic sections of the RVF wetland, leaving the 25% of the bottom gravel layer nearest the wetland inlet uncovered (Figure 5).

Figure 4. *Collection 4" PVC manifold at the outlet end of the wetland.*

Next, put a top layer of 4-mm (1/4-in) diameter gravel (pea gravel) over the membrane and gravel. Position a set of perforated pressure-distribution lines about 6 in deep in the top of the pea gravel layer to uniformly load the wetland with effluent.

Effluent overflowing the septic tank, as well as treated effluent that has passed through the top portion of the wetland, passes through the gravel at the bottom of the wetland and drains to the sump basin.

Figure 5. *Upper or second liner covering 75% wetland cell.*

The sump basin consists of a 5-ft long section of 24-in diameter black corrugated drain tile, installed vertically (Figure 6a). Pour concrete in and around the bottom of the sump basin to seal the tile and prevent the entry of ground water and the outward seepage of effluent into the surrounding ground. Fit the top of the sump basin with a secure, insulated plastic or concrete cover. Position the bottom of the sump below frost line to prevent freezing. The sump basin holds the recirculation pump (Figure 6b), which distributes the effluent over the top of the wetland; the wetland water level adjustment mechanism (Figure 6c), which consists of a 4-in PVC “T” with end screw cap; and a 4 x 3-in PVC-to-PVC flexible sewer coupler reducer and 3-in PVC pipe at the top to adjust and maintain the water level. The water level in the wetland is normally set around 20 inches above the wetland bottom. An electronic repeat cycle timer (Figure 7) controls the effluent pump.

Figure 6a. *Sump basin station using 24" drain tile.*

Figure 6b. *Sump basin station showing pump, water level adjustment, and quick disconnector to service the pump.*

Figure 6c. *Wetland water level adjustment showing the PVC to PVC 4" x 3" flexible sewer couple reducer.*

Figure 7. *Electronic repeat cycle timer.*

Every 30 minutes, the timer activates the pump for a 2-minute cycle to pressurize a 1-in PVC manifold and perforated distribution pipe and to distribute effluent uniformly across the top pea gravel layer. The pressure distribution system consists of a closed piping network using 1-in diameter PVC lateral pipes fed through a manifold by the cycle pump. Place the laterals no more than 2 ft apart with equally spaced 1/8-in holes drilled in the top every 2 ft and protected with an orifice shield to disperse the effluent. The orifice shields prevent plugging of 1/8-in openings (Figure 8).

Figure 8. *Recirculating 1" PVC manifold, pressure laterals, and orifice shields.*

Place the last hole (air relief point) in each lateral just ahead of the screw-on cap. The manifold and force-main pipe must drain back to the sump after each cycle. You can drill a ¼-in pressure relief hole in the feed line inside the sump pit to facilitate draining, and use a quick-disconnect pipe coupling to facilitate pump servicing. Completely cover both the manifold and lateral distribution lines with 6 in of pea gravel (Figure 9).

Figure 9. *Pea gravel covering pressure laterals.*

Figure 10. *Finished RVF wetland with regular stone around edges.*

The outside edges of the wetland are typically finished with regular leach field stone (Figure 10) or other locally available material.

Plant the top of the pea gravel layer in rows with river bulrush (*Scirpus fluviatilis*), hard-stemmed bulrush (*Scirpus acutus*), soft-stemmed or great bulrush (*Scirpus validus creber*), prairie cord grass (*Spartina pectinata*), common rush (*Juncus effuses*), dark green rush (*Scirpus atrovirens*), sedges (*Carex spp.*), and great spike rush (*Eleocharis palustris*) with a density of one plant per square foot (Figures 11a and 11b), with a foot separation between rows. These plants have deeper root systems than cattails or bulrushes and function better in constructed wetlands. Wetland flowering plants, such water iris (*Iris virginica*), swamp milkweed (*Asclepias incarnata*), cardinal flower (*Lobelia cardinalis*), swamp rose mallow (*Hibiscus palustris*), great blue lobelia (*Lobelia siphilitica*), and New England aster (*Aster novae-angliae*) can be planted between the sedges and bulrush. Conventional garden plants such as morning glory vines (*Ipomoea leptophylla*), cheddar bath's pinks (*Dianthus gratianopolitanus*) and ferns have also performed well in LaGrange county RVF wetlands (Figure 11c).

Figure 11a. *Wetland immediately after planting.*

Figure 11b. *Wetland two months after planting*

Figure 11c. *Wetland planted with garden plants.*

Figure 12. *Landscaping around the wetland edges.*

Landscaping with low flowering plants and a border around the wetland edge of perennial flowers can create the visual effect of a conventional flower garden (Figure 12). When the system is fully operational, it can be walked on, since the sewage effluent is well below the surface.

Operation

As sewage effluent leaves the septic tank, it enters the inlet manifold at the front of the RVF constructed wetland where it is treated by passing horizontally across the bottom gravel layer. The timer-controlled pump in the sump basin periodically recirculates effluent back to the buried distribution pipe in the top layer of pea gravel. The effluent trickles vertically down through this aerobic upper zone, flows laterally across the impermeable liner separating the two layers of stone, and drops down into the uncovered front portion of the bottom gravel, after which it passes horizontally back to the sump basin. As treated effluent builds up in the sump basin, the pump starts another wetland recirculation cycle (timer is in the "on" position) or if the pump is in the resting cycle (timer is in the "off" position), the overflow effluent is discharged to a conventional leach field, mound sand system, drip irrigation, or other approved soil absorption system.

Maintenance Requirements

Removal of all solids from the septic tank every three to five years is highly recommended to prevent the overflow of solids. Depending on daily water usage or site specific circumstances, the tank effluent filter may require more frequent cleaning service. Ideally, you should check and/or service the filter at least annually to maintain peak performance. Cleaning the effluent filter is very simple and usually just involves hosing the solids off the exterior of the filter with a garden hose back into the septic tank (Figure 13). Wear protective, waterproof gloves when cleaning the filter or performing other maintenance to the onsite system as a safety precaution to ensure you do not directly contact the wastewater, especially if you have open wounds.

When the wetland is first used, some pea gravel can fall down into the larger stone at the uncovered section. If this creates a shallow depression at the top surface, fix the surface by raking the pea gravel to level it.

Green, vegetative leaves should appear in a wetland in Indiana by early spring (April-May), grow vigorously throughout the warmer months, and turn brown in late fall or early winter as the plants enter dormancy. Leave this brown, vegetative material in the RVF constructed wetland during winter, because it provides insulation during the winter months. Old growth can remain in place for several growing seasons, but should be removed after three to four seasons by cutting the plants at ground level.

Figure 13. *To clean a septic tank effluent filter, simply lift it out of the tank and hose it off. Let solids fall back into the tank.*

Pulling them can damage roots of other plants. If you must remove old vegetation, cut it in early spring before new growth appears. *NEVER BURN* old growth in place, since this can damages both growing and dormant plants, and possibly even the liner or PVC distribution pipe. Wetland plants do not require much maintenance, but should be checked annually. Consider a maintenance contract with a local installer to ensure that the pumps, floats, and plants function as intended and that a pump failure or other problems can be repaired quickly.

Expected Performance

When compared to a conventional septic tank and soil absorption system, which discharges 100% of the septic tank effluent contaminants into the

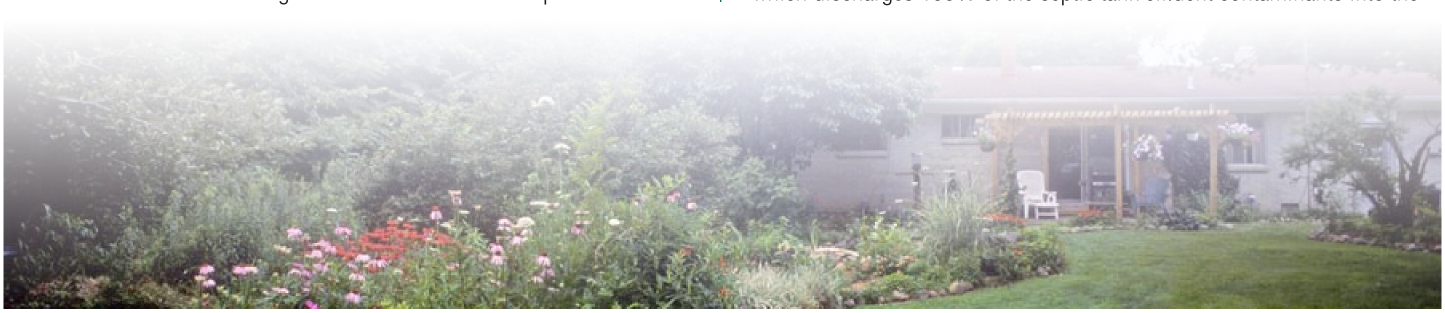


Figure 14a. *Septic tank (left) versus wetland (right) effluent.*

Figure 14b. *Effluent from the RVF constructed wetland installed at the LaGrange County Animal Shelter.*

ground, a well designed, constructed, and maintained RVF constructed wetlands removes up to 99% of the fecal bacteria (*E. coli*) and 80%–99% of other contaminants even before the effluent is discharged to the soil absorption field (Figures 14a and 14b). The physical, chemical, and biological treatment processes, and the alternating aerobic (oxygen is present) and anaerobic (oxygen is not present) environments created in the constructed wetland layers should destroy most pathogens and remove most contaminants. While unusual, the first RVF constructed wetland installed in LaGrange county in 2001 has not discharged effluent to the conventional absorption field during the last three years (2005–2007) because of water uptake by the plants, the evapo-transpiration process, and the low occupancy of the three-bedroom home (only two people present).

Figure 15 shows water quality performance of three RVF constructed wetlands regularly monitored in LaGrange County over the past seven years. The first Lagrange County residential RVF constructed wetland was designed for 450 GPD, with a wetland size cell of 15 x15 ft. For specific details about this system and its water quality performance go to the following Internet Web page: http://www.nesc.wvu.edu/nsfc/Articles/SFQ/SFQ_f06_PDF/Juried2.pdf.

The LaGrange County Animal Shelter was designed to treat 480 GPD using a 20 x 20-ft wetland cell, and the Brushy Prairie wetland received wastewater from a poultry processing plant generating 1600 GPD. It is designed with two 26 x 26-ft cells.

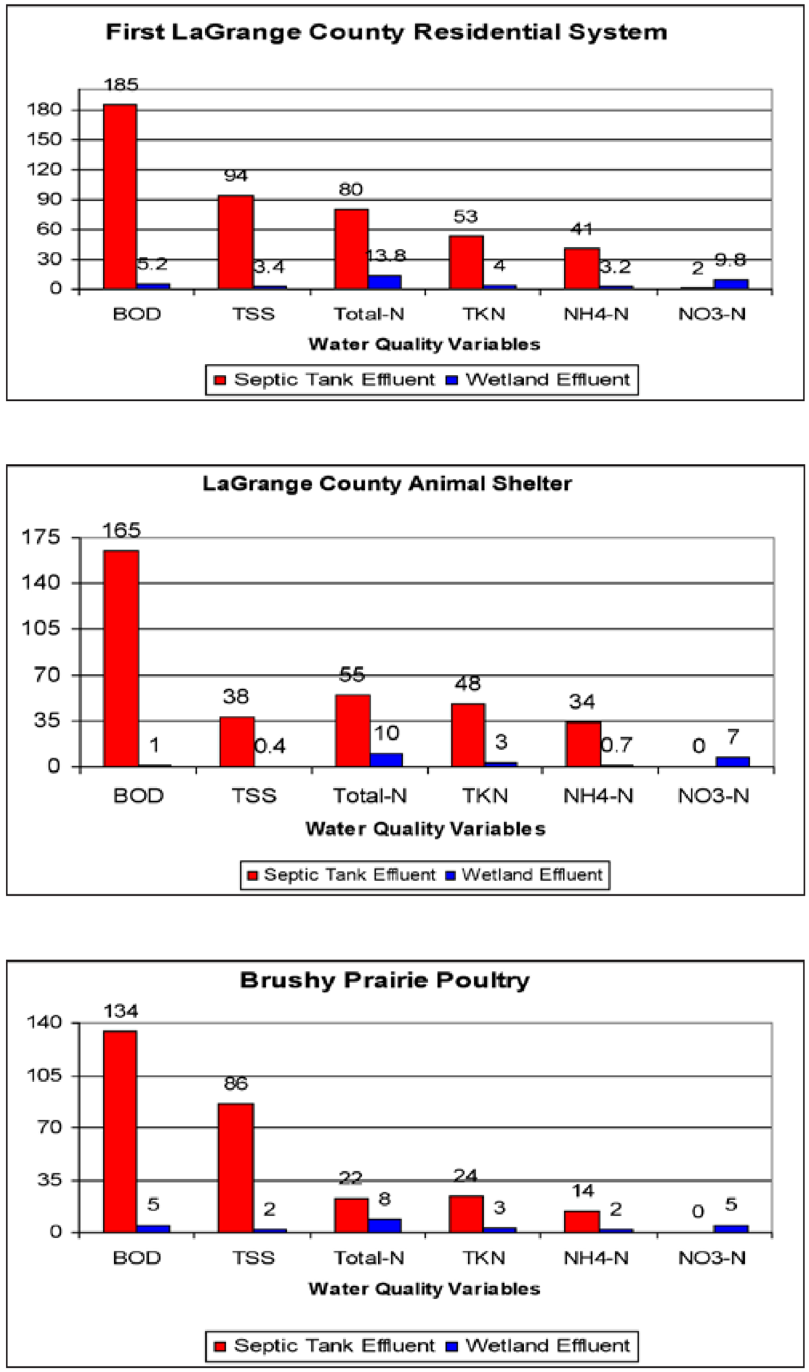


Figure 15. RVF constructed wetlands water quality performance. *Biochemical Oxygen Demand (BOD) measures the decomposition of organic material and Total Soluble Solids (TSS) measures the removal of particulate material suspended in the sewage. Total Kjeldahl Nitrogen (TKN) is the sum of Ammonia Nitrogen (NH3) plus organic Nitrogen, such as proteins. Total Nitrogen (TN) is the sum of all nitrogen forms present in the effluent [TKN + NO2–. (Nitrite) + and NO3– (Nitrate)]. Fecal Coliform bacteria testing is an indicator that other more dangerous bacteria could be present.*

Costs

The cost for an RVF constructed wetland depends on a number of local factors, such as availability of distributors, type of final disposal system, local labor and material costs, time of the year, and installer experience. It also depends on distance from a local gravel pit, capital costs, plant availability, and regulatory compliance.

The first RVF constructed wetland was installed in LaGrange County at a home with space limitations where the existing system needed to be upgraded. At that time (2001), the cost was about $3,000 for both the constructed wetland and 300 square feet of soil absorption area. The existing 1000-gal septic tank was used in the new system, and all work was done by the property owner. The RVF constructed wetland at the LaGrange County Animal Shelter, completed more recently, cost fifteen thousand dollars ($15,000), including construction by a licensed installer, but the system was considerably larger. It consisted of two 1000-gal septic tanks, a 20 x 20 x 4-ft deep RVF wetland, a dosing pump station (1000-gal tank) and a subsurface drip irrigation soil absorption system (2400 ft^2) as well as electronic controllers, two pumps, plumbing material and labor. In LaGrange County, the average 2007 cost for an RVF constructed wetland for a three-bedroom home (15 x 15 x 4 ft) was around $4,000 including installation, plus the cost of the septic tank and soil absorption field.

Legal Requirements and Restrictions

Proper authorization, as required by state and local regulations, must be obtained before installation of an RVF constructed wetland. In Indiana, the State Department of Health regulations consider constructed wetlands as experimental systems at this point and as such, state-level approval will be approved in most counties.

Summary

Recirculating, vertical flow constructed wetlands are sometimes defined as vegetated recirculating gravel filters. They treat wastewater by passing sewage through the constructed wetland where it is filtered through the gravel media in the bottom layer and then recirculated back around the roots and rhizomes several times for more filtration and treatment before it is finally discharged to the soil absorption area. This simple sewage treatment system is a reasonable, economical, and effective alternative to conventional wastewater treatments with low maintenance requirements.

PURDUE AGRICULTURE

New 01/08

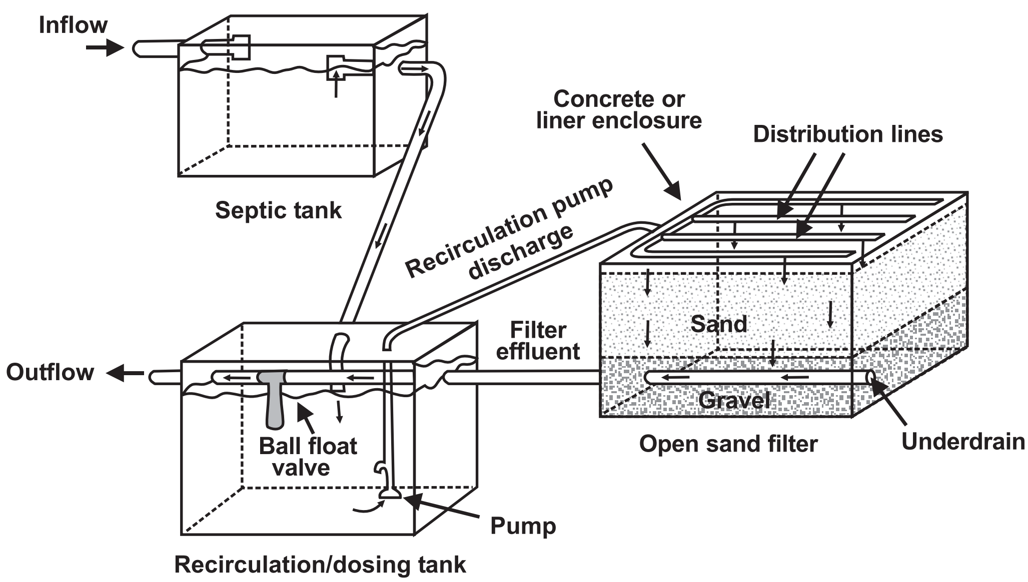
Onsite Wastewater Treatment Systems Technology Fact Sheet 11

Recirculating Sand/Media Filters

Description

Recirculating filters using sand, gravel, or other media provide advanced secondary treatment of settled wastewater or septic tank effluent. They consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system (see figure 1). The wastewater is dosed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system. The underdrain system collects and recycles the filter effluent to the recirculation tank for further processing or discharge.

Figure 1. Typical recirculating sand filter system



Recirculating sand filters (RSFs) are aerobic, fixed-film bioreactors. Other treatment mechanisms that occur in sand filters include physical processes, such as straining and sedimentation, that remove suspended solids within the pores of the media. Also, chemical sorption of pollutants onto media surfaces plays a finite role in the removal of some chemical (e.g., phosphorus) constituents. Bioslimes from the growth of microorganisms develop as films on the sand particle surfaces. The microorganisms in the slimes absorb soluble and colloidal waste materials in the wastewater as it percolates over the sand surfaces. The absorbed materials are incorporated into a new cell mass or degraded under aerobic conditions to carbon dioxide and water.

Most biochemical treatment occurs within approximately 6 inches of the filter surface. As the wastewater percolates through this layer, suspended solids and carbonaceous biochemical oxygen demand (BOD) are removed. Most suspended solids are strained out at the filter surface. The BOD is nearly completely removed if the wastewater retention time in the sand media is sufficiently long for the microorganisms to absorb waste constituents. With depleting carbonaceous BOD in the percolating wastewater, nitrifying microorganisms are able to thrive deeper in the surface layer, where nitrification will readily occur.

Chemical adsorption can occur throughout the media bed. Adsorption sites in the media are usually limited, however. The capacity of the media to retain ions depends on the target constituent, the pH, and the mineralogy of the media. Phosphorus is one element of concern that can be removed from wastewater in this manner, but the number of available adsorption sites is limited by the characteristics of the media.

The basic components of recirculating filters include a recirculation/dosing tank, pump and controls, distribution network, filter bed with an underdrain system, and a return line. The return line or the underdrain must split the flow to recycle a portion of the filtrate to the recirculation/dosing tank. A small volume of wastewater and filtrate is dosed to the filter surface on a timed cycle 1 to 3 times per hour. Recirculation ratios are typically between 3:1 and 5:1. In the recirculation tank, the returned aerobic filtrate mixes with the anaerobic septic tank effluent before being reapplied to the filter.

Recirculating filters must use a coarser media than single-pass filters because recirculation requires higher hydraulic loadings. Both coarse sand and fine gravel are used as filter media. Because of the high hydraulic conductivities of the coarse media, filtrate recirculation is used to provide the wastewater residence times in the media necessary to meet the treatment requirements. Based on forward flow, daily hydraulic loadings are typically about 3 gpd/ft^2 (2 to 5 gpd/ft^2) when the filter media is coarse sand. Therefore, the corresponding combined daily filter hydraulic loading, including the recirculated flow, may be 6 to 25 gpd/ft^2. Where gravel is used as the media, the daily hydraulic loadings are increased to as much as 10 to 15 gpd/ft^2 with a combined daily loading of 30 to 75 gpd/ft^2. BOD and TSS removals are generally the same as those achieved by single-pass filters. Nearly complete ammonia removal by nitrification is also achieved. In addition, the mixing of the return filtrate anaerobic septic tank effluent removes approximately 50 percent of the total nitrogen. However, because of the greater hydraulic loadings and coarser media, fecal coliform removal is somewhat less than in single-pass filters.

Recirculating filters offer advantages over single-pass filters. Greater control of performance is possible because recirculation ratios can be changed to optimize treatment. The filter can be smaller because of the higher hydraulic loading. Recirculation also reduces odors because the influent wastewater (septic tank effluent) is diluted with return filtrate that is low in BOD and high in dissolved oxygen.

Many types of media are used in packed-bed filters. Washed, graded sand was the most common, but pea gravel has generally replaced it in recent times. Other granular media used include crushed glass, garnet, anthracite, plastic, expanded clay, expanded shale, open-cell foam, extruded polystyrene, and bottom ash from coal-fired power plants. Coarse-fiber synthetic textile materials are also used. These materials are generally restricted to proprietary units. Contact the system manufacturers for application and design using these materials.

Other modifications to the basic RSF design include the type of distribution system, the location and design of the recirculation tank, the means of flow splitting the filtrate between discharge and return flows, and enhancements to improve nitrogen removal. The last is addressed in Technology Fact Sheet 9 on nitrogen removal.

Applications

Recirculating sand filters can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities. They are frequently used to pretreat wastewater prior to subsurface infiltration on sites where soil has insufficient unsaturated depth above ground water or bedrock to achieve adequate treatment. They are also used to meet water quality requirements before direct discharge to a surface water. RSFs are primarily used to treat domestic wastewater, but they have also been used successfully in treatment trains to treat wastewaters high in organic materials such as those from restaurants and supermarkets. Single-pass filters are most frequently used for smaller applications and at sites where nitrogen removal is not required. Recirculating filters are used for both large and small flows and are frequently used where nitrogen removal is necessary. RSFs frequently replace aerobic package plants in many parts of the country because of their high reliability and lower O/M requirements.

Design

Packed-bed filter design starts with the selected media. The media characteristics determine the necessary filter area, dose volumes, and dosing frequency. Availability of media for a specific application should be determined before completing the detailed design. Typical specifications, mass loadings, and depths for sand and gravel media are presented in chapter 4. The sand or gravel selected should be durable with rounded grains. Only washed material should be used. Fine particles passing the U.S. No. 200 sieve (<0.074 mm) should be limited to less than 3 percent by weight. Other granular media are bottom ash, expanded clay, expanded shale, and crushed glass. These media should perform similarly to sand and gravel for similar effective sizes, uniformity, and grain shape. Newer commercial media such as textile materials have had limited testing, but should be expected to perform as well as the above types.

Traditionally, media filters have been designed based on hydraulic loadings. However, since they are primarily aerobic biological treatment units, it is more appropriate that they be designed based on organic loadings. Unfortunately, insufficient data exist to establish well-defined organic loading rates. Experience suggests that BOD_5 loadings on sand media should not exceed about 5 lb/1000 ft^2 per day (0.024 kg/m^2 per day) where the effective size is approximately 1.0 mm and the dosing rate is at least 12 times per day. Higher loadings have been measured in short-term studies, but designers are cautioned about exceeding this loading rate until quality-assured data confirm these higher levels. The BOD_5 loading should decrease with decreasing effective size of the sand. Because of the larger pore size and greater permeability, gravel filters can be loaded more heavily. BOD_5 loadings of 20 lb/1000 ft^2 per day (0.10 kg/m^2 per day) have been consistently successful, but again higher loadings have been measured. Some often-quoted design specifications for RSFs are given in table 1.

Table 1. Typical design specifications for individual home recirculating sand filters

Design parameter	Typical design value
Median	Durable, washed sand/gravel with rounded grains
Specifications	
Effective size	
Sand	1.0 – 5.0 mm
Gravel	3.0 – 20.0 mm
Uniformity coefficient	< 2.5
Percent fines (passing 200 sieve or < 0.074 mm)	≤ 3
Depth	24 in. (18 to 36 in.)
Mass loadings	
Hydraulic loading [1]	
Sand	3 -5 gpd/ft^2
Gravel	10 –15 gpd/ft^2
Organic loading [2]	
Sand	≤ 5 lb BOD_5/1000ft^2-d
Gravel	≤ 15 lb BOD_5/1000ft^2-d
Underdrains	
Type	Slotted or perforated pipe
Slope	0 – 0.1%
Transition bedding	0.6 – 1.0 cm washed pea gravel
Size	0.6 – 4.0 cm washed gravel or crushed stone
Dosing	
Frequency	48 times/day (every 30 min.) or more
Per Dose	1 to 2 gal./orifice
Recirculation tank	
Volume	1.5 times design daily flow
Recirculation rate	3 to 5 times daily flow

[a] 1 gpd/ft^2 = 4 cm/day = 0.04 m^3 / m^2 per day (forward flow only).
[b] 1 lb BOD/1,000 ft^2 per day = 0.00455 kg/m^2 per day.

The RSF dose volume depends on the recirculation ratio, dosing frequency, and distribution network:

Dose Volume = Design Flow (gpd) x (Recirculation Ratio + 1) ÷ Number of Doses/Day

Small dose volumes are preferred because the flow through the porous media will occur under unsaturated conditions with higher moisture tensions. Better wastewater media contact and longer residence times occur under these conditions. Smaller dose volumes are achieved by increasing the number of doses per day.

The recirculation ratio increases the hydraulic loading without increasing the organic loading. For example, a 4:1 recirculation ratio results in a hydraulic loading of five times the design flow (1 part forward flow to 4 parts recycled flow). The increased hydraulic loading reduces the residence time in the filter so that recirculation is necessary to achieve the desired treatment. Typical recirculation ratios range from 3:1 to 5:1. As the permeability of the media increases, the recirculation ratio may need to increase to achieve the same level of treatment.

Media characteristics can limit the number of doses possible. Media reaeration must occur between doses. As the effective size of the media decreases, the time for drainage and reaeration of the media increases. For single pass filters, typical dosing frequencies are once per hour (24 times/day) or less. Recirculating sand filters dose 2 to 3 times per hour (48 to 72 times/day).

Distribution network requirements will also limit the number of doses possible. To achieve uniform distribution over the filter surface, minimum dose volumes are necessary and can vary with the distribution method selected. Therefore, if the dose volume dictated by the distribution network design is too high, the network should be redesigned. Since the dose volume is a critical operating parameter, the method of distribution and the distribution system design should be considered carefully.

Distribution methods used include rigid pipe pressure networks with orifices or spray nozzles, and drip emitters. Rigid pipe pressure networks are the most commonly used method. Orifices with orifice shields, facing upward, minimize hole blockage by stones. Since the minimum dose volume required to achieve uniform distribution is five times the pipe volume, large multihome filters are usually divided into multiple cells. Drip emitter distribution is being used increasingly because the minimum dose volumes are much less than the rigid pipe network volumes.

Recirculation tanks are a component of most recirculation filter systems. These tanks consist of a tank, recirculation pump and controls, and a return filter water flow splitting device. The flow splitting device may or may not be an integral part of the recirculation tank. Recirculation tanks store return filtrate, mix the filtrate with the septic tank effluent, and store peak influent flows. The tanks are designed to either remain full or be pumped down during periods of low wastewater flows. Since doses to the recirculating filter are of a constant volume and occur at timed intervals, the water level in the tank will rise and fall in response to septic tank effluent flow, return filtrate flow, and filter dosing.

In tanks designed to remain full, all filtrate is returned to the recirculation tank to refill the tank after each dosing event. When the tank reaches its normal full level, the remaining return filtrate is discharged out of the system as effluent. This design is best suited where treatment performance must be maintained continuously. For single-family home systems, the recirculation tank is typically sized to be equal to 1.5 times the design peak daily flow.

When the filtrate flow is continuously split between the return (to the recirculation tank) and the discharge, the liquid volume in the recirculation tank will vary depending on wastewater flows. During low flow periods the tank can be pumped down to the point that the low-water pump off switch is activated. This method leaves less return filtrate available to mix with the influent flow. While simple, this method of flow splitting can impair treatment performance because minimum recirculation ratios cannot be maintained. This is less of a disadvantage, however, for large, more continuous flows typical in small communities or large cluster systems.

The recirculation pump and controls are designed to dose a constant volume of mixed filtrate and septic tank effluent flow onto the filter on a timed cycle. The pump must be sized to provide the necessary dosing rate at the operating discharge head required by the distribution system. Pump operation is controlled by timers that can be set for pump time on and pump time off. A redundant pump-off float switch is installed in the recirculation tank below the minimum dose volume level. A high water alarm is also installed to provide notice of high water caused by pump failure, loss of pump calibration, or excessive influent flows.

Recirculation tank sizing

In many types of commercial systems, daily flow variations can be extreme. In such systems, the recycle ratios necessary to achieve the desired treatment may not be maintained unless the recirculation tank is sized properly. During prolonged periods of high influent flows, the recirculation ratio can be reduced to the point that treatment performance is not maintained unless the recirculation tank is sized to provide a sufficient reservoir of recycled filtrate to mix with the influent during the high-flow periods.

To size the tank appropriately for the application, assess the water balance for the recirculation tank using the following procedure:

1. Select the dosing frequency based on the wastewater strength and selected media characteristics.
2. Calculate the dose volume based on the average daily flow:

   $$V_{dose} = [(\text{recycle ratio} + 1) \times Q_{ave.\ daily}] \div (\text{doses/day})$$

   $$Q_{dose} = V_{dose} \div (\text{dose period})$$

   Where V and Q are the flow volume and flow rate, respectively.
3. Adjust the dose volume if the calculated volume is less than the required minimum dose volume for the distribution network.
4. Estimate the volumes and duration of influent peak flows that are expected to occur from the establishment.
5. Calculate the necessary recirculation tank "working" volume by performing a water balance around the recirculation tank for the peak flow period with the greatest average flow rate during that peak period.

   $$\text{Inputs} = Q_{inf.} \times T + Q_{recycle} \times T = Q_{inf.} \times T + (Q_{dose} - Q_{eff}) \times T = V_{inf.} + V_{recycle}$$

   $$\text{Outputs} = V_{dose} \times (T \div \text{dose cycle time})$$

   Where T is the peak flow period duration.

   If the inputs are greater than the outputs, then $Q_{eff} = Q_{dose}$ and the peaks are stored in the available freeboard space of the recirculation tank. If the inputs are less than the outputs, then $Q_{eff.} = Q_{inf.}$

   To provide the necessary recycle ratio, sufficient filtrate must be available to mix with the influent septic tank effluent. The filtrate is provided by the return filtrate flow and the filtrate already in the recirculation tank.

   $$\text{Recycle ratio} \times Q_{inf.} \times T \leq Q_{recycle} \times T + \text{minimum tank working volume}$$

   $$\text{Where minimum tank working volume} = \text{Recycle ratio} \times (Q_{inf.} - Q_{recycle}) \times T$$
6. Calculate the necessary freeboard volume for storage of peak flows when the influent volume is greater than the dosing volume during the peak flow period.

   $$\text{Freeboard volume} = Q_{inf.} \times T + Q_{recycle} \times T - Q_{dose} \times T$$

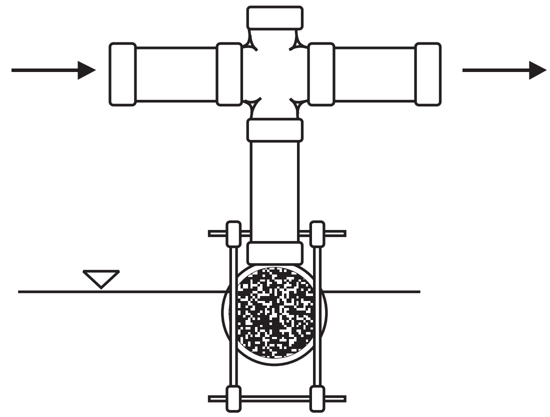
   $$= Q_{inf.} \times T(Q_{dose} - Q_{eff.}) - Q_{dose} \times T$$
7. Calculate the minimum total recirculation volume.

   $$\text{Total tank volume} = \text{minimum tank working volume} + \text{freeboard volume}$$

(Adapted from Ayres Associates, 1998.)

Several flow splitting devices may be used. The most common are ball float valves and proportional splitters. The ball float valve is used where the recirculation tank is designed to remain full. The valve is connected to the return filtrate line inside the recirculation tank (see figure 2). The return line runs through the tank. The ball float valve is open when the water level is below the normally full level. When the tank fills from either the return filtrate or the influent flow, the ball float rises to close the valve, and the remaining filtrate is discharged from the system. The proportional splitters continuously divide the flow between return filtrate and the filtrate effluent (see figure 3). Another type of splitter consists of a sump in which two pipes are stubbed into the bottom with their ends capped. In the crowns of each capped line, a series of equal-sized, pluggable holes are drilled. The return filtrate floods the sump, and the flow is split in proportion to the relative number of holes left open in each perforated capped pipe.

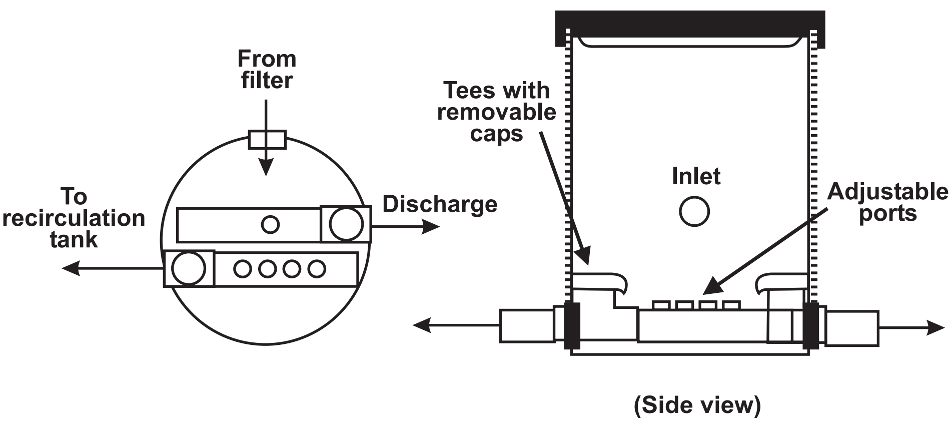
Figure 2. Flow splitter operated by a float ball valve



Another type of splitter divides flow inside the filter. The filter floor is raised so that it slopes in opposite directions. The raised point is located so that the ratio of the floor areas on either side is in proportion to the desired recirculation ratio. Each side has its own underdrain. One side drains back to the recirculation tank, the other side drains to discharge. This method has the disadvantage that adjustments to the recirculation ratio cannot easily be made.

Most RSFs are constructed aboveground and with an open filter surface; however, in cold climates, they can be placed in the ground to prevent freezing. Placing a cover over an RSF is recommended to reduce odors and to provide insulation in cold climates, although no freezing was observed in an open RSF in Canada using coarse gravel media. Covers must provide ample fresh air venting, because reaeration of the filter media occurs primarily from the filter surface.

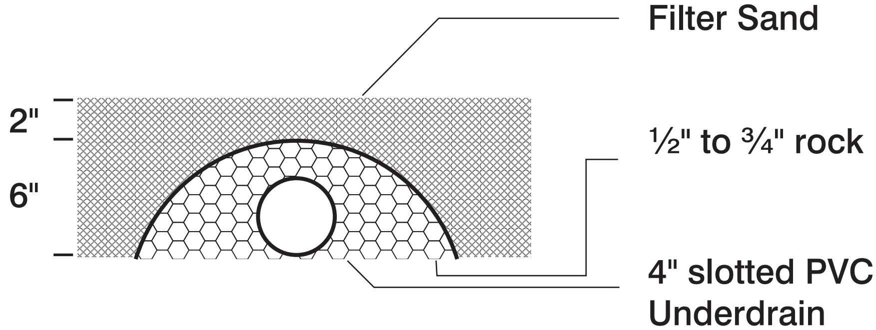
Figure 3. Splitter basin



The filter basin can be a lined excavation or fabricated tank. For single-home systems, prefabricated concrete tanks are commonly used. Many single-home filters and most large filters are constructed within lined excavations. Typical liner materials are polyvinyl chloride and polypropylene. A liner thickness of 30 mil can withstand reasonable construction activities yet be relatively easy to work with. A sand layer should be placed below the liner to protect it from puncturing if the floor and walls of the excavation are stony. The excavation walls should be brought above the final grade to prevent entry of surface water. It is often necessary to cover the filter surface to reduce the effects of algae fouling, odors, cold weather impacts, precipitation, and snow melt. The cover must provide ample fresh air venting, however. Reaeration of the filter media primarily occurs from the filter surface.

The underdrain system is placed on the floor of the tank or lined excavation (figure 4). Ends of the underdrains should be brought to the surface of the filter and fitted with cleanouts that can be used to clean the underdrains of biofilms if necessary. The underdrain outlet is cut in the basin wall such that the drain invert is at the floor elevation and the filter can be completely drained. The underdrain outlet invert elevation must be sufficiently above the recirculation tank inlet to accommodate a minimum of 0.1 percent slope on the return line and any elevation losses through the flow splitting device. The underdrain is covered with washed, durable gravel to provide a porous medium through which the filtrate can flow to the underdrain system. The gravel should be sized to prevent the filter media from mixing into the gravel, or a layer of 1/4- to 3/8-inch-diameter gravel should be placed over the underdrain gravel before the filter media is added.

Figure 4. Typical underdrain detail.



Performance

RSF systems are extremely effective and reliable in removing BOD, TSS, and contaminants that associate with the particulate fraction of the incoming septic tank effluent. Some typical performance data are provided in table 2.

Normally, BOD and TSS effluent concentrations are less than 10 mg/L when RSF systems are treating residential wastewater. Nitrification tends to be complete, except in severely cold conditions. Natural denitrification in the recirculating tank results in 40 to 60 percent removal of total nitrogen (TN). Fecal coliform removal is normally 2 to 3 logs (99 to 99.9 percent). Phosphorus removal drops off from high percentages to about 20 to 30 percent after the exchange capacity of the media becomes exhausted. Some media and media mixes have very high iron and/or aluminum content that extends the initial period of high phosphorus removal. (See Enhanced Nutrient Removal—Phosphorus, Technology Fact Sheet 8.)

Table 2. Recirculating filter performance

Reference	BOD (mg/L) Influ. Efflu. *(% Removal)*	TSS (mg/L) Influ. Efflu. *(% Removal)*	TKN (mg-N/L) Influ. Efflu. *(% Removal)*	TN (mg-N/L) Influ. Efflu. *(% Removal)*	Fecal Coliform (#/100mL) Influ. Efflu. *(% Removal)*
Louden et al., 1985 [a] (Michigan)	150 6 *(96.00%)*	42 6 *(85.71%)*	55 2.3 *(95.82%)*	55 26 *(52.73%)*	3.40E+03 1.40E+01 *(99.59%)*
Piluk and Peters, 1994 [b] (Maryland)	235 5 *(97.87%)*	75 8 *(89.33%)*	Not reported	57 20 *(64.91%)*	1.80E+06 9.20E+03 *(99.49%)*
Ronayne, et al., 1982 [c] (Oregon)	217 3 *(98.62%)*	146 4 *(97.26%)*	57.1 1.1 *(98.07%)*	57.5 31.5 *(45.22%)*	2.60E+05 8.50E+03 *(96.73%)*
Roy and Dube, 1994 [d] (Quebec)	101 6 *(94.06%)*	77 3 *(96.10%)*	37.7 7.9 *(79.05%)*	37.7 20.1 *(46.68%)*	4.80E+05 1.30E+04 *(97.29%)*
Ayres Assoc., 1998 [e] (Wisconsin)	601 10 *(98.34%)*	46 9 *(98.35%)*	65.9 3 *(95.45%)*	65.9 16 *(75.72%)*	> 2500 6.20E+01 *(> 98%)*
Owen and Bobb, 1994 [f] (Wisconsin)	80 8 *(90.00%)*	36 6 *(83.33%)*	- - *(> 95%)*	Not reported	Not reported

[a]Single-family home filters. Sand media: es = 0.3 mm; uc = 4.0. Average loadings = 0.9 gpd/ft^2 (forward flow) / 1.13 lb BOD/1,000 ft^2 –day. Recirculation ratio = 3:1. Dosed 4-6 times per hour. Open surface.

[b]Single-family home filters. Sand media: es = 1 mm; uc = <2.5. Design hydraulic loadings = 3.54 gpd//ft^2 (forward flow). Actual flow not measured. Recirculation ratio = 3:1. Doses per day = 24.

[c]Single-family home filters. Sand media: es = 1.2 mm; uc = 2.0. Maximum hydraulic loading (forward flow)= 3.1 gpd/ft^2. Recirculation ratio = 3:1-4:1. Doses per day = 48.

[d]Single-family home filters. Gravel media: es = 4.0 mm; uc = <2/5. Design hydraulic loading (forward flow)= 23.4 gpd/ft^2. Recirculation ratio = 5:1. Doses per day = 48. Open surface, winter operation.

[e]Restaurant (grease and oil inf./eff. = 119/<1 mg/L, respectively). Gravel media: pea gravel (3/8 in. dia.) Design hydraulic loading (forward flow) = 15 gpd/ft^2. Recirculation ratio = 3:1- 5:1. Doses per day = 72. Open surface, seasonal operation.

[f]Small community treating average 15,000 gpd of septic tank effluent. Sand media: es = 1.5 mm; uc = 4.5. Design hydraulic loading (forward flow) = 2.74 gpd/ft^2. Recirculation ratio = 1:1-4:1. Open surface, winter operation.

Management needs

As with all treatment systems, the RSF should be constructed carefully according to design specifications using corrosion-resistant materials. Every truckload of media delivered to the site should be tested for compliance with the specifications. All tanks and lined basins, including the entry and exit plumbing locations, must be watertight.

Inspection and operation/maintenance (O/M) needs are primarily related to inspection and calibration of the recirculation pump and controls. For sand media units, frequent removal of vegetation and scraping of the surface are required. Regular maintenance tasks include periodic checks on the pressure head at the end of the distribution system, draining of the accumulated solids from lines, and occasional brushing of the lines (at least once per year), with bottle brushes attached to a plumber's snake.

The recirculation tank should be checked for sludge accumulation on each visit and pumped as necessary (usually one to three times per year).

Risk management issues

RSFs are extremely reliable treatment devices and are quite resistant to flow variations. Toxic shocks are detrimental to RSF treatment performance because of the resistance of biofilms to upset and the extended period of contact between biofilms and wastewater.

Gravel RSFs (or RGFs) are likely viable throughout the United States when proper precautions (e.g., covering, insulation) are taken. These systems perform best in warmer climates, but they increase opportunities for odor problems. In general, gravel RSF systems are far less prone to odor production than ISFs. Increased recycle ratios should help minimize such problems. However, power outages will stop the process from treating the wastewater, and prolonged outages would be likely to generate some odors.

Costs

Construction costs for recirculating sand filters are driven by treatment media costs, the recirculating tank and pump/control system costs, and containment costs. Total costs are therefore site specific, but tend to vary from $8,000 to $11,000. Low-cost alternative media can reduce this figure significantly.

Power costs for pumping at 3 to 4 kWh/day are in the range of $90 to $120 per year, and management costs for monthly visits/inspections by semiskilled personnel typically cost $150 to $200 annually.

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United States Environmental Protection Agency

Wastewater Management Fact Sheet
Membrane Bioreactors

INTRODUCTION

The technologies most commonly used for performing secondary treatment of municipal wastewater rely on microorganisms suspended in the wastewater to treat it. Although these technologies work well in many situations, they have several drawbacks, including the difficulty of growing the right types of microorganisms and the physical requirement of a large site. The use of microfiltration membrane bioreactors (MBRs), a technology that has become increasingly used in the past 10 years, overcomes many of the limitations of conventional systems. These systems have the advantage of combining a suspended growth biological reactor with solids removal via filtration. The membranes can be designed for and operated in small spaces and with high removal efficiency of contaminants such as nitrogen, phosphorus, bacteria, biochemical oxygen demand, and total suspended solids. The membrane filtration system in effect can replace the secondary clarifier and sand filters in a typical activated sludge treatment system. Membrane filtration allows a higher biomass concentration to be maintained, thereby allowing smaller bioreactors to be used.

APPLICABILITY

For new installations, the use of MBR systems allows for higher wastewater flow or improved treatment performance in a smaller space than a conventional design, i.e., a facility using secondary clarifiers and sand filters. Historically, membranes have been used for smaller-flow systems due to the high capital cost of the equipment and high operation and maintenance (O&M) costs. Today however, they are receiving increased use in larger systems. MBR systems are also well suited for some industrial and commercial applications. The high-quality effluent produced by MBRs makes them particularly applicable to reuse applications and for surface water discharge applications requiring extensive nutrient (nitrogen and phosphorus) removal.

ADVANTAGES AND DISADVANTAGES

The advantages of MBR systems over conventional biological systems include better effluent quality, smaller space requirements, and ease of automation. Specifically, MBRs operate at higher volumetric loading rates which result in lower hydraulic retention times. The low retention times mean that less space is required compared to a conventional system. MBRs have often been operated with longer solids residence times (SRTs), which results in lower sludge production; but this is not a requirement, and more conventional SRTs have been used (Crawford et al. 2000). The effluent from MBRs contains low concentrations of bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD), and phosphorus. This facilitates high-level disinfection. Effluents are readily discharged to surface streams or can be sold for reuse, such as irrigation.

The primary disadvantage of MBR systems is the typically higher capital and operating costs than conventional systems for the same throughput. O&M costs include membrane cleaning and fouling control, and eventual membrane replacement. Energy costs are also higher because of the need for air scouring to control bacterial growth on the membranes. In addition, the waste sludge from such a system might have a low settling rate, resulting in the need for chemicals to produce biosolids acceptable for disposal (Hermanowicz et al. 2006). Fleischer et al. 2005 have demonstrated that waste sludges from MBRs can be processed using standard technologies used for activated sludge processes.

MEMBRANE FILTRATION

Membrane filtration involves the flow of water-containing pollutants across a membrane. Water permeates through the membrane into a separate channel for recovery (Figure 1). Because of the cross-flow movement of water and the waste constituents, materials left behind do not accumulate at the membrane surface but are carried out of the system for later recovery or disposal. The water passing through the membrane is called the *permeate*, while the water with the more-concentrated materials is called the *concentrate* or *retentate*.

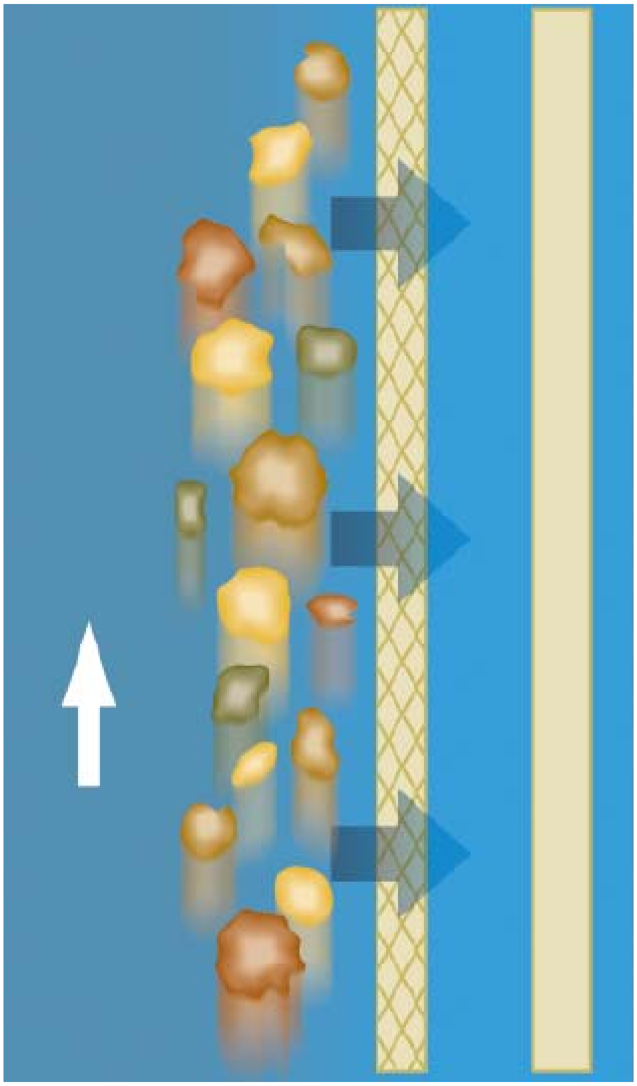

Figure 1. Membrane filtration process (Image from Siemens/U.S. Filter)

Membranes are constructed of cellulose or other polymer material, with a maximum pore size set during the manufacturing process. The requirement is that the membranes prevent passage of particles the size of microorganisms, or about 1 micron (0.001 millimeters), so that they remain in the system. This means that MBR systems are good for removing solid material, but the removal of dissolved wastewater components must be facilitated by using additional treatment steps.

Membranes can be configured in a number of ways. For MBR applications, the two configurations most often used are hollow fibers grouped in bundles, as shown in Figure 2, or as flat plates. The hollow fiber bundles are connected by manifolds in units that are designed for easy changing and servicing.

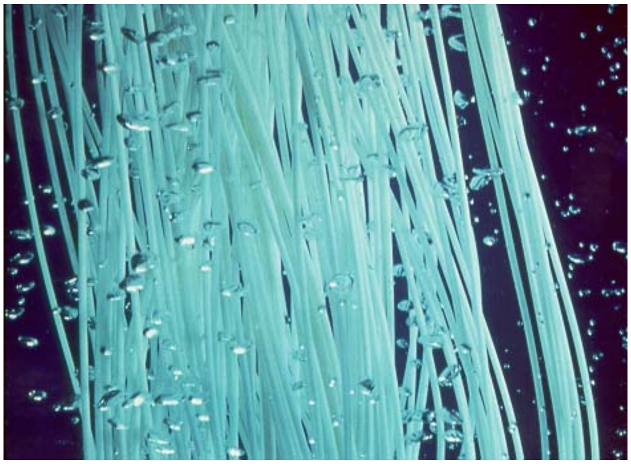

Figure 2. Hollow-fiber membranes (Image from GE/Zenon)

DESIGN CONSIDERATIONS

Designers of MBR systems require only basic information about the wastewater characteristics, (e.g., influent characteristics, effluent requirements, flow data) to design an MBR system. Depending on effluent requirements, certain supplementary options can be included with the MBR system. For example, chemical addition (at various places in the treatment chain, including: before the primary settling tank; before the secondary settling tank [clarifier]; and before the MBR or final filters) for phosphorus removal can be included in an MBR system if needed to achieve low phosphorus concentrations in the effluent.

MBR systems historically have been used for small-scale treatment applications when portions of the treatment system were shut down and the wastewater routed around (or bypassed) during maintenance periods.

However, MBR systems are now often used in full-treatment applications. In these instances, it is recommended that the installation include one additional membrane tank/unit beyond what the design would nominally call for. This "N plus 1" concept is a blend between conventional activated sludge and membrane process design. It is especially important to consider both operations and maintenance requirements when selecting the number of units for MBRs. The inclusion of an extra unit gives operators flexibility and ensures that sufficient operating capacity will be available (Wallis-Lage et al. 2006). For example, bioreactor sizing is often limited by oxygen transfer, rather than the volume required to achieve the required SRT—a factor that significantly affects bioreactor numbers and sizing (Crawford et al. 2000).

Although MBR systems provide operational flexibility with respect to flow rates, as well as the ability to readily add or subtract units as conditions dictate, that flexibility has limits. Membranes typically require that the water surface be maintained above a minimum elevation so that the membranes remain wet during operation. Throughput limitations are dictated by the physical properties of the membrane, and the result is that peak design flows should be no more than 1.5 to 2 times the average design flow. If peak flows exceed that limit, either additional membranes are needed simply to process the peak flow, or equalization should be included in the overall design. The equalization is done by including a separate basin (external equalization) or by maintaining water in the aeration and membrane tanks at depths higher than those required and then removing that water to accommodate higher flows when necessary (internal equalization).

DESIGN FEATURES

Pretreatment

To reduce the chances of membrane damage, wastewater should undergo a high level of debris removal prior to the MBR. Primary treatment is often provided in larger installations, although not in most small to medium sized installations, and is not a requirement. In addition, all MBR systems require 1- to 3-mm-cutoff fine screens immediately before the membranes, depending on the MBR manufacturer. These screens require frequent cleaning. Alternatives for reducing the amount of material reaching the screens include using two stages of screening and locating the screens after primary settling.

Membrane Location

MBR systems are configured with the mem-

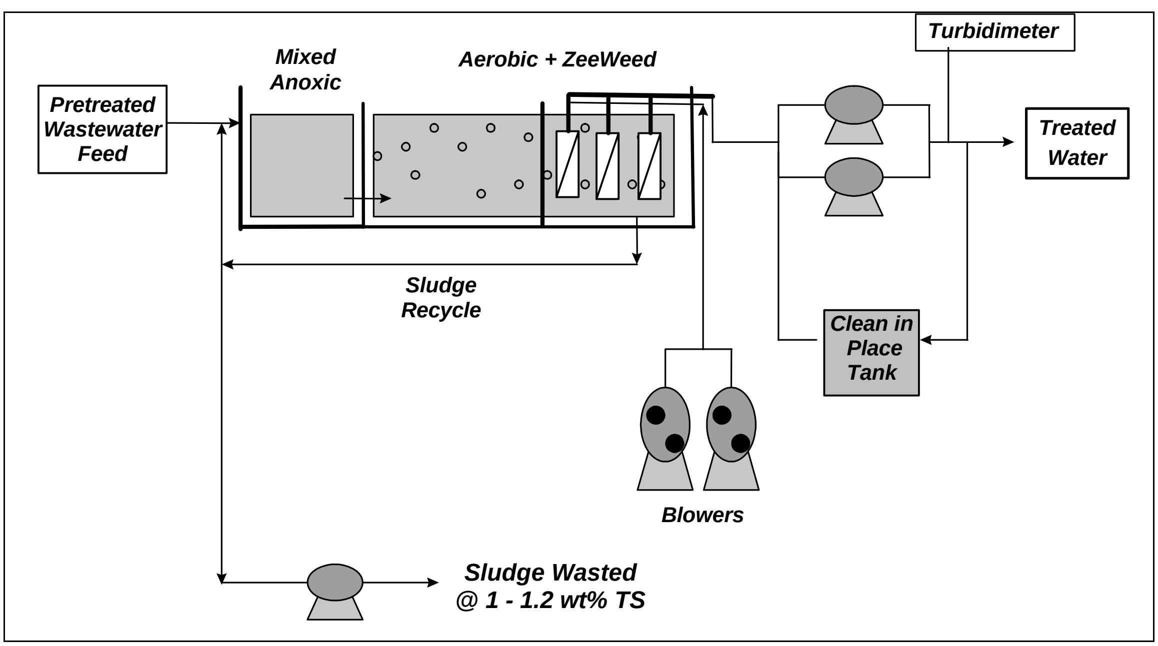

Figure 3. Immersed membrane system configuration (Image from GE/Zenon)

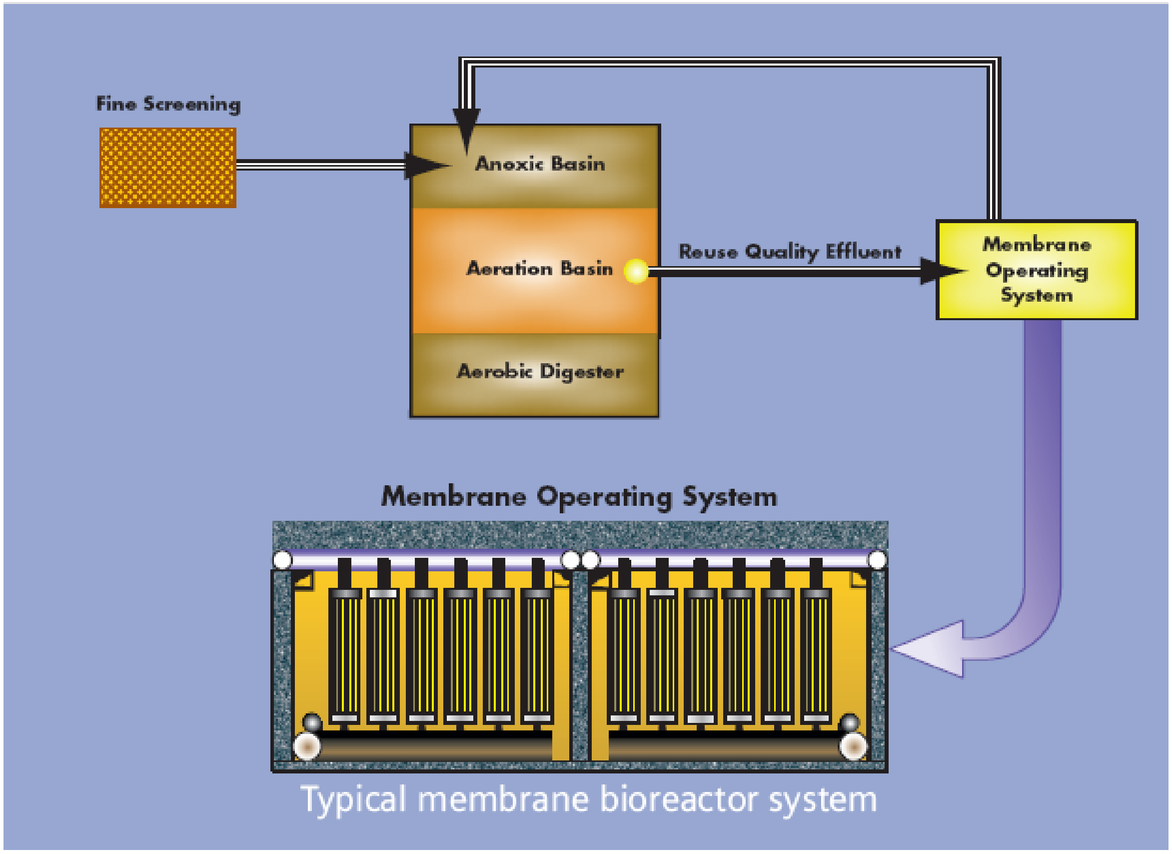

Figure 4. External membrane system configuration (Image from Siemens/U.S. Filter)

branes actually immersed in the biological reactor or, as an alternative, in a separate vessel through which mixed liquor from the biological reactor is circulated. The former configuration is shown in Figure 3; the latter, in Figure 4.

Membrane Configuration

MBR manufacturers employ membranes in two basic configurations: hollow fiber bundles and plate membranes. Siemens/U.S.Filter's Memjet and Memcor systems, GE/Zenon's ZeeWeed and ZenoGem systems, and GE/Ionics' system use hollow-fiber, tubular membranes configured in bundles. A number of bundles are connected by manifolds into units that can be readily changed for maintenance or replacement. The other configuration, such as those provided by Kubota/Enviroquip, employ membranes in a flat-plate configuration, again with manifolds to allow a number of membranes to be connected in readily changed units. Screening requirements for both systems differ: hollow-fiber membranes typically require 1- to 2-mm screening, while plate membranes require 2- to 3-mm screening (Wallis-Lage et al. 2006).

System Operation

All MBR systems require some degree of pumping to force the water flowing through the membrane. While other membrane systems use a pressurized system to push the water through the membranes, the major systems used in MBRs draw a vacuum through the membranes so that the water outside is at ambient pressure. The advantage of the vacuum is that it is gentler to the membranes; the advantage of the pressure is that throughput can be controlled. All systems also include techniques for continually cleaning the system to maintain membrane life and keep the system operational for as long as possible. All the principal membrane systems used in MBRs use an air scour technique to reduce buildup of material on the membranes. This is done by blowing air around the membranes out of the manifolds. The GE/Zenon systems use air scour, as well as a back-pulsing technique, in which permeate is occasionally pumped back into the membranes to keep the pores cleared out. Back-pulsing is typically done on a timer, with the time of pulsing accounting for 1 to 5 percent of the total operating time.

Downstream Treatment

The permeate from an MBR has low levels of suspended solids, meaning the levels of bacteria, BOD, nitrogen, and phosphorus are also low. Disinfection is easy and might not be required, depending on permit requirements..

The solids retained by the membrane are recycled to the biological reactor and build up in the system. As in conventional biological systems, periodic sludge wasting eliminates sludge buildup and controls the SRT within the MBR system. The waste sludge from MBRs goes through standard solids-handling technologies for thickening, dewatering, and ultimate disposal. Hermanowicz et al. (2006) reported a decreased ability to settle in waste MBR sludges due to increased amounts of colloidal-size particles and filamentous bacteria. Chemical addition increased the ability of the sludges to settle. As more MBR facilities are built and operated, a more definitive understanding of the characteristics of the resulting biosolids will be achieved. However, experience to date indicates that conventional biosolids processing unit operations are also applicable to the waste sludge from MBRs.

Membrane Care

The key to the cost-effectiveness of an MBR system is membrane life. If membrane life is curtailed such that frequent replacement is required, costs will significantly increase. Membrane life can be increased in the following ways:

- Good screening of larger solids before the membranes to protect the membranes from physical damage.

- Throughput rates that are not excessive, i.e., that do not push the system to the limits of the design. Such rates reduce the amount of material that is forced into the membrane and thereby reduce the amount that has to be removed by cleaners or that will cause eventual membrane deterioration.

- Regular use of mild cleaners. Cleaning solutions most often used with MBRs include regular bleach (sodium) and citric acid. The cleaning should be in accord with manufacturer-recommended maintenance protocols.

Membrane Guarantees

The length of the guarantee provided by the membrane system provider is also important in determining the cost-effectiveness of the system. For municipal wastewater treatment, longer guarantees might be more readily available compared to those available for industrial systems. Zenon offers a 10-year guarantee; others range from 3 to 5 years. Some guarantees include cost prorating if replacement is needed after a certain service time. Guarantees are typically negotiated during the purchasing process. Some manufacturers' guarantees are tied directly to screen size: longer membrane warranties are granted when smaller screens are used (Wallis-Lage et al. 2006). Appropriate membrane life guarantees can be secured using appropriate membrane procurement strategies (Crawford et al. 2002).

SYSTEM PERFORMANCE

Siemens/U.S. Filter Systems

Siemens/U.S.Filter offers MBR systems under the Memcor and Memjet brands. Data provided by U.S. Filter for its Calls Creek (Georgia) facility are summarized below. The system, as Calls Creek retrofitted it, is shown in Figure 5. In essence, the membrane filters were used to replace secondary clarifiers downstream of an Orbal oxidation ditch. The system includes a fine screen (2-mm cutoff) for inert solids removal just before the membranes.

The facility has an average flow of 0.35 million gallons per day (mgd) and a design flow of 0.67 mgd. The system has 2 modules, each containing 400 units, and each unit consists of a cassette with manifold-connected membranes. As shown in Table 1, removal of BOD, TSS, and ammonia-nitrogen is excellent; BOD and TSS in the effluent are around the detection limit. Phosphorus is also removed well in the system, and the effluent

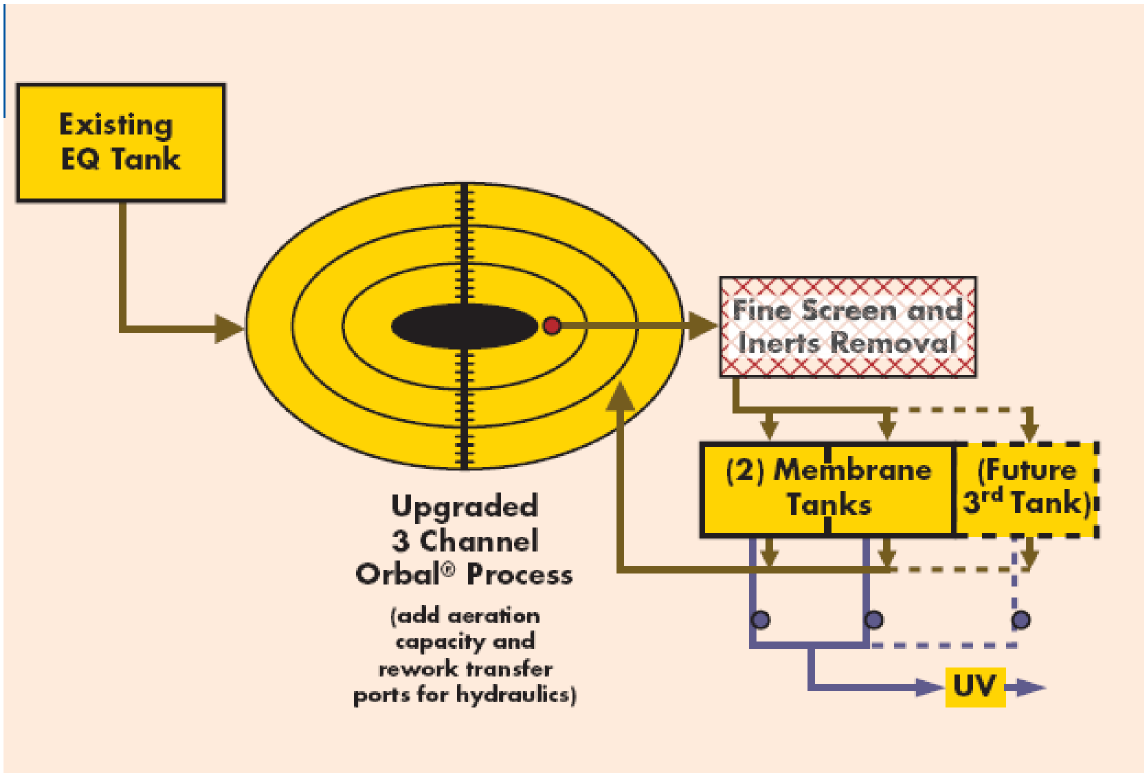

Figure 5. Calls Creek flow diagram (courtesy of Siemens/U.S. Filter)

Table 1.
Calls Creek results 2005

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	0.35	--	0.44	0.26
BOD (mg/L)	145	1	1	1
TSS (mg/L)	248	1	1	1
Ammonia-N (mg/L)	14.8	0.21	0.72	0.10
P (mg/L)	0.88	0.28	0.55	0.12
Fecal coliforms (#/100 mL)	--	14.2	20	0
Turbidity (NTU)	--	0.30	1.31	0.01

has very low turbidity. The effluent has consistently met discharge limits.

Zenon Systems

General Electric/Zenon provides systems under the ZenoGem and ZeeWeed brands. The ZeeWeed brand refers to the membrane, while ZenoGem is the process that uses ZeeWeed.

Performance data for two installed systems are shown below.

Cauley Creek, Georgia. The Cauley Creek facility in Fulton County, Georgia, is a 5-mgd wastewater reclamation plant. The system includes biological phosphorus removal, mixed liquor surface wasting, and sludge thickening using a ZeeWeed system to minimize the required volume of the aerobic digester, according to information provided by GE. Ultraviolet disinfection is employed to meet regulatory limits. Table 2 shows that the removal for all parame-

Table 2.
Cauley Creek, Georgia, system performance

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.27	--	4.66	3.72
BOD (mg/L)	182	2.0	2.0	2.0
COD (mg/L)	398	12	22	5
TSS (mg/L)	174	3.2	5	3
TKN (mg/L)	33.0	1.9	2.9	1.4
Ammonia-N (mg/L)	24.8	0.21	0.29	0.10
TP (mg/L)	5.0	0.1	0.13	0.06
Fecal coliforms (#/100 mL)	--	2	2	2
NO3-N (mg/L)	--	2.8		

ters is over 90 percent. The effluent meets all permit limits, and is reused for irrigation and lawn watering.

Traverse City, Michigan. The Traverse City Wastewater Treatment Plant (WWTP) went through an upgrade to increase plant capacity and produce a higher-quality effluent, all within the facility's existing plant footprint (Crawford et al. 2005). With the ZeeWeed system, the facility was able to achieve those goals. As of 2006, the plant is the largest-capacity MBR facility in North America. It has a design average annual flow of 7.1 mgd, maximum monthly flow of 8.5 mgd, and peak hourly flow of 17 mgd. The membrane system consists of a 450,000-gallon tank with eight compartments of equal size. Secondary sludge is distributed evenly to the compartments. Blowers for air scouring, as well as permeate and back-pulse pumps, are housed in a nearby building.

Table 3 presents a summary of plant results over a 12-month period. The facility provides excellent removal of BOD, TSS, ammonia-nitrogen, and phosphorus. Figure 6 shows the influent, effluent, and flow data for the year.

Operating data for the Traverse City WWTP were obtained for the same period. The mixed liquor suspended solids over the period January to August averaged 6,400 mg/L, while the mixed liquor volatile suspended solids averaged 4,400 mg/L. The energy use for the air-scouring blowers averaged 1,800 kW-hr/million gallons (MG) treated.

COSTS

Capital Costs

Capital costs for MBR systems historically have tended to be higher than those for conventional systems with comparable throughput because of the initial costs of the membranes. In certain situations, however, including retrofits, MBR systems can have lower or competitive capital costs compared with alternatives because MBRs have lower land requirements and use smaller tanks, which can reduce the costs for concrete. U.S. Filter/Siemen's Memcor package plants have installed costs of $7–$20/gallon treated.

Fleischer et al. (2005) reported on a cost comparison of technologies for a 12-MGD design in Loudoun County, Virginia. Because of a chemical oxygen demand limit, activated carbon adsorption was included with the MBR system. It was found that the capital cost for MBR plus granular activated carbon at $12/gallon treated was on the same order of magnitude as alternative processes, including multiple-point alum addition, high lime treatment, and post-secondary membrane filtration.

Operating Costs

Operating costs for MBR systems are typically higher than those for comparable conventional systems. This is because of the higher energy

Table 3.
Summary of Traverse City, Michigan, Performance Results

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.3	--	5.1	3.6
BOD (mg/L)	280	< 2	< 2	< 2
TSS (mg/L)	248	< 1	< 1	< 1
Ammonia-N (mg/L)	27.9	< 0.08	< 0.23	< 0.03
TP (mg/L)	6.9	0.7	0.95	0.41
Temperature (deg C)	17.2	--	23.5	11.5

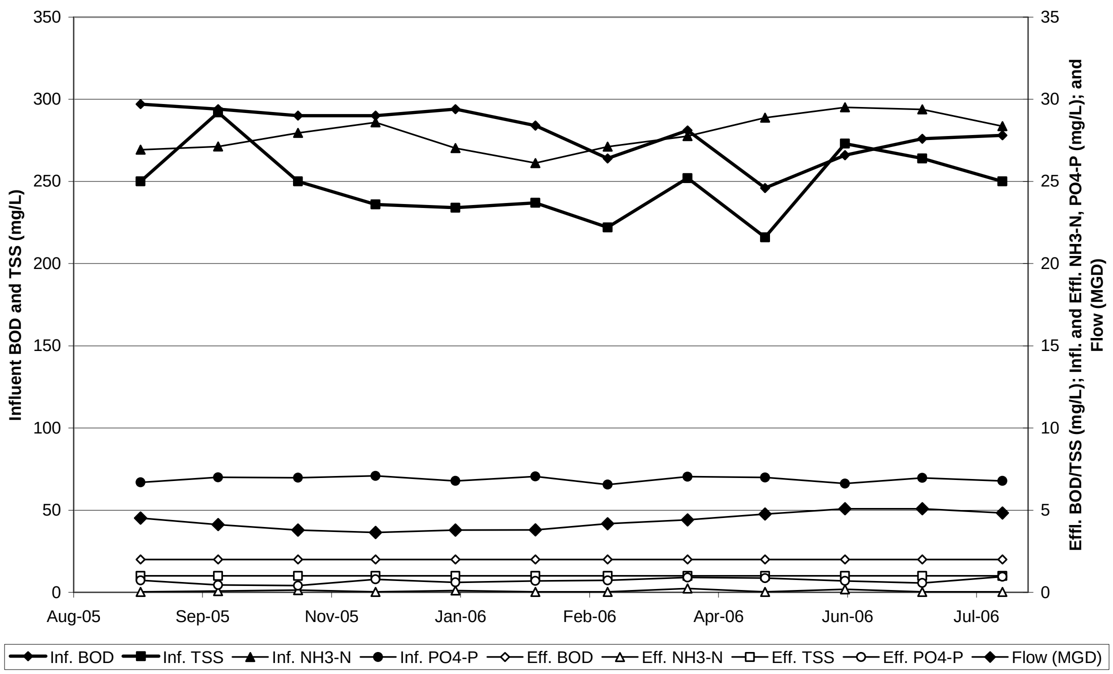

Figure 6. Performance of the Traverse City plant

costs if air scouring is used to reduce membrane fouling. The amount of air needed for the scouring has been reported to be twice that needed to maintain aeration in a conventional activated sludge system (Scott Blair, personal communication, 2006). These higher operating costs are often partially offset by the lower costs for sludge disposal associated with running at longer sludge residence times and with membrane thickening/dewatering of wasted sludge.

Fleischer et al. (2005) compared operating costs. They estimated the operating costs of an MBR system including activated carbon adsorption at \$1.77 per 1,000 gallons treated. These costs were of the same order of magnitude as those of alternative processes, and they compared favorably to those of processes that are chemical-intensive, such as lime treatment.

ACKNOWLEDGMENTS

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Decentralized Systems Technology Fact Sheet
Aerobic Treatment

DESCRIPTION

Natural treatment of biological waste has been practiced for centuries. However, engineered aerobic biological treatment of wastewater has been practiced in the United States, on a large scale, for only a few decades. In fact, in 1925, 80 percent of all cities in the United States with populations of over 100,000 had no treatment systems at all (Linsley 1972). The basic aerobic treatment process involves providing a suitable oxygen rich environment for organisms that can reduce the organic portion of the waste into carbon dioxide and water in the presence of oxygen. With the ever increasing development of land, both suburban and rural, large central sewerage systems have not always been cost-effective or available. Many homeowners still rely on individual septic tank or other systems to treat and dispose of household wastewater onsite.

Historically, aerobic treatment was not feasible on a small scale, and septic tanks were the primary treatment device, but recent technology advances make individual aerobic treatment systems efficient and affordable. Aerobic systems are similar to septic systems in that they both use natural processes to treat wastewater. But unlike septic (anaerobic) treatment, the aerobic treatment process requires oxygen. Aerobic treatment units, therefore, use a mechanism to inject and circulate air inside the treatment tank. Because aerobic systems use a higher rate process, they are able to achieve superior effluent quality. The effluent can be discharged to the subsurface as in a septic tank leach field or, in some cases, discharged directly to the surface.

Current Technologies

Individual aerobic systems have been in place since the 1950's, however, these early systems consisted of little more than an aerator placed in a traditional septic tank. They were prone to noise, odor and maintenance complaints, and were used only where standard septic tanks were not feasible. The newer aerobic treatment units are pre-engineered and operate at a high level of efficiency. The demand for these units and the desire for direct surface discharge of the treated waste stream has led to a certification process by the National Sanitation Foundation (NSF). This certification (NSF Standard 40 for Individual Wastewater Treatment Plants) applies to plants with capacities of up to 1,500 gallons per day, and leads to approval as a Class I or Class II plant. A Class I certification indicates performance to EPA Secondary Treatment Guidelines for three parameters: BOD, suspended solids and pH. Noise levels, odors, oily films and foaming are also measured.. The Class II criteria require that not more than 10% of the effluent $CBOD_5$ values exceed 60 mg/L and that TSS not exceed 100 mg/L.

As of June 2000, 15 manufacturers carry NSF 40 Class I Certification with available capacities ranging from 1514.2 Liters/day to 5,678.1 Liters/day (400 to 1,500 gallons per day). Table 1 provides a list of the certified manufacturers, the number of models available, and the range of flows treated. It is important to note that the NSF certified Product Listing is continually changing. The NSF should be contacted directly to confirm the status of the listing provided in Table 1. Table 2 shows the NSF Class I effluent performance limits.

TABLE 1 MANUFACTURERS CARRYING NSF CLASS I CERTIFICATION*

Company	Location	Number of Certified Models	Flow Range (gpd)
Alternative Wastewater Systems, Inc.	Batavia, IL	5	500-1500
American Wastewater Systems, Inc.	Duson, LA	1	500
Aquarobic International	Front Royal, VA	24	500-1500
Bio-Microbics	Shawnee, KS	4	500-1500
Clearstream Wastewater Systems, Inc.	Beumont, TX	10	500-1500
Consolidated Treatment Systems, Inc.	Franklin, OH	10	500-1500
Delta Environmental Productss	Denham Springs, LA	9	400-1500
H.E. McGrew, Inc.	Bossier City, LA	4	500-750
Hydro-Action, Inc.	Beaumont, TX	7	500-1500
Jet, Inc.	Cleveland, OH	6	500-1500
Microseptec, Inc.	Laguna Hills, CA	2	600-1500
National Wastewater Systems, Inc.	Lake Charles, LA	1	500
Nordbeton North America, Inc.	Lake Monroe, FL	1	600
Norweco, Inc.	Norwalk, OH	10	500-1500
Thomas, Inc.	Sedro Woolley, WA	6	500-1000

* As of June 19, 2000. This list is continually changing. Please contact NSF to confirm the status of any listing.
Source: National Sanitation Foundation, 2000

TABLE 2 NSF CLASS I EFFLUENT PERFORMANCE LIMITS

BOD & SS	pH	Color	Odor	Foam	Noise
#30mg/L (2.504 x 10^{-7} lb/gal) (Monthly Average)	6.0-9.0 Units	15 Units	Non-Offensive	None	<60dbA @20 feet

Source: NSF Evaluation of JET Model J-500 (1998).

APPLICABILITY

Although there have been small scale "home aerobic systems" in the United States for more than 50 years, their use has been fairly limited, in part, because of the widespread use of septic systems, which are relatively inexpensive and easy to maintain. They are the most common onsite wastewater treatment systems in rural areas. However, many households may not be well suited for septic systems.

For example, septic systems are not suitable for all decentralized wastewater treatment applications. In fact, approximately two-thirds of all land area in the United States is estimated to be unsuitable for the installation of septic systems (Linsley 1972). Some homes may not have enough land area or appropriate soil conditions to accommodate the soil absorption drainfield. In some communities, the water table is too high to allow the drainfield to give adequate treatment to the wastewater before it is returned to the groundwater.

Other site-related concerns include homes located on wooded lots or on lots close to a body of water. Homeowners in wooded areas may not want to clear enough land to install a septic tank and drainfield, and wastewater treated by a septic system is often not of high enough quality to be discharged near a body of water.

One of the most common reasons to select aerobic wastewater treatment units is to replace failing septic systems, which are a major source of groundwater pollution in some areas. If a failed septic system needs to be replaced or if a site is inappropriate for a septic system, aerobic wastewater treatment may be a viable option.

ADVANTAGES AND DISADVANTAGES

Advantages:

- Can provide a higher level of treatment than a septic tank
- Helps protect valuable water resources where septic systems are failing
- Provides an alternative for sites not suited for septic systems
- May extend the life of a drainfield
- May allow for a reduction in drainfield size
- Reduces ammonia discharged to receiving waters

Disadvantages:

- More expensive to operate than a septic system
- Requires electricity
- Includes mechanical parts that can break down
- Requires more frequent routine maintenance than a septic tank
- Subject to upsets under sudden heavy loads or when neglected
- May release more nitrates to groundwater than a septic system

DESIGN CRITERIA

On-site aerobic processes typically produce a higher degree of treatment than septic tanks, but periodic carryover of solids due to sludge bulking, chemical disinfection addition, or excessive sludge buildup can result in substantial variability of effluent quality. Regular, semi-skilled operation and maintenance are required to ensure proper functioning of moderately complex equipment. Inspections every two months are recommended. Power is required to operate aeration equipment and pumps. Absorption beds are dependent upon site and soil conditions, and are generally limited to sites with percolation rates less than 2.4 minutes/millimeter (60 minutes/inch), depth to water table or bedrock of 0.61 to 1.2 meters (2 to 4 feet), and level or slightly sloping topography.

Two aerobic primary systems have been adapted for onsite use: suspended growth and fixed film. In suspended growth systems, the microorganisms responsible for the breakdown of wastes are maintained in a suspension with the waste stream. In fixed film systems, the microorganisms attach to an inert medium. Very few commercially produced fixed film systems are available for onsite application, and they include a variety of proprietary devices, making it difficult to prescribe design guidelines. In many cases, however, design guidelines for fixed film systems are similar to those applied to suspended growth systems.

Configuration

Most aerobic treatment units designed for individual home application range in capacity from 1514 to 5678 Liters (400 to 1,500 gallons), which includes the aeration compartment, settling chamber, and in some units, a pretreatment compartment. Based upon average household flows, this volume will provide total hydraulic retention times of several days.

Pretreatment

Some aerobic units provide a pretreatment step to remove grease, trash and garbage grindings. Pretreatment devices include trash traps, septic tanks, comminutors, and aerated surge chambers. The use of a trash trap or septic tank before the extended aeration process reduces problems with floating debris in the final clarifier, clogging of flow lines, and plugging of pumps. Pretreatment is required in fixed film systems to prevent process malfunction.

Flow Mode

Suspended growth aerobic treatment plants may be designed as continuous or batch flow systems. The simplest continuous flow units provide no flow equalization and depend upon aeration tank volume and/or baffles to reduce the impact of hydraulic surges. Some units use more sophisticated flow dampening devices, including air lift or float-controlled mechanical pumps to transfer the wastewater from aeration tank to clarifier. Still other units provide multiple-chambered tanks to attenuate flow. The batch (fill and draw) flow system eliminates the problem of hydraulic variation. This unit collects and treats wastewater over a period of time (usually one day), then discharges the settled effluent through pumping at the end of the cycle. Fixed film treatment plants operate on continuous flow.

Method of Aeration

Oxygen is transferred to the waste stream by diffused air, sparged turbine, or surface entrainment devices. When diffused air systems are used, low pressure blowers or compressors force the air through diffusers on the bottom of the tank. The sparged turbine uses a diffused air source and external mixing, usually from a submerged flat-bladed turbine. The sparged turbine is more complex than the simple diffused air system. A variety of surface entrainment devices are used in package plants to aerate and mix the wastewater. Air is entrained and circulated in the mixed liquor through violent agitation from mixing or pumping. Oxygen transfer efficiencies for these small package plants are normally low (3.4 to 16.9 kg O_2/MJ or 0.2 to 1.0 lb O_2/hp/hr) as compared with large-scale systems which may transfer 50.7 kg O_2/MJ or more (3+ lbs O_2/hp/hr). This difference is primarily due to the high power inputs to the smaller units. Normally, there is sufficient oxygen transferred to produce high oxygen levels. In an attempt to reduce power requirements or enhance nitrogen removal, some units use cycled aeration periods. Care must be taken to avoid developing poor settling biomass when cycled aeration is used.

Mixing the aeration tank contents is also an important consideration in the design of oxygen transfer devices. Rule of thumb requirements for mixing in aeration tanks range from 0.465 to 0.931 kW/m^3 (0.5 to 1 hp/1,000 ft^3) depending upon reactor geometry and type of aeration or aeration system configuration. Commercially available package units are reported to deliver mixing inputs ranging from 0.005 to 2.8 kW/m^3 (0.2 to 3 hp/1,000 $ft^{3)}$. Solids deposition problems may develop in units with lower mixing intensities.

Biomass Separation

The clarifier is critical to the successful performance of the suspended growth process. A majority of commercially available package plants provide simple gravity separation. Weir and baffle designs have not been given much attention in package units. Weir lengths of at least 12 in. (30 cm) are preferred and sludge deflection baffles (Stamford baffles) should be included as a part of the outlet design. The use of gas deflection barriers is a simple way to keep floating solids away from the weir area.

Upflow clarifier devices have been used to improve separation, but hydraulic surges must be avoided in these systems. Filtration devices have also been employed in some units, but they are very susceptible to clogging.

Controls and Alarms

Most aerobic units are supplied with some type of alarm and control system to detect mechanical breakdown and to control the operation of electrical components. They do not normally include devices to detect effluent quality or biomass deterioration. These control systems are subject to corrosion because they contain electrical components. All electrical components should be waterproofed and regularly serviced to ensure their continued operation.

Additional Construction Features

Typical onsite extended aeration package plants are constructed of noncorrosive materials, including reinforced plastics and fiberglass, coated steel, and reinforced concrete. The unit may be buried as long as there is easy access to all mechanical parts, electrical control systems, and appurtenances requiring maintenance such as weirs, air lift pump lines, etc. Units may also be installed above ground, but should be properly housed to protect against severe climatic conditions. Installation should be in accordance with the manufacturers specifications.

Appurtenances for the plant should be constructed of corrosion-free materials including polyethylene plastics. Air diffuser support legs are normally constructed from galvanized steel or an equivalent. Large-diameter air lift units should be used to avoid clogging problems. Mechanical units should be waterproofed and/or protected from the elements.

For fixed film systems, synthetic packing or attachment media are preferred over naturally occurring materials because they are lighter, more durable, and provide better void volume-surface area characteristics.

Since blowers, pumps, and other prime movers are abused by exposure to severe environments, lack of attention, and continuous operation, they should be designed for heavy duty use. They should be easily accessible for routine maintenance and tied into an effective alarm system.

PERFORMANCE

In extended aeration package plants, long hydraulic and solids retention times (SRT) are maintained to ensure a high degree of treatment at minimum operational control, to hedge against hydraulic or organic overload to the system, and to reduce sludge production. Since waste of accumulated solids is not routinely practiced in many of these units, SRT increases to a point where the clarifier can no longer handle the solids, which will be uncontrollably wasted in the effluent. Treatment performance (including nitrification) normally improves with increasing hydraulic retention time and SRT to a point where excessive solids build-up will result in high suspended solids washout. This is one of the biggest operational problems with these extended aeration units, and is often the reason for poor performance.

Dissolved oxygen concentrations in the aeration tank should exceed 2 mg/L (1.669×10^{-8} pounds/gallon) to insure a high degree of treatment and a good settling sludge. Normally, onsite extended aeration plants supply an excess of dissolved oxygen due to minimum size restrictions on blower motors or mechanical drives. An important element of aeration systems is the mixing provided by the aeration process. Package units should be designed to provide sufficient mixing to ensure good suspension of solids and mass transfer of nutrients and oxygen to the microbes.

Wastewater characteristics may also influence performance of the process. Excess amounts of certain cleaning agents, grease, floating matter, and other detritus can cause process upsets and equipment malfunctions.

Process efficiency may also be affected by temperature, generally improving with increasing temperature.

The clarifier is an important part of the treatment process. If the biomass cannot be properly separated from the treated effluent, the process will fail. Clarifier performance depends upon the settleability of the biomass, the hydraulic overflow rate, and the solids loading rate. Hydraulic surges can result in serious clarifier malfunctions. As mentioned previously, high solids loadings caused by accumulation of mixed liquor solids result in eventual solids carryover. Excessively long retention times for settled sludges in the clarifier may result in gasification and flotation of these sludges. Scum and floatable material not properly removed from the clarifier surface will also impair effluent quality.

Generally, extended aeration plants produce a high degree of nitrification since hydraulic and solids retention times are high. Reductions of phosphorus are normally less than 25 percent. The removal of indicator bacteria (fecal coliforms) in onsite extended aeration processes is highly variable and not well documented. Reported values of fecal coliforms appear to be about two orders of magnitude lower in extended aeration effluents than in septic tank effluents.

Aerobic units can achieve higher BOD_5 removals than septic tanks, but suspended solids removals, which are highly dependent on solids separation methods, are similar. Nitrification is normally achieved, but little reduction in phosphorus is accomplished. NSF studies indicate that suspended growth units can provide from 70 to 90 percent BOD_5 and SS reductions for combined household wastewater, yielding effluent BOD_5 and suspended solids concentrations as low as 20 mg/l.

OPERATION AND MAINTENANCE

General Plant Operation

The activated sludge process can be operated by controlling only a few parameters; the aeration tank dissolved oxygen, the return sludge rate, and the sludge wasting rate. For onsite package plants, these control techniques are normally fixed by mechanical limitations so that very little operational control is required. Dissolved oxygen is normally high and cannot be practically controlled except by "on or off" operation. Experimentation with the process may dictate a desirable cycling arrangement using a simple time clock control that results in power savings and may also achieve some nitrogen removal.

The return sludge rate is normally fixed by pumping capacity and pipe arrangements. Return sludge pumping rates often range from 50 to 200 percent of the incoming flow. They should be high enough to reduce sludge retention times in the clarifier to a minimum (less than one hr), yet low enough to discourage pumping of excessive amounts of water with the sludge. Time clock controls may be used to regulate return pumping.

Sludge wasting is manually accomplished in most package plants, usually during routine maintenance. Through experience, the technician knows when mixed liquor solids concentrations become excessive, resulting in excessive clarifier loading. Usually 8 to 12-month intervals between wasting is satisfactory, but this varies with plant design and wastewater characteristics. Wasting is normally accomplished by pumping mixed liquor directly from the aeration tank. Wasting of approximately 75 percent of the aeration tank volume is usually satisfactory. Wasted sludge must be handled properly.

Start-up

Prior to actual start-up, a dry checkout should be performed to insure proper installation. Seeding of the plant with bacterial cultures is not required as they normally develop within a 6 to 12-week period. Initially, large amounts of white foam may develop, but will subside as mixed liquor solids increase. During start-up, it is advisable to return sludge at a high rate. Monitoring by qualified maintenance personnel is desirable during the first month of startup.

Routine Operation and Maintenance

The maintenance process for suspended growth systems is more labor-intensive than for septic systems and requires semi-skilled personnel. Based upon field experience with these units, 12 to 48 man-hours per year plus analytical services are required to ensure reasonable performance. Power requirements are variable, but range between 2.5 to 10 kWh/day (8,530.8 to 34,123.2 Btu/day). Maintenance for fixed film systems is less labor-intensive but still requires semi-skilled personnel. Based upon limited field experience, 8 to 12 man-hours per year plus analytical services are required for adequate performance. Power requirements depend upon the device employed, but range from 1 to 4 kWh/day (3,412.3 to 13,649.3 Btu/day). Maintenance for both types of aerobic treatment units is usually completed through routine contract services. No chemicals are required for either method unless chemical disinfection or additional nutrient removal (N and P) is required for surface discharge.

Operational Problems

Major mechanical maintenance problems for onsite treatment units include blower or mechanical aerator failure, pump and pipe clogging, electrical motor failure, corrosion and/or failure of controls, and electrical malfunctions. Careful attention to a maintenance schedule will reduce these problems and alleviate operational problems due to the biological process upset. Emphasis should be placed on adequate maintenance checks during the first 2 or 3 months of operation.

COSTS

Costs for both suspended growth and fixed film systems of between 1,892 and 5,678 Liters/day (500 to 1,500 gallons per day) are typically in the $2,500 to $9,000 cost range, installed. These costs have been updated using the ENR construction cost index (ENR=6076). These units need more frequent maintenance than a traditional septic tank, and quarterly servicing is recommended. This maintenance cost averages $350 per year. Since many of these systems are being installed to replace failed septic systems, additional costs may be incurred to account for site conditions and additional piping.

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Appendix D: Supplemental LCA information

Table D.1 - Literature sources for GWP lifecycle impacts of different technologies

Technology	CO2e (kg/ p.e. year)	Lifecycle Phases	Life	Notes	Source
Activated Sludge	8.02	Includes construction, operation and EOL. No sludge disposal	10 years	Includes CO2 and N2O, no CH4	Machado et al., 2007
Activated Sludge	33.60	Includes construction and operation. No EOL and sludge disposal	10 years	Only includes CO2.	Dixon et al, 2003
Activated Sludge	25.30	Includes construction and operation. No EOL and sludge disposal	10 years	Only includes CO2.	Dixon et al, 2003
Activated Sludge	12.90	Includes construction and operation. No EOL and sludge disposal	10 years	Only includes CO2.	Dixon et al, 2003
Activated Sludge	32.35	Includes construction and operation. No EOL and sludge disposal	10 years	Only includes CO2.	Dixon et al, 2003
Activated Sludge	16.43	Includes construction, operation and EOL. No sludge disposal	20 years	Includes CO2, CH4, N2O	Gaterell et al., 2005
Activated Sludge	28.50	Includes construction, operation and EOL. No sludge disposal	20 years	Includes CO2, CH4, N2O	Gaterell et al., 2005
Activated Sludge	35.00	Includes construction, operation and EOL. No sludge disposal	20 years	Includes CO2, CH4, N2O	Gaterell et al., 2005
Activated Sludge	38.00	Includes construction, operation and EOL. No sludge disposal	20 years	Includes CO2, CH4, N2O	Gaterell et al., 2005
Activated Sludge	41.60	Includes construction, operation and EOL. No sludge disposal	20 years	Includes CO2, CH4, N2O	Gaterell et al., 2005
Activated Sludge	20.35	Includes construction and EOL. No operation and sludge disposal.	30 years	Includes CO2, CH4, N2O	ecoinvent v.2.2
Activated Sludge	27.14	Includes construction and EOL. No operation and sludge disposal.	30 years	Includes CO2, CH4, N2O	ecoinvent v.2.2
Activated Sludge	29.10	Includes construction and EOL. No operation and sludge disposal.	30 years	Includes CO2, CH4, N2O	ecoinvent v.2.2
Activated Sludge	29.95	Includes construction and EOL. No operation and sludge disposal.	30 years	Includes CO2, CH4, N2O	ecoinvent v.2.2
Activated Sludge	30.16	Includes construction and EOL. No operation and sludge disposal.	30 years	Includes CO2, CH4, N2O	ecoinvent v.2.2

Table D.1 (Cont.): Literature sources for GWP lifecycle impacts of different technologies

Technology	CO2e (kg/ p.e / year	Lifecycle Phases	Life	Notes	Source
Constructed Wetland	-24.40	Includes construction, operation and EOL. Excludes sludge disposal	10 years	Does not include methane.	Machado et al., 2007
Constructed Wetland	0.08	Includes construction, operation and EOL.	50 years	Includes CO2, CH4 and N2O	Fuchs et al., 2011
Constructed Wetland	0.31	Includes construction, operation and EOL.	50 years	Includes CO2, CH4 and N2O	Fuchs et al., 2011
Constructed Wetland	16.10	Includes construction and operation. No EOL, sludge disposal	10 years	Only includes CO2	Dixon et al, 2003
Constructed Wetland	-1.30	Includes construction and operation. No EOL, sludge disposal	10 years	Only includes CO2	Dixon et al, 2003
Constructed Wetland	-4.90	Includes construction and operation. No EOL, sludge disposal	10 years	Only includes CO2	Dixon et al, 2003
Constructed Wetland	0.16	Includes emissions from use of constructed wetlands. Does not consider construction or end of life.	N/A	Winter Values HSSF Kodijarve. CO2, CH4 and N2O	Sovik et al., 2006
Constructed Wetland	27.40	Includes emissions from use of constructed wetlands. No construction or EOL.	N/A	Summer values HSSF Kodijarve. Includes CO2, CH4 and N2O	Sovik et al., 2006
Constructed Wetland	4.20	Includes emissions from use. No construction or EOL.	N/A	Winter values HSSF Nowa S. CO2, CH4 and N2O	Sovik et al., 2006
Constructed Wetland	41.10	Includes emissions from use. No construction or EOL.	N/A	Summer values HSSF Nowa S. CO2, CH4 and N2O	Sovik et al., 2006
Membrane Bioreactor	63.88	Includes construction, operation and EOL. Excludes sludge disposal	25 years	Only includes CO2	Ortiz et al., 2007
Membrane Bioreactor	68.02	Includes construction, operation and EOL. Excludes sludge disposal	25 years	Only includes CO2	Ortiz et al., 2007
Septic Tank	0.47	Includes construction and EOL. Excludes use and sludge disposal	100 years	CO2, CH4 and N2O	NPCA, 2010
Septic Tank	23.38	Includes construction, operation and EOL. Excludes sludge disposal	20 years	Includes CO2, CH4 and N2O	Gaterell et al., 2005

Table D.2: Literature Sources for Energy Use

Technology	kWh	Gallons	kWh/ 1000 gallon	Source
The Living Machine (Constructed Wetland)				
The Living Machine	2.8	1000	2.8	Parker Goodyear (Living Machine rep)
Constructed Wetlands	0	1000	0	Tchobanoglous et. al. (2007) - Chapter 9 - pp. 9-2
The Living Machine	3	1000	3	Parker Goodyear (Living Machine rep)
Recirculating Filters (PreFabricated Modular)				
Trickling Biofilter	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-16
Trickling Biofilter	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-35
Trickling Biofilter	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-38
Trickling Biofilter	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-40
Trickling Biofilter	500	164250	3.04	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-38
Trickling Biofilter	500	164250	3.04	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-40
Trickling Biofilter	300	164250	1.83	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-16
Trickling Biofilter	150	164250	0.91	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-10
Trickling Biofilter	150	164250	0.91	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-22
Trickling Biofilter	150	164250	0.91	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-28
Trickling Biofilter	150	164250	0.91	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-32
Trickling Biofilter	150	164250	0.91	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-35
trickling biofilter	50	164250	0.30	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-28
Trickling Biofilter	50	164250	0.30	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-32
Trickling Biofilter	0	164250	0.00	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-10
Trickling Biofilter	0	164250	0.00	Tchobanoglous et. al. (2007) - Chapter 6 - pp. 6-22

Table D.2 (Cont.): Literature Sources for Energy Use

Technology	kWh	Gallons	kWh/ 1000 gallon	Source
Activated Sludge (PreFabricated Modular)				
continuous flow, aerated suspended growth	3000	164250	18.26	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-5
sequency batch reactor	3000	164250	18.26	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-29
continuous flow, aerated suspended growth	3000	164250	18.26	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-9
continuous flow, aerated suspended growth	2500	164250	15.22	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-16
continuous flow, aerated suspended growth	2160	164250	13.15	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-19
continuous flow, aerated suspended growth	2000	164250	12.18	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-5
continuous flow, aerated suspended growth	2000	164250	12.18	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-9
continuous flow, aerated suspended growth	2000	164250	12.18	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-16
continuous flow, aerated suspended growth	1500	164250	9.13	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-13
continuous flow, aerated suspended growth	1500	164250	9.13	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-13
continuous flow, aerated suspended growth	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-7
continuous flow, aerated suspended growth	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-13
continuous flow, aerated suspended growth	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-21
continuous flow, aerated suspended growth	1000	164250	6.09	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-13
continuous flow, aerated suspended growth	750	164250	4.57	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-7
continuous flow, aerated suspended growth	600	164250	3.65	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-19
continuous flow, aerated suspended growth	500	164250	3.04	Tchobanoglous et. al. (2007) - Chapter 7 - pp. 7-21
continuous flow, aerated suspended growth	500	164250	3.04	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-15
continuous flow, aerated suspended growth	400	164250	2.44	Tchobanoglous et. al. (2007) - Chapter 8 - pp. 8-15
small activated sludge plant	0.5	264.17	1.89	Ortiz et. al. (2007) pp. 126

Table D.2 (Cont.): Literature Sources for Energy Use

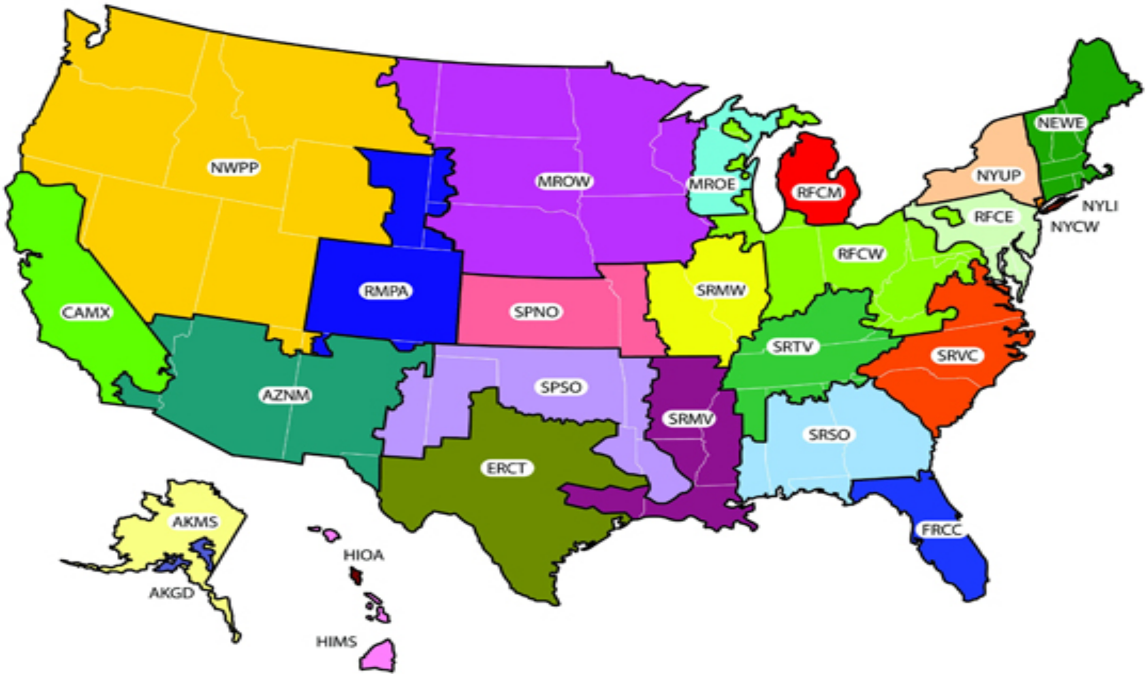
Technology	kWh	Gallons	kWh/ 1000 gallon	Source
Subsurface treatment				
aerobic biofilter	300	164250	1.83	Tchobanoglous et. al. (2007) - Chapter 6
aerobic biofilter	100	164250	0.61	Tchobanoglous et. al. (2007) - Chapter 6
aerobic biofilter	100	164250	0.61	Tchobanoglous et. al. (2007) - Chapter 6
MBR				
MBR	n/a	n/a	6.02	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	2.08	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	18.47	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	2.65	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	20.37	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	6.44	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	22.94	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)
MBR	n/a	n/a	3.03	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)

Table D.3: Global Warming Potential for 100-year period for U.S. Electricity Mix

eGRID subregion name	Annual kg CO2e/kWh	Non-base load (including peak use) kg CO2e/kWh
ASCC Alaska Grid	0.56	0.67
ASCC Miscellaneous	0.23	0.66
WECC Southwest	0.60	0.55
WECC California	0.33	0.49
ERCOT All	0.60	0.51
FRCC All	0.60	0.62
HICC Miscellaneous	0.70	0.77
HICC Oahu	0.83	0.85
MRO East	0.84	0.83
MRO West	0.83	0.98
NPCC New England	0.42	0.60
WECC Northwest	0.41	0.61
NPCC NYC/Westchester	0.37	0.69

Table D.3 Cont.: Global Warming Potential for 100-year period for U.S. Electricity Mix

eGRID subregion name	Annual kg CO2e/kWh	Non-base load (including peak use) kg CO2e/kWh
NPCC Long Island	0.70	0.69
NPCC Upstate NY	0.33	0.69
RFC East	0.52	0.82
RFC Michigan	0.71	0.76
RFC West	0.70	0.91
WECC Rockies	0.86	0.74
SPP North	0.89	0.99
SPP South	0.76	0.63
SERC Mississippi Valley	0.46	0.57
SERC Midwest	0.83	0.96
SERC South	0.68	0.77
SERC Tennessee Valley	0.69	0.91
SERC Virginia/Carolina	0.52	0.81



NWPP
MROW
MROE
RFCM
NEWE
NYUP
NYLI
RFCE
NYCW
RFCW
CAMX
RMPA
SPNO
SRMW
SRTV
SRVC
AZNM
SPSO
SRMV
SRSO
ERCT
FRCC
AKMS
HIOA
AKGD
HIMS

Appendix E: Supplement 1

Decentralized Wastewater Treatment Valuation Matrix

Valuation Category						Constructed Wetlands				Prefabricated and Modular			
										Recirculating Filters			
			Leach Field	Mound System	Evapotranspiration	Subsurface Horizontal Flow	Free Water Surface	Tidal Flow Living Machine	Recirculating Vertical Flow Wetlands (VF)	Sand or Gravel	Advanced Media	Membrane Bioreactors (MBR)	Activated Sludge Systems
Economic	Initial Investment	Land Requirement	1	1	1	2	2	3	3	3	3	3	3
		Construction	3	2	2	2	2	1	2	2	2	1	2
	Operation & Maintenance	Materials	3	3	3	3	3	1	2	2	2	1	2
		Energy Requirements	3	3	3	3	3	2	2	2	2	1	1
		Operational Labor	3	2	3	3	3	1	1	1	1	1	1
	Regulation	Current Permitting	3	1	1	1	1	1	1	1	1	1	1
		Predicted Future Permitting	3	1	1	2	2	2	2	2	2	2	2
Enviromental	Reliability		1	1	1	2	2	3	3	3	3	3	3
	Performance	Removal of Total Suspended Solids (TSS)	3	3	2	2	2	3	3	3	3	3	2
		Final Total Nitrogen Concentration*	3	3	2	2	3	2	1	1	1	2	2
		Biological Oxygen Demand (BOD)	3	3	2	2	2	3	3	3	3	3	2
		Removal of Potential Pathogens	3	3	2	2	1	3	3	3	3	3	1
	Site Constraints	Soil	1	1	2	2	2	3	2	3	3	3	3
		Slope	1	1	1	1	1	3	2	3	3	3	3
	Natural Environment	Habitat Creation Potential	1	1	2	3	3	2	2	1	1	1	1
Social	Aesthetic	Visual	2	1	3	3	3	3	3	2	2	1	1
		Odor	3	3	2	3	2	3	3	3	3	3	1
		Noise	3	3	3	3	3	3	3	3	3	3	1
	Education		1	1	3	3	3	3	3	1	1	1	1
	Ownership & Participation		3	2	3	3	3	1	1	1	1	1	1
	Quality of Life	Health - Risk of Vector Contact	3	3	2	3	2	3	2	2	2	3	2

Appendix E: Supplement 2

Decentralized Wastewater Treatment Valuation Rank Choices					
			Green	Yellow	Red
Economic	Capital	Land Requirement	less than 0.25 sq ft. per GPD	greater than 0.25 less than 0.75 sq ft. per GPD	greater than 0.75 sq ft per GPD
		Construction	Leachfield	Natural Systems and prefabricated modular conventional	Membrane and Proprietary
	Operation & Maintenance	Materials	Low Cost expected	Intermediate Cost expected	High Cost Expected
		Energy Requirements	Less than $0-.25 per 1000 gallons on Energy (based on $0.14 per KWh)	Less than $0.25-1.00 per 1000 gallons on Energy (based on $0.14 per KWh)	Less than $1.00 per 1000 gallons on Energy (based on $0.14 per KWh)
		Operational Labor	Minimal Supervision	Informed Owner	Licensed Operator
	Regulation	Permitting (Current and Future)	Approximate time to permit approval less than 6 weeks and established system	Approximate time to permit around 6 weeks (anticipated future)	Approximate time to permit around 6 months
Enviromental	Reliability		Tightly controled; consistent minimal variation in final effluent	Climatic variation in final effluent	Sensitive to increased strength and volume of wastewater
	Performance	Total Suspended Solids (TSS)	Meets Title 22 Restricted Requirements = less than or equal to 10 mg/L	Meets Title 22 Restricted Requirements = (less than or equal to 30 mg/L)	(greater than 30 mg/L)
		Total Nitrogen Concentration*	equal to or less than 5 mg/L	equal to or less than 10 mg/L	greater than 10 mg/L
		BOD	Meets Title 22 Unrestricted (less than or equal to 10 mg/L)	Meets Title 22 Restricted (less than or equal to 30 mg/L)	Does not Meet Title 22 Requirements (greater than 30 mg/L)
		Fecal Coliforms	greater than or equal to 3 log removal	2 log removal	less than 2 log removal
	Site Constraints	Soil	Any Soil Type is Acceptable	Minimal / flexible requirements of soil type	Strict requirements of soil type
		Slope	No Grading Requirement	Minimal /flexible Grading Requirement	Strict Grading Requirements
	Natural Environment	Habitat Creation Potential	Significant Habitat Potential Generated	Some Habitat Potential Generated	Negative / No Impact on Habitat
Social	Aesthetic	Visual	Impacts Visual Aesthetic Positively	Neutral Impact on Visual Aesthetic	Negative Impact on Visual Aesthetic
		Odor	No chance of odor	Possible seasonal odor or odor due to high organic loading	High chance of odor due to organic loading
		Noise	No noise generated during treatment	Minimal noise generated during treatment	High noise generation during treatment process
	Quality of Life	Educational Opportunity	Creates Public Education Opportunities	N/A	Does not create Public Education Opportunities
		Ownership & Participation	Low Supervision	Informed Owner	Licensed Operator
		Health - Risk of Vector Contact	No risk of contact with vector	Minimal risk of contact with vector	High risk of contact with vector

Appendix E: Supplement 3

Decentralized Wastewater Treatment Valuation Parameter Descriptions			
Economic	Capital	Land Requirement	Different systems require different amounts of land to treat wastewater. Depending on the process utilized to treat wastewater, and the intended use, the amount of land required will vary.
		Installation	Installation includes the costs to prepare a site for the construction of an onsite treatment system, as well as the construction process itself.
	Operation & Maintenance	Materials	Operation and Maintenance refers to all costs associated with maintaining system function, including parts replacement, monitoring, and the addition of chemicals or other products required for treatment.
		Energy Requirements	Different systems will utilize different processes to treat wastewater. Generally, passive systems utilizing biological processes will require less energy than active systems which use some mechanical processes.
		Operational Labor	Operational labor refers to the costs required to employ an operator to maintain and ensure system function.
	Regulation	Permitting (Current and Future)	Refers to the approximate time requirement needed to legally permit a system in Santa Barbara County. Independent of the number of agencies as most approvals work concurrently. Independent of costs, but the more complex the system, the higher the cost for permitting.
Enviromental	Reliability		Reliabilty refers to the level of variation possible in effluent.
	Performance	Removal of Total Suspended Solids (TSS)	This refers to the milligrams per liter of total suspended solids expected in final effluent.
		Final Total Nitrogen Concentration	This refers to the miligrams per liter of Total Kjendahl Nitrogen expected in final effluent.
		Biological Oxygen Demand (BOD)	This refers to the biological oxygen demand expected in final effluent.
		Removal of Pathogens	This refers to the total coliforms in final effluent.
	Site Constraints	Soil	This refers to the degree to which soil characteristics are important for system function.
		Slope	Slope refers to the degree to which the slope of the land on the site must meet certain standards for systems to function.
	Natural Environment	Habitat Creation Potential (Provides additional ecosystem Services)	Habitat creation refers to the potential for a system to provide ecosystem services onsite. Ecosystem services are defined as "the benefits of nature to households, communities, and economies."
Social	Aesthetic	Visual	This refers to the ability of a system to affect the visual aesthetic of a site.
		Odor	Some systems are characterized by having increased likelyhood of odor associated with treatment.Depending on the process utilized odor will be minimal.
		Noise	Some systems generate noise during the treatment process. Generally, passive systems will not generate as much noise, while activated systems, which utilize aeration processes are more likely to generate noise.
	Educational Opportunity		This refers to the ability of a system to provide community education opportunities. For example, Wetland systems have been used to explain wastewater treatment processes to the general public, while other systems, like leach fields, whose primary treatment methods are subsurface, do not provide that opportunity.
	Ownership & Participation		This refers to the amount of participation required by owners of systems. As a system increases in complexity, ownership awareness and participation will increase.
	Quality of Life	Health - Risk of Vector Contact	This refers to the chance for humans to come in contact with disease vectors associated with wastewater. Generally, properly functioning subsurface treatment will have no risk for vector contact, while systems utilizing above surface processes, like Wetlands, may contain some risk for vector contact.

Appendix E: Supplement 4

Decentralized Wastewater Treatment Valuation Citations

Valuation Category			Subsurface Treatment: Leach Field	Subsurface Treatment: Mound System	Subsurface Treatment: Evapotranspiration
Economic	Initial Investment	Land Requirement	(Burkhard et. al., 2000), (U.S. EPA, 2002[c]), (Converse, J. & Tyler E., 1998)	(Burkhard et. al., 2000), (U.S. EPA, 2002[c]), (Converse, J. & Tyler E., 1998)	(U.S. EPA, 2002[c]), (U.S. EPA, 2000[b]), (Environmental Technology Initiative, 1998[c])
		Construction	(C. Clay, Personal communication, January 30, 2012), (Leverenz & Tchobanoglous, 2002), (WERF, 2010[a])	(Environmental Technology Initiative, 1998[a]: Table 2), (Rutgers Cooperative Extension, 2005: p. 3), (WERF, 2010[a])	(U.S. EPA, 2002[c]), (U.S. EPA, 2000[b]), (Environmental Technology Initiative, 1998[c]), (WERF, 2010[a]: p. 186)
	Operation & Maintenance	Materials	(D. Hallahan. Personal Communication. February, 6, 2011), (C. Clay, Personal communication, January 30, 2012)	(D. Hallahan. Personal Communication. February, 6, 2011), (Environmental Technology Initiative, 1998[a]: Table 2)	(WERF, 2010[a]: p. 186)
		Energy Requirements	(Babcock, Roger W. Jr. 2004 p. 770), (Kivaisi, Amelia 2001. p. 545-560)	(C. Haset, Personal Communication, February 2, 2011), (U.S. EPA, 1998), ("Mound Systems" 1995. Retrieved from: www.ci.austin.tx.us)	(U.S. EPA, 2008: p. TFS6)
		Operational Labor	(C. Clay, Personal communication, January 30, 2012), (Leverenz and Tchobanoglous, 2002), (WERF, 2010[a])	(C. Haset, Personal Communication, February 2, 2011), (WERF, 2010[a])	(WERF, 2010[a])
	Regulation	Current Permitting	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	(Santa Barbara County Code, 2011)(B. Banks, personal communication, January 3, 2012 and Eric Graham, personal communication, January 4, 2012.)	(Santa Barbara County Code, 2011). (B. Banks, personal communication, January 3, 2012 and Eric Graham, personal communication, January 4, 2012).
Enviromental	Reliability				
	Performance	Removal of Total Suspended Solids (TSS)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)
		Final Total Nitrogen Concentration*	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)
		Biological Oxygen Demand (BOD)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000), (WERF, 2010[a]), (Crites and Tchobanoglous, 1998)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000), (WERF, 2010[a]), (Crites and Tchobanoglous, 1998)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000), (WERF, 2010[a]), (Crites and Tchobanoglous, 1998)
		Removal of Potential Pathogens	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)	(Crites, R. W., Reed, S. C., & Bastian, R. K., 2000)
	Site Constraints	Soil	(Converse, J. C. and Tyler, E., 1998), (Tyler, E. J., 2001), (U.S. EPA, 2002[c])	(Converse, J. C. and Tyler, E., 1998), (Tyler, E. J., 2001), (Reed, Crites, Middlebrooks, 1995), (U.S. EPA, 2000[d])	(WERF, 2010[a]), (Leverenz and Tchobanoglous, 2002)
		Slope	(Crites and Tchobanoglous, 1998: p 911), (U.S. EPA, 2002[c])	(Converse, J. C. and Tyler, E., 1998), (Tyler, E. J., 2001), (Reed, Crites, Middlebrooks, 1995) (U.S. EPA, 2000[d])	(WERF, 2010[a]), (Leverenz and Tchobanoglous, 2002)
	Natural Environment	Habitat Creation Potential	Assumption: Because of the subsurface nature of this treatment, there is no habitat creation.	Assumption: Because of the subsurface nature of this treatment, there is limited habitat creation.	Assumption: Due to the regular introdution of plant communities, ET systems are known to offer Habitat Creation Potential.
Social	Aesthetic	Visual	Assumption: Due to the nature of the subsurface treatment involved in leach field treatment, visual impacts are not expected.	(Leverenz H., Tchobanoglous, G., and Darby, J., 2008), (Rutgers Cooperative Extension, 2005: p. 3)	(U.S. EPA, 2000[b]) (WERF, 2010[a]: p. 185)
		Odor	(U.S. EPA, 2002[c]), (Crites R. and Tchobanoglous G., 1998)	(Crites R. and Tchobanoglous G., 1998), (U.S. EPA, 2000[d])	(U.S. EPA, 2000[b]), (WERF, 2010: p. 185), (U.S. EPA, 2000[d])
		Noise	Assumption: Passive systems that do not utilize aeration or other process which require energy are not expected to generate noise.	Assumption: Passive systems that do not utilize aeration or other process which require energy are not expected to generate noise.	Assumption: Passive systems that do not utilize aeration or other process which require energy are not expected to generate noise.
	Education		Assumption: Systems that do not have above ground natural features will not offer educational component.	Assumption: Systems that do not have above ground natural features will not offer educational component.	(Magliaro and Lovins, 2004) & Assumption: Technologies incorporating natural treatment systems will be assumed to generate some capacity for educational opportunities
	Ownership & Participation		(U.S. EPA, 2002[c]), (Reed, Crites, Middlebrooks, 1995)	(U.S. EPA, 2002[c]), (Reed, Crites, Middlebrooks, 1995)	(U.S. EPA, 2002[c]), (Reed, Crites, Middlebrooks, 1995)
	Quality of Life	Health - Risk of Vector Contact	Assumption: Wastewater not exposed at surface. No risk of vector contact expected.	Assumption: Wastewater not exposed at surface. No risk of vector contact expected.	(WERF, 2010[a])

Appendix E: Supplement 5

Decentralized Wastewater Treatment Valuation Citations

Valuation Category			Constructed Wetlands: Subsurface Horizontal Flow	Constructed Wetlands: Free Water Surface	Constructed Wetlands: Tidal Flow Living Machine	Constructed Wetlands: Recirculating Vertical Flow Wetlands (VF)
Economic	Initial Investment	Land Requirement	(City and County of San Francisco, 2009: p. 802_11).	(City and County of San Francisco, 2009: p. 802_11).	(City and County of San Francisco, 2009: p. 802_11).	(City and County of San Francisco, 2009: p. 802_11), (City and County of San Francisco, 2009: p. 802_11).
		Construction	(Wallace, 2006: p. 11.1-11.19). & (U.S. EPA., 2002[d]: p.7-8) & (Kadlec, 2009: p. 793-817)	(Wallace, 2006: p.11.1-11.19).& (U.S. EPA. (2000[c]:p. 6-7). & (Kadlec, 2009: p.793-817).	(U.S. EPA., 2002[b]:p. 6)	Garcia-Perez, A., Jones, D., Grant, W., & Harrison, M. (2008). Recirculating Vertical Flow Constructed Wetlands for Treating Residential Wastewater. Purdue Extension-Rural Wastewater. Retrieved from https://mdc.itap.purdue.edu/
	Operation & Maintenance	Materials	(Wallace, 2006: p. 11.1-11.19) & (U.S. EPA. 2002[d]:p. 7-8)	(Wallace, 2006: p. 11.1-11.19) & (U.S. EPA. 2000[c]: p.6-7)	(U.S. EPA. 2002[b]: p.5-6)	(Garcia-Perez, 2008: p.)
		Energy Requirements	(Machado, 2007:p. 15–22)	(Haase, 2011: p.13).	Personal communication with Parker Goodyear, Solutions Specialist from Living Machine Systems	(Machado, 2007:p. 15–22) & (Pan, 2011:p. 248–254)
		Operational Labor	(Wallace, 2006: p 10-8; 11-17). &(U.S. EPA., 2002[d]: p.6-7)	(Wallace, 2006: p.10-1;11-17) & (U.S. EPA. 2000[c]: p.6-7)	(U.S. EPA. 2002[b]: p.5-6)	(Garcia-Perez, 2008: p.6).
	Regulation	Current Permitting	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012
Enviromental	Reliability					
	Performance	Removal of Total Suspended Solids (TSS)	(Tchobanoglous, et. al., 2002: p. 9-3). & (U.S. EPA. 2002[d]. p:5-6) & (Vymazal, 2008: p.278-279). & (Wallace, S. 2006: p.8-8)	(Seabloom, 2005: p.13) & (Tchobanoglous, et. al., 2002: p. 9-1) &(U.S. EPA.,2000[c]: p.5)	(P. Goodyear, personal communication, January 20, 2012)& (U.S. EPA. 2002[b]:p.4-5)	(Garcia-Perez, 2006:p.6-7). & (Garcia-Perez, 2008:p.34-38) & (Gustafson, 2002)
		Final Total Nitrogen Concentration *	(Tchobanoglous, et. al., 2002: p. 9-3). & (U.S. EPA. 2002[d]. p:5-6) & (Vymazal, 2008: p.278-279). & (Wallace, S. 2006: p.8-8)	(Seabloom, 2005: p.13) & (Tchobanoglous, et. al., 2002: p. 9-1) &(U.S. EPA.,2000[c]: p.5)	(P. Goodyear, personal communication, January 20, 2012)& (U.S. EPA. 2002[b]:p.4-5)	(Garcia-Perez, 2006:p.6-7). & (Garcia-Perez, 2008:p.34-38) & (Gustafson, 2002)
		Biological Oxygen Demand (BOD)	(Tchobanoglous, et. al., 2002: p. 9-3). & (U.S. EPA. 2002[d]. p:5-6) & (Vymazal, 2008: p.278-279). & (Wallace, S. 2006: p.8-8)	(Seabloom, 2005: p.13) & (Tchobanoglous, et. al., 2002: p. 9-1) &(U.S. EPA.,2000[c]: p.5)	(P. Goodyear, personal communication, January 20, 2012)& (U.S. EPA. 2002[b]:p.4-5)	(Garcia-Perez, 2006:p.6-7). & (Garcia-Perez, 2008:p.34-38) & (Gustafson, 2002)
		Removal of Potential Pathogens	(Tchobanoglous, et. al., 2002: p. 9-3). & (U.S. EPA. 2002[d]. p:5-6) & (Vymazal, 2008: p.278-279). & (Wallace, S. 2006: p.8-8)	(Seabloom, 2005: p.13) & (Tchobanoglous, et. al., 2002: p. 9-1) &(U.S. EPA.,2000[c]: p.5)	(P. Goodyear, personal communication, January 20, 2012)& (U.S. EPA. 2002[b]:p.4-5)	(Garcia-Perez, 2006:p.6-7). & (Garcia-Perez, 2008:p.34-38) & (Gustafson, 2002)
	Site Constraints	Soil	(U.S. EPA., 2000: p.21). & (U.S. EPA. 2000[e]:p.2)	(U.S. EPA.,2000:p.17). & (U.S. EPA. (2000)[c]:p.1)	Assumption: Due to the modular nature of the Living Machines System, Soil Requirements will be similar to systems in the "Prefabricated & Modular" Category	(U.S. EPA., 2000:p 17).
		Slope	(Kadlec,2009:p.736) (U.S. EPA.,2000: p.19)	(Kadlec,2009:p.680) & (U.S. EPA. 2000:p.19)	Assumption: Due to the modular nature of the Living Machines System, Slope Requirements will be similar to systems in the "Prefabricated & Modular" Category	(U.S. EPA. 2000:p.19)
	Natural Environment	Habitat Creation Potential	(U.S. EPA. 2000[e]:p.3)	(Kadlec, 2009:p.5).& (Wallace, 2006:p.108).	Assumption: While Living Machines Systems utilize natural systems to treat wastewater, the amount of potential habitat they are able to provide is small when compared to HSSF and FWS wetland systems due to the small land footprint that these systems demonstrate and will be most closely represented by a similar score as VF Wetlands	Assumption: While VF Wetlands utilize natural systems to treat wastewater, the amount of potential habitat they are able to provide is small when compared to HSSF and FWS wetland systems due to the small land footprint that these systems demonstrate.
Social	Aesthetic	Visual	(Kadlec, 2009:p.691).. & (Wallace, 2006:p. 9.1-9.28)	(Kadlec, 2009:p.691-713). (U.S. EPA. 2000:p.10).& (Wallace, 2006:p.108).	(U.S. EPA., 2002[b]:p.4)	(Garcia-Perez, 2006:p.1-2.). & (Garcia-Perez, (2008:p.5-6)
		Odor	(U.S. EPA.,1993:p.2.1) & (U.S. EPA. 2002[d])	(Wallace, 2006:p.109).	(U.S. EPA., 2002[b]:p.2).	Assumption: Due to VF Wetlands similar design and the fact that water is not exposed to the surface there is no expectation of odors associated with this systems use. Additionally, literature specific to these systems make no mention of odor being associated with these systems use assume they are functioning normally
		Noise	Assumption: HSSF Wetlands are passive systems that do not utilize aeration through blowers or other processes which expected to generate noise.	Assumption: FWS Wetlands are passive systems that do not utilize aeration through blowers or other processes which expected to generate noise.	(Seattle Public Utilities. 2008:p.8)	Assumption: Due to VF Wetlands similar energy requirements and system design mimicking RF Filters, noise is expected to be similar to these systems
	Education		Assumption: Technologies incorporating natural treatment systems will be assumed to generate some capacity for educational opportunities	(Wallace, 2006: p.10-7).	(Hurd,2006:p.1).	Assumption: Technologies incorporating natural treatment systems will be assumed to generate some capacity for educational opportunities
	Ownership & Participation		(Gauss, 2008) (Wallace, 2006:p.10.6;10-13). & (U.S. EPA., 2000[e]:p.6-7)	(Wallace, 2006:p. 10.1;10.6).	(Seattle Public Utilities, 2008:p.5)). & (U.S. EPA, 2002[b]:p.8)	(Brix, 2005:p.498-499). & (Garcia-Perez, 2008:p.6)
	Quality of Life	Health - Risk of Vector Contact	(Wallace, 2006:p. ES-1) & (U.S. EPA, 1993:p.2-1).	(Wallace, 2006:p. ES-1). & (Water Environmental Resource Foundation, 2010:p.109).	Assumption: Wastewater is not exposed to the surface. No risk of vector contact expected.	Assumption: Wastewater is exposed during pumping to filter, some inherent risk of localized vector contact associated with aerosolization of wastewater as it is applied.

Appendix E: Supplement 6

Decentralized Wastewater Treatment Valuation Citations

Valuation Category			Prefabricated and Modular			
			Recirculating Filters		Membrane Bioreactors (MBR)	Activated Sludge Systems
			Sand or Gravel	Advanced Media		
Economic	Initial Investment	Land Requirement	(Crites, 2006: p. 6464)	(Crites, 2006: p. 6464)	(Crites, 2006: p. 6464)	(City and County of San Francisco, 2009: p. 802_11).
		Construction	(U.S. EPA, 2002[c]: p. TFS68),	(U.S. EPA, 2002[c]: p. TFS68)	(Salveston, et. al., 2010: p. 128).	(U.S. EPA, 2002 [a]: p. TFS-4), (U.S.
	Operation & Maintenance	Materials	(U.S. EPA, 2002[c]: p. TFS68). (EPA, 2005: p. 5). (Obropta et. al., 2005: p. 2), (Salveston, et. al., 2010: p. 133).	Assumption: Construction costs will be similar to Sand/Gravel RSF systems. The cost of advanced materials (e.g. biotextiles or other engineered media) may increase the cost. Cost estimates differentiating these systems were not available in literature.	(U.S. EPA, 2007: p. 7-8), (Graham, 2008: p. 21), (Salveston, et. al., 2010: p. 136).	(U.S. EPA, 2002[c]: p. TSF4). (U.S. EPA, 2005: p. 5) (Tchobanoglous, 2002: p 7_5), (Obropta, et. al., 2005: p. 1), (Salveston, et. al., 2010: p. 131).
		Energy Requirements	(Tchobanoglous, 2007: p. 6-16, 6-22)	(Tchobanoglous, 2007: p. 6-35, 6-38)	(Wallis-Lage, 2010: p. 5828-5838), (Gil et al, 2010p. 997-1001)	(Tchobanolglous, 2002: p. 7-5) (Ortiz et. al, 2007: p. 126)
		Operational Labor	(U.S. EPA, 2002[c]: p. TFS 58), (Tchobanoglous, 2002: p. 6_16), (Obropta, et. al., 2005: p. 2), (Salveston, et. al., 2010: p. 141).	Assumption: Labor costs will be similar to Sand/Gravel RSF systems.	(U.S. EPA, 2007: p. 8), (Graham, 2008: p. 21). (Salveston, et. al., 2010: p. 143-144).	(U.S. EPA, 2002[c]: p. TSF4). (U.S. EPA,2005: p. 5), (Obropta, et. al., 2005: p. 1), (Salveston, et. al., 2010: p. 139).
	Regulation	Current Permitting	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012	P. Jenzen, personal communication, December 14, 2011 and D. Lacaro, personal communication, January 24, 2012
Enviromental	Reliability					
	Performance	Removal of Total Suspended Solids (TSS)	(Ball, 1998: p. 5), (Washington State Department of Health, 2007: p.10), (Environmental Technology Initiative, 1998[b]: p. 3), (U.S. EPA, 2002[c]: p. TFS 57).	(U.S. EPA, 2002[c]: p. TFS-67), (Orenco Systems, Inc., (2011)[a]: p.4), (Orenco Systems, Inc., 2005: p1-4).	(D. Higgins, personal communication, January 13, 2012), (Ovivo Water, 2011[b]: p. 2), (Ovivo Water, 2011[a]: p. 4), (U.S. EPA, 2007: p. 8).	(U.S. EPA, 2002[c]: p. TSF4), (U.S. EPA, 2000[a]: p. 6), (Salveston, et. al., 2010: p. 147).
		Final Total Nitrogen Concentration *	(Ball, 1998: p. 5), (Washington State Department of Health, 2007: p.10), (Environmental Technology Initiative, 1998[b]: p. 3), (U.S. EPA, 2002[c]: p. TFS 57).	(U.S. EPA, 2002[c]: p. TFS-67), (Orenco Systems, Inc., (2011)[a]: p.4), (Orenco Systems, Inc., 2005: p1-4).	(D. Higgins, personal communication, January 13, 2012), (Ovivo Water, 2011[b]: p. 2), (Ovivo Water, 2011[a]: p. 4), (U.S. EPA, 2007: p. 8).	(U.S. EPA, 2002[c]: p. TSF4), (Salveston, et. al., 2010: p. 147).
		Biological Oxygen Demand (BOD)	(Ball, 1998: p. 5), (Washington State Department of Health, 2007: p.10), (Environmental Technology Initiative, 1998[b]: p. 3), (U.S. EPA, 2002[c]: p. TFS 57).	(U.S. EPA, 2002[c]: p. TFS-67), (Orenco Systems, Inc., (2011)[a]: p.4), (Orenco Systems, Inc., 2005: p1-4).	(D. Higgins, personal communication, January 13, 2012), (Ovivo Water, 2011[b]: p. 2), (Ovivo Water, 2011[a]: p. 4), (U.S. EPA, 2007: p. 8).	(U.S. EPA, 2002[c]: p. TSF4), (U.S. EPA, 2000[a]: p. 6), (Salveston, et. al., 2010: p. 147).
		Removal of Potential Pathogens	(Ball, 1998: p. 5), (Washington State Department of Health, 2007: p.10), (U.S. EPA, 2002[c]: p. TFS 57).	(U.S. EPA, 2002[c]: p. TFS-67), (Orenco Systems, Inc., (2011).	(D. Higgins, personal communication, January 13, 2012), (Ovivo Water, 2011[b]: p. 2), (Ovivo Water, 2011[a]: p. 4), (U.S. EPA, 2007: p. 8).	(U.S. EPA, 2002[c]: p. TSF4), (U.S. EPA, 2000[a]: p. 6), (Salveston, et. al., 2010: p. 147).
	Site Constraints	Soil	Assumption: No soil requirements for boxed treatment systems due to the self contained nature of these systems and the lack of associated soil treatment processes.	Assumption: No soil requirements for boxed treatment systems due to the self contained nature of these systems and the lack of associated soil treatment processes.	Assumption: No soil requirements for boxed treatment systems due to the self contained nature of these systems and the lack of associated soil treatment processes.	Assumption: No soil requirements for boxed treatment systems due to the self contained nature of these systems and the lack of associated soil treatment processes.
		Slope	Assumption: No grading requirements for boxed treatment systems due to the self contained nature of these systems and their small land use footprint.	Assumption: No grading requirements for boxed treatment systems due to the self contained nature of these systems and their small land use footprint.	Assumption: No grading requirements for boxed treatment systems due to the self contained nature of these systems and their small land use footprint.	Assumption: No grading requirements for boxed treatment systems due to the self contained nature of these systems and their small land use footprint.
	Natural Environment	Habitat Creation Potential	Assumption: Moduler and Prefabricated treatment systems will not generate potential habitat space due to the self contained nature of these systems.	Assumption: Moduler and Prefabricated treatment systems will not generate potential habitat space due to the self contained nature of these systems.	Assumption: Moduler and Prefabricated treatment systems will not generate potential habitat space due to the self contained nature of these systems.	Assumption: Moduler and Prefabricated treatment systems will not generate potential habitat space due to the self contained nature of these systems.
Social	Aesthetic	Visual	Assumption: Due the subsurface nature of RSF systems, these technologies are not expected to impact the visual aesthetic of the area they are constructed in.	Assumption: Due the subsurface nature of RSF systems, these technologies are not expected to impact the visual aesthetic of the area they are constructed in.	(U.S. EPA, 2007: p. 3-4). Assumption: MBR Systems may be above surface or submerged.	(U.S. EPA, 2002[c]: p.TSF4). (WERF, 2010: p. 88).
		Odor	Environmental Technology Initiative, 1998[b]: p. 1), (U.S. EPA, 2002[c]: p. TFS68).	(U.S. EPA, 2002[c]: p. TFS68).	(WERF, 2010: p. 88). (Chapman, et. al., p.3), (Water Factory Company, 2011).	(U.S. EPA, 2002[c]: p. TSF4), (WERF, 2010: p. 88).
		Noise	Assumption: Passive systems that do not utilize aeration or other process which require energy are not expected to generate noise.	Assumption: Passive systems that do not utilize aeration or other process which require energy are not expected to generate noise.	(Chapman et. al., 2001: p.3), (Water Factory Company, 2011).	(U.S. EPA, 2002[c]: p. TSF4), (WERF, 2010: p. 88).
	Education		Assumption: Modular Systems are not expected to provide educational or ancillary benefits due to the possibility of subsurface application and the self contained nature of these systems.	Assumption: Modular Systems are not expected to provide educational or ancillary benefits due to the possibility of subsurface application and the self contained nature of these systems.	Assumption: Modular Systems are not expected to provide educational or ancillary benefits due to the possibility of subsurface application and the self contained nature of these systems.	Assumption: Modular Systems are not expected to provide educational or ancillary benefits due to the possibility of subsurface application and the self contained nature of these systems.
	Ownership & Participation		(U.S. EPA, 2002[c]: p. TFS 68), (U.S. EPA,: p. 2), (U.S. EPA, 2005: p. 5).	(Bounds, 2002: p. 9).	(Graham, 2008: p. 21).	(U.S. EPA, 2002: p. TSF4), (U.S. EPA, 2000[a]: p. 7).
	Quality of Life	Health - Risk of Vector Contact	Assumption: Wastewater not exposed at surface. No risk of vector contact expected.	(Bounds, 2002: p. 7).	Assumption:Wastewater not exposed at surface. No risk of vector contact expected.	Assumption: Activated Sludge units may have an exposed secondary treatment system, allowing for some risk of vector contact. (Cate School)

Appendix E: Supplement 7: Calculation for Construction Costs for Wastewater Treatment Systems

Data for construction cost for systems was acquired from Carollo Engineers (Salveson, 2010) and WERF (Wallace, 2006). These values were standardized to 2012 prices using RSMeans construction cost information database. Data from Carollo was already standardized to 2008 values using RSMeans while WERF data was assumed to be standardized to 2005 values.

The following equation was utilized to standardize data to 2012 costs:

$$\text{Current Construction Cost (Feb 2012)} = \text{Original Construction Cost} \times \frac{\text{ENR Construction Cost Index (Feb 2012)}}{\text{ENR Construction Cost Index (Date Built)}}$$

ENR Construction Cost Index (Feb 2012) = 9198
ENR Construction Cost Index (2008) = 8551
ENR Construction Cost Index (2005) = 7446

Corrected cost values in millions of dollars for MBR, Constructed Wetlands, Activated Sludge, Living Machine®, and HSSF Wetlands were plotted on the y–axis on a log scale, while MGD capacity of systems were plotted on the x–axis on a log scale and then linearly regressed.

The correlation coefficients of the linear regressions were relatively low with the exception of the Living Machine® (but there were fewer data points for the Living Machine® which could potentially account for this). Correlation coefficients were significant in most cases (the exception being the intercept of the regression for

Activated Sludge). However, data from the two researched sources, Carollo Engineers and WERF, did not compare consistently with each other. This is illustrated by the fact that HSSF Wetlands appear to be more expensive than Living Machine® systems at all given capacities (Figure E1). This discrepancy between the analysis and reality is due to a number of reasons: not all sources of data are reporting costs in the same way, there are limited data sets, and economies of scale will be different for all systems, resulting in non-linear relationships.

Figure E1: Adjusted Construction Cost v. Capacity of Selected Systems