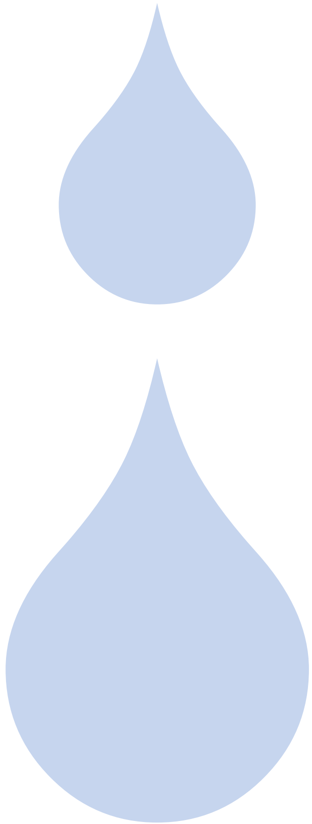
RODALE
INSTITUTE™

WATER purification

Innovative On-site Wastewater Treatment



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Innovative On-site Wastewater Treatment

A project of Rodale Institute

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RODALE INSTITUTE is a 501(c)(3) nonprofit dedicated to pioneering organic farming through research and outreach. For more than sixty years we've been researching the best practices of organic agriculture and sharing our findings with farmers and scientists throughout the world, advocating for policies that support farmers, and educating consumers about how going organic is the healthiest option for people and the planet.

LETTER FROM THE EXECUTIVE DIRECTOR

Rodale Institute has been dedicated to making the world a better place through organic agriculture since J.I. Rodale first chalked our motto on a blackboard in 1947. Healthy Soil = Healthy Food = Healthy People drives all of our projects. It is the touchstone against which we test all of our efforts, including making improvements to our buildings and nonagricultural landscapes.

The need to upgrade our public facilities offered us the perfect opportunity to expand our research on sustainable systems into an area we hadn't considered in the past but that has an impact on farmers nationwide: wastewater management.

Rural agricultural land is being lost every day to encroaching development. There is continual pressure to build new residential, commercial and industrial facilities on prime agricultural lands simply because water and wastewater systems are easier to install. These productive lands are often selected solely on the soil's ability to percolate water without regard for the food-growing potential being lost.

But we believe in the transformative power of demonstration. Perfecting and promoting a simple system that works on marginal land and is still cost effective can deflect development pressure from agricultural lands to lands that are hilly or contain poorly draining soils. These marginal lands could then be used for residential or commercial construction.

We hope everyone—from individual homeowners to community planners—can find something within these pages they can use to create a more sustainable wastewater management system in their community. And let's preserve our rich soil resources for growing healthy food to feed America's families.

Coach Mark Smallwood

FOREWORD

In the spring of 1997, the Environmental Protection Agency (EPA) responded to a request from Congress to assess the benefits and costs and the applicability of decentralized wastewater treatment technology and management as a means to help address the nation's water quality problems. In a landmark report, "Response to Congress on Use of Decentralized Wastewater Treatment Systems", EPA wrote that "Adequately managed decentralized wastewater systems are a cost-effective and long-term option for meeting public health and water quality goals, particularly in less densely populated areas."

The EPA report set the stage for a number of initiatives at the federal level to support advancements in the field and to provide guidance to state and local officials and experts across the country. In 1999, Congress began funding a series of National Community Decentralized Wastewater Demonstration Projects, with twenty-one sites designated at funding levels ranging from $700,000 to $5.5 million. These demonstration projects were intended to "jump start" technology transfer of improved treatment methods and management approaches, and were selected to provide a diversity of climate, soils, and ecosystems, while focusing on different challenges or aspects of innovative technology and/or management.

The Rodale Institute was selected as a site to demonstrate the effective use and treatment of water resources, including rainwater collection for toilet and urinal flushing and constructed wetlands treatment of wastewater. EPA views this particular project, now referred to as the Water Purification Eco-Center, as an important opportunity to help educate diverse audiences, including municipal officials, watershed management groups, children, interested individuals affiliated with the Rodale Institute and the general public about the capabilities and benefits of decentralized wastewater treatment systems.

Bob Bastian
Office of Wastewater Management, U.S. Environmental Protection Agency

INTRODUCTION

Water is one of the most undervalued resources we have. Less than 1 percent of all the water on earth is considered potable and available for our use. Today, an average American household uses 400 gallons of water per day, most of this precious resource literally going down the drain. In Pennsylvania more than 30 percent of all households use a well as their source of water and an on-lot or decentralized system for handling the waste water coming from their residences. According the U.S. EPA, more than 10 percent of these sewage systems fail every year.

When Rodale Institute began looking at replacing our outdated public facility we started by looking more closely at the source of our water and the systems we were using to manage our waste water. The idea of simply hooking up to public utilities such as municipal water and sewage is not always the answer and many on-lot systems are in some stage of periodic failure. Our waste water systems, nationally, are taxed beyond their ability for expansion and we felt it only right to view our system within this context.

Rather than add to this problem with our own expansion, we explored innovative systems to bring water into our facility for use and to handle it once it had been used. We began the journey of discovery by reaching out to others more closely involved in the source water and waste water communities such as the Pennsylvania Department of Environmental Resources and the National Environmental Protection Agency. At the same time we set in motion the internal task of defining what a successful design would look like from a philosophical prospective.

The design criteria we identified was this: The appropriate system had to be based on complex biological principles, it had to be rooted in natural processes, it had to be simple in its design, it had to be easily adaptable to any size, it had to be easily adoptable by the general public, it had to be aesthetically pleasing and it had to be cost effective. Since the roots of Rodale Institute's mission are grounded in agriculture we wanted to design a system that could function on marginal lands to reduce development pressure on prime agricultural land which is often selected for the soil's ability to easily "pass perc." We also wanted to design a system that would demonstrate methods of handling waste water more effectively and efficiently that municipal sewage treatment plants so that even small to mid-sized communities could adopt the technology. Since we were dealing with new construction, we also addressed bringing water into the system with an eye toward conservation and sustainability.

We chose a constructed wetlands system with rain water catchment component.

The pages that follow are an attempt to capture the process we followed to identify these criteria, the path that lead us to selecting a constructed wetlands system and the design features that make it possible. It also lays out the reasons the technology works, the documented science that proves it works, and the parameters anyone can use to adopt this technology as a retro fit to an existing on-lot system or in new construction.

Jeff Moyer
Farm Director, Rodale Institute

THE NEXT GENERATION SEPTIC SYSTEM

Traditional on-site wastewater treatment systems, when functioning and sited properly, adequately remove biological pollutants before the wastewater enters the wider environment. But, according to the Environmental Protection Agency, more than two thirds of U.S. land is not suitable for conventional septic systems. And septic system failures are rampant. In Indiana alone, an estimated 15.3 billion gallons of raw sewage from failing or inadequate septic systems are discharged into the environment every year. This sewage, containing bacteria and viruses, can run off into surface water or into wells and groundwater reserves, contaminating drinking water and endangering wildlife.

The fact is, the vast majority of on-site, decentralized sewage systems in use today rely on technology developed more than a century ago. Conventional on-site wastewater treatment systems are usually made up of a septic tank and some sort of subsurface wastewater infiltration system (commonly known as a drain field or leach field).

On the other hand, the available technology for the collection and on-site treatment of wastewater has rapidly evolved in the last few decades. The introduction of “advanced” decentralized treatment systems (consisting of more than a septic tank and leach field) has made sustainable nutrient management and safe water reuse applications possible if not yet widely practiced.

Alternative technologies for on-site wastewater treatment run the gamut from the now ubiquitous sand mound to aerobic lagoons and activated sludge where oxygen is pumped into the effluent to trickling and recirculating filters of both natural and synthetic materials to constructed wetlands and other systems that model natural processes. No matter the system, experience over the last three decades has shown that the following design criteria are critical in developing a viable decentralized treatment plan: simplicity, cost efficiency and energy efficiency.

A decentralized wastewater infrastructure system should be simple to construct, operate and maintain. Local contractors should be able to build the system without resorting to specialized equipment or contractors. The design should avoid proprietary equipment that requires specially trained personnel.

Using gravity to transport water whenever possible can significantly minimize the cost of water infrastructure, while equipment power requirements are minimized by avoiding high rate processes. In addition to the monetary cost of power, which is expected to increase in coming years, every kilowatt of electricity required to run equipment puts approximately 1.34 pounds of carbon dioxide into the atmosphere, as well as 5 mg of methane and 9 mg of nitrous oxide, all of which are considered “greenhouse gases,” believed to contribute to global climate change.

The system should require minimal operator involvement. High rate processes should be avoided, as they require near-constant supervision. The design should rely on biologically robust, low-energy technologies with relatively longer detention times. Mechanically simple systems have fewer pieces of equipment that will need to be repaired or replaced. Small community and building-specific systems should be designed to operate using equipment that is readily available from the local wholesale plumbing supply. And the system should be as cost-effective to construct and operate as possible.

Constructed Wetlands PLUS

Constructed wetlands are a little-known yet incredibly efficient way to deal with all those things we flush down our pipes. Less in-your-face than a composting toilet, this literally green method for sewage treatment can lead to some long-term savings over traditional septic systems, not to mention reducing the potential pitfalls of pump-reliant sand mounds.

THE ABCs OF SUCCESS

In wastewater treatment, success is often measured by looking at **BOD** and **TSS**.

BOD, aka biochemical oxygen demands

According to the EPA: "Wastewater from sewage treatment plants often contains organic materials that are decomposed by microorganisms, which use oxygen in the process. (The amount of oxygen consumed by these organisms in breaking down the waste is known as the biochemical oxygen demand or BOD."

TSS, aka total suspended solids

According to the EPA: "Total solids are dissolved solids plus suspended and settleable solids in water... Higher concentrations of suspended solids can serve as carriers of toxics, which readily cling to suspended particles."

Natural wetlands are considered "earth's kidneys" because they filter impurities and pollutants from our waterways. Constructed wetlands replicate this natural process in creating biological answers to some of the waste issues related to a growing human population. The natural processes of constructed wetlands scrub wastewater twice as clean as that of a traditional septic system and are capable of removing pathogens and organic contaminants. Research suggests wetland plants may even be able to neutralize pharmaceuticals and pesticides. Best of all, constructed wetlands cycle nutrients and water through the landscape, creating greater fertility, ecological vibrancy and cleaner groundwater.

There are two types of wetlands; free water surface wetlands (FWS) and subsurface flow (SF) wetlands. Figures 1 and 2 show their respective cross sections. Each type has its advantages and disadvantages and they must be properly evaluated in the context of the collection system, the possible methods of discharge of the treated effluent, and the permit requirements. Although the technology is simple, understanding the proper role of each type of wetlands is no trivial process and requires experienced designers to properly evaluate the most appropriate system.

Efficient and Cost Effective

Wetlands, as one part of a multi-part treatment system, can meet state environmental department criteria for both total nitrogen and nitrates in the groundwater while maintaining very simple operating conditions. And the technology can be scaled up and down to suit a variety of needs from a single homeowner to a decentralized system for multiple homes in a residential development to a an institution, organization or a public facility.

When comparing performance of wetlands, the comparison should be based on the performance of complete systems remembering that wetlands are only one part of a larger system. A multistep system with multiple microbial ecologies is more robust than a single-step microbial ecology system. Multiple, distinct microbial ecologies provide different opportunities for biological degradation

Figure 1. Free Water Surface Constructed Wetlands

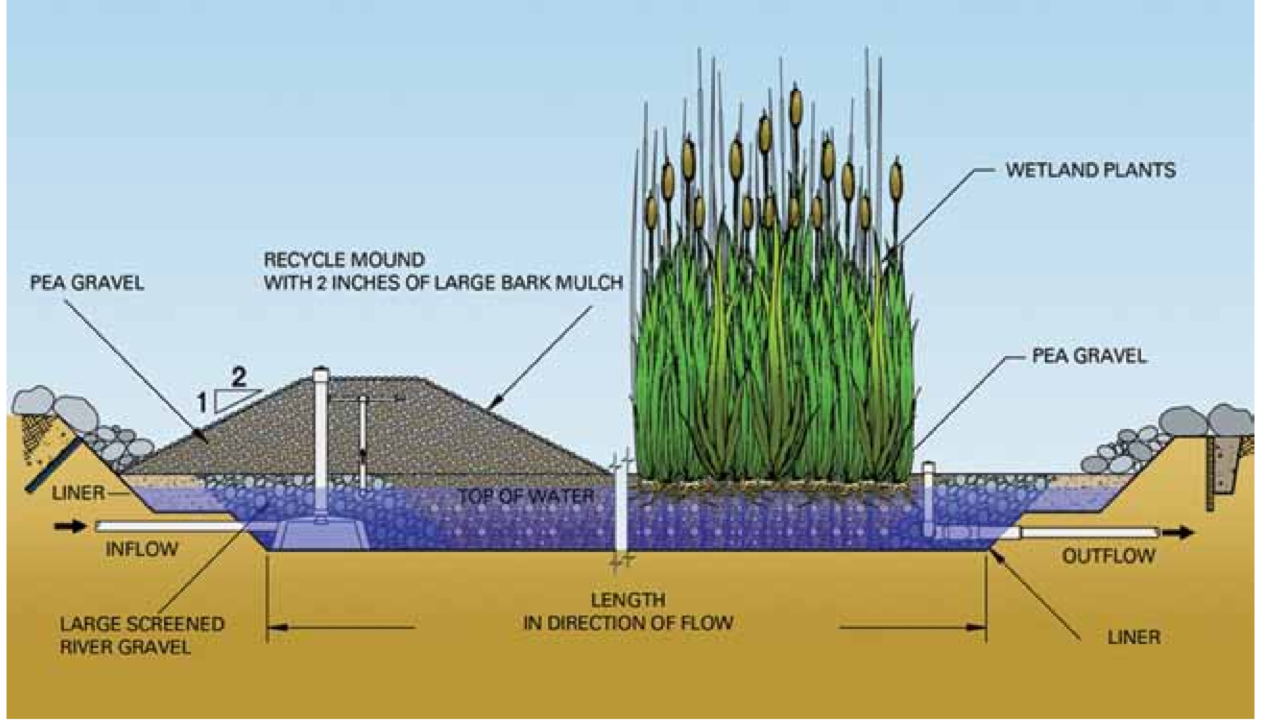

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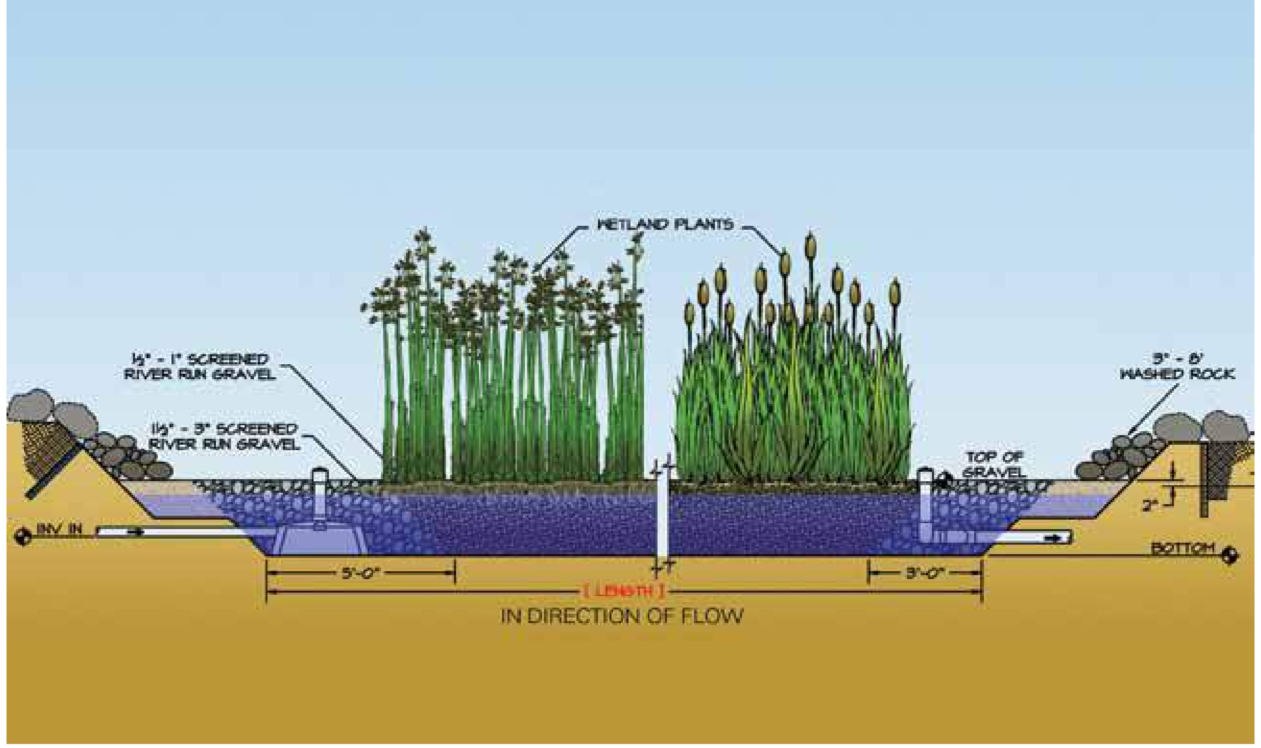
Figure 2: Subsurface Constructed Wetland



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of pollutants. For example, a three-step treatment system, operating at its lowest overall BOD removal rate, would result in a 99% efficiency. The inclusion of a constructed wetlands cell in a multistep system actually improves the individual efficiency of the other treatment processes as well.

When properly designed, built and operated, constructed wetlands can be counted on to remove 40 – 80% of the total nitrogen in wastewater. Additionally, they will remove 99.0 to 99.9% of fecal coliforms, as well as other pathogens, including viruses. Constructed wetlands are primarily biological so removal rates vary seasonally, being greater in the summer.

The energy costs for a small package treatment facility processing 25,000 gallons per day (gpd) is approximately $300/month. The monthly energy cost for an operating wetlands is $0. Wetlands rely on self-maintaining, self-regulating biological processes and when compared to other technologies that accomplish the same task, they come out ahead of the curve on energy use. Wetlands can consistently meet design parameters established by regulatory agencies, and unlike mechanical systems, they are able to treat low flow volumes as well as those more nearly approaching the maximum.

A system in Nebraska, which is designed for stream discharge, is currently being monitored by both an independent laboratory and the University of Nebraska College of Engineering under the direction of Prof. M.F. Dahab. This system serves 120 homes plus a clubhouse. Except for the discharge pumps, this system does not use any energy. The operating bill, including testing, is $12,000 per year, or $100/year/home.

For the individual homeowner, a wetlands system can be comparable to an elevated sand mound system. The life cycle cost over twenty years is actually in a narrow range. The following spreadsheet is based on a typical four-bedroom home designed to conform to Pennsylvania Department of Environmental Protection regulations at 500 gallons per day.

Multistep Treatment efficiencies

Primary treatment tank/ setting tank	**Constructed wetland**	**Recirculating sand filter**
Anaerobic digestion and settling	BOD/TSS reduction	Organic and nutrient polishing
BOD reduction 40%	BOD reduction 85%	BOD reduction 90%
Reduction range 40-45%	Reduction range 85-95%	Reduction range 90-95%

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Lifetime Cost Comparison (All costs are estimates)

System	Installation	Septic tank (cleaning every 3 years)	Other annual maintenance	Effluent pump preplacement	20-years maintenance	Annual cost (based on 20-year payoff)
Elevated sand mound	$30,000	$360	$0	$1,600	$1,200	$2,420
Wetlands	$25,000	$360	$375	$1,600	$1,200	$2,445
Wetlands w/Drip Dispersal	$37,000	$360	$600	$1,600	$1,200	$2,830

NOTE: PaDEP regulations require a 4-bedroom house be designed for 500-gallons-per-day flow. Annual lifetime cost does not include interest. All dollar amounts are estimates. Regulations require an annual maintenance of the wetlands systems. Twenty-year maintenance for sand mound system is the estimate to remove and replace ESM cover soil, aggregate and piping, and top 12" of contaminated sand. Twenty-year maintenance for wetlands systems is the estimate to remove and replace filter media.

The elevated sand mound includes a 1250-gallon, two-compartment septic tank, 500-gallon pump tank with effluent dosing pump, and a 1,000-square-foot sand mound. Depending upon site conditions, this system would cost between $27,000 and $30,000 on average. Septic tank cleaning every three years has been included as good average preventative maintenance. In general, there are no other annual costs to maintain an elevated sand mound system and there are no regulatory requirements for any such maintenance. All systems described here have one pump as part of the designed system. Eight years is the average lifespan of such pumps.

An elevated sand mound may not last forever, even with good maintenance. The single problem that will occur eventually is a clogging of that top layer of sand just under the dispersal aggregate. Twenty years is an average time at which the mound would need to be refurbished by removing the soil cover and the aggregate and distribution piping. Then the layer of clogged sand is removed and replaced with clean sand. The aggregate, distribution piping, and soil cover are then reinstalled. This puts the sand mound back in "like new" condition.

The constructed wetlands system consists of a 1250-gallon, two-compartment septic tank, a media filter (sand or other media), a 500-gallon pump tank with dosing pump, and a wetlands cell from which the clean water either dissipates directly into the soils below the cell or overflows upon the surface of the ground. The installation cost of this basic configuration is less than an elevated sand mound. Septic tank cleaning is the same as recommended for all septic systems, but there will be a permit requirement to have an operation and maintenance agreement with a firm knowledgeable in such systems, and there is some cost to this annually. A pump will be included in the system unless there is enough topography to have gravity convey the water flow. This pump will have the same lifespan as any pump in a septic system application. It is estimated that the media filter will have to be replaced after approximately twenty years.

The constructed wetlands system with drip dispersal added to the backend is most similar to the system installed at Rodale Institute. The drip dispersal portion of the system adds about $12,000 to the installation cost and adds some annual cost of maintenance.

Permitting

While a collaborative multi-step system is the most vibrant way to process wastewater, it complicates the permitting procedure. Portions of the system may be permitted through local municipalities while other portions may require additional paperwork and a state-level review process. The challenge is that most regulations are on a state-by-state or even county-by-county basis, so anyone interested in installing constructed wetlands really has to do some footwork for their own particular area. And there are definitely some areas of the country where it is more widespread, well-known and accepted by the water authorities. Patience and persistence are essential when considering an innovative wastewater treatment system.

Where you live will often determine how difficult the red tape may or may not be. In Pennsylvania, every township has a sewage enforcement officer (SEO) who issues permits, but an SEO can't issue a permit for all systems. And not every state has SEOs. In Ohio, the County Health Department issues the permits and in New Jersey, the County Health Department issues a primary permit and each township issues a secondary permit. New Jersey also requires a professional engineer to design everything. For the Rodale Institute's Water Purification Eco-Center, the permitting process from application through testing and then final permitting took approximately one year and involved township authorities, the local SEO, and state-level Pennsylvania Department of Environmental Protection approval.

A recommendation appropriate to all states would be to obtain the services of a quality wastewater professional if you're contemplating innovative technologies. Finding someone who is familiar with the local procedure and requirements to help guide you through the permitting process could save both time and money in the long run and avoid costly mistakes that could shut down your project. Look for engineers, surveyors, soil scientists, or SEOs who don't work for the county but who consult. The local municipality can help point out wastewater professionals who might be utilized in a particular region. For example, Hunterdon County, New Jersey has a website on sewage disposal where each municipality lists the projects permitted each month and the wastewater professionals involved.

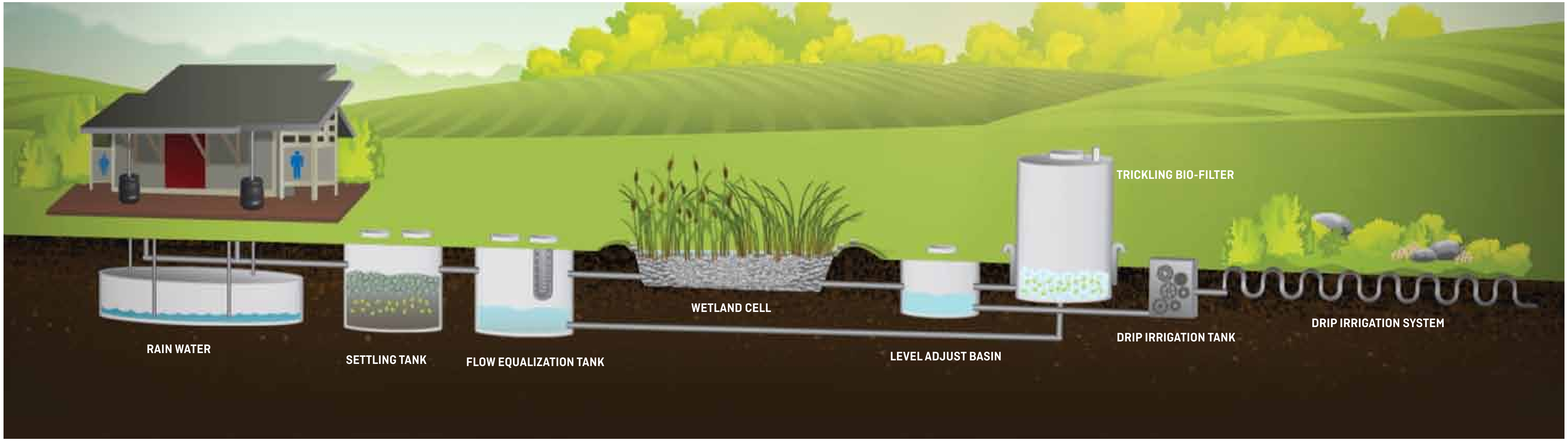
The Environmental Protection Agency's Decentralized Wastewater Management Program has compiled a list of states that have reviewed and approved advanced wastewater treatment solutions. The links also include information about individual state approval processes and the departments with authority over wastewater management and is a great place to start.

CASE STUDY: WATER PURIFICATION ECO-CENTER AT RODALE INSTITUTE

The Water Purification Eco-Center (WPEC) is essentially a decentralized wastewater treatment and disposal system for the new visitor center restrooms. The system incorporates both traditional and alternative systems in a multi-step process including a septic/equalization tank, a constructed wetland cell, a recirculating bio-filter, and subsurface drip irrigation. The footprint of the system would fit in most backyards and treats about 300-500 gallons per day, the output from a typical 3-bedroom house.

In brief, the Rodale Institute system works by collecting rainwater from the building's roof and storing it in a cistern underneath the building. The rainwater is then used to flush toilets after which it flows into another storage tank where water and solid wastes are separated. The water is sent into a wetland area to be treated with the help of microbes growing in the roots of plants. Finally, the clean water flows through a drip irrigation system to nearby perennial gardens.

The star components of the project are the wetland cell and a recirculating feature between the wetland cell and the equalization tank. The liquid effluent recirculates several times between the wetland and the equalization tank through a bio-filter. The end goal of the wetland-recirculation design is to treat the effluent to a level clean enough to discharge to the ground or to a stream.



Above the Ground: Construction

The Water Purification Eco-Center is a very complicated project that does not visually appear to be so. In fact the most important elements of the WPEC are located below the aesthetically pleasing landscape. But thought and care were still given to the design and construction of the above-ground structure so that it functioned seamlessly with the below-ground system and met both the environmentally conscious and budgetary goals of the Rodale Institute.

The architectural aspects of the WPEC were designed in an integrative format where the designers worked with the Institute staff and the builder. Original design goals included shelter on the inside to house the bathroom facilities and a welcoming public educational facility on the exterior. The Center was originally designed as a LEED (Leadership in Energy and Environmental Design) top level facility that would achieve the Platinum Certification level and included:

- A farm-like silo that incorporated a rural element and would serve as the main "body" of the facility and served as the shelter for the WPEC's rainwater cistern—the source for the collection of all the rainwater that fell onto the entire building's roofs. The rainwater cistern would be warmed in the winter by the south-facing windows in order to avoid it to be frozen. All the heat gained in the silo during the winter was designed to be moved over the WPEC bathroom wings through insulated ducts with hot air source grilles located and the top of the silo delivering the warm air into the lower level of the bathroom wings.

- Two bathroom wings designed to include what are called "roof monitors" that are raised roof areas with wide awning windows that have the hinges at the top of the window frames. These awning windows are operable electronically with remote controls for temperature maintenance.

- A central exterior education space that would be attached to the silo with an extensive roof overhang protecting guests from either precipitation and/or the summer sun rays.

- A "tight envelope" (also called a very thermal protective building exterior walls and roof). The floor of the building would be a concrete slab poured over at least 2" of rigid insulation. The walls were designed with ICFs (Insulated Concrete Forms) at the foundation below grade, SIPs (Structural Insulated Panels) for both the walls and the roof and highly efficient windows that allow the sun to warm the interior of the building in the winter while avoiding the overheating in the summer.

When the construction cost estimates were submitted, the initial design needed to be revisited and revised to meet the budgetary goals of the project. The project then went through the V.E. Phase (Value Engineered Phase) that focuses on revising the architectural design in an effort to reduce the cost of construction:

- To reduce the size of the facility overall, the central silo element was eliminated and the rainwater re-use cistern was relocated below-ground in a concrete foundation format. The two "arms" of the facility were then brought together with an 8' wide utility room between the women's and men's restrooms. This both reduced the size and reduced the complicated aspects of building walls on angles and in curvilinear format.

- The exterior walls were then designed to be built with standard dimensional lumber including basic batt insulation that still complied with the IBC (International Building Code). Even though this reduces the theoretical energy conservation substantially from the original design, the functional use of this facility does not require a high level of energy for heating or cooling.

- The windows and doors were still maintained in the design to provide natural lighting for both comfort and energy conservation based on lighting. All the windows were kept high on the exterior walls and up in what is called a "roof monitor." The roof monitor is a raised roof with small walls located on the center of the main roof. This provides cost-free natural lighting to come into the facility, while providing full privacy and roof overhangs that protect the interior during the summer when natural heating is not required. That sun-provided natural heating does enter in the fall, winter and spring seasons.

- The roof serves as a portion of the facility's water supply. All the precipitation that touches the roof is brought down to the sub-grade cistern which is then pumped to supply the non-potable and free water for the toilets and urinals. In an effort to ease the rainwater management, standing seam metal roofing was installed as per the original design. The original roof overhang designs were also retained to ensure the windows were shadowed during the summer season.

- The extensive roof overhang was moved to the new area that includes the "education center." The education center is basically an outdoor area that provides a flat screen TV on an exterior wall in between the women's and men's restrooms.

The master plan included the option to add a Ground Source Heat Pump (a.k.a. Geothermal) heating and cooling system along with a Photovoltaic array that can be installed adjacent to the WPEC building. Both of these renewable energy systems can be installed in the future and easily attached to the WPEC for its heating, cooling and electricity source.

Some of the other green elements include reliable and local material/products which include locally harvested and manufactured cement, fiber-cement (or cementitious) siding, recycled drywall, recycled metal roofing, efficient water/plumbing fixtures and, most importantly, native vegetation that match our local environment and climate zone. In the end, the LEED Certification process was released while the guidelines provide by the U.S. Green Building Council's LEED program were followed to help verify the WPEC was as sustainable and green as can be.

Below the Ground: Design and Installation

As with the above-ground construction, the below-ground design went through a visioning stage and then a revised to-budget revision with the idea of achieving the same results at a lower cost.

- The original single 4000-gallon fiberglass tank was replaced with two single-compartment 2000-gallon concrete tanks which were 1/3 the cost of the single fiberglass tank.
- The second 2000-gallon concrete tank replaced the recirculating tank from the original plans.
- The recirculating sand filter originally envisioned was large in size and presented both cost and installation challenges due to lack of space at the site. Changing to a single-tank trickle filter resulted in both substantial savings in costs and solved a major site problem.
- Even a minimal reduction in the size of the wetland cell and some small changes in pipe and material were enough to make a difference in cost.

By making slight changes that would not change the function of the system but would allow for greater control over both material and installation costs, we were able to reduce the price tag by 50%. Following are summaries of the system components and how they work in the Rodale Institute Water Purification Eco-Center.

Wastewater collection and primary treatment

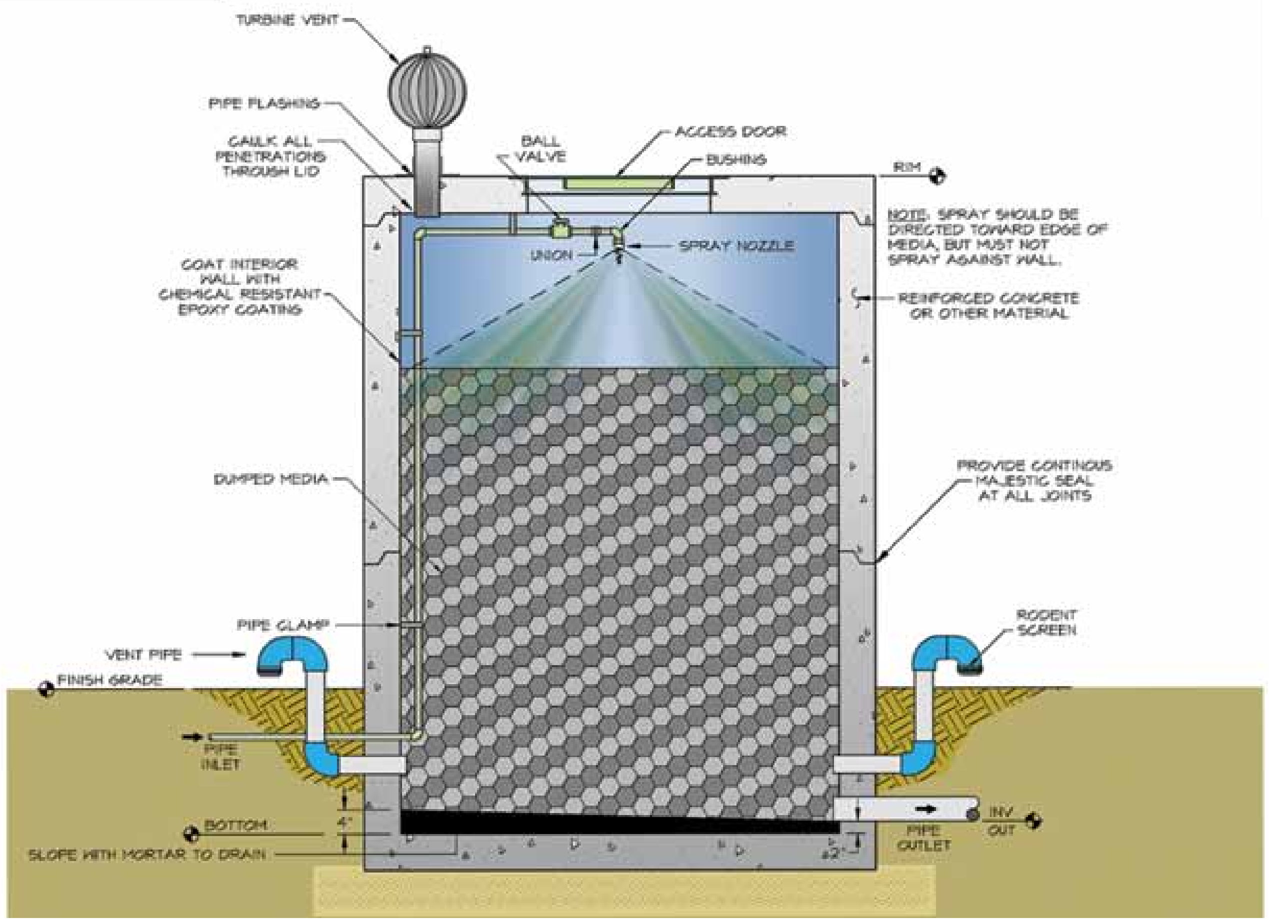
Wastewater generated from the WPEC restrooms flows by gravity to a buried primary treatment septic tank. Solids settle in the bottom of the tank as sludge that will be decomposed by microorganisms. The septic tank effluent is collected from the primary tank by septic tank effluent pumps (STEP) via buried small-diameter collection pipes. The collection system includes:

- Primary treatment tank
- Flow equalization tank (or chamber)
- In-tank high-head effluent pumps, and
- Small-diameter collection mains

Trickling Bio-Filter

Trickling filters are very efficient in reducing soluble BOD and removing nitrogen. The trickling filter is located after primary treatment, and helps reduce high levels of soluble BOD to levels such that nitrification can proceed. They consist of loosely packed high-surface-area media within an enclosed tower. The media in the WPEC site is made of plastic “honeycomb” boxes which create a sturdy home for a biofilm of beneficial bacteria. The bacteria that grow on the media surfaces break down organics and nutrients in the effluent. Periodically these biofilms slough off and fall to the bottom where they are also returned to the tank.

Wastewater is sprayed intermittently over the media and allowed to trickle down to the bottom where it is collected and flows by gravity back to the tank. The trickling filter provides an ideal environment for ammonia to be converted into nitrates. The nitrified effluent is further treated in the tank and wetlands, where the denitrification process transforms the nitrates into harmless nitrogen gas. In this way, the system minimizes the amount of nitrates being released into the environment. In normal continuous use, trickling filters require 10-50% of the energy required for the same level of treatment in an aerated lagoon or an activated sludge process.



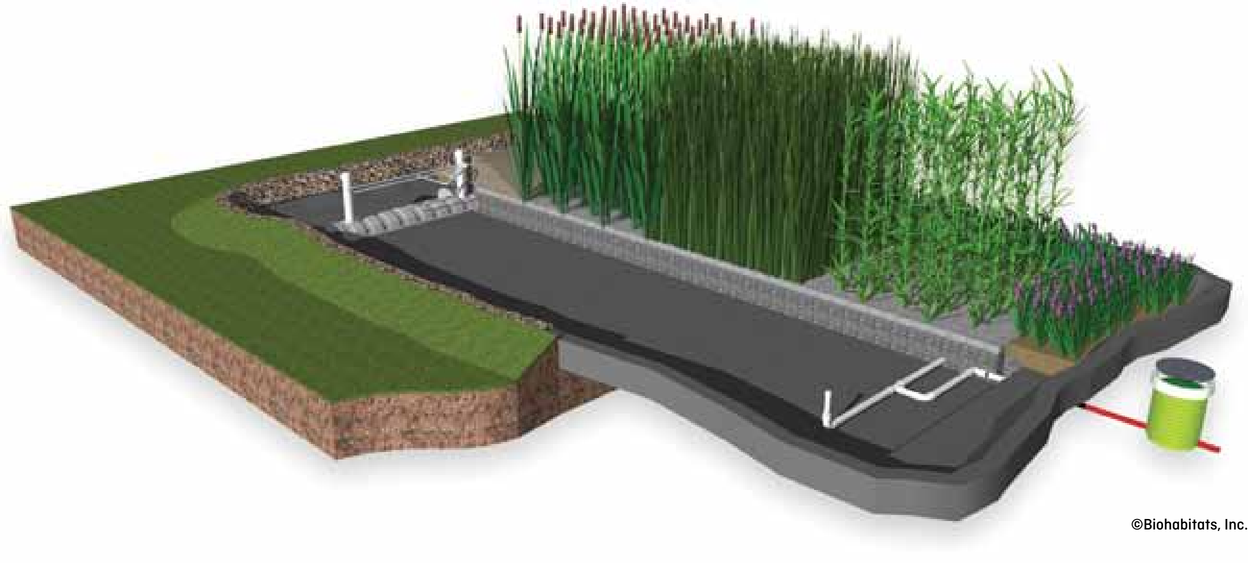
Constructed Wetlands

Water is pumped into the wetland cell where plants and microorganisms reduce pollutants and remove odorous gases. The WPEC system utilizes a subsurface horizontal-flow constructed wetlands where lined gravel filters are planted with wetland plant species. As water moves through the gravel and plant roots, bacteria attached to these surfaces break down and/or remove organic waste (BOD), suspended solids, and nitrogen.

Ammonia is not consistently removed to desired levels from constructed wetlands alone, which is why the wetlands are paired with a trickling bio-filter and a dispersal system that maximizes the nitrogen removal capability of the soil.

The service life of subsurface flow wetlands has been estimated to be about 100 years, assuming regular maintenance. A more conservative operational lifetime estimate is 30 - 40 years, at which point the front end gravel may need to be removed and cleaned or replaced, and the liner should be tested for water-tightness prior to gravel replacement.

From the wetland cell, water flows to the level adjust basin which controls the amount of water contained in the wetland cell. It also provides a staging zone which determines if the water should flow through the trickling filter for recirculation, through the wetland cell or if it should be processed through to the drip irrigation field.



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Subsurface Drip Dispersal

The upper layers of native soil contain a complex ecology and are excellent natural systems for the removal, sequestration and transformation of nutrients that are toxic or problematic to water bodies. Compounds and pathogens that soil systems remove, sequester or transform include ammonia, nitrate, nitrite, organic nitrogen, phosphorus compounds, suspended and dissolved solids, fecal coliforms, viruses, carbonaceous compounds, heavy metals, pesticides, cosmetics and medications. The EPA Manual “Land Treatment of Municipal Wastewater” describes the treatment provided by the soil column: any remaining ammonia, BOD, TSS, phosphorus and fecal coliform are generally removed within the first 2 feet of soil.

Effluent disposal to the shallow soil system continues the process of water quality improvement begun in the treatment phase. Treated effluent is first collected in a dosing tank and then pumped to an undeveloped area of native soil, where it is spread via a system of perforated drip tubing buried approximately 6-10 inches below the soil surface. The drip tubing is trenched into the ground and is designed to avoid freezing by draining out after each dose, while the distribution piping is either buried beneath the frost depth or allowed to drain back to a central pumping point. After dispersal, the treated effluent percolates through the soil matrix, providing nutrients for plant growth and microorganisms. Effluent moves through the undisturbed soil system until it joins the water table in an improved condition.

The Science

Research studies on small constructed wetland systems are few and far between. The Water Purification Eco-Center (WPEC) affords us the opportunity to increase the amount of research on this kind of revolutionary system. Since the WPEC opened researchers have been collecting and testing water samples between each section of the system and from the soil surrounding each area. The water is analyzed for various biological contaminates to ensure the water leaving the system is clean and safe to release to the surrounding landscape. Because this system adds at least two additional cleansing steps to treat the water that would normally be released from a traditional septic system, we expect the end product to be that much cleaner.

In order to evaluate the functioning of the WPEC, routine sampling was performed at 14 locations around the site. Samples were taken from "cleanest" to "dirtiest" points throughout the system to prevent cross contamination of the samples. The water samples were poured into different bottles for different tests. Samples were analyzed for levels of phosphorous, fecal coliform, nitrogen (including nitrates, ammonia, total organic nitrogen, and Total Kjeldahl Nitrogen), dissolved oxygen (measured as carbonaceous biochemical oxygen demand or CBOD), and Total Dissolved Solids (TDS).

A total of seven rounds of sampling took place between March and December 2012. The septic tank, pre-cell, in-cell (wetland cell), and irrigation tank were sampled each time. The 10 remaining samples were taken from leachate collected 2 feet and 4 feet underneath the landscaped areas which receive the wetland effluent as irrigation. At some of these sampling locations, it was not always possible to collect enough leachate in order to run all of the tests, and so there are some gaps in the data. However, as these irrigated sites all perform the same treatment, that is, soil filtration of the effluent, the information that we were able to collect is sufficient to evaluate the efficacy of all parts of the system.

Phosphorus

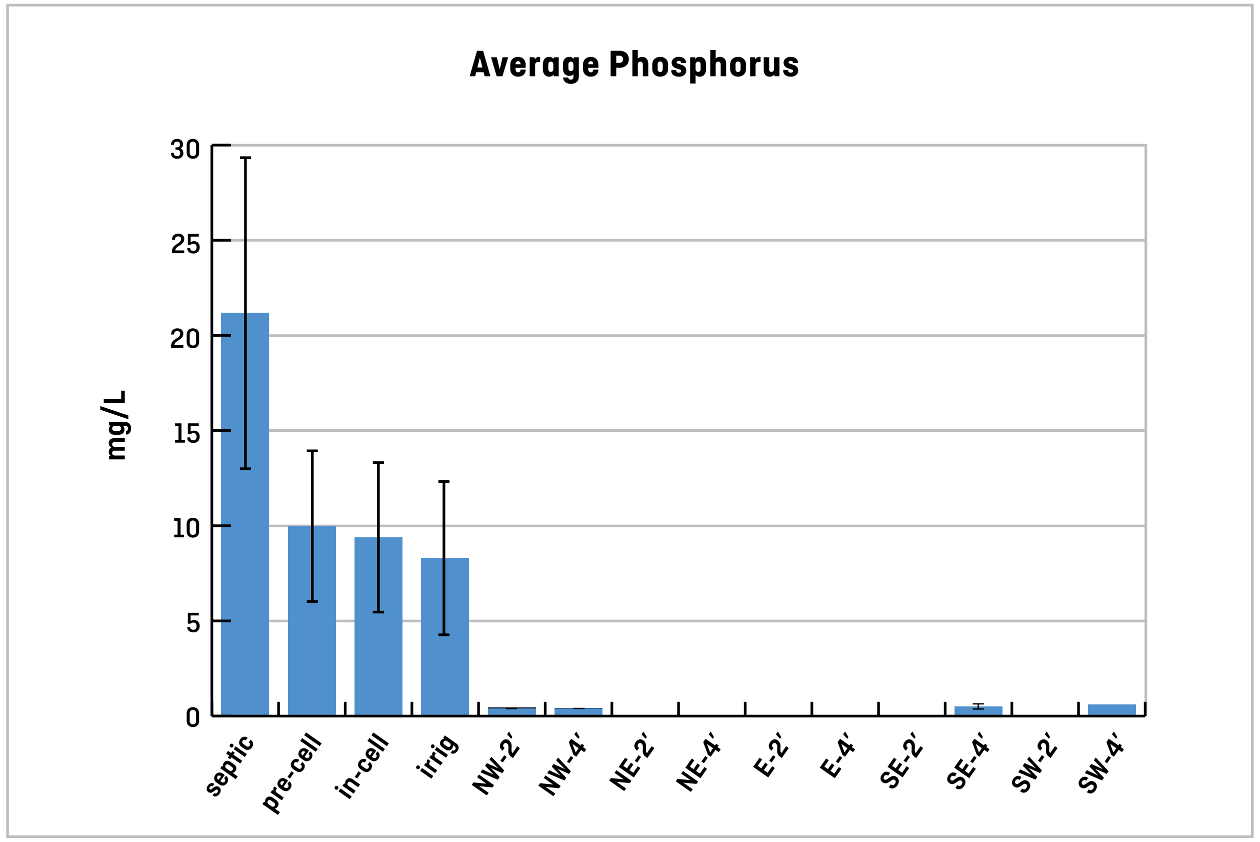
Phosphorous, in the form of phosphate, was measured at different locations throughout the WPEC. This chart shows the average for each point across seven sampling dates, with the earliest being March 14, 2012 and the latest December 4, 2012. Notice the dramatic difference in phosphorous levels between the water held in the irrigation tank and the leachate collected from the irrigated areas.

There was a substantial drop in phosphorous levels between the septic and the pre-cell chambers, likely due to solids settling out of the water. The wetland cell seems to have had little overall effect on phosphorous levels throughout the season. Removal of phosphorous in constructed wetland systems is largely due to adsorption to rock surfaces or soil particles. It is possible that the phosphorous storage capacity of the wetland cell was used up quickly, thereby limiting the phosphorous removal from the wastewater. Luckily, because the effluent from the wetland cell is used to irrigate plants, the phosphorous still present in the wastewater appears to have been filtered out by the soil. This is evidenced by the low levels of phosphorous in the leachate from the irrigated areas.

For subsurface flow wetland systems, such as the WPEC, the EPA recommends maximum phosphorous levels of 3 mg/L in the effluent. While the effluent from the wetland cell itself does not meet this recommended level, averaging 8.3 mg/L, the phosphorous levels in the leachate are well below, with an average of .4 mg/L across the irrigated areas.

Fecal Coliform

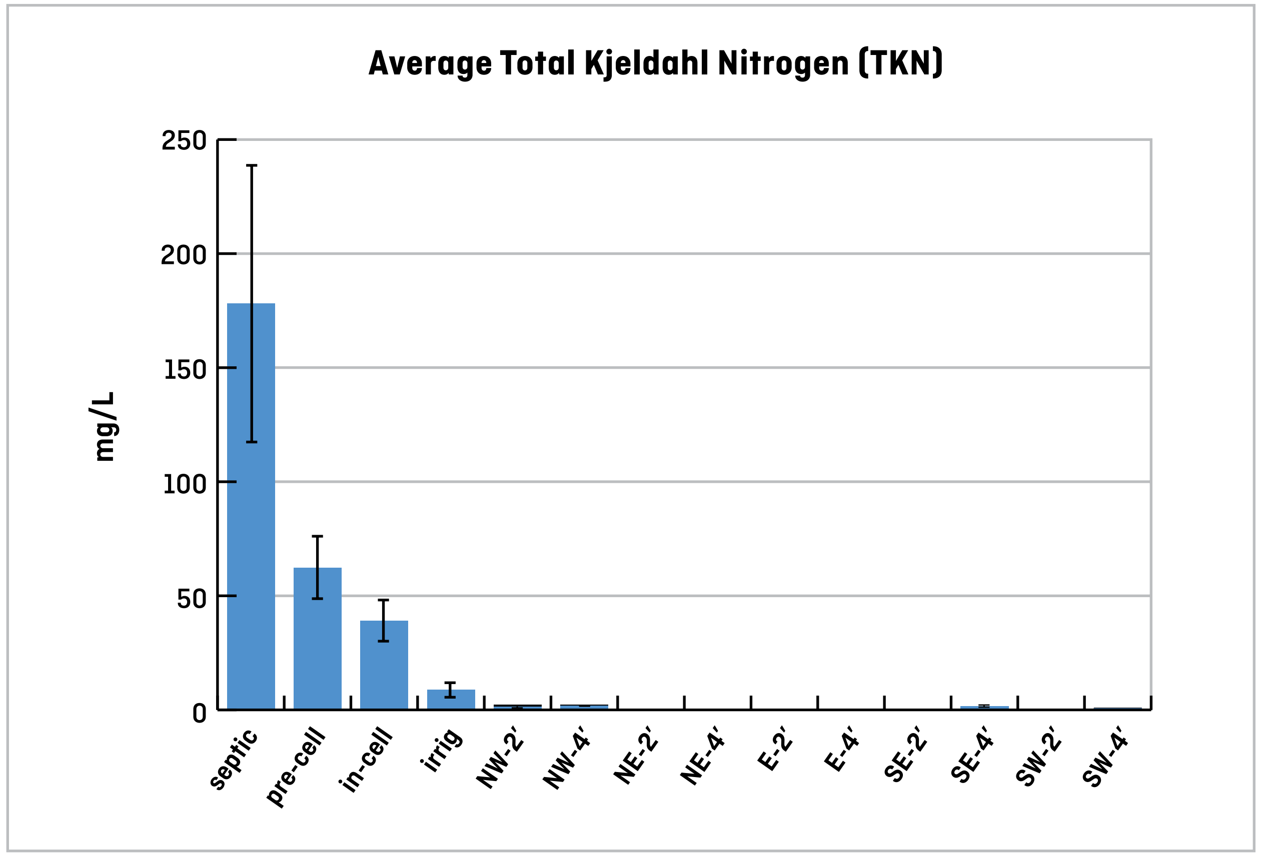
Fecal coliform is an indicator of human waste. The WPEC reduced the levels of fecal coliform (FC) by 99.99% by the time the wastewater was released to the irrigation system. Whereas the septic tank contained an average of 120,000 FC/mL, the water leaving the wetland cell averaged only 6.5 FC/mL. Filtration by soil in the irrigated areas reduced the fecal coliform levels even further, with an average of 3.6 FC/mL in the leachate.



Nitrogen

Nitrogen is also present in human waste. From the septic tank to the irrigation system, total levels of nitrogen fall dramatically, and that which remains is transformed into plant-available forms that can be utilized by the flowers and shrubs in the surrounding landscape via the drip irrigation system.

Total Kjeldahl Nitroten (TKN), which is the sum of ammonia, ammonium, and organic nitrogen, was measured at different locations throughout the WPEC. This chart shows the average for each point across seven sampling dates, with the earliest being March 14, 2012 and the latest December 4, 2012. These forms of nitrogen were greatly reduced by the time they reached the irrigation tank, where the average level across the sampling period was 8.8 mg/L. This was reduced even further when the effluent was filtered through soil, resulting in an average TKN level of 1.3 mg/L in the leachate.



The WPEC was very effective in processing ammonia, with a 93% reduction by the time the water reached the irrigation tank. Fairly low levels of nitrates were found in the irrigation leachate, with an average of 6.4 mg/L, comfortably below the EPA's maximum contaminant level goal (MCLG) of 10 mg/L for drinking water.

Total Dissolved Solids

Total Dissolved Solids (TDS) describes the amount of salts and very small particles of organic matter in water. TDS differs from Total Suspended Solids (TSS) in the size of the particles: TDS particles are smaller than 2 µm, while TSS particles are larger.

As most of the dissolved solids are usually ions from salt compounds (calcium, magnesium, potassium, carbonate, etc.) TDS levels can be quite high without having negative impacts on human health. High TDS levels do, however, affect the taste and appearance of drinking water. For matters of aesthetics and taste, the EPA has established a recommended maximum of 500 mg/L TDS in drinking water. Levels above this may be undesirable for consumption, as they will start to appear cloudy and taste salty.

We found that the WPEC did not significantly decrease the TDS as the water moved through the system: the septic averaged 483 mg/L, while the average level in the irrigation leachate was 439 mg/L. If TSS or Total Solids (TS) had been measured, we would likely find these numbers to be greatly reduced as solids settle and are filtered out of the system.

Dissolved Oxygen

Dissolved oxygen measures how much decomposition is going on in the water and how much (and what kinds of) microbial life can survive. The dissolved oxygen in the septic tank (from which a traditional septic system releases wastewater to the environment) is less than 1 mg/L. By the time the wastewater reaches our wetlands cell in the WPEC system, the dissolved oxygen has risen to at least 5 mg/L, a level that is high enough to support aquatic life.

Most of the regulatory and design language surrounding constructed wetlands uses Biochemical Oxygen Demand (BOD) as a measure of the system's effectiveness. While we did not measure BOD, we did measure the Carbonaceous Biochemical Oxygen Demand (CBOD), which is a subset of BOD. Whereas BOD measures the oxygen required for the breakdown of all organic matter in a sample, the CBOD measures the oxygen used in the decomposition of only the carbon-based material. CBOD testing is becoming popular in the water quality industry because it can be performed much faster than BOD testing, which takes five days.

In a set of case studies done by the EPA and published in 2000, twenty constructed wetlands demonstrated a reduction of 81% between the average influent and effluent BOD levels. In 2012, the WPEC reduced CBOD by 98.8%, with an average of 3.2 mg/L observed in the irrigation leachate.

COMMONLY ASKED QUESTIONS

What happens when it rains?
Rainwater shortens the treatment time while diluting the wastewater. There is no effect on treatment. Surface water is kept out by a surrounding berm. No wastewater is allowed to overflow out of the wetlands.

What happens in cold weather?
Wetlands, like all wastewater treatment processes, are temperature dependent. The engineer must design for the worst case, which is the low temperatures occurring in winter. Snow cover actually helps. Systems have been designed for use in Wyoming and mountain communities in the Rockies. There are even Norwegian systems above the Arctic Circle.

What about odor?
One of the virtues of subsurface wetlands is that wastewater flow is under the gravel surface. Noxious odors are trapped and actually become food for the microorganisms attached to the gravel and plant root surfaces. A similar event takes place with surface-flow wetlands on plant stems; often small floating plants such as duckweed and azolla contribute to odor removal. However, primary treatment must be aerobic in surface-flow wetlands.

Can they be included in a public or high-visibility landscape, for example at visitor centers, schools or next to golf course fairways?
Absolutely. The EPA has a publication showing 17 examples of municipal treatment wetlands that serve both as parks and wildlife habitats. The PGA has a publication showing man made wetlands adjacent to fairways and greens and their effects on improving habitat. And, the book Constructed Wetlands in the Sustainable Landscape documents numerous examples of treatment wetlands in the public landscape.

How much land is required and how much do they cost?
See the chart "Lifetime Cost Comparison" in the text above for information on a home-scale system. The system is scalable both up and down but even small changes in design can affect cost. Water quality, winter temperatures, amount of flow to be processed and more all affect size and ultimate price tag.

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RESOURCES

Rodale Institute WPEC Page
rodaleinstitute.org/our-work/water-purification-eco-center

Biohabitats, Inc.
www.biohabitats.com

Franc Environmental, Inc.
www.francenviro.com

Down to Earth Design Foundation
www.toearth.org

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