INNOVATIVE AND ALTERNATIVE

ON-SITE TREATMENT

of

RESIDENTIAL WASTEWATER

by
James Wynn
TERRAFORMS
22 Mulligan Road
Athens, Ohio 45701

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PANICH, NOEL, + ASSOCIATES
ARCHITECTS AND ENGINEERS
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INNOVATIVE AND ALTERNATIVE ON-SITE TREATMENT OF RESIDENTIAL WASTEWATER

This resource guide to innovative and alternative on-site waste treatment technologies has been funded by a Housing and Urban Development grant; and compiled for Panich, Noel and Associates Architects and Engineers under contract from the Corporation for Ohio Appalachian Development. This guide summarizes "innovative and alternative" technologies for on-site residential waste treatment.

Technologies that have been selected for review consist of innovative and alternative systems that utilize natural processes to treat wastewater. Waste treatment systems considered "innovative and alternative," use technologies that are not readily available to residents or developers in many areas. The intent of presenting this information is to promote alternative waste treatment systems that provide environmentally sound and cost effective on-site treatment of residential wastewater. Waste treatment technologies to be summarized include both manufactured and owner-built composting toilets, greywater treatment systems, constructed wetlands, and related innovations.

One impetus for this resource guide is to provide options for waste treatment that can be utilized on affordable, rural land, which can be suitable for the development of low-cost cluster housing units. Affordable, rural land is often not serviced by conventional waste treatment infrastructure. Affordable land is often marginal for conventional commercial development and is frequently sloped, with soil types that are often not optimal for building homes and treating their wastewater. Technologies that can provide effective and affordable waste treatment on sloping rural land will be given special consideration.

Each technology or combination of technologies has benefits and limitations depending on site-specific factors such as climate, slope, soil structure, ground water level, and area available for treatment and disposal. Other factors include cost, appropriate system design and maintenance, perceptions of residents, and regulatory protocol of different state and county health departments. Technologies employed at each site must be selected based on multiple design factors in order to be effective and affordable.

Manufacturers, distributors, designers, and installers of these innovative and alternative waste treatment systems are summarized. Plans available for owner-built systems and design guidelines published by federal, state and local authorities are listed. Research articles have been sited for further reference. This resource guide can help residents and developers understand and access specific information relative to on-site waste treatment.

FOREWORD

On-site septic systems are a common method of waste treatment, and serious public health concern. Approximately 25 percent of the homes in the United States use on-site septic systems to treat wastewater.[1]

Three billion cubic meters of septic tank effluent is discharged into the soil each year.[2] Estimates suggest that fewer than half of these soil types adequately treat wastewater.[3] Failing and inadequate septic systems are the most frequently reported source of ground water contamination in the United States.[4] Approximately half of all know waterborne disease outbreaks in the United States are attributed to contaminated groundwater.[5]

Adequate soils, proper site selection, appropriate system design, and regular maintenance are all factors that can influence the effectiveness of a wastewater treatment system. Even commonly approved systems can fail if they are not properly installed and maintained. Many innovative and alternative systems are being built and operated that provide adequate results while costing less to maintain than conventional waste treatment technologies. This paper will review some of the more promising innovative technologies that provide alternatives to conventional septic tank and leach field systems and commercially available aerated package plants.

The easiest way to reduce the volume and concentration of waste in our wastewater is to stop defecating in it. Separating out feces or toilet water significantly reduces the area and energy required for treating the remaining household wastewater, or greywater, [6] and can provide for resource recovery through production of biomass fertilizer. This paper will explore technologies and system designs for diverting or removing bacterial contaminants and other organic nutrients from wastewater using natural processes. Many of these systems, while unconventional, are affordable to operate, and can meet state or local criteria for safe discharge into the soil.

COMPOSTING TOILETS

Definition

Composting toilets are self-contained, waterless units designed to facilitate the decomposition of human waste and render it safe for subsurface soil application. These toilets often require regular addition of a carbonaceous bulking agent to prevent ammonia production. Bulking agents such as sawdust or peat moss are added to achieve a carbon-to-nitrogen ratio of between 20:1 and 30:1. Size of composting piles in chambers is ideally about a cubic yard to reach optimal composting temperatures of around 160 degrees F, or 68 degrees C in center of pile.[7] Most composting toilets are well insulated and some have electric heaters to maintain temperatures ideal for the breakdown of waste and pathogenic bacteria. Some have electric fans to maintain composting moisture contents of 40-60%, and screened vents to remove odors and exclude insects.

Composting toilets are frequently used to conserve the 40% of household potable water normally consumed by flush toilets.[8] These toilets can be installed on steep land that would normally be unacceptable for septic systems.[9] Composted waste can be used as a fertilizer around fruit trees, shrubs and ornamental plantings.[10] It must be buried at least six inches below the soil surface,[11] and two hundred feet from water sources to prevent contamination.[12] Urine can also be used as a fertilizer[13] and greywater can be used for irrigation or recycled for reuse such as toilet flushing.[14]

History

Rickard Lindstrom developed composting toilets in Sweden in 1939. The primary use of these early units was in summer cottages where rocky soils prevented the installation of conventional systems. When first introduced into the United States in the early 1970's, they were not yet designed for year-round use. Scandinavian authorities began research to evaluate these increasingly popular devices in the early 1970's; and both Norway and Sweden developed certification processes in 1978. The National Sanitation Foundation International (NSFI) developed certification processes in the United States in 1981.

Composting toilets have been manufactured and sold in the United States since the early 1970's. Reports estimate the number commercial systems in the US as 5,000 in 1981,[15] and 20,000 in 1990. A 1996 survey by the author documented 5,200 composting toilets sold between 1990 and 1997.[16] An additional number of owner-built systems have been installed at homes and public locations.

Research and Evaluation

The Norwegian government conducted the first study of composting toilets in 1973. Units in this study were kept at a temperature of 17 degrees Celsius over a 150-day testing period. Units were loaded with quantified amounts of human waste and food scraps to simulate normal use. Compost temperature, weight reduction, bacterial concentrations, viral survival rates, and visual assessments of final composted matter were recorded. The tests identified problems with flies and excess liquid buildup, and the composted material was deemed unsafe for garden use. Conclusions indicated that heating elements, fans, and user maintenance were critical to successful performance.[17]

Similar results were obtained from subsequent tests by independent researchers in Canada,[18] at the Oregon State Department of Environmental Quality,[19] California Department of Health Services,[20] and Maine Department of Human Services.[21] The US Forest Service tested the effectiveness and operation of a bin-composting unit at high-elevation sites, and reported it economical and durable.[22] The US Army Corps of Engineers initiated a composting toilet research program,[23] including trials to develop and evaluate airflow designs.[24] High acceptance rates led the Army Corps to conclude that composting toilets were appropriate for ARMY use.[25]

Several reviews of composting toilet technology have been conducted to assess economic barriers, consumer preferences, and maintenance concerns.[26] A review of experience with composting toilets in Maine from 1974 to 1977 noted that financial institutions were reluctant to provide loans to residents planning to install composting toilets due to the uncertainty of the home resale value. This study identified a need for public education, design improvements, and a testing program.[27] A National Bureau of Standards report concluded that the main difficulty in marketing composting toilets is that most of the public had never heard of them.[28] Other reports note consumer reluctance to handle and bury the composted wastes.[29] Recent surveys report a high level of user satisfaction.[30] Comments from composting toilet manufacturers and experts in the field support the continuing need for public education and for confronting regulatory barriers.[31]

The National Sanitation Foundation International (NSFI) is an independent laboratory that evaluates wastewater recycling and water conservation devices. Their "Standard 41" approval is given to technologies which pass testing over a six-month period. NSFI's Wastewater Treatment Unit Certification Program evaluates composting toilets for structural soundness, liquid containment, and odor production, and monitors the end product to ensure that levels of fecal coliform indicator bacteria do not exceed 200 fcu. per gram. NSFI has considered restructuring this evaluation process to more accurately quantify its criteria for odor and end product assessment.[32]

Certification and Regulation

Certification of composting toilet systems by the NSFI is a widely accepted means of determining the efficiency of these systems, and is required by many states. Some states allow for local health departments to review and approve plans for innovative and alternative systems that have not been evaluated and approved by the NSFI. The Massachusetts Plumbing Code allows the Board of Plumbing Examiners to approve technologies that have not been certified by NSFI or the Massachusetts Department of Environmental Protection.[33]

Regulatory barriers include restricted or inconsistent state health department approval and wide variability of local regulations regarding waste disposal.[34] For example, some local plumbing codes require homeowners to install full-sized septic tanks to treat greywater on-site,[35] or install sewer lines and a flush toilet as a back-up system.[36]

A wide variety of manufactured composting toilets are available from distributors listed below. The National Sanitation Foundation International (NSFI) has certified most of the commercial composting toilets on the market. Plans are available for 'owner-built' composting toilets that have not been tested or certified the NSF.[37]

Manufacturers and Distributors of Composting Toilets:

AlasCan Toilets & Greywater Treatment Systems 3498 St. Albans Rd., Cleveland Heights, OH 44121 Tel: (216) 382 4151 Email: SF@cris.com

Advanced Compost Systems, Inc. 195 Meadows Rd., Whitefish, MT 59937

Biolet International, Weidstrasse 18, 6300 Zug Switzerland, 41/42 224728

Bio-Recycler Co. 5308 Emerald Dr. Sykesville, MD 21784 Tel: (301) 795 2607

Bio-Sun Systems RR# 2, Box 134A, Millerton, PA 16936 Tel: (800) 847 8840 Fax: (717) 537 6200 Email: bio-sun@ix.netcom.com

Clivus Multrum USA 21 Canal Street Lawrence, MA 01840 Tel: (508) 794 1700

Composting Toilet Systems. Route 2 Newport, WA 99156 Tel: (509) 447 3708 Email: daverem@webomat.com (Four models approved by NSF in 1996

ECOS Inc. Concord, MA 01742 Tel: (800) 462 3341 Fax: (508) 369 2484 Email: watercon@igc.apc.org

Envirovac, Inc. 1260 Turret Dr. Rockford, IL 61111 Tel: (815) 654 8306

Human Endeavors Box 278 Healy, AK 97743 Tel: (907) 683 2698

Sancor 140-30 Milner Ave., Scarborough, ON, Canada M1S 3R3. Tel: (800) 387 5126 Website: http://www.envirolet.com

Sun-Mar Corp. 600 Main Street, Tonawanda, NY 14150. Tel: (800) 461 2461 Website: http://www.sun-mar.com

Water Conservation Systems Damonmill Square Suite 41-A, Concord, MA 01742 Tel: (508) 369 3951

Owner Built Systems

Designs for many different owner-built composting are being demonstrated at educational centers and have been published by sources listed on page 12.[38]

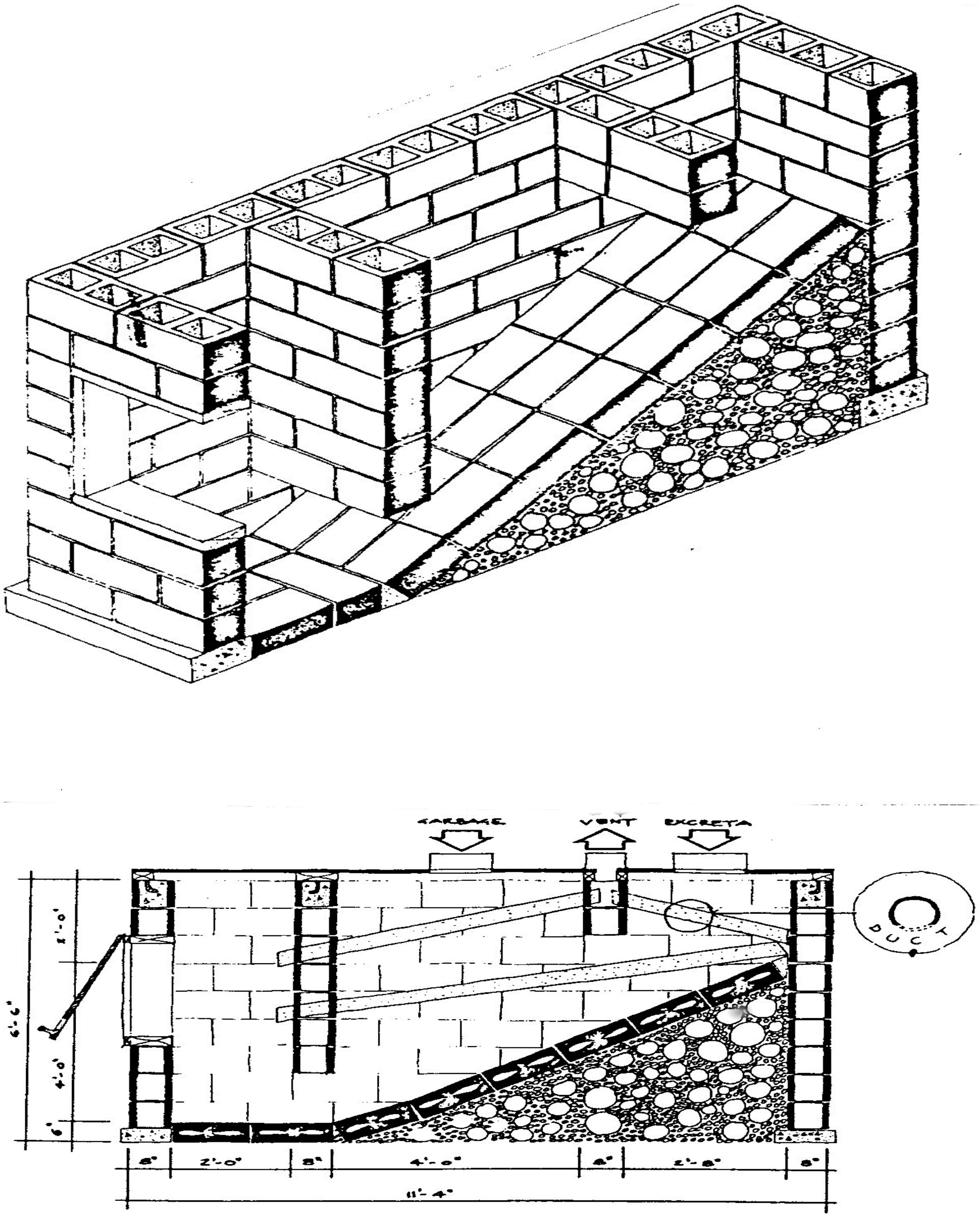

Diagram 1: Maine Tanks – From **The Toilet Papers** by Sim Van Der Ryn

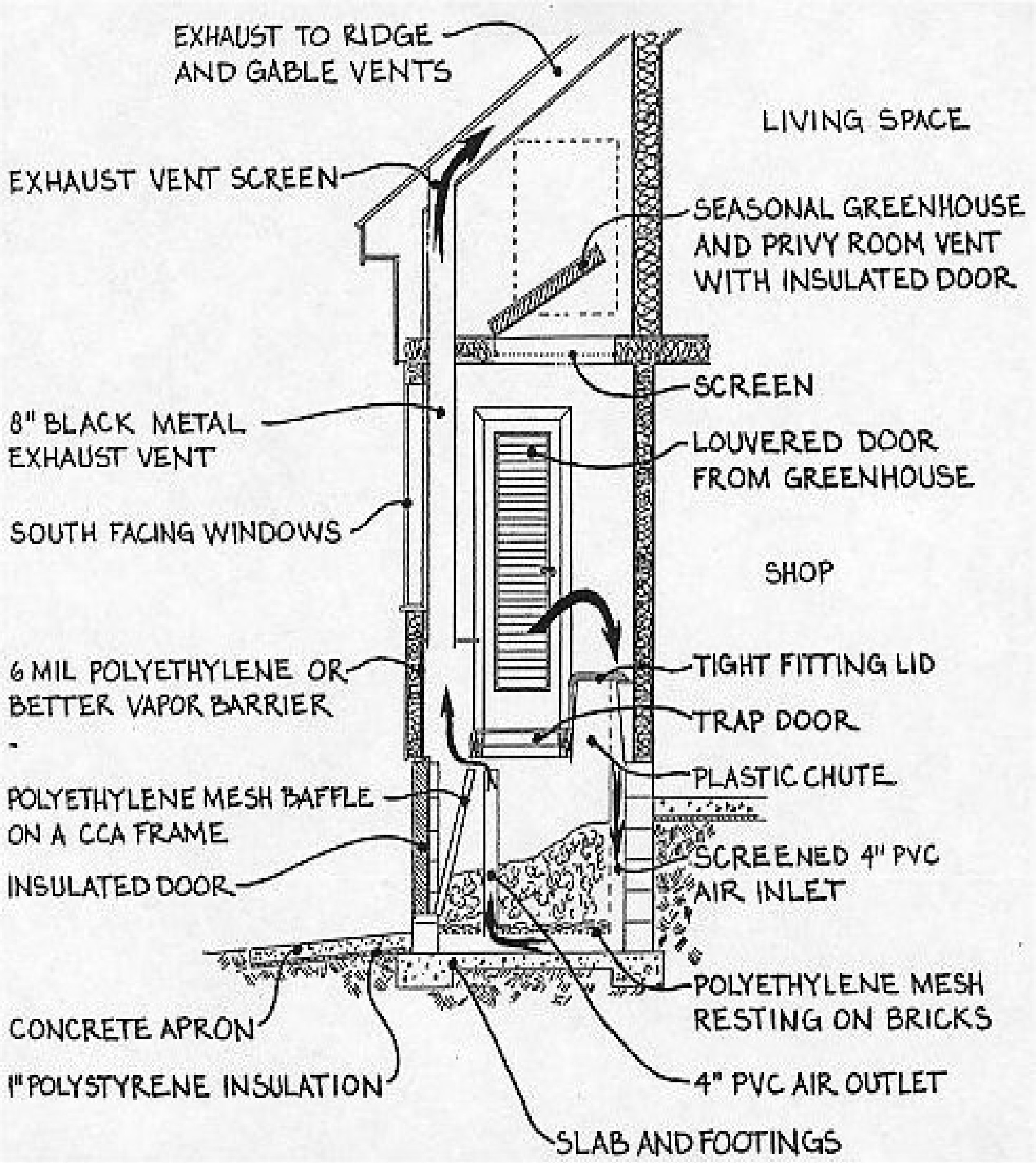

Diagram 2: The Gap Mountain Permaculture Mouldering Toilet.[39]

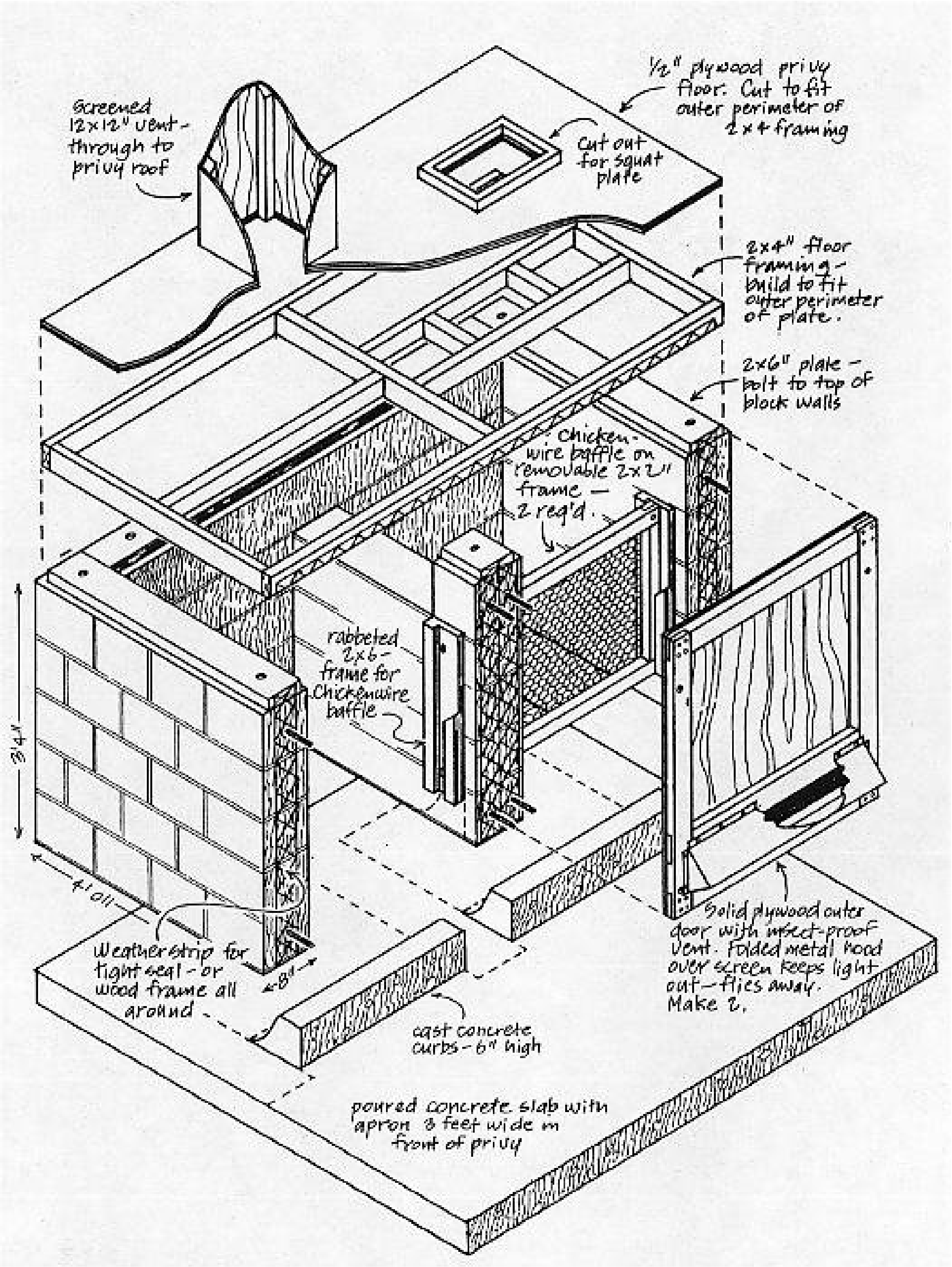

Diagram 3: Farallones Design - **The Toilet Papers** by Sim Van Der Ryn

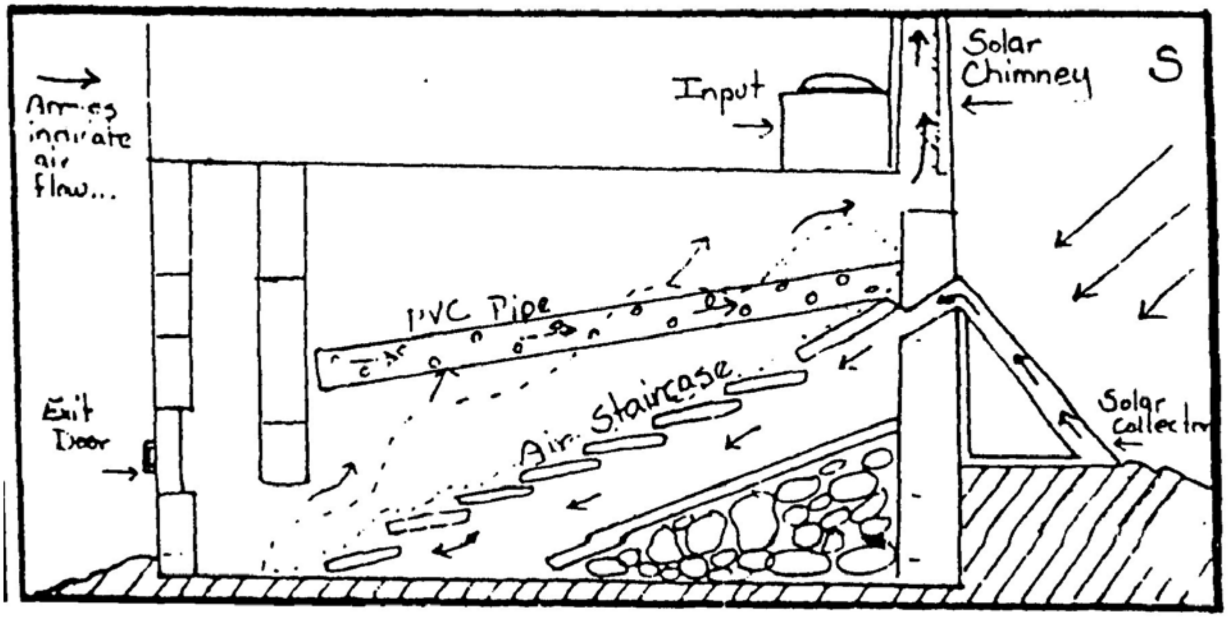

Diagram 3: The Passive Solar Composting Toilet.[40]

Innovative Designs

Many designs for owner-built composting toilets have been developed as a result of tinkering in the field – small adjustments made in response to experience – rather than from controlled studies.[41] The presence of flying insects, attracted to lighted or reflective surfaces, has been reduced by painting interior surfaces black,[42] trapping the insects,[43] and by adding extra carbonaceous material such as peat moss, leaves or sawdust.[44] Problems with excess liquid build-up have been addressed by installing drains,[45] separating out the urine,[46] adding fans or heaters,[47] providing space or vents for evaporation,[48] or by adding extra carbonaceous material such as peat moss, leaves or sawdust.[49]

Innovative composting toilet designs include vermicomposting, solar and wind powered fans and heating units, freestanding commercial passive solar units, and remote-monitoring equipment. Vermicomposting, the use of worms in the composting chamber to consume bacterial and viral pathogens, accelerates the decomposition process.[50] Solar and wind powered generators provide energy for fans, heating elements, and motorized agitators where site constraints limit access to utility grids.[51] Both solar heating panels and solar chimneys have been developed for improved air circulation.[52] A commercial, passive solar freestanding unit has been developed that does not need to be adapted into the home or located near power sources.[53] Remote monitoring equipment can allow for regular checkups of capacity and function to be carried out from a remote location.[54]

Composting Toilet Plans:

55 Gallon Drum Compost Toilet. Guidebook & plans from The Water Center P.O. Box 264 Eureka Springs, AR 72632 $7.95 ppd.

Composting Toilet Plans. From Appalachian Science in the Public Interest, (ASPI). Route 5, Box 423, Livingston, KY 40445 Tel: (606) 453 2105

Design and Operation of Composting Toilets. Technical bulletin available from the Michigan Department of Public Health. Lansing, MI. 1984.

Design, Construction, and Operation of the Big Batch Composting Toilet. Plans from EKAT/TOP, 414 South Wenzel St, Louisville, KY 40204. Tel: (502) 589 0975.

Drum Privy. Plans from Peter Warshall, Box 42 Elm Road, Bolinas, CA 94924.

Gap Mountain Permaculture Mouldering Toilet. Technical Bulletin. Published by Gap Mountain Permaculture, Jaffrey NH. Out of Print.

Mother's Compost Commode. Plans from *Mother Earth News* (Jan./Feb. 1984): 104-106.

The Passive Solar Composting Toilet. Blueprints and materials list is available for $35 from Long Branch Environmental Education Center P.O. Box 369 Big Sandy Mush Creek, Leicester, NC 28748. Tel: (828) 683-3662 Fax: (828) 683-9221
Email: paulg@buncombe.main.nc.us

Solar Assisted Composting Toilet. Plans from Ron Hughes. Arkansas Energy Office. One Capital Mall, Little Rock, AR 72201. Tel: (800) 482 1122.

GREYWATER

Definition

Greywater is household wastewater from uses such as bathing, laundry, and dish washing.[55] Greywater may contain organic material including food particles, suspended solids, phosphorus compounds, grease, and residues.[56] Greywater comprises about 60% of household wastewater.[57] Non-toilet uses of water in the home amount to about 30-50 gallons per person each day.[58] Greywater should not contain water used to launder soiled diapers; which must instead be diverted to a septic tank or sewer.[59] Many greywater systems are available for residential installation:

Treatment

Most greywater is treated through a combination of settling, filtering, and disinfecting processes. A standard septic tank can also be used for the primary treatment of greywater. Homemade or manufactured roughing filters can be used to remove grease, particles, and solid residues. Disinfection of greywater may be required in situations where fecal matter or urine from laundry water is mixed with household greywater. Commercially available disinfecting units employ chlorine, iodine, ozone, or ultraviolet light.[60] Greywater is purified to a high degree in the upper, most biologically active region of the soil. Greywater should not be stored, and should be used within 24 hours, before bacteria can multiply.[61]

Recycling

A few companies that install composting toilet systems are also installing greywater gardens. Greywater gardens provide alternatives to conventional leach fields. These systems allow for greywater and excess liquid from the toilets to be filtered and drained into lined, ornamental gardens for absorption and transpiration,[62] or recycled for reuse such as in toilet flushing.[63]

Permitting and Regulation

Greywater is used in some areas for irrigating orchards, vineyards, seed, pasture, and fiber crops.[64] Local plumbing codes can require homeowners to install full-sized septic tanks to treat greywater.[65] California passed a law in 1992 legalizing the use of greywater for subsurface landscape irrigation, and adopted state greywater reuse standards in 1994. The International Plumbing Code was revised in 1995 to allow permitting of greywater systems.[66] According to one systems designer, greywater use will remain stymied in building and health department bureaucracies until enough pilot projects prove the logic of its use.[67]

Greywater Resources

Aquatic Ecosystems. 1767 Benbow Court Apopka, FL 32703 Tel: (407) 886 3939
Email: info@aquaticeco.com Web: http://www.aquaticeco.com

Center for Ecological Pollution Prevention. P.O. Box 1330 Concord, MA 01742
Tel: (978) 318 7033, Web: http://www.cepp.cc

Earthship Biotecture. PO Box 1041, Taos, NM 87571, Tel: (505) 751 0462
Email: biotecture@earthship.org Web: http://www.earthship.org

Jade Mountain. P.O. Box 4616 Boulder, CO 80306-4616 Tel: (800) 442 1972
Web: http://www.jademountain.com

Homestead Utilities. 17366 E. Meadow Lane, Mayer, AZ 86333-4119
Tel: (800) 292 5342

NutriCycle Systems. Lewis Mill, 3205 Poffenberger, Jefferson, MD 21755
Tel: (301) 371 9172 Web: http://www.nutricyclesystems.com

Oasis Design. 5 San Marcos Trout Club, Santa Barbara, CA 93105-9726
Tel: (805) 967 9956 Fax: (805) 967 3229, Web: http://www.graywater.net

ReWater Systems. 477 Marina Parkway, Chula Vista, CA 91910 888
Tel: (619) 585 1196 Fax: (619) 585 1919.

Solar Survival Architecture P.O. Box 1041 Taos, New Mexico 87571
Tel: (505) 751 0462 Email: earthship@taos.newmex.com

Sustainable Strategies 50 Beharrell Street P.O. Box 1313 Concord, MA 01742-1313
Tel: (978) 369 9440 Email: info@ecologocal-engineering.com
Web: http://www.ecologicalengineering.com

Symbiosystem. Round River Alternatives. 5879 Nikolai Road, Finland, Minnesota
55603. Tel: (877) 391 0888 Web: http://www.symbiosystem.com

Wolverton Environmental Services, Inc. 514 Pine Grove Road. Picayune, MS 39466
Tel: (601) 798-5177, Fax: (601) 798-5875, Email: wes.inc@datastar.net
Web: http://www.wolvertonenvironmental.com

CONSTRUCTED WETLANDS

Definition

A constructed wetland is a wastewater treatment system component that is engineered to mimic the physical and biological purification processes of a natural wetland. Constructed wetlands can reduce suspended solids, biological oxygen demand (BOD), nutrients, metals, and pathogens through a variety of processes including sedimentation, filtration, aerobic and anaerobic microbial metabolism, plant uptake and respiration, soil absorption, and additional chemical processes.[68] They are reported to be effective at treating storm water runoff,[69] municipal wastewater, acid mine drainage, and at removing effluents from industrial and agricultural sources.[70] Constructed wetlands provide on-site wastewater treatment for individual residences and small communities.

There are two common types of constructed wetland treatment beds in use in the United States. Subsurface flow wetlands (SF), treat wastewater in gravel beds or trenches characterized by the water level remaining below a surface layer of gravel or similar bed media. Plant species selected for these systems have root systems that colonize the bed media and anchor the plants as though they were growing in soil or sediment of a shallow wetland. SF wetlands are also commonly called rock reed filters, root-zone systems, or vegetated, submerged bed systems.

Free water surface wetlands (FWS) consist of small ponds or channels characterized by floating aquatic vegetation and water that is exposed to the surface, providing wildlife habitat and bird watching opportunities.[71] This review will focus specifically on SF wetlands as they have the following advantages over FWS wetlands: faster treatment, smaller area required, greater heat retention, less odors, and less risk of insect vectors.[72] SF wetlands are recommended in several design manuals for individual residences.

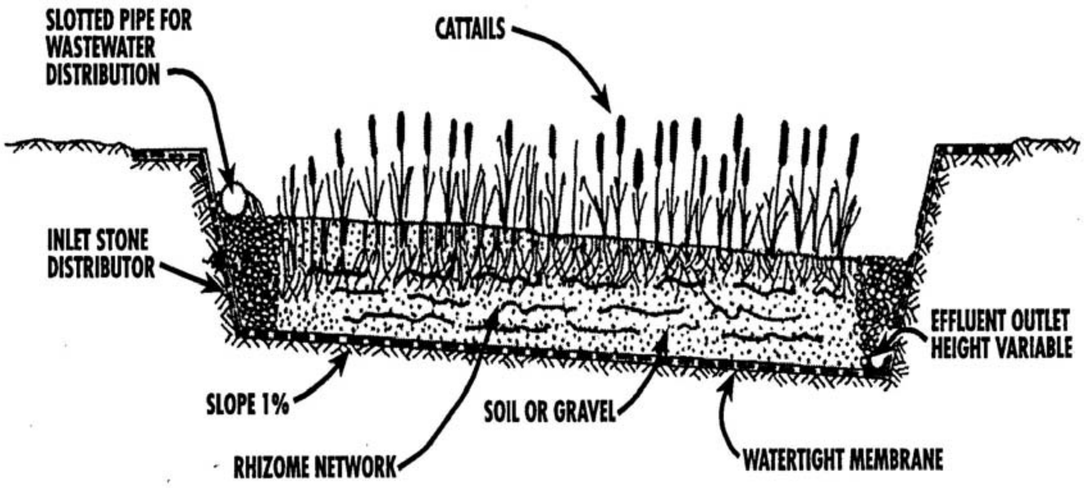

Diagram 5: Subsurface flow wetland – From USEPA

History

Constructed wetlands were first developed to treat wastewater in Europe in the 1960’s.[73] The European Community/European Water Pollution Control Association published guidelines on the use of constructed wetlands in 1990.[74] As of 1990, about five hundred of these systems had been installed in European countries including Austria, Denmark, Germany, and Switzerland.[75] Wolverton in Louisiana and Gersberg in California conducted research on constructed wetlands in the United States in the early 1970’s.[76] The Tennessee Valley Authority (TVA) published a design manual in 1988, which has been revised to include new design standards.[77] Guidance information on constructed wetlands has been developed with funding from the National Science Foundation, National Aeronautics and Space Administration, Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Dept. of the Interior, and the U.S. Dept. of Agriculture.[78]

Plants

Wetland plants pump atmospheric oxygen into their submerged stems, roots, and shoots; thus providing oxygen to microbial decomposers on these underwater plant surfaces. Plants also play an active role in the uptake of nitrogen and phosphorous. Some of this nitrogen and phosphorous is released back into the water as plants die and decompose.[79] Shallow beds provide enhanced root penetration and provide for increased oxygenation.[80] Wetland beds contain plant species including cattails, reeds, bulrush,[81] and bamboo,[82] growing in a substrate such as river rock or gravel. Several publications list recommended plant species,[83] and planting guidelines.[84] Native plants are recommended as they ensure proven regional adaptation.[85] Potential cash crop species for wetlands include blueberry, cranberry, watercress, and wild rice.[86] Trees growing near wetlands can puncture liners with their roots, and trees planted on the south, east, or west sides of wetlands can shade plants and suppress their growth. Wastewater treatment using natural, wooded wetlands has been demonstrated. Willow trees have colonized unlined secondary wetland beds.[87] Trees able to withstand wetland conditions include alder, bald cypress, river birch, swamp white oak, water oak, white cedar, and black gum or tupelo.[88]

Substrates

Most current wetlands use gravel, and early systems used soil substrates.[89] Preferred gravel sizes are ½ inch to 1 inch. Gravel sized 1½ to 3 inches is used in the first three feet of the wetland to allow for settling and digestion of suspended solids. Pea gravel can be placed on top to facilitate planting.[90] Depth of the substrate is often about 1 foot, as to not exceed the plant root depths.[91] Native sandstone has been used in Kentucky,[92] mine spoil has been used effectively by the TVA,[93] and the used of shredded tires has been tested at Texas A&M. Tires worked as a substrate, however, the tires produced a thin layer of grease during the first month of operation. Sharp iron fragments posed a safety hazard and added small amounts of dissolved iron.[94]

Bed Liners

Wetland beds are usually lined with an impermeable layer of material such as plastic or a bentonite clay mixture, to both prevent untreated wastewater from seeping into groundwater, and to prevent groundwater from entering the constructed wetland beds. Recommended liners include a heavy duty, UV resistant, 30-40 mil. membrane such as ethylene propylene diene monomer (EPDM) rubber, polyvinyl chloride (PVC), polyethylene (PE),[95] or polypropylene (PPE).[96] Reinforced concrete bed liners have been used on sites with steep slopes.[97]

Berms

Berms are commonly installed around the perimeter of constructed wetlands to maintain consistent water levels. Up-slope berms are utilized to divert surface runoff, and down slope berms are used to maintain adequate water levels in the wetland.[98] Berms can also be constructed to contain water from high rainfall events,[99] or to prevent introduction of soil particles into the substrate from surface runoff.[100] Timber berms have been used to minimize digging and land area required.[101]

Primary Treatment

Recommended designs for SF wetland systems include a standard multi-compartment septic tank for primary treatment.[102] Septic tanks provide for primary treatment through screening and sedimentation,[103] as well as bacterial digestion,[104] and for partial removal of biological oxygen demand, (BOD).[105] A constructed wetland system designed by Solar Survival Architecture has a solar assisted septic tank "incubator" with a trombe wall that heats up waste, accelerating the anaerobic treatment process.[106] Other septic tank modifications and additional treatment units such as trickling filters within the tanks and intermittent sand filters can be integrated to provide improved treatment levels.[107] Filters are typically installed on the effluent side of the septic tank to further reduce solids and organic loads into the wetland beds.[108]

Secondary Treatment, Tertiary Treatment, and Sludge De-watering.

Most constructed wetlands are designed to meet specific treatment goals. They are used for secondary and tertiary treatment of wastewater and can be used to de-water sludge.[109] Secondary treatment uses anaerobic bacteria for decomposition to render sludge more biologically stable and inert.[110] Secondary standard quality is less than 30mg/l biological oxygen demand, BOD.[111] Tertiary treatment is a complex and expensive process that removes 95% or more of the solids.[112] Sludge dewatering can be done by using sand drying beds or reed beds. Reed bed lagoons are lined with plastic, fitted with drainpipes, and partially filled with sand and reeds. Such systems can be used for ten years before composted sludge requires removal and replanting of reeds is required.[113]

Effluent Disposal

Effluent disposal subsequent to wetland treatment can be into unlined secondary beds, subsurface soil layers via a subsurface drainpipe,[114] or into approved soil absorption areas.[115] Unlined wetland beds can be used to replace the leach bed component of conventional on-site septic systems.[116] Safe subsurface disposal may be difficult to achieve in heavy clay soils, rocky soils, or on slopes. Soil absorption areas have been designed for use on slopes, and can become colonized by volunteer wetland vegetation. A successful example of a soil absorption area on a steep slope is a municipal system in Michigan that provides wastewater treatment for 825 residents.[117] In areas with poor soils or high water tables, it may be possible to design above ground mounds of sand and soil to disperse water via percolation and evaporation.[118] Effluent disposal into surface waters must be approved by state agencies.[119]

Zero Discharge and Recycling

Zero discharge or recycling is achieved via evapotranspiration, irrigation, and reuse for toilets.[120] Evapotranspiration beds with periodic misting units have been employed in public systems, which produce no effluent and do not require an NPDES permit. Onsite irrigation is an accepted means of effluent disposal.[121] A public system in North Carolina uses treated wastewater for both irrigation and toilet flushing.[122] A public system in Florida is designed to recycle 90% of treated wastewater back into rest rooms for toilet flushing.[123]

Treatment Goals

Constructed wetlands and other components have been designed for removal of phosphorus, ammonia and nitrogen, as well as removal of pathogens and biological oxygen demand (BOD). Adequate treatment is dependent on factors such as the design of system components, operation and maintenance, and climate. Discharge limits for various effluents have been set to ensure that their treatment and disposal will not cause health hazards or environmental degradation.

SF constructed wetlands can have a limited capacity for phosphorus removal due to insufficient hydraulic retention times (HRT), and lack of interaction with soil minerals. HRT is the average time water remains in a wetland.[124] Shorter retention times provide inadequate treatment, and longer than optimal retention times can result in stagnant, anaerobic conditions.[125] Excess discharge of phosphorus into surface waters can cause eutrophication.[126] Composting toilets can be used in conjunction with wetlands,[127] which can reduce the required wetland size by 40 percent.[128]

High phosphorus removal rates can be achieved by increasing the size of the wetland and by providing for more interactions with soil minerals.[129] Subsoil disposal of effluent has been employed to eliminate phosphorus discharge.[130] Areas with good to marginal soil percolation typically have no surface discharge from unlined secondary wetland beds.[131]

Harvesting of aquatic vegetation has been employed to remove excess phosphorus,[132] and the harvesting of duckweed from pond components has proved cost effective and been endorsed by the US EPA.[133] Duckweed has limited seasonal growth in areas with winter snowfall, but can be harvested weekly in warm regions as a source of animal feed.[134]

Ammonia and nitrogen treatment is necessary to protect groundwater and aquatic ecosystems. High ammonia levels have been reported to kill juvenile fish and other aquatic organisms.[135] High nitrogen levels can kill aquatic organisms,[136] and can be a source on groundwater contamination.[137]

Availability of oxygen is a limiting factor in the removal of ammonia and nitrogen.[138] Methods for improving oxygenation include enhancing root penetration, increasing HRT of wastewater, and installing vertical flow system components.[139] Other approaches include the use flowforms,[140] or step aeration on sloping sites that can utilize gravity flow to aerate water as it passes through cascades, waterfalls, and open channel transects.[141]

Increased HRT can improve oxygenation, and retention of wastewater for six days or more has achieved successful ammonia removal rates.[142] Short retention times provide inadequate treatment, and longer periods of HRT can lead to stagnant, anaerobic conditions.[143] Regulation of water levels is the primary method for varying HRT.[144]

Mound Systems

Mound systems have the capacity for greater phosphorus removal than wetlands,[145] and have been used in combination with wetlands for enhanced treatment. In these systems, a grass covered, pressure dosed mound composed of a course sandy loam precedes the wetland cell. Water passes through the sand medium via gravity flow, and is captured by a plastic liner before flowing into the wetland cell for further treatment.[146]

Vertical Flow Wetlands

Vertical flow wetlands have been used in Europe since the 1950's, but are not commonly used in the United States. These wetland systems are reported to be more effective at removal of ammonia than SF wetlands.[147] Vertical flow wetlands can provide a cost-effective method for removal of ammonia and nitrogen. These systems have performed well when receiving intermittent applications of wastewater. Vertical flow wetlands must be used in combination with other system components such as constructed wetlands, as they do not contain sufficient anaerobic environments necessary for denitrification.[148] Vertical flow wetlands, when used in combination with SF have been reported to effectively lowered concentrations of nitrogen, ammonia, phosphorus, total suspended solids TSS, and biological oxygen demand BOD.[149]

Climate Considerations

Treatment efficiencies in constructed wetlands are both temperature and season-dependant.[150] Cold weather, drought, high rainfall, and seasonal flooding can all effect treatment processes. Insulation can be used to retain heat,[151] or wetland components can be enclosed in greenhouses.[152] Wetlands may require supplemental water if dry weather coincides with periods of low flow.[153] Wetlands can be flooded prior to dry periods, or rainwater can be diverted into wetlands during periods of low-flow.[154] High rainfall can cause surface water to enter wetlands. Berms should be constructed to both exclude runoff and contain water from high rainfall events. Sediment carried by floodwaters can clog wetlands,[155] and they should not be placed in areas of regular flooding.[156]

Design Considerations

The arrangement of wetland cells, as well as and their size and shape can influence treatment goals. Multiple, or parallel treatment beds are recommended to enable systems to remain operable if one of the beds is being serviced. Multiple beds also provide more design flexibility on sloping sites.[157] Early constructed wetlands were designed with length to width ratios of 10:1 or more. These early systems were cited as causing surface flow problems.[158] To address concerns of surface flow, length to width ratios of 4:1 to 3:1 have been recommended,[159] and a ratio of 1:1 may offer even more advantages in cold climates due to the reduced perimeter area relative to volume.[160]

Operation and Maintenance

The TVA has developed operation and maintenance guidelines for on-site residential systems.[161] Basic maintenance activities required for municipal systems include mowing of berms, periodic cleaning of discharge risers, monitoring of dikes for erosion, and sometimes trapping of muskrats and woodchucks to prevent their burrowing into the dikes.[162] Water levels must be maintained for plant growth. Springtime flooding or manual weeding can be done to control weeds. Flow distribution and water control structures should be maintained to optimize the rate and volume of influent during climactic extremes such as high rainfall events.[163] Supplemental water may need to be added if periods of dry weather coincide with periods of low flow.[164] This can be address by recycling effluent back into the system,[165] but this may lead to salination of wetlands if evaporation rates are high.[166] Homeowners can flood beds prior to periods of dry weather or low flow,[167] or they can install structures to divert rainwater into beds to reduce the impact of evaporation.[168]

Costs

Cost effectiveness of constructed wetlands is dependent on both site specific factors and treatment requirements.[169] Some researchers have concluded the wetlands can provide cost effective wastewater treatment given the availability of suitable land at a reasonable price.[170][clxx] Climate may effect system cost, as cold regions may require insulation of wetland beds. Cold climate designs may require recirculating filters, intermittent loading, or temporary storage of wastewater to ensure adequate nitrogen removal.[171] Cost of the substrate, as well as transportation requirements, can effect the cost of constructing a wetland. Gravel can account for one half of SF wetland costs. Liners generally run 15-25% of the total system cost.[172] Zoning or regulatory requirements for wetland siting, capacity, and effluent quality can effect system cost.

Additional site-specific cost variables include soil type, depth to water table, slope, site vegetation, and rainfall. Soils with high clay contents may reduce cost by providing a natural, on-site alternative to imported liners. High water tables may add to the costs of site studies and liners that may be required. Land that has a slope of less than 2 percent may require added costs for mechanical pumping. Land with a slope of more than 15 percent present considerable challenges, as costly excavation may be required. Site vegetation may require clearing, or the planting of windbreaks to screen from cold winter winds. The cost or availability of wetland vegetation can also affect overall cost. Rainfall affects the need to purchase pumps for draining during storms or recharging during dry spells.[173]

Municipal Systems

The US EPA's North American Constructed Wetland Treatment Database lists about 160 public or municipal constructed wetlands which each treat more than 50,000 gallons per day of wastewater.[174] Most public systems operate year-round, however some systems in cold climates have employed lagoons for water storage during winter months and treatment and discharge during warmer weather.[175] Greenhouse enclosed systems called "Living Machines" have been used in extremely cold conditions.[176]

Living Machines

Living Machines, also called “Advanced Ecologically Engineered Systems,” are biological treatment systems consisting of constructed wetlands and related innovations. These systems may be more cost effective that SF wetlands for public systems with extreme cold climates, steep slopes, high groundwater, and limited land area.[177] The technology can be licensed from Living Technologies, Inc.,[178] and is marketed under the name Solar Aquatic Systems by Ecological Engineering Associates.[179]

Components of these public systems are often enclosed in greenhouses for year-round treatment of effluent in cold weather conditions. Living Machines produce less sludge than conventional systems due to their diversity of waste-processing organisms.[180] Primary treatment takes place in a “three stage bioreactor”. Secondary treatment occurs in series of aerated tanks with floating aquatic vegetation.[181] Some system designs include constructed wetlands for tertiary treatment, or dedicated sludge de-watering.[182]

Storm Water Wetlands

Constructed wetlands specifically designed to treat storm water wetlands were first employed in the late 1970’s, and since the hundreds of these systems have been built at various locations. These systems include components such as vegetated swales, wet ponds, and wetland beds. According to the EPA’s National Urban Runoff Program, the first flush of storm water in urban areas may contain higher levels of contamination that those normally found in sewage wastewater. Contamination levels of storm water are generally less than 50% of levels for municipal sewage. Such contaminants include hydrocarbons, asbestos from brake linings, heavy metals, bird and animal wastes, herbicides, and pesticides. Storm water presents additional treatment challenges due to its unpredictable flows during storm events. Storm water wetlands have been shown to remove 41 to 73 percent of lead, zinc, and total suspended solids.

Permitting and Regulation

Individual states have established water quality parameters for various discharge options including discharge to surface waters, land application, and subsurface soil disposal. Parameters regulate biological oxygen demand (BOD), total suspended solids, nitrogen, and phosphorus levels.[183] Compliance monitoring for safe effluent discharge is necessary for municipal systems, and discharge to surface waters may be limited to ice free high flow periods. Surface water discharge requires a National Pollution Discharge Elimination System (NPDES) permit.[184] Land application permits are frequently more lenient than those for surface water discharge, as crops have the ability to utilize ammonia, nitrogen, and phosphorus. Soil is which these crops are grown can further absorb and degrade organic nutrients. Subsurface soil disposal is frequently used and often provides the most cost effective alternative due to the soils ability to remove ammonia, nitrogen, phosphorus, and viruses year-round. Section 402(p) of the 1987 Federal Clean Water Act (required the US EPA to establish (NPDES) storm water permits. These were phased in between 1989 and 1994 in most states. It requires a storm water discharge permit from municipalities and an erosion control plan for all construction development that affects areas of 5 acres or more. [185]

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[1] US General Accounting Office, *Water Pollution Information*, 4; Sauter, *Natural Home Remedy*, 1.

[2] Office of Water Supply, *Waste Disposal Practices*, 1.

[3] Macler, *Update on Groundwater Disinfection*, 14.

[4] Office of Water Supply, Waste Disposal Practices, 22.

[5] Hagedorn, Groundwater Pollution, 192; and Macler, *Update on Groundwater Disinfection*, 14.

[6] Greywater is defined a household wastewater from sinks, showers, laundry, etc. While this water does not contain waste from toilets, it contains similar pathogens and must be treated prior to soil disposal, irrigation, or reuse.

[7] Van der Ryn, *The Toilet Papers*, 60.

[8] Clayton, *Gap Mountain Permaculture*, 3; Fritsch, *Domestic Water and Waste*, 18; Moreau, *Maine's Perspective*, 19*;* Van der Ryn, *Toilet Papers*, 81; and Siegrist as cited in Costner, *We all Live*, 47.

[9] Long Branch Environmental Education Center, *Passive Solar Composting Toilet*.

[10] Van der Ryn, *Toilet Papers*, 69.

[11] Kreissl, *Experience with Biological Toilets*, 94; Clayton, *Gap Mountain Permaculture*, 6, Kourik, *The Straight Poop*, 22; *Domestic Wastewater, 18.*

[12] Cook, *Field Evaluation*, 90.

[13] Van der Ryn, *The Toilet Papers*, 64; Evans, Urine as a Fertilizer, 3.

[14] Van der Ryn, *The Toilet Papers*, 81.

[15] Smith, as cited in Kreissl, *Experience with Biological Toilets*, 93.

[16] Survey conducted by James Wynn April of 1997.

[17] Kreissl, *Experience with Biological Toilets*, 96.

[18] Kreissl, *Experience with Biological Toilets*, 95; Leich, *Sanitary Innovations*, 17.

[19] Spies, *Alternative Systems*, 25.

[20] Enferadi, *Field Investigation of Biological Toilet Systems*, 4; Kreissl, *Experience with Biological Toilets*, 96.

[21] Moreau, *Maine's Perspective on Composting Toilets*, 18.

[22] Leonard, *Bin for Privy Wastes*, 1: and Fay, *The Composting Option for Human Waste*.

[23] Scholze, *Remote Waste Treatment*, 37.

[24] Engelder, *Innovative Airflow*, 41.

[25] Scholze, *Technology for Waste Treatment*, 80; and Smith, *Appropriate Technology*, 54.

[26] Kourik, *The Straight Poop*: Kreissl, *Experience with Biological Toilets*; and Riggle, *Technology Improves*.

[27] (Hoxie and Hinkley as cited in Kreissl, 95).

[28] Geist, *Composting Privy*, 36.

[29] Enferadi, *Field Investigation of Biological Toilet Systems*, 4: and Kourik, *The Straight Poop*, 22.

[30] Riggle, *Technology Improves*, 39; Scholze, *Technology for Waste Treatment*, 80; Smith, *Appropriate Technology for Wastewater*, 56; and Wilson, *Composting Toilets*, G-3.

[31] Clayton, *Gap Mountain Permaculture*, 6; Riggle, *Toilets Reach*, 70; Riggle, *Technology Improves*, 39.

[32] Personal Communication – Al White, NSFI Advisory Board.

[33] Riggle, *Technology Improves*, 40.

[34] Fritsch, *Domestic Wastewater*, II-26.

[35] Clayton, *Gap Mountain Permaculture*, 5; and Moreau, *Maine's Perspective*, 19.

[36] Riggle, *Technology Improves*, 39.

[37] Clayton, Gap Mountain Permaculture; Costner, *We All Live*, 40; Fritsch, *Domestic Wastewater*, II-22, II-23; Mother Earth, *Composting Commode*, 4; and "Solar Assisted Composting Toilet." Plans available from Ron Hughes. Arkansas Energy Office. One Capital Mall, Little Rock, AR 72201. Tel: (800) 482 1122.

[38] Clayton, *Gap Mountain Permaculture*; Fritsch, *Domestic Water*, II-22,II-23; Hughes, *Solar Assisted Composting*; Mother Earth, *Composting Commode*, Van der Ryn, *The Toilet Papers*, 44, 50; and Costner, *We all Live*, 39.
Stoner, *Living with a Composting Toilet*, 86.

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[39] Gap Mountain Permaculture publishes plans for a slow-rate composting or "mouldering" toilet. (Clayton, *Gap Mountain Permaculture)*. Their passive solar unit is based on a design from the Farallones Institute in Occidental, CA (Van der Ryn, *The Toilet Papers*, 60), that has been was modified to function in colder climates and require less turning of the composting material. Such double vault composters are used alternately and require compost removal every few years. (Costner, *We All Live*, 44). The freestanding unit is reported to cost less than $2,000 for materials; units incorporated into initial construction cost less than $1000, and require minimal reconfiguration. (Clayton, *Gap Mountain Permaculture)*. Gap Mountain Permaculture, 9 Old County Road Jaffrey, NH 03452 Tel: (603) 532-6877. Email: dnclayton@monad.net

[40] The Passive Solar Composting Toilet can accommodate a dozen or more people with daily use and can be adapted to a larger capacity if so desired. This design has been utilized in North Carolina, Georgia, Kentucky, Tennessee, South Carolina, Massachusetts, Maine, and New York. Plans have been sent to other states here in the US, in addition to Peru, Indonesia, the Philippines, Haiti, the Dominican Republic, Mexico, and Australia. The state Departments of Health of North Carolina, Georgia and Kentucky approve this design, and the state of New York is currently reviewing the plans for approval. (Paul Gallimore, Long Branch Environmental Education Center).

[41] Clayton, *Gap Mountain Permaculture*, 2; Fritsch, *Domestic Water,* II-22; Mother Earth, *Compost Commode*, 104.

[42] Averill, *Wood Frame Toilet*, 9.

[43] Averill, *Wood Frame Toilet*, 9; Stoner, *Living with a Composting Toilet*, 85.

[44] Stoner, *Living with a Composting Toilet*, 85.

[45] Averill, *Wood Frame Toilet*, 10; Mother Earth, *Compost Commode*, 105.

[46] Averill, *Wood Frame Toilet*, 11; Franceys, *On-Site Sanitation*, 73 Fritsch, *Domestic Water*, 19; Anonymous. *New Compost Toilet on Trial*; and Costner, *We all Live*, 44.

[47] Stoner, *Living with a Composting Toilet*, 85.

[48] Clayton, *Gap Mountain Permaculture*, 23; Stoner, *Living with a Composting Toilet*, 85; Organic Gardening and Farming. *A Consumer's Guide*, 89.

[49] Stoner, *Living with a Composting Toilet*, 85.

[50] Clayton, *Gap Mountain Permaculture*, 6; Riggle, *Technology Improves*, 42; White, *Plan for Remote Alaska*, 3.

[51] White, *Plan for Remote Alaska*, 3.

[52] Long Branch Environmental Education Center, *Passive Solar Composting Toilet*; Sieg, *Toilet Keeps Resources*.

[53] Anonymous, *Toilet on Trial*, 57; Riggle, *Composting Toilets Reach*, 69. (SOLTRAN unit developed by ECOS of Concord, MA.)

[54] Riggle, *Technology Improves*, 43.

[55] Costner, *We All Live*, 47.

[56] Van der Ryn, *The Toilet Papers*, 82.

[57] Costner, *We All Live*, 47; Ludwig, *Create an Oasis*, 2.

[58] Van der Ryn, *The Toilet Papers*, 82.

[59] Ludwig, *Create an Oasis*, 4.

[60] Costner, *We All Live*, 48-50.

[61] Ludwig, *Create an Oasis*, 2.

[62] Steinfield, *Property Owners*, 30; Personal Communication – Dave Del Porto, designer.

[63] Van der Ryn, *The Toilet Papers*, 81.

[64] Van der Ryn, *The Toilet Papers*, 82; and Hylton, *Municipal Reed Bed*, 36.

[65] Clayton, *Gap Mountain Permaculture*, 5; Moreau, *Maine's Perspective*, 19.

[66] Campbell, *Wetlands in the Sustainable Landscape*, 84.

[67] Hylton, *Municipal Reed Bed*, 36.

[68] Kadlec, *Treatment Wetlands*, 44.

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[71] US EPA, *Wetlands for Wastewater Treatment*, 3.

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[73] US EPA, *Subsurface Flow Wetlands*, 2-1, 2-2.
[74] Water Research Centre, *European Guidelines*.
[75] US EPA, *Subsurface Flow Wetlands*, 2-1, 2-2.
[76] Jester, *Plant Rock Filter*, 1; and Wolverton, *Enhanced Purification Systems*, 20.
[77] Steiner, *Design Guidelines*.
[78] US EPA, *Wetlands for Wastewater Treatment*, iii.
[79] US EPA, *Wetlands for Wastewater Treatment*, 4.
[80] Freeman, *Experience in the Southeast*, 6; US EPA, *Subsurface Flow Wetlands*, 3-13; and Watson, *Bear Creek*, 16.
[81] Reed, *The First Generation*, 777.
[82] Campbell, *Wetlands in the Sustainable Landscape*, 24-25, 119.
[83] Corbitt, *Wastewater Treatment*, 231; and Watson, *State of the Art*; and Campbell, *Wetlands in the SustainableLandscape*, 84.
[84] Jester, *Plant Rock Filter*, 43-45; and Steiner, *Design Guidelines*, 23.
[85] Smith, *Design and Construction*, 8; and Steiner, *Design Guidelines*, 22.
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[87] US EPA, *Wetlands for Wastewater Treatment*, 42, 51.
[88] Zim, *Trees*, 75, 40, 71, 84, 96, 39, 41.
[89] US EPA, *Subsurface Flow Wetlands*, 2-1, 2-2.
[90] Campbell, *Wetlands in the Sustainable Landscape*, 117.
[91] Reed, *Performance Evaluation*, 247.
[92] ASPI, *Appalachian Alternatives*, (Spring 1995), 2.
[93] Brodie, *Evaluation of Substrate*, 393.
[94] Turner, *Bed Media*, 5.
[95] Steiner, *Design Guidelines*, 15.
[96] Campbell, *Wetlands in the Sustainable Landscape*, 106.
[97] Watson, *Sand Mountain*, 4-5.
[98] Campbell, *Wetlands in the Sustainable Landscape*, 106.
[99] Piney Woods, *Trinity Watershed*, 46.
[100] Amberg, *Rock-Plant Filter*, 5; Sabo, *Constructed Wetlands*, 78; and Steiner, *Design Guidelines*, 13.
[101] Steiner, *Design Guidelines*, 22; and Watson, *Sand Mountain*, 2.
[102] Lorain County Health Department, *Installers Guide*, 1; and Steiner, *Design Guidelines*, 6.
[103] Kadlec, *Treatment Wetlands*, 572-3.
[104] Hylton, *Municipal Reed Bed*, 36.
[105] Corbitt, *Wastewater Treatment*, 231; and Watson, *State of the Art*, 14.
[106] Solar Survival Architecture, *Black Water Treatment by SSA*, 1.
[107] Campbell, *Wetlands in the Sustainable Landscape*, 119.
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[126] Jensson, *Adapting Wetlands,* 2.

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ADDITIONAL RESOURCES

American Consulting Engineers Council 1015 15th St. NW Suite 802, Washington, D.C. 20005 Tel: (800) 548 2723 Email: acec@acec.org

Appalachian Clean Streams Initiative, Office of Surface Mining, 1951 Constitution Ave. NW Washington, D.C. 20240 Tel: (412) 937 2863 Email:majordomo@osmre.gov

Association of Plumbing and Mechanical Officials, 20001 Walnut Drive South, Walnut CA 91789 2852 Tel: (909) 595 8449 Web: http://www.iapmo.org

Centre for Alternative Technology, Machynlleth, Powys SY20 9AZ UK Tel: 01564 7024000 Fax: 01654 702782 Email: cat@gn.apc.org

Center for Environmental Research Information, 26 West Martin Luther King Dr., Cincinnati, OH 45268 Tel: 513-569-7562

Energy Efficiency and Renewable Energy Clearinghouse (EREC), PO Box 3048, Merrifield, VA 22116 Tel: (800) 363 3732

Ocean Arks International, One Locust Street, Falmouth, MA 02540 Tel: (508) 540 6801 Fax: (508) 540 6811

National Water Center – Recently published study: “Use of Reclaimed Water and Sludge in Food Crop Production”. PO Box 548, Eureka Springs AR 72632

Small Flows Clearinghouse, West VA University, Box 6064, Morgantown, WV 26506 Tel: (800) 624 8301

The Regional Waste Department, Valley Resource Center, Tennessee Valley Authority, 2B Old City Hall Building, Knoxville, TN 37902, Tel: 615-632.6433

Texas Water Resources Institute Texas A&M University 301 Scoates Hall, MS 2118 College Station, TX 77843 Tel: (409) 845 1851 Email: twri@twri.tamu.edu

Water Environment Federation, Email: webfeedback@wef.org

Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314 Tel: (703) 684 2400 Fax: (703) 684 2492