Rural Action
Working Together to Revitalize Appalachian Ohio

Sewage Treatment in Small Communities Literature Review

The complexity of the process seems challenging when a small community in Ohio progresses from private disposal of septic waste to municipal treatment of wastewater. Obtaining funding and permits for such infrastructure or improvements can be the biggest hurdles. Next, gaining consent and access from residents to the wastewater streams they generate must be done. The hiring of capable staff knowledgeable in wastewater treatment system operation and science, understanding the available wastewater treatment options and choosing the most feasible system for the public good are yet more challenges communities may face.

Largely, the main objective of small communities is to reduce the environmental and health risks associated with "straight pipes," private wastewater and septic storage, and disposal and transport of these wastes by replacing them with municipal treatment and discharge of clean effluent in an economically and environmentally sustainable and socially responsible manner. If the sewage generated by a home is treated at the home site it would be an example of onsite wastewater treatment. In some communities or applications decentralized or onsite wastewater treatment may be a viable alternative to centralized treatment, this is not examined here but more information can be found in the EPA's Onsite Wastewater Treatment Systems Manual (2002). Some of the factors with which to assess the sustainability of wastewater treatment systems are reviewed by Balkema et al. (2002) and also by Muga and Mihelcic (2008).

Federal agencies across the board such as the US Environmental Protection Agency (EPA), US Department of Agriculture (USDA), and the Federal Highway Administration (FHA) are strongly recommending and supporting Multisector Asset Management for communities large and small. Multisector management involves the allocation of resources across the community's economies. A recently published joint report of the EPA and FHA cites the benefits communities across the US and Canada are realizing through a comprehensive approach when it comes to the consideration, implementation and management of infrastructure improvements and assets such as municipal wastewater treatment systems and other core utilities and services. Read more about their multisector asset management approach here: http://www.fhwa.dot.gov/asset/if09022/. Some of the small Ohio communities, such as New Bremen, are already well ahead in a multisector management approach.

Fortunately for small communities in Ohio where funds are often limited, some governmental resources are available to help finance the implementation of wastewater treatment facilities and infrastructure. A good portion of this help stems from the Clean Water Act (CWA) of 1972, the amendments made to it in 1981 and 1987, and changes made to its implementation and standards by the Great Lakes Critical Programs Act of

1990. The EPA outlines this history (http://www.epa.gov/laws-regulations/history-clean-water-act). Nearly a third of all public program economic support for community wastewater treatment comes from the Clean Water State Revolving Fund (CWSRF http://www.epa.gov/cwsrf) where the federal EPA partners with state agencies in administering these funds. Another significant source of public funding for wastewater infrastructure is the Water and Environmental Program (WEP) of the USDA's Rural Utilities Service (RUS) (http://www.rd.usda.gov/about-rd/agencies/rural-utilities-service). In Appalachian Ohio, the Appalachian Regional Commission (ARC) also provides funding and other assistance for water and wastewater infrastructure, as outlined in detail in their report on Drinking Water and Wastewater Infrastructure: An Analysis of Capital Funding and Funding Gaps (http://www.arc.gov/research/researchreportdetails.asp?REPORT_ID=21). Information about additional resources for funding, training and technical assistance for small communities can also be found through the EPA's program for small and rural wastewater systems (http://www.epa.gov/small-and-rural-wastewater-systems).

Effective Sewage Treatment

Effective sewage treatment for small communities is based on the natural models provided by the scientific understanding of where organic pollutants are broken down and made innocuous in the first place, in wetlands and estuaries. The natural processes that occur in wetlands by microbes, algae and plants in are the same processes that occur in wastewater treatment, particularly in systems used in rural small communities (Crites and Tchobanoglous 1998, Gersberg et al. 1986).

Most organic pollutants that are the very products of life that move through terrestrial and aquatic habitats end up being broken down and recycled in wetlands. Sewage and pollutant wastes include metabolites, proteins, products of their decomposition and other nitrogen-rich toxins (in larger amounts) and nutrients (in smaller amounts), such as ammonia and ammonium (Kuai et al. 1998). These nitrogen-rich pollutants must be broken down through the microbial processes of nitrification and then denitrification to become the relatively inert gas nitrogen that makes up about 70% of our atmosphere. Wastewater treatment is modeled on these important processes, and other natural chemical absorptions, accumulations, reactions and transformations that occur in wetlands.

The primary function of sewage treatment systems is to remove nitrogen from the waste stream. Therefore, some understanding of the processes involved is fundamental in choosing the community's sewage treatment. Microbial nitrification reactions require oxygen, or aerobic, and end up in part transforming ammonia into nitrite in the first stage, and then into nitrate in the second stage. The need for oxygen, in these reactions in wetlands and in wastewater treatment is measured by biochemical oxygen demand (BOD or the measured use of oxygen by microbes also referred to as BOD_5 in wastewater treatment) and by chemical oxygen demand (COD or the oxygen requirement for all reactions occurring in a system) (Grady et al. 2011). The relationship of these relative measures is used as an indicator of the level of pollutants. These aerobic (requiring oxygen) reactions can only occur within certain parameters (e.g. it can't be too acidic) and without the presence of inhibitors. The nitrates produced by nitrification can be taken up by plants and algae to some degree, but to convert nitrates to nitrogen requires microbe denitrifiers. The denitrification reactions that follow nitrification require conditions that are anaerobic, or without oxygen, and these transform the nitrates into nitrogen. This may occur at a variety of scales in wastewater treatment, from small areas within individual autotrophic microbes (e.g. *Anabaena*), adjacent to vegetative litter, to lower stratified layers within lagoons or treatment wetlands, or in whole lagoons dominated by heterotrophic anaerobes (Hwang et al. 2005). Just as nitrification requires certain parameters, denitrification does as well (e.g. a carbon source or carbon-rich substrate). Many other organic and inorganic pollutants can be broken down by some of the same microbes responsible for nitrification and denitrification or bound to organic matter, while others may be removed more effectively by added substrates (e.g. phosphates bound by iron-rich compounds), depending on the type of wastewater treatment system used (Isaacs et al. 1995). Further details about nitrogen removal from municipal wastewater and the nitrogen cycle as it relates to treatment systems are provided in the EPA's Manual: Nitrogen Control (1993) and the removal of other pollutants such as phosphates from municipal wastewater in their Nutrient Control Design Manual (2010).

Of growing concern in the realms of sewage treatment, water quality and health are the impacts of pharmaceutically active compounds, antibiotics, and byproducts of personal care products that are not removed by many conventional sewage treatment systems. Tertiary sewage treatment by a combination of some of the sewage treatment systems discussed here, lagoon systems followed by constructed wetland systems, has been shown to be the most effective means to remove these hazards to human and environmental health (Conkle et al. 2008, Karthikeyan and Meyer 2006, Lishman et al. 2006).

A basic overview of wastewater treatment and discharge systems used can be found in the Primer for Municipal Wastewater Treatment Systems from the US EPA (http://www.epa.gov/sites/production/files/2015-09/documents/primer.pdf). Here we are concerned with the types of wastewater treatment systems in use in small communities in Ohio. The Ohio Environmental Protection agency (OEPA) classifies a wastewater treatment system as "Class A" if the system receives 25,000 gallons of wastewater a day or less. The OEPA's Class A Training Manual provides a detailed summary of the operational knowledge and permitting requirements of wastewater treatment plant operators (http://web.epa.state.oh.us/dsw/CAP/Class%20A%20Training%20Manual%20Complete.pdf).

Stemming from the outgrowth and implementation of the CWA are the permitting processes for the operation, approval, and installation of wastewater treatment plants, such as the National Pollutant Discharge Elimination System (NPDES). These NPDES permits applicable to Ohio are administered by the OEPA (http://www.epa.ohio.gov/dsw/permits/index.aspx). Permits for the NPDES for wastewater treatment can be individual and unique to the facility, or generalized, and most have a renewal cycle such as every five years. Additionally in the consideration of installing municipal wastewater treatment facilities is the Permit to Install (PTI) program which the OEPA also administers (http://www.epa.ohio.gov/dsw/pti/index.aspx). The design standards required for the installation of wastewater treatment operations equal to or less than 100,000 gpd in Ohio are outlined in the “Greenbook” document (http://www.epa.ohio.gov/Portals/35/documents/greenbook_2013.pdf). Some types of wastewater treatment systems are more prevalent in or suited for use in the small communities of Ohio. These systems reviewed here are such as the Lagoon subtypes of Aerated and Facultative Lagoons, as well as Packed-Bed Media Biological Reactors (Recirculating Media Filters) and Constructed Wetlands.

Lagoon Systems

The majority of the small communities we surveyed across Ohio have lagoon systems to treat their wastewater. Many of these systems were installed back in the 1970’s and 1980’s and are still functioning well today, notably with upgrades to improve performance and reduce accumulation of solids such as aeration. Lagoons are considered to be among the oldest types of wastewater treatment (Gerardi 2015). They are generally in ground earthen or clay bound basins, but may also be lined. Both the number of lagoons in succession and the depths of lagoons may vary depending in part on the type of system, the volume of influent and whether aerobic or anaerobic. Primary and secondary wastewater treatments are often lagoon systems, and sometimes of different lagoon classes, while tertiary treatment may be better suited to another treatment class, such as a constructed wetland (Gschlößl et al. 1998). Lagoon systems in small communities are predominantly supplied by gravity-fed sanitary sewers, but many do have lift or pump stations in the sewage collection system or at the lagoon itself. They consist of a number of cells or lagoons in sequence, with cells earlier in the wastewater stream for treatment and cells later in the sequence for storage and sludge stabilization. Cells are more aerobic, anaerobic, or mixed depending on their function. A typical lagoon system for a small community may have three cells, two for treatment and one for storage and stabilization until discharge or sludge removal (https://www.michigan.gov/documents/deq/wrd-ot-lagoon-manual_426356_7.pdf). Lagoon systems have the advantage of being relatively inexpensive to construct and operate and are recommended by international agencies to remote communities worldwide as according to reports of the United Nations Environment Programme’s *Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia*. Though low cost in terms of installation, technology and maintenance they do require sizable land areas, each million gallons per day of wastewater influent requires about 30 acres for treatment of 50 lbs. of BOD per day in a lagoon system (Gerardi 2015).

Facultative Lagoons

Simple facultative or stabilization lagoons have been in operation for close to 100 years (Gerardi 2015). Historically they have been the most common form of sewage treatment in rural and small communities of the world. This is in part because of relative simplicity in construction and operation but also because of the low cost of maintenance (Gschlößl et al. 1998). Facultative lagoons are shallow and stratified into three horizontal zones. They have aerobic and anaerobic zones in the same lagoon, with the aerobic zone near the surface, a facultative or zone of exchange in the middle layer, and an anaerobic zone on the bottom where sludge can stabilize and collect. This approach is generally less expensive to design, install and maintain than other lagoon types, as aeration is often by wind movement of the water surface, and the photosynthesis of microalgae rather than by mechanical means. Oxgenation by the photosynthesis of algae creates a diurnal fluctuation of BOD, with greater BOD at night when algae are solely respiring. Algae and aerobic microbes are present in the aerobic zone nearer the water's surface; these algae can remove nitrates and phosphates from the wastewater stream effectively. Supplemental aeration can be provided by mechanical aeration or diffusers as in a partial mix aerated lagoon, but they do not rely solely on these means so equipment can be smaller and require less power to operate. Sometimes mechanical aeration is added as a retrofit of an existing facultative lagoon to improve biodegradation of solids, to reduce odor as of seasonal turnover, and to respond to higher BOD. Removal of nutrients such as nitrates and phosphates from facultative lagoons is sometimes facilitated by duckweeds or other plants as well, and in some situations the duckweed itself can become a harvestable resource such as for biomass for feedstocks (Alaerts et al. 1996). Duckweed can also be used to reduce algae growth by competing for nutrient pollutants and reducing light penetration while also improving performance of the lagoon in removing nitrates and phosphates (Al-Nozaily et al. 2000). Microalgae in wastewater treatment lagoons also have the potential to be harvested as a source of biomass and carbohydrates for biofuels and other resources as well (Christenson and Simms 2011), however some algae and especially cyanobacteria may require additional treatment if they are not removed from the system before discharge as by a constructed wetland. Algae blooms in facultative and other lagoon types can cause a secondary pollution with discharge of the effluent into streams, mostly by the decay and increased BOD as the algae dies off and bacterial degradation increases (Racault 1993). Having secondary or tertiary treatment of this effluent via constructed wetlands can be an effective way of mitigating the impacts of algal blooms to streams receiving effluent (Steinman et al. 2003, Vymazal). Facultative lagoons, however, provide effective removal of pathogens and produce effluent within acceptable standards for secondary treatment in additional settling, polishing, other cells and treatment types (Gerardi 2015).

Aerated Lagoons

In aerated lagoons, mechanical means are used to mix (completely or partially) or diffuse air or oxygen into the entire lagoon (Rich 2003). Extended aeration of wastewater and sludge stabilization may be among the most effective means for the degradation and removal of pharmaceuticals, harmful metabolites and substances from personal care products from wastewater (Lishman et al. 2006). These lagoons require more energy consumption than other lagoon types, and back-up power generation is required, but they usually require less time for primary sewage treatment, and sludge stabilization and accumulation may be faster as well reducing the land area required somewhat. Although aerobic microbes and reactions, and nitrification are intensified, secondary treatment for denitrification or nitrate take up by algae or plants will also have to occur outside the aerated lagoons, however aerated lagoon systems are often designed to discourage the development of algae (Rich 2003). In aerated lagoon systems nitrification inhibitors are used to reduce nitrate production and BOD, but this will likely increase the volatilization of ammonia and require additional equipment or substrates to handle the ammonia (Barth 1981). Aerated lagoons produce relatively high levels of suspended solids in the treatment system which affects the quality of effluent undesirably. Because of this, secondary or tertiary treatment such as with intermittent sand filtering or constructed wetlands is often part of aerated lagoon effluent treatment (Nabizadeh et al. 2015). Macrophytes can compete with algae for nitrogen uptake and can take up ammonia as well as nitrate depending on the species present. In an aerated lagoon system all settleable solids are kept in suspension by aeration or mixing, and they and their BOD are removed by flocculation into larger solids while dissolved mater and removed by additional filtration or settling in other cells. Algae can increase the generation of solids, but organic solids such as these provide substrate for nutrients and toxins to be bound to and removed from the wastewater stream. They also influence the diurnal cycle of BOD with the increased demand for oxygen at night with respiration, the rigorous mixing in aerated lagoons reduces this demand. While physical and chemical means to remove excess nutrients and algae are existing, algae-based treatment can provide a less expensive and safer alternative for removing nitrogen and phosphorus, and the cost of treatment has the potential to further offset by the production of strains for biofuel or methane production from dewatered sludge and algae (Park et al. 2011, Bhattacharjee and Siemann 2015). For an US EPA Wastewater Technology Fact Sheet see Aerated, Partial Mix Lagoons.

Packed Bed Media Biological Reactors

Several names for this category of wastewater treatment exist that are the same in principal, such as packed bed filters and recirculating media filters. This is in part based on the type of media it contains. Smaller scale versions of this treatment were originally designed to be an improvement on sand filters and septic leach fields for onsite wastewater treatment for homes, commercial complexes, and small communities with decentralized wastewater treatment (see the US EPA's Onsite Wastewater Treatment Systems Manual 2002), but this method is also applied as primary or secondary treatment in subdivisions and municipalities. In these systems treatment is compartmentalized, and different types of media or compartments may house different microbial communities to be more aerobic or anaerobic. The media through which the stream recirculates provides ideal conditions for nitrification and is one of the strengths of this method, dentitrification in this system type is more difficult to obtain without it being handled separately in an anaerobic filter or subsurface flow wetland (Grady et al 2011). These systems may be used in conjunction with other types of treatment. As in a lagoon, the shallow system is generally lined. A lift station collects the wastewater or effluent from other treatment which is trickled down from above (often subsurface) through a layer of gravel, then through filtration media, substrates or membranes chosen for specific microbial communities and pollutant removal, and by availability (Buchanan 2011). Media types include sand, clay pellet, plastic and textile based substrates. Recirculation tanks then collect the wastewater stream and it is recirculated through the system at least several times, and the system is designed to hold several times the volume of the influent. After treatment the effluent may be discharged from dose tanks through subsurface drip irrigation in land based application or released for polishing in constructed wetlands. Bacterial levels, such as fecal coliforms are lessened in packed bed media filters, but not to the levels required for surface water discharge where additional treatment or disinfection would be required (Hantzsch 2007).

Constructed Wetlands

Constructed wetlands (CWS) and other treatment systems containing plants have the advantage of less reliance on anaerobic processes to consume nitrates, yet they also provide excellent habitat for anaerobic denitrifiers and carbon substrate through litter (Winans et al. 2012, Vymazal 2010, Hammer 1990). They have become important to small and remote communities worldwide for being sustainable alternatives to far more expensive, energy-intensive and excessive operational requirements of conventional treatment of domestic wastewater, however the successful and sustainable application of CWS requires attention to their design and, like lagoon systems, they are land intensive (Wu et al 2015, Vymazal 2010). They are modeled after natural wetland systems but also rely on liners and impervious barriers to contain the treatment (Hammer 1990). Their most widespread uses are for secondary and tertiary treatment of municipal wastewater and for applications such as treatment for specific pollutants such as those coming from mining operations and acidic mine drainage (O'Sullivan et al. 2004, Weider 1989), landfill leachate (Bulc 2006), agriculture (Grismer and Shepard 2011, Boyd et al. 2005), and other impacts to surface and groundwater. They can provide ideal conditions for nitrification and denitrification through their generally greater diversity of organisms, habitats, and their incorporation of macrophytes (Winans et al. 2012; Vymazal 2008; Gersberg et al. 1986). Constructed wetlands excel at mitigating the impacts of algae and detritus on BOD and nutrient excess in receiving water bodies of effluent discharged from lagoons and other wastewater treatment systems, especially for small and rural communities (Cameron et al. 2003, Steinmann et al. 2003, Gschlößl et al. 1998). The Lagoon systems that are followed with secondary or tertiary treatment in constructed wetlands are much more effective in removing pharmaceutically active compounds (PhACs) and antibiotics from wastewater than the removal reported for conventional wastewater plants (Conkle et al. 2008, Karthikeyan and Meyer 2006). Further information regarding constructed wetlands including treatment, design, guiding principles for water quality and habitat, as well as case studies can be obtained from the US EPA: http://www.epa.gov/wetlands/constructed-wetlands. The US EPA's detailed Design Manual: Constructed Wetlands Treatment of Municipal Wastewater and A Handbook of Constructed Wetlands can also be accessed through this page. Another design resource for CWS treatment systems is D.A. Hammer's (1990) *Constructed Wetlands for Wastewater Treatment*.

Three main categories of constructed wetlands are often described in the literature, free water surface constructed wetlands (FWS CW), horizontal flow subsurface constructed wetlands (HFS CW) and vertical flow subsurface constructed wetlands (VFS CW) as described in the review by Vymazal (2008). Free water surface wetlands can be further classified by the type of vegetation the FWS CW uses for treatment such as free floating (such as water hyacinth or duckweed), floating leaved, submerged, and emergent vegetation (such as bulrushes). Subsurface HF CWs have been implemented in Ohio, such as the one at the Fernald Preserve about 18 miles northwest of Cincinnati (Powell et al. 2009). In addition, a PTI has been developed by the OEPA for the implementation of HFS CWs that treat 10,000 gpd or less with land application of effluent in Ohio (OEPA 2007), Small Subsurface Flow Constructed Wetlands with Soil Dispersal System.

Living Machines, are wastewater treatment systems conceived by John Todd (Todd and Josephson 1996), and are “task-oriented mesocosms” that have design principles based on twelve key concepts developed in the paper “The design of living technologies for wastewater treatment.” They are essentially an adaptation to FWS CW systems that can be applied in all climates, even those extremely arid or cold due to their inclusion of cells or tanks in temperature controlled greenhouses. For a review of their application in case studies see Todd et al. (2003). They consist of a series of tanks that become increasingly biologically complex and diverse along the wastewater stream, this series is based on natural processes and cycles in mesocosms (medium-sized contained environments). They can be very effective and can even become attractions for tourists and visitors. Successful examples can be found in various countries, one notable one is in Vermont at the Welcome Area along I-89 outside Sharon which can be read about in the FHA’s *Public Roads* (Farrell et al. 2000) and was even highlighted in *The New York Times* (Zezima 2005). This living machine treats all of the wastewater year round at a volume that is comparable to many small communities with more than 500,000 visitors each year. The Old Trail School near Bath, Ohio in the Cuyahoga Valley National Park has implemented a Living Machine wastewater treatment system which apparently meets the requirements for surface discharge into a tributary of the Cuyahoga River, the very river along which events unfolded that helped to prompt passage of the CWA in 1972. This Living Machine is used to teach the school’s about 500 students about the water cycle (http://www.oldtrail.org/).

References and Additional Resources:

Alaerts, G. J., Rahman Mahbubar, and P. Kelderman. 1996. "Performance analysis of a full-scale duckweed-covered sewage lagoon." *Water Research* 30.4: 843-852.

Al-Nozaily, F, G Alaerts, S Veenstra, 2000. Performance of duckweed-covered sewage lagoons—II. Nitrogen and phosphorus balance and plant productivity, Water Research, Volume 34: 2734-2741, ISSN 0043-1354, http://dx.doi.org/10.1016/S0043-1354(00)00004-X.

Balkema, A.J., Preisig, H.A., Otterpohl, R., Lambert, F.J.D. 2002. “Indicators for the sustainability assessment of wastewater treatment systems” Urban Water 4: 153-161.

Bhattacharjee, M and Siemann, E. 2015. Low algal diversity systems are a promising method for biodiesel production in wastewater fed open reactors. Algae, March 2015 DOI: 10.4490/algae.2015.30.1.067

Boyd, N., R. Gordon, L. Cochrane, R. Jamieson., R. DeHaan, V. Glass. 2005. Constructed Wetlands for the Treatment of Agricultural Wastewater. Atlantic Committee on Land and Engineering, Canada.

Buchanan, J.R. 2011. Recirculating packed-bed media filters. University of Tennessee, Dept. of Biosystems Engineering and Soil Science. Available at: http://www.ces.ncsu.edu/plymouth/septic/OpeningBuchanan.pdf

Bulc, T.G. 2006. Long term performance of a constructed wetland for landfill leachate treatment. Ecological Engineering 26: 365-374.

Cameron, K., C. Madramootoo, A. Crolla, C. Kinsley. 2003. Pollutant removal from municipal sewage lagoon effluents with a free-surface wetland, Water Research, Volume 37, Issue 12 Pages 2803-2812, ISSN 0043-1354, http://dx.doi.org/10.1016/S0043-1354(03)00135-0.

Christenson, Logan, and Ronald Sims. 2011. "Production and harvesting of microalgae for wastewater treatment, biofuels, and bioproducts."*Biotechnology advances* 29.6: 686-702.

Conkle, Jeremy L., John R. White, and Chris D. Metcalfe. 2008. "Reduction of pharmaceutically active compounds by a lagoon wetland wastewater treatment system in Southeast Louisiana." *Chemosphere* 73.11: 1741-1748.

Crites, R., Tchobanoglous, G., 1998. *Small and Decentralized Wastewater Management Systems*. McGraw-Hill, Boston.

Farrell, M., L. Van der Hoven, T Olsen. 2000. Vermont Rest Area Uses Green Wastewater Treatment System. *Public Roads*. 63(6). https://www.fhwa.dot.gov/publications/publicroads/00mayjun/vermont.cfm

Gerardi, Michael H. 2015. *The Biology and Troubleshooting of Facultative Lagoons.* John Wiley & Sons.

Gersberg, R. M., et al. 1986. "Role of aquatic plants in wastewater treatment by artificial wetlands." Water research 20.3: 363-368.

Ghermandi, A., D. Bixio, C. Thoeye, 2007. The role of free water surface constructed wetlands as polishing step in municipal wastewater reclamation and reuse, Science of The Total Environment, Volume 380, Issues 1–3, 15, Pages 247-258, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2006.12.038. (http://www.sciencedirect.com/science/article/pii/S0048969706009958) Keywords: Wastewater reclamation; Water reuse; Tertiary treatment; Free water surface constructed wetlands

Grady Jr, CP Leslie, et al. 2011. *Biological wastewater treatment*. CRC Press.

Grismer, M.E., H.L. Shepard. 2011. Plants in constructed wetlands help to treat agricultural processing wastewater. *California Agriculture* 65(2): 73-79. doi: 10.3733/ca. v065n02p73.

Gschlößl, T, C Steinmann, P Schleypen, A Melzer. 1998. Constructed wetlands for effluent polishing of lagoons, *Water Research*, Volume 32, Issue 9, Pages 2639-2645, ISSN 0043-1354, http://dx.doi.org/10.1016/S0043-1354(98)00047-5. (http://www.sciencedirect.com/science/article/pii/S0043135498000475)Keywords: algae; constructed wetlands; effluent polishing; filtration; lagoons; pollution control; post-treatment; reed bed

Hammer, D.A. 1990. *Constructed Wetlands for Wastewater Treatment.* Lewis Pubs.

Hammer, M. J., and M. J. Hammer, Jr 2004. *Water and Wastewater Technology*. 5th ed. Upper Saddle River, NJ: Prentice-Hall, Inc.

Hantzch, G. 2007. Recirculating media filter technology assessment and design guidance. Iowa Department of Natural Resources.

Horan, Nigel J. 1989.*Biological wastewater treatment systems: theory and operation*. John Wiley & Sons Ltd.

Hwang, Y., Kim, C., Choo, I. 2005 “Simultaneous Nitrification/Denitrification in a Single Reactor using Ciliated Columns Packed with Granular Sulfur.” Water Quality Research Journal of Canada.

Isaacs, SH, and Henze, M. 1995. "Controlled carbon source addition to an alternating nitrification-denitrification wastewater treatment process including biological P removal." Water Research 29.1: 77-89.

Karthikeyan, K.G., M. T. Meyer, 2006. Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA, Science of The Total Environment, Volume 361, Issues 1–3, 15 May 2006, Pages 196-207, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2005.06.030. (http://www.sciencedirect.com/science/article/pii/S0048969705004432) Keywords: Antibiotics; Wastewater; Influent; Effluent; Tetracyclines; Sulfonamides; Fluoroquinolones; Macrolides; Trimethoprim

Kuai, Linping, and Willy Verstraete.1998. "Ammonium removal by the oxygen-limited autotrophic nitrification-denitrification system." Applied and environmental microbiology 64.11: 4500-4506.

Lishman, L., S.A. Smyth, K. Sarafin, S. Kleywegt, J. Toito, T. Peart., B. Lee., M. Servos, M. Beland, P. Seto. 2006. Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada. *Science of the Total Environment* 367 (544-558).

Muga, HE, Mihelcic, JR. 2008 “Sustainability of wastewater treatment technologies” Journal of Environmental Management 88: 437-447.

Nabizadeh, R., K. Naddafi, M. Khazaei, R.F. Fard, H. Izanloo, Z. Yavari. 2015. Upgrading the effluent quality of an aerated lagoon with horizontal roughing filtration. Environmental Protection Engineering 41(3): 121-136.

Ohio Environmental Protection Agency (OEPA). 2007. Small Subsurface Flow Constructed Wetlands with Soil Dispersal System. OAC 3745-42. Ohio EPA, Division of Surface Water.

Pochana, K., Keller J. 1999. "Study of factors affecting simultaneous nitrification and denitrification (SND)." Water Science and Technology 39: 61-68.

Powell, J., J. Homer, C. Glassmeyer, N. Sauer. 2009. Alternative Wastewater Treatment: On-Site Biotreatment Wetlands at the Fernald Preserve Visitors Center. Waste Management Symposium 2009. Phoenix, AZ.

Racault, Y. 1993. Pond malfunction: case study of three plants in the south-west of France. Water Science Technology 28: 183-192.

Rich L.G. 2003. Aerated Lagoon Technology, Clemson University, Clemson, SC, USA. https://www.clemson.edu/ces/departments/eees/documents/AERATEDLAGOONTECHNOLOGY.pdf

Steinmann, C. R., Weinhart, S., & Melzer, A. 2003. A combined system of lagoon and constructed wetland for an effective wastewater treatment. *Water Research*, *37*(9), 2035-2042

Todd, J., E.J.G. Brown, E. Wells. 2003. Ecological design applied. *Ecological Engineering* 20: 421-440.

Todd, J., Josephson, B. 1996. The design of living technologies for wastewater treatment. Ecological Engineering. 6: 109-136.

Vymazal, J. 2008. Constructed Wetlands for Wastewater Treatment: A Review. Sengupta, M. and Dalwani, R. (Eds.). Proceedings of Taal 2007: The 12th World Lake Conference: 965-980

Vymazal, J. 2010. Constructed wetlands for wastewater treatment. *Water* 2: 530-549. doi:10.3390/w2030530. http://www.mdpi.com/2073-4441/2/3/530/pdf

Weider, R.K. 1989. A survey of constructed wetlands for acid coal mine drainage treatment in the eastern United States. *Wetlands* 9: 299-315.

Winans, K., S. Speas-Frost, M. Jerauld, M. Clark, G. Toor. 2012 Small-scale natural wastewater treatment systems: Principles and regulatory framework. SL365.Gainesville: University of Florida Institute of Food and Agricultural Sciences.

Wu, H., J. Zhang, H.H. Ngo, W. Guo, Z. Hu, S. Liang, J. Fan. 2015. A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. *Bioresource Technology* 175: 594-601.

Zezima, K. 2005. “Vermont Blends ‘Green’ Flush Toilets and a Greenhouse” *The New York Times* August 31, 2005.

Additional links

http://www.epa.gov/small-and-rural-wastewater-systems/tools-training-and-technical-assistance-small-and-rural

http://www.epa.gov/small-and-rural-wastewater-systems/asset-management-water-and-wastewater-treatment-systems-local

http://www.epa.gov/small-and-rural-wastewater-systems http://www.arc.gov/research/researchreportdetails.asp?REPORT_ID=21

http://www.epa.gov/cwsrf

http://www.epa.gov/small-and-rural-wastewater-systems/funding-sources-small-and-rural-wastewater-systems