Scholarly Horizons: University of Minnesota, Morris Undergraduate Journal

Volume 1 | Issue 2 Article 12

August 2014

Pharmaceuticals in Wastewater Treatment Plant Effluent Waters

Nicole Deziel
University of Minnesota, Morris

Pharmaceuticals in Wastewater Treatment Plant Effluent Waters

Nicole Deziel

Abstract

Pharmaceuticals are being used at an increasing rate, and end up in wastewater through excretion and disposal. They also end up in the effluent water of wastewater treatment plants because they are not specifically designed for pharmaceutical removal. Several studies suggest diverse negative effects on aquatic life that are exposed to these trace amounts of pharmaceuticals in their habitats. There is also a concern for human exposure in areas that utilize wastewater reuse, although there is limited study in this area. Despite these concerns, there are very few policies that address the issue of pharmaceutical pollution. The evaluation of the treatment methods of activated sludge, advanced membrane treatment, and constructed wetlands help to determine which of these options should be improved or replaced by different strategies. Additionally, there are other ways of solving this issue, such as developing more environmentally-friendly drugs and different ways of treating health problems.

Pharmaceuticals have been detected in effluent waters of wastewater treatment plants worldwide (Daughton 2004). This is because of their increased use (CDC 2010) as well as them not being targeted for removal during wastewater treatment. This issue should be of concern because these trace amounts have the potential to cause potentially harmful changes in aquatic life and possibly humans (EPA 2010). Current wastewater treatment has been researched to determine how well treatment plants in operation removal pharmaceutical compounds. Through this research, conclusions can be drawn about whether to utilize current wastewater treatment plants or instead find other practical solutions.

Pharmaceuticals are commonplace today in both prescription and over-the-counter (OTC) varieties. The FDA has approved over 100,000 drug compounds which make up over 10,000 drug products. The latter number is actually less because of multiple brand names of drug products, but this amount is still striking. Additionally, there are drugs and drug compounds in use that have not been counted because they have not been approved by the FDA which should be taken into consideration when estimating the amount of pharmaceuticals in the waste stream (National Center for Biotechnology Information 2012). Based on a 2007 survey of U.S. residents, it can be estimated that almost half of the population has used at least one prescription drug in the past month, which breaks down to one out of every five children and 9 out of 10 adults (Qiuping et al 2010). This is a high rate, especially considering that only prescription drugs were included in the survey. OTC drugs are used at a much higher rate, with another survey estimating that 79 percent of Americans have used at least one in the past year (Consumer Healthcare Products Association 2010).

In order for pharmaceuticals to work properly, they must be able to remain stable in the harsh conditions of the human body. This results in the inability of the compounds in many drugs to break down after they are excreted or otherwise disposed of. This is why pharmaceuticals are commonly found in wastewater both before and after going through treatment plants (Keil 2008). Pharmaceuticals may enter the water through excretion, disposal down drains, as well as through hospital and industry effluent. These routes encompass a range from the time they are being produced until their use or disposal. There are also many classes that pharmaceuticals can be

DOI: 10.61366/2576-2176.1017

grouped into, such as antibiotics, antidepressants, anti-inflammatory, antiepileptic, as well as various hormones (EPA 2010).

The concentrations of these pharmaceuticals are measured in micrograms or nanograms per liter, depending on equipment sensitivity. One microgram per liter is equivalent to one part per million, and one nanogram per liter is equivalent to one part per trillion. These seem too small to be significant, but even in these trace amounts, suspicions have arisen that they are changing the appearance and behavior of aquatic-dwelling organisms (Ternes 2004). Aquatic life has a higher risk than humans of being affected because of the direct and constant exposure that they have to the contaminated water; their habitat may consist of effluent wastewater treatment plant water. Several different aquatic organisms have been studied, and it is important to realize that organisms may have different reactions to pharmaceutical compounds based on how their systems process them (EPA 2010). Some compounds are hormones or mimic the properties of hormones, which are capable of feminizing or masculinizing fish (Ternes 2004). In some cases, it has been observed that male fish have produced a protein that is typically only found in female fish because it is used for egg production (Gilbert 2012). The impact of neuro-active pharmaceuticals has also been an area of study. Some of these studies suggest that this group of pharmaceuticals may alter the reproductive behavior of fathead minnows which could potentially decrease their populations. Additionally, the accumulation of neuro-active pharmaceutical metabolites in brain tissues has been observed in white suckers as well as brook trout, with the suggestion of negative impacts (EPA 2010). Finally, another drug, the anti-inflammatory, diclofenac, has shown to have damaged the gills and lungs of fish (Gilbert 2012). The “cocktail” effect is an important concept when discussing the possible effects of these pharmaceuticals. This phrase refers to the mixture of many different pharmaceuticals that are present in the effluent water. These trace amounts of several different drugs make it difficult to predict exactly which drugs are affecting each other, and how this might contribute to the organisms that are exposed to this “cocktail” of drugs. The “cocktail” effect is a large reason why researching the impact pharmaceuticals have on aquatic life is very difficult (Ternes 2004).

Human exposure to these trace levels of pharmaceuticals differs because of the lack of constant and long-term exposure to the contaminated water (EPA 2010). However, in some areas, water scarcity has resulted in the practice of wastewater reuse, and the drinking water has been detected to have parts per million or trillion levels of pharmaceuticals, including iburofen, carbamazepine, and sulfamethoxazole (Luo et al 2014). Wastewater reuse involves treating wastewater so that it can be consumed again instead of using the often scarce resource of groundwater. (Bixio et al 2006). However, these wastewater treatment processes are often not designed to remove trace levels of pharmaceuticals (EPA 2010). One major study was executed to see if humans could potentially be affected by trace pharmaceutical levels. In this study, human embryos were exposed to a mix of 13 different pharmaceuticals meant to mimic the levels that would be found in the treated effluent wastewater (Potami et al 2006). This is an example of an attempt to account for the “cocktail” effect of the variety of pharmaceuticals that would be consumed in a scenario such as wastewater reuse. Physical changes to the shapes and appearance of the cells were observed in this study, indicating that these low levels carry potential to effect humans (Potami et al 2006). It is important to realize, however, that the results of this study are difficult to compare to interaction with reused wastewater in fully-developed humans.

Despite limited research, there have been some pushes to recognize pharmaceutical contaminants in water sources. The Safe Drinking Water Act (SDWA) has done the most to address this issue in the United States, although there are currently no formal US policies that deal with pharmaceuticals as water contaminants. The SDWA contains the Contaminant Candidate List (CCL), in which contaminants are periodically nominated for through a lengthy process. Being on this list does not guarantee regulation, but under the SDWA, the EPA is required to decide if at least five contaminants are to be regulated or not. The most recent list, the CCL 3, contains several contaminants that are found in pharmaceuticals. The contaminants 17alpha-estradiol, Ethinyl Estradiol, estrone, estriol, Estradiol, equilin, and equilenin are all estrogenic hormones which are used in pharmaceuticals. This list also includes the antibiotic Erythromycin (EPA 2012b). Along with the CCL, the SDWA has proposed for the EPA to do more research regarding the environmental effects of pharmaceuticals in water bodies (Tiemann 2010).

Apart from the SDWA, the Proper Disposal of Prescription Drugs as well as a proposal by the Resource Conservation and Recovery Act (RCRA) somewhat address pharmaceuticals in wastewater. The Proper Disposal of Prescription Drugs deals with the consumer side of pharmaceuticals. It is a government document that was put forth in 2007 which clearly explained to consumers how to dispose of unwanted prescription drugs. It emphasized that flushing them down drains should not be done unless specifically dictated by the drug packaging. Although this government action was originally proposed for drug abuse prevention, if consumers follow the proposal, it could also apply to pharmaceutical presence in wastewater (Office of National Drug Control Policy 2007). The RCRA proposal in 2008 was to add hazardous pharmaceutical waste to the Universal Waste Program (EPA 2013b). This would have placed hazardous pharmaceutical waste in a category that governs the regulation of other widely generated wastes such as batteries, pesticides, and mercury-containing equipment (EPA 2012a). The original proposal did not get public support, so it was instead replaced with new standards for hazardous pharmaceutical waste from these facilities. (EPA 2013b). This could potentially prevent the contribution of especially potentially harmful pharmaceuticals into the wastewater.

Europe has somewhat addressed the issue of pharmaceutical regulation because of environmental concerns, but they also do not have complete policies. The EU Water Framework Directive is the main force for addressing water issues in Europe (European Commission 2014). Towards the end of 2012, the Water Framework Directive proposed the addition of 15 new contaminants to be placed on their list of priority substances, which included three pharmaceuticals. Two of these pharmaceuticals to be included were 17 alpha-ethinylestradiol (EE2), 17 beta-estradiol (E2), which are compounds that are used in contraceptive medications. The anti-inflammatory drug, diclofenac, was the third pharmaceutical included on the list. This proposed addition would have required that those pharmaceuticals be phased out within 20 years (Blöch). However, this proposal was never put into effect and was instead voted down by European Parliament. It was rejected because of the combination of projected high costs for implementation as well as uncertainty of whether these pharmaceuticals are actually doing harm. The voting members were likely swayed by the lobbying of both the water and pharmaceutical industries (Gilbert 2012). In general, European environmental law operates on the Precautionary Principle, which essentially means that they carefully weigh all of the consequences before introducing substances into the environment. Pharmaceuticals are an exception to this because they are necessary for the health of many of their citizens. However, the mindset of the Precautionary Principle could lead Europe to become a leader of pharmaceutical change in regards to which compounds go into drugs as well as considering holistic options of treating health problems (Keil 2008).

One strategy for finding a solution to pharmaceuticals in effluent waters of wastewater treatment plants is through exploration of already-operating wastewater treatment plants. By evaluating how well certain wastewater treatment plants already remove pharmaceuticals, solutions for their improvement or other ways to navigate this issue can be more effectively devised. This is because time and money could potentially be saved by considering the wastewater treatment options which are already in operation instead of trying to think of completely new solutions. These diverse wastewater treatment methods include activated sludge, advanced membrane treatment, and constructed wetlands.

Activated sludge is a common method for wastewater treatment; this is a biological treatment method in which microorganisms help degrade the organic compounds in the wastewater (Ternes 2004). Although it is fairly cheap to maintain this system, the major fault with using activated sludge is disposing of the waste it creates. The end product of this treatment method is a thick sludge that harbors the contaminants which have been removed from the wastewater (Deegan 2011). There is controversy as to how to dispose of this potentially dangerous product. Nutrients such as phosphorus are found in this sludge, so one solution that has been utilized is spreading it onto agricultural fields as a fertilizer. However, if the sludge is not treated for harmful contaminants such as heavy metals, health problems may result for people that come into contact with that land, or if it used to grow food for consumption. Incineration is another option, but then the issue comes about of how to prevent many of the contaminants from entering the atmosphere (George pp.151-168).

Another wastewater treatment method is advanced membrane treatment, which has been recently appearing in areas such as Europe and the Middle East that are utilizing wastewater reuse as a result of water scarcity (Bixio et al 2006). This method is an additional treatment step to wastewater treatment which uses membranes to filter the water (Luo et al 2014). Two types of this membrane treatment are nanofiltration and reverse osmosis. Both of these processes are carried out through pressure changes and have the capacity to prevent certain contaminants from crossing over at the molecular level. However, there are some small differences between these two membrane treatment methods. One difference is that nanofiltration has pores in the membrane, whereas reverse osmosis consists of a semi-permeable membrane. Reverse osmosis uses hydraulic pressure which forces water from the side containing dissolved contaminants over to the dilution side instead of pores. In short, water is allowed to pass through the membrane, but not the solutes (EPA 2013a). One difficulty with implementing advanced membrane treatment is that is potentially costly to add another step to wastewater treatment when it is not absolutely vital. If a wastewater treatment plant is working perfectly fine, it may be difficult to convince leaders to see any value in investing in this additional step. The lack of research in the area of pharmaceutical contaminants in water, especially in regards to human effects may hinder social support because it may be difficult to see the worth of this treatment. Another difficulty of using membrane filtration systems is the brine that is produced with their use, which contains pharmaceutical and other contaminant residues that have been filtered out. Even though only a small amount is diluted into the effluent water, it is still a source of pollution. Knowing that there is evidence for trace amounts of pharmaceuticals causing harm, this impact should be considered, because it would be best to remove as many of these pharmaceutical contaminants as possible (Radjenovic et al 2008).

Constructed wetlands are a form of secondary wastewater treatment built with substrates and vegetation that imitate the way natural wetlands filter out impurities in water. There are many different designs that can be built along with various vegetation and substrate options.

DOI: 10.61366/2576-2176.1017

However, there are some downfalls to this wastewater treatment method. Since a constructed wetland contains aspects found in a natural wetland, several species may be attracted, including those such as mosquitoes, which are seen as pests which may also carry disease. (Natural Resources Conservation Service) As it is a step in treating wastewater, pathogens are likely to be present and could infect the vegetation, (Li et al 2014) but there is usually a greater concern of humans contracting infections. The constructed wetland would need to be in an area a good distance away from human habitation as well as have a large plot of land. The substrate and vegetation also need to be carefully selected for this wastewater treatment method to work effectively. In addition to this, vegetation is not as productive during cold winter months, so if a constructed wetland is built where cold weather occurs, it would not possess the same efficiency all year round (Natural Resources Conservation Service).

Activated sludge treatment has the ability to break down certain pharmaceuticals to some degree. In general, there is a time range in which particular drugs degrade through activated sludge treatment. In 2-5 days, one antibiotic, sulfamethoxazole degrades to some degree, along with ibuprofen and acetylsalicylic acid, which is the breakdown product of Aspirin. However, some drugs generally need from 5-15 days to significantly degrade. These drugs include the anti-inflammatory diclofenac and the antibiotic roxithromycin. Although these particular drugs experience degradation after some period of time, some are not generally shown to degrade even after a period of over 20 days. These include the pharmaceuticals carbamazepine, an anti-epileptic, as well as diazepam, a psychoactive drug (Ternes 2004). The previous numbers are approximate, but one study in the United Kingdom looked at pharmaceutical removal efficiencies rates of a currently operating activated sludge wastewater treatment plant. The results indicated that removal rates of anti-inflammatory and analgesics were high. In particular, Aspirin and salicyclic acid were almost completely removed at a rate of 98% and ibuprofen also had a high removal efficiency. Another noteworthy drug is the antiepileptic, gabapentin, which had an average removal efficiency of 84%. On the contrary of these high removal rates, one anti-inflammatory, diclofenac, increased in concentration. This phenomenon is not unheard of and has been observed elsewhere with the pharmaceuticals erythromycin, an antibiotic, and carbamazepine, an anti-epileptic (Kasprzk-Hordern 2009). One reason this may occur is related to the breakdown products of the drugs as they pass through the human body. When drugs begin to break down in the human body, they may produce transformation products called metabolites. When biological treatment occurs, these breakdown products have the capacity to transform back into the original compounds, which are called the parent compounds. The presence of more parent compounds could yield test results of higher concentrations of that particular drug (Ternes 2004).

It would be economically viable to extend the sludge age of wastewater treatment plants that are already in operation. This could potentially result in the removal of more pharmaceuticals. However, a negative to this solution would be the aforementioned drugs that either do not decrease or instead increase in concentrations following activated sludge treatment. Many pharmaceuticals have not been extensively studied in regards to finding the most effective ways of removing them from our water (Kasprzk-Hordern 2009). Therefore, it would be the most logical to have concurrent research with a sludge age increase because the removal efficiencies of several pharmaceuticals with this wastewater treatment method are still fairly high. An increase in sludge age could also be a good temporary method until better treatment technologies are developed, or better ways of disposing of the massive amounts of sludge waste are devised.

A downfall to this strategy would be finding funding and support for pharmaceutical research and wastewater treatment development.

The different characteristics of membrane filtration determine the efficiency of pharmaceutical removal during the wastewater treatment method of advanced membrane treatment. Nanofiltration and reverse osmosis membranes both have structures that are very tight, but are still semi-permeable to some pharmaceuticals. In one study examining the removal of pharmaceuticals through this treatment method, it was found that the factor of polarity plays a large role in removal efficiencies. The negatively-charged surface of the nanofiltration membrane allowed the pharmaceuticals diclofenac and naproxen to be rejected and thus successfully removed by the membrane surface, whereas carbamazepine was only partially removed. However, when pharmaceuticals were uncharged, it was the physical and chemical properties of the compounds which determined how well they were retained by the nanofiltration method instead of the charge of the membrane surface (Luo et al 2014).

The removal efficiencies of certain pharmaceuticals for these two advanced membrane treatment methods were compared in this study as well. Nanofiltration had the ability to slightly remove carbamazepine, which is a drug that activated sludge treatment does not usually remove. Additionally, 60% of diclofenac was removed by nanofiltration, (Luo et al 2014) which is a much better removal efficiency compared to activated sludge treatment, in which it had a post-treatment concentration increase (Kasprzk-Hordern 2009). Reverse osmosis fared better at removing diclofenac, with an efficiency of 95%. However, data was not collected for carbamazepine removal, so it is not known how reverse osmosis performs with that particular drug. The antibiotic, sulfamethoxazole had a 97% removal efficiency with reverse osmosis treatment, which is typically only found to degrade to a smaller degree with activated sludge treatment. Reverse osmosis also resulted in an almost complete removal of ibuprofen. Reverse osmosis is a good solution and is overall effective for pharmaceutical removal, but it would be best to use among other treatment methods (Luo et al 2014). This treatment method would have a good place in a wastewater treatment plant as a polishing step to ensure better removal of pharmaceuticals.

The mechanisms of substrate, plants, and microbes in constructed wetlands determine how well pharmaceuticals will be removed. A 2014 review compiled data on several constructed wetland treatment plants and discussed how substrates and plants contribute to pharmaceutical removal. Substrates use sorption processes which filter out certain pharmaceuticals. It was found that gravel worked well for drugs such as carbamazepine that had relatively high hydrophobicity but were not well removed through biological mechanisms. Another substrate, light expanded clay aggregate (LECA) was found to be good for sorption of acidic and neutral pharmaceutical compounds such as ibuprofen and carbamazepine. Granulated cork substrate was found to be able to remove a wider variety of pharmaceuticals. One consideration with substrate efficiencies is competition with pharmaceuticals as a result of the many different pharmaceuticals that are present in the wastewater. The sorption of certain pharmaceuticals may end up preventing the sorption of others. Plants aid in pharmaceutical removal because of their ability to take up certain drugs as well as their oxygen contribution to aid in biological pharmaceutical degradation. Pharmaceuticals with a moderate hydrophobicity and water solubility are able to pass through the membrane layer of plant cells as well as through to the plant cell fluids. Carbamazepine has been shown to be able to be taken up by the plant, *Typha spp.* because of these properties. On the contrary, diclofenac lacks these properties, and was found that it is difficult for it to be taken up by the plant, *scirpus validus*. When pharmaceuticals have been taken up by these plants, they are

DOI: 10.61366/2576-2176.1017

further metabolized by processes within the plants. Plants also ensure that there is enough oxygen for the microorganisms which are needed for effective biological treatment. Their rhizosomes release oxygen which allow the microorganisms to break down pharmaceuticals more effectively. Biofilms are able to grow on the roots of plants, and have been demonstrated to largely remove ibuprofen. It is argued whether specific plants do better in general at pharmaceutical removal, and there is not enough information to determine if certain plants are more successful at this than others.

The data analyzed in this review was taken from different countries, which included both urban and rural areas, and the average removal efficiencies for certain pharmaceuticals were calculated. Sulfamethoxazole had a high mean removal efficiency of 80%. The average removal efficiency of salicyclic acid ranged from 60-76%, whereas ibuprofen had a lower average of about 35-60% (Li et al 2014). This is a much lower removal efficiency than the reverse osmosis method, which almost completely removed ibuprofen (Luo et al 2004). Carbamazepine was removed at an average efficiency of 15-20%, and diclofenac was removed at an average efficiency of 12-32% for constructed wetlands (Li et al 2014). In comparison to the other wastewater treatment methods, activated sludge treatment had a much higher removal efficiency of salicyclic acid at 98%. In the activated sludge treatment, diclofenac was the pharmaceutical which increased in concentrations (Kasprzk-Hordern 2009), so even though constructed wetlands may hardly remove a third of it, they still perform better for this particular drug. To further compare, nanofiltration treatment had a high removal efficiency of diclofenac of 60%, which is nowhere near perfect, but is much higher than what the constructed wetlands were able to remove. This leaves reverse osmosis as the best method for diclofenac removal at a high removal efficiency of 95% (Luo et al 2014). Carbamazepine removal has not usually been observed during activated sludge treatment (Kasprzk-Hordern 2009) so the low removal efficiency in constructed wetlands is still superior (Li et al 2014). Additionally, nanofiltration fares about the same as constructed wetlands because it only slightly removes carbamazepine (Luo et al 2014).

Constructed wetlands appear to be an economical solution when compared to more-developed technology such as advanced membrane treatment because they are less costly to construct. This method would be a good solution for areas that have adequate space to build a constructed wetland, but do not have large amounts of money (Li et al 2004). More research would be very beneficial to this solution so that constructed wetlands could be built for the most effective removal of the pharmaceuticals that are of the most concern. This research would need to encompass the possible effects of certain pharmaceuticals as well as which plants and substrates perform the best. If more information is available on this, then it would be even easier for communities to build constructed wetlands because decisions on material choices could be more easily guided.

There are additional wastewater treatment possibilities that have not been entirely researched. An additional solution could be using membrane bioreactor treatment, which involves combining the steps of biological treatment and advanced membrane filtration (Luo et al 2014). Another possibility to be explored is the method of ecological sanitation. This often involves source separation, which is sequestering the urine and leaving it in a tank so that possible contaminants can degrade, and then using it as a valuable fertilizer. (Langergraber and Muellegger 2004). This could prevent some pharmaceuticals from entering the wastewater because many of them are found in urine. A 2007 study examined the active ingredients of 212 pharmaceuticals to find out how much they are excreted through urine. It was found that there is large variability between groups of pharmaceuticals as well as within the groups themselves.

DOI: 10.61366/2576-2176.1017

Therefore, it is difficult to generalize which groups of pharmaceuticals are readily excreted in urine. According to this study, acetylsalicyclic acid showed over 90% excretion through urine. Carbamazepine was excreted at 72%, and another antiepileptic drug, gabapentin is able to be completely excreted. Estrogenic compounds are excreted through urine at 73%. However, a drug in this class, ethinylestradiol, is an exception with only a 38% excretion by urine. In general, pharmaceuticals are more hydrophilic than pharmaceuticals that are excreted in feces, which are more lipophilic. Therefore, hydrophilic pharmaceuticals would be the targeted drugs if ecological sanitation was implemented. (Lienert et al 2007).

Out of all of these solutions, there is not one that can be confirmed as the absolute best solution. A best solution would consider the environment, the people, and the economy in the particular area that is being looked at. A best solution would have a balance of giving benefit to all of these areas instead of sacrificing something in one area for the benefit of another. For example, it would not be the best solution to force everyone to discontinue the use of pharmaceuticals, because that would be neglecting the needs of many people that rely on them for their well-being. Similarly, using money that is needed for another problem such as poverty to invest in a high-technology wastewater treatment system would be economically and socially damaging, even if it would have environmental benefits.

Gradual changes in the area of pharmaceutical use and attitudes could be a solution that would take into consideration the environment and the people, and in some ways economic stability. Research could be invested in for the development of drugs that are less detrimental to and break down more easily in the environment. Additionally, a focus on a more holistic method of treating health problems could be beneficial because by looking for root causes of health problems, long-term healthcare costs could potentially decrease along with an increase in the health of the people. Another solution could be investing in research to see which drugs are the most detrimental and then slowly phasing them out. This would work well in conjunction with developing more environmentally-friendly pharmaceuticals. Overall, it is important to consider the needs of the environment, the people, and the economy when trying to devise a solution for decreasing pharmaceutical contaminants in effluent wastewater (Keil 2008).

References

Bixio, Davide, Chris Thoeye, et al. "Wastewater Reclamation and Reuse in the European Union and Israel: Status Quo and Future Prospects."*International Review for Environmental Strategies* . 6.2 (2006): 251-268. Web. 28 Apr. 2014.

Blöch, Helmut . "Water Framework Directive: further priority substances." *European Water Association*. European Water Association . Web. 6 May 2014. <http://www.dwa.de/portale/ewa/ewa.nsf/home?readform&objectid=04FE8F58EAB20312C12579B300570506>.

Consumer Healthcare Products Association , . "The Value of OTC Medicine to the United States." . N.p., January 2012. Web. 19 May 2014.

Daughton, CG., and K (Ed) Kümmerer. *Pharmaceuticals in the Environment* . 2nd edition. Springer: 2004. 463-495. Web.

Deegan, A , and B Shaik. "Treatment options for wastewater effluents from pharmaceutical companies ." *International Journal of Environmental Science & Technology* . 8.3 (2011): 649-666. Web. 28 Apr. 2014.

Environmental Protection Agency. "Pharmaceuticals and Personal Care Products (PPCPs): Frequent Questions." *U.S. Environmental Protection Agency* . N.p., 28 OCT 2010 . Web. 24 Feb 2014. <http://www.epa.gov/ppcp/faq.html>.

Environmental Protection Agency. "Particulate and Turbidity Removal Technologies ." *United States Environmental Protection Agency*. N.p., 16 Jan 2013. Web. 7 May 2014. <http://www.epa.gov/nrmrl/wswrd/dw/smallsystems/ptr.html>.

Environmental Protection Agency. "Wastes-Hazardous Waste: Management of Hazardous Waste Pharmaceuticals." *United States Environmental Protection Agency*. 9 Dec 2013. Web. 31 Mar 2014. <http://www.epa.gov/wastes/hazard/generation/pharmaceuticals.htm>.

Environmental Protection Agency , . "Wastes-Hazardous Waste-Universal Waste ." *United States Environmental Protection Agency*. N.p., 21 Dec 2012. Web. 8 May 2014. <http://www.epa.gov/osw/hazard/wastetypes/universal/index.htm>.

Environmental Protection Agency , . "Water: Contaminant Candidate List: Contaminant Candidate List 3-CCL." *United States Environmental Protection Agency*. N.p., 25 July 2012. Web. 31 Mar 2014. <http://water.epa.gov/scitech/drinkingwater/dws/ccl/ccl3.cfm>.

European Commission, . "Introduction to the New EU Water Framework Directive ." *European Commission* . N.p., 25 April 2014. Web. 7 May 2014. <http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm>.

George, Rose. *The Big Necessity: The Unmentionable World of Human Waste and Why It Matters*. Holt Paperbacks , 2009. Print.

Gilbert, Natasha. "Drug-pollution law all washed up ."*Nature: International Weekly Journal of Science*. 491. (2012): 503–504. Web. 8 May. 2014. <http://www.nature.com/news/drug-pollution-law-all-washed-up-1.11854>.

Kasprzk-Hordern B et al. 2009. The removal of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs during wastewater treatment and its impact on the quality of receiving waters. *Water Research.* 44(6): 363-380. Web. 30 Mar. 2014.

Keil F. 2008. Pharmaceuticals for Human Use: Options of Action for Reducing the Contamination of Water Bodies. Frankfurt/Main, Germany: Institute for Social-Ecological Research (ISOE) GmbH. 51 p. Web. 29 Mar. 2014.

Langergraber, Gunter, and Elke Muellegger. "Ecological Sanitation—a way to solve global sanitation problems?." *Environment International* . 31. (2005): 433 – 444. Web. 8 May. 2014.

Li et al. "A review on removing pharmaceutical contaminants from wastewater by constructed wetlands: Design, performance and mechanism." *Science of the Total Environment*. 468-469 (2013): 908-932. Web.

Lienert, J, and T Burki. "Water Science & Technology."*Reducing micropollutants with source control: substance flow analysis of 212 pharmaceuticals in faeces and urine*. 56.5 (2007): 87-94. Web. 19 May. 2014.

Luo, Yunlong, Wenshan Guo , et al. "A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment." *Science of The Total Environment*. 473–474. (2014): 619–641. Web. 28 Apr. 2014.

National Center for Biotehnology Information, . "The NCGC Pharmaceutical Collection: A comprehensive resource of clinically approved drugs enabling repurposing and chemical genomics." *US National Library of Medicine National Institutes of Health* . Science Translational Medicine , 27 April 2012 . Web. 28 Apr 2014. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3098042/>.

Natural Resources Conservation Service . "Natural Resources Conservation Service Conservation Practice Standard: Constructed Wetland ." *United States Department of*

Agriculture . N.p., n.d. Web. 24 Feb 2014. <http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025770.pdf>.

Office of National Drug Control Policy. United States. Office of National Drug Control Policy . *Proper Disposal of Prescription Drugs* . 2007. Web. <https://www.ncjrs.gov/ondcppubs/publications/pdf/prescrip_disposal.pdf>.

Potami, Francesco, Sara Castiglioni, et al. "Effects of a Complex Mixture of Therapeutic Drugs at Environmental Levels on Human Embryonic Cells."*Environmental Science and Technology* . 40. (2006): 2442-2447. Web. 28 Apr. 2014. <http://pubs.acs.org.ezproxy.morris.umn.edu/doi/pdf/10.1021/es051715a>.

Qiuping, Gu , and Charles Dillon. "NCHS Data Brief." . Prescription Drug Use Continues to Increase: U.S. Prescription Drug Data for 2007–2008, n.d. Web. 19 May 2014.

Radjenovic, J, M Petrovic, et al. "Rejection of pharmaceuticals in nanofiltration and reverse osmosis membrane drinking water treatment ."*Water Research* . 42. (2008): 3601–3610. Web. 8 May. 2014.

Ternes, T.A., et al. 2004. Scrutinizing Pharmaceuticals and Personal Care Products in Wastewater Treatment. *Environmental Science & Technology*. 38(20): 392A-399A. Web. 30 Mar. 2014. <http://pubs.acs.org/doi/pdf/10.1021/es040639t>.

Tiemann, Mary. "Congressional Research Service." *Safe Drinking Water Act (SDWA): Selected Regulatory and Legislative Issues* . Congressional Research Service, 27 Jul 2010. Web. 25 Feb 2014. <https://www.fas.org/sgp/crs/misc/RL34201.pdf>.