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Feasible policy development and implementation for the destruction of endocrine disruptors in wastewater

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HIGHLIGHTS

- Endocrine disrupting chemicals mimic some of the body's natural hormones.
- The treatment of certain EDCs can be handled in the activated sludge process.
- Endocrine disruptors, can be treated using the denitrification process.

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ABSTRACT

Endocrine disruptors when introduced to waterways have many adverse health effects on wildlife and humans. These health effects vary from neurological, immune, carcinogenic and reproductive disorders. Currently, there are few wastewater treatment facilities that are purposefully treating endocrine disruptors as part of the normal wastewater treatment process. Current literature has shown that endocrine disruptors can be treated using conventional methods. These conventional methods are centered around the denitrification process, which is rarely adopted in Canada. This paper investigates the current wastewater effluent regulations and guidelines in Canada, Ontario and the European Union. The research identifies a policy strategy that would include denitrification in the wastewater treatment process to help eliminate endocrine disruptors and acutely toxic nitrogen based compounds. Our emphasis here is on action possible in the Province of Ontario Canada, give the context of the Great Lakes basin and the potential for early action to stimulate other jurisdictions to follow. Our recommendations while aimed at one jurisdiction, have broad application globally.

1. Introduction

In Canada, endocrine disruptors are a very topical issue in wastewater effluent quality. We define endocrine disruptors as chemicals that can interfere with the endocrine or hormone systems in wildlife and humans. Results can vary from different forms of cancer, birth defects and developmental disorders (National Institute of Environmental Health Sciences, 2010). Since these substances are considered to represent a chronic toxicity issue, and since federal wastewater treatment regulations have focused acutely toxic substances such as ammonia, nitrates/nitrites, suspended solids and carbonaceous biochemical oxygen demanding matter (BOD) (Ministry of Justice, 2017), their treatment has been not been overtly considered since they do not cause acute toxicity at the end of the pipe. This paper investigates three hormonal endocrine disruptors that we consider "important" based on the United States Environmental Protection Act. We describe these pollutants, 17alpha-Ethinylestradiol,17beta-Estradiol and Estrone based on their sources, attributes and effects, to better illustrate the need for treatment.

Discoveries made in the late 1990s and 2000s have determined that17alpha-Ethinylestradiol, 17beta-estradiol and estrone can be treated using conventional wastewater methods that are meant to treat the acutely toxic ammonia/ammonium and their byproducts, specifically the nitrates/nitrites (Andersen et al., 2003; Ternes et al., 1999; Andersen et al., 2003; Ternes et al., 1999). The collateral benefits of treating these toxins simultaneously with the acutely toxic substances reveal the potential for a policy shift. We also review two future technologies for treating endocrine disrupting pollutants, photocatalysis for UV systems and membrane nanofiltration.

These treatment discoveries highlight an opportunity to review current Canadian wastewater effluent regulations for improvement and inclusion of endocrine disruptors, and too review the requirements of Ontario's Treatment for Sewage Treatment Works. In this research, the European Commission's regulations have been reviewed for comparison.

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When reporting on endocrine disruptors (EDCs) and potential treatments, we decided to target specific compounds. EDCs come from a variety of sources such as industrial run-off, personal care products, hormone based contraceptives, leachate from a variety of plastics and even medicine from hospital waste (NIEHS, 2010; National Institute of Environmental Health Sciences, 2010). Therefore, due to the varied sources and types, it is unlikely that there would be a catch-all solution for treating all the endocrine disrupting pollutants. Importantly, certain chemicals have different concentrations in wastewater effluent and different potencies. We targeted those endocrine disruptors that have high concentrations and high potency to research potential EDC treatment methods and policy responses.

The United States Environmental Protection Agency (USEPA), considers the following ten endocrine disruptors to be the most concerning, based on their studies of bioactivity (Endocrine Disruptor Screening Program (EDSP) Estrogen Receptor Bioactivity, 2015). Note that the Estrogen Receptor Bioactivity (ER Bioactivity) uses 17alpha-Ethinylestradiol as the denominator, to which the other compounds are compared. Numbers in Table 1 that are >1.000 are more potent than 17alpha-Ethinylestradiol and those <1.000 are less potent.

Despite the greater estrogen receptor bioactivity of 17alpha-Estradiol, the ability to feminise is significantly less than that of 17beta-Estradiol (Moos et al., 2008). Moos et al. determined that 17alpha-Estradiol can be 2 to 200 times less potent in its ability to feminise organisms, specifically in humans.

Wastewater effluent from the Boulder WWTP in Boulder, Colorado (Vajda, 2008) (Vajda AM1, 2008) had high concentration offenders of 17alpha-Ethinylestradiol, 17beta-Estradiol and Estrone. These three offending compounds are considered the most likely to cause reproductive damage in fish (Vajda, 2008). Based on the Boulder WWTP study, the USEPA data and further reasons we describe below, we focus on 17alpha-Ethinylestradiol, 17beta-Estradiol and Estrone for treatment possibilities and policy responses.

2. Sources and attributes

17beta-Estradiol (E2) is a synthetic and naturally occurring steroid hormone. As a medication, E2 is frequently used in hormone replacement therapy and for birth-control (PubChem, 2004a, 2004b). E2 is also produced in women and men naturally. For women, this is largely during the developmental stages and during fertile adulthood. Production in women is roughly an order of magnitude higher than men. This compound usually enters the wastewater stream through normal bodily functions. 17alpha-Ethinylestradiol (EE or EE2) is a synthetic form of Estradiol. It is used in the same applications as E2 (PubChem, 2005). EE2 is not naturally occurring. Entrance to the wastewater stream is through normal bodily functions from a user of EE2. Estrone (E1) is a naturally occurring steroid hormone which enters the wastewater stream through normal bodily functions (PubChem, 2004a, 2004b). In the past there was a synthetic version of Estrone, it has been discontinued from use due to the superior effectiveness of synthetic E2 and EE2.

Table 1
US-EPA top 10 endocrine disruptors by estrogen receptor bioactivity (Endocrine Disruptor Screening Program (EDSP) Estrogen Receptor Bioactivity, 2015).

Chemical name	ER Bioactivity
17alpha-Estradiol	1.06
17alpha-Ethinylestradiol	1
meso-Hexestrol	0.993
Diethylstilbestrol	0.943
17beta-Estradiol	0.935
Equilin	0.822
Estrone	0.807
Estriol	0.786
Mestranol	0.742
Zearalenone	0.71

2.1. Effects on fish

EDCs can have very serious effects on fish, both behaviourally and physiologically (Thorpe, 2003). The effects may range from reproductive issues to evidence of intersex fish (Vajda, 2008). Testing on small fish types such as the Japanese medaka, has shown the negative effects of EDC exposure to EE2 in concentrations as low as 63.9 ng/L (Seki, 2002). Hormonal EDCs, such as E1, E2 and EE2, exist in concentrations on the order of 1–1000 ng/L, which impact fish that are in direct contact with the wastewater effluent (Sigreist, 2005). The effect of EDCs on larger fish such as smallmouth bass in the Potomac River has been inconclusive (Blazer, 2007).

There is evidence that exposure to E1, E2 and EE2 additive and thus exposure even at low levels can produce the same effects on fish over time because the exposure is from multiple present hormones. By exposing rainbow trout to known constant low dose of EDCs (<63.9 ng/L) and measuring the hormonal responses in fish, Thorpe (2003) found that the vitellogenic (VTG) response was found to be is directly related to the feminization of male fish Over the 14-day exposure, the trout had an increasing VTG responses.

2.2. Effects on humans

The human body's normal endocrine system is affected by very small changes in hormone levels. EDCs can mimic these hormones and exposure can cause dramatic changes in these hormone levels in humans (NIEHS, 2010). When absorbed these EDCs can decrease and increase certain hormone levels, mimic some of the body's natural hormones and even alter natural hormone production, thereby reducing male fertility, reducing the number of males being born, interfering with male reproductive organs, causing female reproductive issues, increasing mammary, ovarian and prostate cancer and increasing autoimmune diseases (NIEHS, 2010). These effects seem to be greatest during key development stages in humans. Greater detail on these impacts is detailed by the National Institute of Environmental Health Sciences[1]:

Having briefly summarized the ecological and human health threats of these substances, we now examine technological options for their destruction before they leave the wastewater treatment plants and enter the receiving water.

3. Current technology

3.1. Activated sludge treatment

Activated sludge treatment is a commonly used secondary treatment method in wastewater treatment that uses a biological process to treat ammonia and remove the biological oxygen demand (BOD). Activated sludge treatment or secondary treatment is the bare minimum level of treatment required by the EU and Canada through their respective wastewater effluent regulations (European Commission, 2016a, 2016b, 2016c; Ministry of Justice, 2017) Importantly, E1, E2, EE2 can be treated by the activated sludge treatment process (Siegrist, 2005). There are certain modifications that can remove additional pollutants. Fig. 1 shows the evolution of the activated sludge processes including advances in the types of contaminants treated.

The most common activated sludge treatment in Ontario, in large scale wastewater treatment plants are aeration basins or aeration tanks. In reference to Fig. 1, the most common installation in Ontario

[1] http://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm