A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

The Current System of Estrogenic Compounds and its Transformation towards a Future Vision of Wastewater Management in the City of New York

Amanda STEEN

May, 2013

Budapest

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfillment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Supported by the European Commission's Erasmus Mundus Programme

Education and Culture

Erasmus Mundus

Notes on copyright and the ownership of intellectual property rights:

(3) For bibliographic and reference purposes this thesis should be referred to as:

Steen, A. 2013. The Current System of Estrogenic Compounds and its Transformation towards a Future Vision of Wastewater Management in the City of New York. Master of Science thesis, Central European University, Budapest.

Author's declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Amanda STEEN

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:
Amanda STEEN
for the degree of Master of Science and entitled: The Current System of Estrogenic Compounds and its Transformation towards a Future Vision of Wastewater Management in the City of New York

Month and Year of submission: May, 2013.

Natural and synthetic estrogenic hormones as well as nonylphenol have been found to contribute to the estrogenicity of water and cause endocrine disruption in fish and other aquatic species. Concentrations of these contaminants have been measured in the sediments of New York City. Using system dynamics modeling, this thesis characterizes the collective dynamics of the current estrogenic system, from synthesis to degradation, by modeling the system's flows, actors and feedback mechanisms. In addition, a positive vision is created for the future by describing the details of a sustainable estrogenic system that can be shared by everyone. Using this vision as a goal, a transformation model is created by altering the system at intervention points, which can move the current system from its present basin of attraction to a new sustainable one. The main findings that resulted from these models show that in order to achieve the future vision, chemical and pharmaceutical regulations need to be reformed and incentives need to be created to explore sustainable wastewater management practices. Ecological sanitation is a well studied practice that can solve the problems associated with aquatic pollution such as endocrine disruption. However, more research is needed to design the specific details of the action plan necessary to transform the estrogenic system.

Keywords: estrogenic hormones, nonylphenol, wastewater, systems dynamics, New York City, endocrine disruption, ecological sanitation

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Prof. "Jack" Corliss who has been a great source of inspiration, for his guidance, encouragement and dedication to this project. To Prof. Tamara Steger, I am deeply grateful for her enthusiasm and support. I would also like to thank Prof. Anne McElroy and Prof. Bruce Brownawell for the meaningful discussions and valuable information they have provided to this project and over the years. My sincere thanks and appreciations also go to Edward Furlong for eagerly sharing his knowledge and Pete Septoff for his valuable comments. I would like to say how truly grateful I am to Jonah Norresen for all the support and encouragement. Last but not least, my love and gratefulness goes to my mother and friends for their support. To all those who helped me along the way, I would like to take the opportunity to say once more, thank you from the bottom of my heart.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACC	American Chemistry Council
APE	alkylphenol ethoxylates
BAF	bioaccumulation factor
BOD	biological oxygen demand
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
DDT	dichlorodiphenyltrichloroethane
DEC	Department of Environmental Conservation (New York State)
DEP	Department of Environmental Protection (New York City)
DOC	dissolved organic carbon
DOW	Division of Water
E1	estrone
E2	estradiol
E3	estriol
EDC	endocrine disrupting compounds
EDSP	Endocrine Disrupting Screening Program
EE2	ethinylestradiol
EFC	Environmental Facilities Cooperation
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FY	fiscal year
g	gram
H	Henry's constant
HRT	hormone replacement therapy
kg	kilogram
K_{ow}	water octanol partition coefficient
l	liter
mg	milligram
Mgd	million gallons per day
MWFA	Municipal Water Finance Authority
ng	nanogram
NP	nonylphenol
NPDES	National Pollution Discharge Elimination System
NPE	nonylphenol ethoxylates
NYC	New York City
OC	Oral Contraceptives
OND	Office of New Drugs
OPPT	Office of Pollution Prevention and Toxics
Pa	Pascal
PhRMA	Pharmaceutical Research and Manufacturers of America
PMN	Post Manufacture Notification
SDWA	Safe drinking water act
SRF	State Revolving Fund
TSCA	Toxic Substances Control Act
ug	microgram
US	United States
vtg	vitellogenin
WWTP	wastewater treatment plant

CH 1: INTRODUCTION

1.1 Purpose and Significance

Over the past few decades, endocrine disruption has become in the United States both an increasingly important environmental issue as well as a health concern raised by the scientific community and the public alike (Diamanti-Kandarakis *et al.* 2009; US Environmental Protection Agency 1997). Awareness of endocrine-disrupting compounds was first widely spread to the public in 1962 by Rachel Carson's book *Silent Spring*, a reaction to the widespread use of the pesticide DDT, dichlorodiphenyltrichloroethane, in the 1960s. Her research on pesticides revealed the adverse effects (e.g. reproductive failure) that occur as a result of endocrine disruption. However, this was not an unfamiliar phenomenon at this time.

According to the Environmental Protection Agency (EPA), endocrine disruption occurs when an endocrine disrupting compound or chemical (EDC) "interferes with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction, development, and/or behavior." Regardless of the origin of the compound, whether it be a natural product or a synthetic chemical, EDCs interact with the endocrine system causing hormone mimicry, hormone blocking, or impairment of the endocrine system.

In 1991, heightened concern about the hazards of endocrine disruptors among scientists led to the Wingspread Consensus. As a forum for research and interests groups, a report on the significance of endocrine disruption was written as a result of intensifying pesticide use (Colborn *et al.* 1993). Soon after, extensive research efforts were aimed at identifying the link between health and environmental effects of present EDCs. This awareness created by research resulted in two acts, which govern the majority of endocrine disruptors today: (1) the Food Quality

Protection Act of 1996 and (2) the Safe Drinking Water Amendments Act of 1996 (Jones 2006).

As a result of these two acts, the creation of the Endocrine Disruption Screening Program (EDSP) was mandated in 1996. According to the legislation, program development and testing validation was required to take place within the first two years (1996-1998), program implementation the following year and reporting to Congress by 2000. However, the first deadline was not met, thus resulting in 1999 lawsuit filed by several environmental and public health interest groups (Vogel 2004). According to Vogel (2004), after a settlement was made outside of the courts with lobbyists and legal action from industry and no support from the Bush administration, the progress of EDSP was de-prioritized. In 2009, the EPA finally announced the list of chemicals that will be tested. This is nearly a decade later than what was originally mandated by Congress.

The EDSP's mission statement is "to protect public health and the environment by screening and testing chemicals" (US Environmental Protection Agency 2012b). However, in the time it takes to screen, test and review chemicals that may pose a threat to human and environmental health, an overwhelming number of chemicals are approved and routinely used without being required to test for its complete safety until concerns about exposure are raised (Vogel 2005). Moreover, the EDSP is severely problematic due to (1) the impractical time and resources necessary to carry out such testing, (2) the extremely difficult (or impossible) task of establishing the relationship between EDCs and health hazards, (3) complex dose-response relationships and (4) ineffective regulatory framework involving multiple agencies and no new authority for the regulation of EDCs (Vogel 2005).

Depending on the use of any harmful chemical, the Toxic Substances Control Act (TSCA), the Federal Food, Drug and Cosmetics Act, the Federal Insecticide, Fungicide, and Rodenticide Act, or the Safe Drinking Water Act (SDWA) must first authorize its regulation. Then, either the Environmental Protection Agency (EPA), Food and Drug Administration (FDA) in the US

Department of Health and Human Services, or the Food Safety and Inspection Service in the U.S. Department of Agriculture can regulate the use.

While public health and environmental groups point to more rigorous regulations on chemicals as the solution, there is much difficulty in classifying chemicals as EDCs (Vogel 2005). This is due mostly to the complex interactions as well as synergistic effects caused by the presence of numerous compounds in varying physical and chemical states. Currently, the most widely used classification of endocrine disruptors is based on the target and pathway. EDCs can be defined as estrogenic androgenic or thyroidal by binding, blocking or interfering with the respective receptor (i.e. estrogen receptor)(Snyder *et al.* 2003).

1.2 Characteristics of Estrogenic Compounds

Among EDCs, both natural and synthetic estrogenic hormones have been the focus of many research papers due to their explicit capability to mimic and bind to estrogen receptors in non-target species (Andersson and Skakkebæk 1999; Filby *et al.* 2007; Jobling *et al.* 2003; Larsson *et al.* 1999; Matozzo *et al.* 2008; Reddy and Brownawell 2005; Wise *et al.* 2011). In addition to the research efforts made to understand the estrogenic effects of hormones, an increasing number of studies have focused on the biological effects of nonylphenol ethoxylates (NPE), a group of surfactants derived from nonylphenol (NP) among the larger class of surfactants called alkylphenol ethoxylates (APEs). The use of APEs has been restricted in Europe however, they continue to be widely used throughout North America (Zulkosky *et al.* 2002).

1.2.1 Natural estrogens: E1, E2, E3

Excreted by the endocrine glands of animals, hormones are vital for the communication of information across the body (Willmer *et al.* 2009). Steroidal hormones are specifically responsible for controlling metabolism, inflammation, immune function, sexual development and more.

There are five classes of steroids defined by their receptors: estrogens, progestogens, androgens, mineralocorticoids and glucocorticoids (Simons 2008). Estrogens are primarily female sex hormones and consist of three distinct compounds: estrone (E1), estradiol (E2) and estriol (E3) (Fig. 1). In combination, estrogen and progesterone are present throughout a woman's menstrual cycle at various levels to initiate different stages in preparation for fertilization. Estrogens are not just important for the sexual development of females, they are also synthesized in males yet at lower concentrations (Johnson *et al.* 2000).

1.2.2 Synthetic estrogen: EE2

Similar in composition to the natural estrogens (Fig. 1), 17-ethynylestradiol (EE2) is a synthetic estrogen taken by women as an oral contraceptive (OC) or topically to regulate their hormone levels. OCs are used to inhibit contraception or to minimize side effects caused by estrogen deficiency or imbalance (e.g. menopause). The primary mechanism of action for OCs is considered the prevention of ovulation stage of the menstrual cycle (Rivera *et al.* 1991).

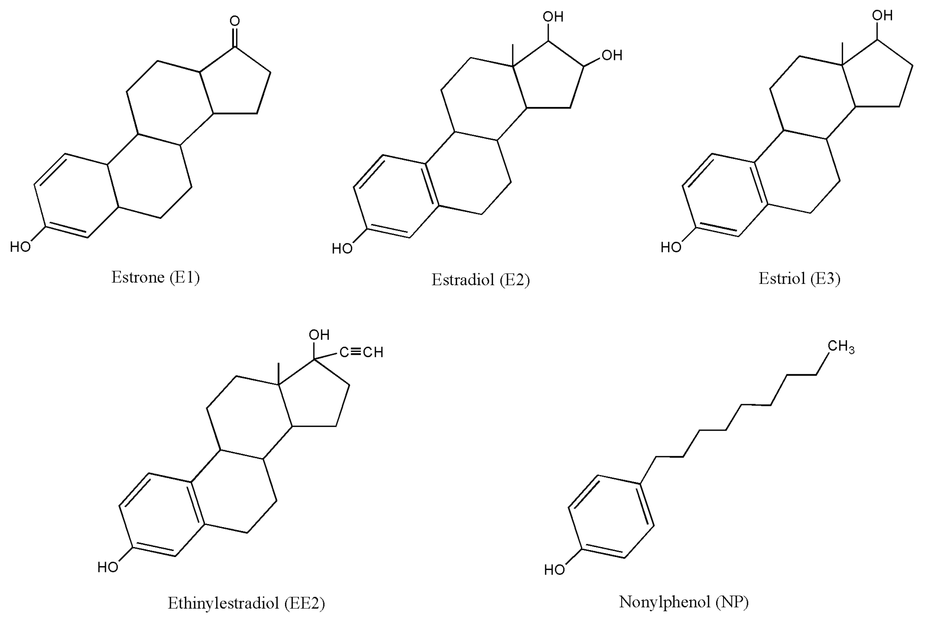


Fig. 1. Natural steroid estrogens (E1, E2, E3) and synthetic estrogenic compounds (EE2, NP).

Ovulation, as well as follicular development and corpus lutein formation, is prevented by the inhibition of pituitary production and secretion of the follicle-stimulating hormone and luteinizing hormone. Ultimately, synthetic estrogen EE2 serves to prevent shedding of the endometrium (Reproductive Health Technologies Project 2000; Rivera *et al.* 1991). Also, synthetic progestins such as norgestimate, desogestrel and gestodene are capable of blocking the mid-cycle rise in LH secretion thus, preventing ovulation due to high levels of a progestogen mimic (Rivera *et al.* 1991). Considering the purpose of OCs, it's not surprising that EE2, due to its capability to act as a ligand and bind to the estrogen receptor, is an estrogen mimic.

1.2.3 Estrogenic surfactant: NP

Nonylphenol (NP) is produced from the refinement of petroleum and coal-tar crudes (US Environmental Protection Agency 2005). Like synthetic steroid estrogen EE2, NP is capable of mimic estrogen due to its chemical structure similarity (Fig. 1). There is little use of NP alone, therefore it is mainly used to synthesize nonylphenol ethoxylates (NPE), which are nonionic surfactants used mainly in detergents, lubricants, textile processes, agrichemicals and emulsifiers (US Environmental Protection Agency 2010). As a surfactant, NPEs serve to produce synthetic textiles by acting as an emulsifier (i.e. soap) in polymerization (The Dow Chemical Company 2013). Emulsifiers aid in the mixing of polar and non-polar molecules to allow for the chemical reactions to occur that will transform monomers into polymers. Synthetic textiles such as nylon and polyester fibers are a result of polymerization (Clayden and Greeves 2001).

Due to the structural similarity of NP to estradiol, it is able to bind to the estrogen receptor and compete with estradiol for the binding site (Lee and Lee 1996; White *et al.* 1994). In addition to being an estrogen mimic, NP was shown to interfere with the functioning of androgens within the endocrine system and alter the normal development of males as well as their reproductive systems (Lee *et al.* 2003).

Currently, NPEOs are commonly used in household laundry detergents to remove dirt which does not dissolve in water alone, but due to widespread concern for the biological consequences, this application will be phased out slowly by 2014. However, NPEs continue and will continue to be used in industrial detergents that may be found as residues of textile products primarily produced in Asia (Brigden *et al.* 2012), thus not removing all NPEs from wastewater systems where textiles are imported (i.e. US, Europe). Since NPEs are among many petrochemicals that are economical due to their plentiful supply from fossil fuel industries (Colborn 2013), they are widely used (Sierra Club 2005).

1.3 Health Concerns

The health concerns associated with all EDCs pertain to their ability to interfere with the endocrine system. However, since natural hormones are synthesized by the human body, more readily degraded in conventional WWTPs (Ternes *et al.* 1999a; Vader *et al.* 2000), are less likely to affect humans compared to more persistent compounds such as EE2, NP and its ethoxylates, possible human health risks of natural estrogens will be considered negligible.

1.3.1 Human risk to exposure

Globally, in 2009, it was estimated that 78.5 million women used OCs and approximately 150 million women have taken OCs at least once during their lives (Meendering *et al.* 2009). Not only are women taking oral contraceptives ingesting EE2, women who take hormone replacement therapy are prescribed or injections containing EE2. A study conducted by the National Center for Health Statistics (1984-1992) stated that 44% of postmenopausal American women in the study had either used or currently use hormone replacement therapy (HRT) to reduce the effects of menopause (Brett and Chong 2001).

With currently over 70 different combinations of OCs prescribed to a growing number of women in the US, with various compounds, doses and ratios of synthetic hormones (EE2 and progestin), the effect of oral contraceptives on women varies considerably (Meendering *et al.* 2009). The use of OCs has been associated with increased cardiovascular and breast cancer risk along with increased occurrence of venous thrombosis (Meendering *et al.* 2009; Rosendaal and Reitsma 2009; Vandenbroucke *et al.* 2001). In recent studies of the effects of EE2 plus progestin and EE2 alone hormone replacement therapy, results suggested that users are at higher risk for breast cancer, stroke, heart attack, blot clots and/or venous thrombosis (US Department of Health and Human Services 2002). It has also been shown that there are individual and ethnic differences in the metabolism of synthetic hormones and contraceptive mechanisms (Rivera *et al.* 1991). Ultimately, since risks have been identified by more than a few studies and the relationships and mechanisms of EE2 are not fully understood, it can be concluded that the human health effects and risks remain uncertain.

Studies of health risks associated with exposure to nonylphenol and its ethoxylates are few and limited. According to the US Environmental Protection Agency 2010, "there are no data on its carcenogenic potential" while the use of NPEs in the US reached between 270 and 370 million pounds annually. Recently, a study by Greenpeace has raised significant concern about the health effects of nonylphenol associated with textiles and especially imported textiles from countries where chemical regulation is absent or risky (Brigden *et al.* 2012).

The risk of endocrine disruption caused by estrogens in drinking water has also caused concern for human health (Wise *et al.* 2011). Research has suggested that human sperm quality and quantity has been attributed to EDCs in the environment (Carlsen *et al.* 1995; Sharpe and Skakkebaek 1993; Stone 1994). The increase of breast, testicular and prostate cancers have also be suggested to have resulted from the increasing use of persistent EDCs (Ahlborg *et al.* 1995; Ashby 1997; Carlsen *et al.* 1995; Gillesby and Zacharewski 1998; Krishnan and Safe 1993).

1.3.2 Fish feminization

In addition to human health risks, estrogens in the aquatic environment pose a threat to a large community of wildlife (Norris 2007; Todorov *et al.* 2002; Wright-Walters and Volz 2009; Zhou *et al.* 2008). The major environmental concern rising from endocrine disruptors in the aquatic environment as a whole, is the phenomenon of feminized fish (Jobling *et al.* 1998; Kidd *et al.* 2007; Nash *et al.* 2004; Todorov *et al.* 2002; Vajda *et al.* 2008). This is critical regarding the reproductive success of a fish species and ultimately the stability of the population. If there are fewer male individuals capable of reproduction, the ratio of male to female fish decreases. This has lead to fish population decline and, in some cases, its collapse. Thus, conclusions have been made that the presence of estrogens and their mimics can impact the sustainability of wild fish populations (Colman *et al.* 2009; Kidd *et al.* 2007).

Research has concluded that fish feminization is linked to the presence of estrogens and xenoestrogens in the water (Routledge *et al.* 1998). However, it was shown that there is considerable temporal dissociation between the vitellogenin response and reproductive failure. Vitellogenin (Vtg) is the precursor protein that serves as a biomarker for fish feminization in males. If males produce Vtg, this is indication that estrogenic compounds bound to the estrogen receptor and initated Vtg induction. Another biomarker is the sex ratio between males and females in a given population exposed to estrogenic compounds.

Considering the complexity of mixtures present in wastewater effluent, integrated studies are crucial to understand the relationship between exposure and response of xenoestrogens such as EE2. In addition, the sensitivity of measurements is often the limiting factor in detecting estrogenic compounds present as well as due to the low levels of biologically significant concentrations (Kolpin *et al.* 2002; Nash *et al.* 2004).

1.4 Current Practice & Regulations in the US

In NYC and the US, endocrine disrupting compounds enter the wastewater treatment facilities and are conventionally treated with activated sludge treatment, which involves biological degradation using microbial populations to reduce nutrients, such as nitrogen and phosphorous (AECOM 2013). In addition to minimizing nutrients, microbes are capable of reducing various contaminants under oxygen-rich or oxygen-free conditions, depending on the biodegradability of the contaminants present. However, WWTPs in New York do not remove all the compounds that have scientific evidence that proves its harm. DEC emphasizes the need to limit the concentrations of EPA's 'priority contaminants' through its permit program yet, little effort is made to measure or reduce the concentrations of potentially harmful pollutants (NYS Department of Environmental Conservation). By and large, US wastewater treatment facilities are concerned with simply meeting compliance, reducing concentrations below permit limits, and minimizing operational costs.

The vast majority of EDCs have not been considered high priority due to funding bias from the pharmaceutical and chemical industry and the over-extended and timely procedures that the EPA uses to classify EDCs (Heath and Greene 2013). These conflict of interests and the lack of transparency have contributed to the lack of public awareness of the risks associated with potential EDCs such as pharmaceuticals, hormones, pesticides, surfactants, and many more. Meanwhile, with population rise, urbanization, the widespread use of drugs and chemicals and an ineffective regulatory process to protect human health, wastewater systems in the US are likely to carry an even larger burden of removing risky contaminants. Thus, the present processes for the approval and regulations of chemicals and drugs needs to be reformed (US Government Accountability Office 2009).

1.5 Research Questions

Thus far, no efforts in research have been made to understand the dynamics within the estrogen system. The relationships between the actors and their influences on the decision made within the system significantly contribute to the functionality of the system and its pattern of behavior. In order to change this unsustainable behavior to a new basin of attraction, attempts must be made to understand it.

- What are the dynamics of the current estrogen system (production, use, wastewater treatment and discharge)? Why are they unsustainable?
- How do the dynamic relationships within the system contribute to the unsustainable patterns of behavior? What are the essential feedbacks that keep the estrogen system in its current state?
- If the current system were to change, how would the desirable future sustainable system function?
- What actions are required to transform the current system to a more sustainable one?
- Who are the key actors that need to change and why?

CH 2: AIMS AND OBJECTIVES

The purpose of this project was to provide a guide for the transformation of the current estrogenic compound system to reduce environmental and health issues associated with endocrine disruption. In order to accomplish this, the following aims and objectives were devised:

The first aim was to characterize the system dynamics of the current system including the production and use of estrogenic compounds, and the treatment and release of wastewater effluent and biosolids into the environment. This was achieved by (1) collecting data on the current flows of estrogenic compounds through the system (sales, consumption, wastewater treatment), (2) modeling the current system by creating stocks, flows and control feedbacks and (3) defining actors (excreters, users, management of pharmaceutical and chemical companies, lawmakers, exposed individuals, agency officials) and their roles within the system.

The second aim was to characterize the system dynamics of a sustainable future system. This was achieved by (1) creating a vision of a future sustainable system that reduces the exposure of the public to estrogenic compounds, (2) modeling the future system based on the vision (3) identifying points of intervention in the current system for the transformation and (4) creating a new model that represents the proposed transformation.

The third aim was to create an action plan for transforming the current system to the future system at the intervention points. This was achieved by (1) designing actions that will change the scripts and roles of actors at the points of intervention, (2) devising strategies to strengthen its stability, and (3) initiating the action plan to transform the system.

CH 3: METHODOLOGY AND METHODS

3.1 Systems Dynamics Approach

Although not necessary until recent times, human have not developed the mental ability to accurately interpret the dynamic behaviors of complex social systems that they are a part of (Forrester 1971). Belonging to the class of 'multi-loop nonlinear feedback systems, social systems are, in Forrester's words (1971), "far more complex and harder to understand than our technological systems"; therefore different sets of methods apply.

From Galileo's words (1618) "the Book of the Universe is written in the language of mathematics" to Newton's creation of the Calculus (1687), mathematics has long established its role in science (Corliss 2013). This has been restated with Gregory Bateson's general assertion that "a scientific explanation is the mapping of a description onto a tautology". From the time of Newton to the mid-20th century, equations have adequately served to explain the behavior of systems; however, today these equations are "inadequate for the complex systems of the real world encounters in modern society, especially the world of social systems" (Corliss 2013).

Extending beyond Newtown's Calculus, today's fast computation for solving differential equations has led to "a vast new mathematical territory of what is called dynamical system theory, which includes Forrestor's multi-loop nonlinear feedback systems" (Corliss 2013). To model real world environmental social systems, descriptions of the systems are to be mapped as graphical representations using Forestor's STELLA software[1] (Corliss 2013). As a result of this approach to modeling complex systems, the patterns of behavior that arise in the simulations reflect those of the real world, "especially the coupled nonlinear feedback loops that prevail in the environmental social systems we seek to transform"(Corliss 2013).

1. Systems Thinking Software STELLA Edition 10. ISEE Systems Inc., Lebanon, New Hampshire, USA.

Understanding systems is fundamental for progress and better organization (Forrester 2000). Yet, without the vision of a future sustainable system, transformation paths have undetermined routes and without a commonality of interest, effective resistance forms. Implementation, the most discussed and active stage of achieving a goal, involves a physical change of the system. Most discussion of implementation is based on models, which may or may not represent the system in a way which guide the creation of a plan for action to transforming the system. A systems dynamics model can serve as a useful guide as to how the system can change.

The fundamental elements within a system model are the (1) stocks, (2) flows and (3) feedback loops (Forrester 2000).

1. Stocks represent an accumulation of matter, energy, money or other measurable quantity within the system.
2. Flows indicate the movement of material between stocks.
3. Feedback loops connect from a particular flow through a chain of stocks and/or actors and/or flows, back to the original flow. In a positive feedback loop, a change in a flow feeds back to increase the magnitude of change of the original flow; whereas in a negative feedback loop, a change in a flow feeds back to decrease the magnitude of change of the original flow.

System dynamics modeling should organize, clarify, and unify knowledge. It should provide more effective understanding about a system, which exhibits controversial behaviors. To do this, it should link the past to the present by showing how the present conditions were formed and extending the model to future scenarios. Without the communication with prior mental models (people's thinking) and adaptation to new knowledge, effective action will not occur (Forrester 2007).

Overall, these connections exist in order to represent the system's stability in its current pattern of behavior. According to Forrester (2007), systems dynamics needs to create understandable, relevant and important writings addressed to the public. Thus, it is understood that the future of systems dynamics lies in the effective communication of models about current controversial systems – an action plan. However just as important, it is the future vision, which should steer the change (Meadows 1996) and determine the ultimate success of a systems dynamics investigation (Forrester 2007).

Using systems dynamics methodology, this project mapped the current system of estrogenic compounds using the following concrete sequence of steps developed by Professor J.B. Corliss (2013): (1) modeling the system, (2) defining the actors and their roles, (3) creating a sustainable vision of the future, and (4) creating an action plan to intervene in the current system dynamics to allow transformation to this future. This goal is achievable and common goals for a systemic transformation towards sustainability. The key transformational step is emphasizing the importance of the future vision for a successful and holistic change for the better.

3.2 Methods

Models of the estrogen system require data from a diverse range of knowledge, which are classified by Forrester as as the mental database, the verbal database and the written database. The approach presented by system dynamics suggests that all types of information must be considered to characterize the behaviors of a system, both qualitative and quantitative when necessary. However, for this project most of the research will be conducted qualitatively.

Firstly, in order to characterize the current system, data was obtained on the consumption, excretion, wastewater treatment and release of the estrogenic compounds: estrone, estadiol, estriol, ethinylestradiol and nonylphenol ethoxylates. This information was gathered by reviewing literature, conducting interviews and/or correspondences with public officials, researchers and private consultants. For the consumption and excretion of estrogenic hormones in New York City, sources were broken down into six sub-categories: foods, oral contraceptives, hormone replacement therapies, laundry detergents, textiles and cosmetics. The regulations on these products were then collected from existing datasets from public environmental and health departments or wastewater treatment plants. Data on the current presence in wastewater treatment plants was obtained from interviews and existing records from a select number of the wastewater treatment plants in operation in New York City. Information was also gathered on the current treatment, progress and plans for the future to address the waste produced by the pharmaceutical & chemical industries.

The second objective was to identify and characterize the stakeholders involved in the current system. To achieve this, literature was reviewed and interviews of known actors involved in the current system were conducted. Their roles and scripts within the current system were described using the gathered information.

The final objective of the first aim was to create a model of the current system. Using STELLA, the stocks, flows and actors within the system were constructed. Then, the actors' roles were described, according to their influence on the flows of stocks in the system. The flows of stocks, defined by this project, are the transfer of money, estrogens and information, and the feedback loops are the transfer of information in the system to influence further actions. Based on information gathered from the literature review, consultations and correspondences, the stocks, flows and actors were joined together to create the model of the present system. This model serves to organize, clarify and unify knowledge of both the past and present systems. With these components, a more effective understanding of the current system will be attained and the patterns of behavior will become more apparent.

Secondly, to characterize the future system, a future vision was defined. This was based on the idea of a sustainable estrogen system, one that will reduce the occurrence of estrogenic compounds in the environment. This future vision furthermore served as the endpoint of the transformation to the future system. Based on the exploration of alternative dynamics, the model of the current system was transformed into a future STELLA model. This was done by adding or and removing stocks, flows, actors and feedback loops to change the current unsustainable pattern of behavior to reduce environmental exposure.

Thirdly, the steps necessary for the transformation were outlined. The current model served to predict intervention points where actions are needed most and to locate points of resistance. Then, a transformation model was created using STELLA. By doing this, strategies for action were devised to change scripts and roles of actors, and minimize resistance. This served as the foundation for the action plan. The aspiration of the action plan was to serve as a tool to provide the public with a clear vision of the future and feasible solution to achieve it. Lastly, the action plan was initiated to spread the ideas of the future vision.

CH 4: THE LIFECYCLE OF ESTROGENIC COMPOUNDS

4.1 Estrogenic Sources

With a population of over 8 million people in NYC (US Census Bureau 2011), of which 50.8% are women, human excretion is a significant source of estrogens in wastewater streams in the remaining marshland ecosystem that once dominated and preexisted the mega metropolitan area. The main sources of both synthetic and natural estrogens to the aquatic environment are human urine and feces. The three naturally existing estrogens in the human body, estrone (E1), 17β estradiol (E2), and estriol (E3) as well as the synthetic hormone ethinylestradiol (EE2) are mixed in the sewers with a cocktail of compounds containing NPEs surfactants from household laundering.

4.1.1 Human excretion

According to Johnson *et al.* (2000), it was estimated that the menstruating females excrete 16.3 µg/day of natural estrogens, whereas males and menopausal females excrete 7 and 7.3 µg/day respectively (Table 1). As for synthetic estrogen, it has been suggested that a typical dose of EE2 ranges between 30 and 35 µg/day, thus an average dose of 26 µg/day is assumed. 43% is metabolized by the body and the rest is excreted, of which 40% (10.5 µg/day/person) reaches the sewers as available EE2 (Johnson and Williams 2004; Kidd *et al.* 2007).

Table 1. Rates of steroid estrogen excretion in humans in µg/day. Source: Johnson *et al.* 2000.

Individual	Estrone E1	Estradiol E2	Estriol E3	Natural Estrogen Total
pregnant women	259	600	6000	6859
menstruating females	3.5	8	4.8	16.3
menopausal females	2.3	4	1	7.3
males	1.6	3.9	1.5	7

Compared to the total amount of estrogens excreted in a Dutch population, EE2 represents just 1% (de Mes *et al.* 2005). However, EE2 is considerably more potent and persistent in WWTPs than natural estrogens (Ternes *et al.* 1999a; Ternes *et al.* 1999b). This is due to the ethynyl-group, which contributes to the stability of the ring and thus resistance to oxidation (Larsson *et al.* 1999). It has been reported that EE2 was 11-130 times more potent than E2, whereas E1 was 2.3-3.2 times less potent than E2 (de Mes *et al.* 2005). In addition to its chemical structure, the EE2 concentrations found in wastewater may be influenced by the partial conversion of other pharmaceuticals such as progestins (norethisterone, norethisterone acetate) (Kuhnz *et al.* 1997; Larsson *et al.* 1999). It is also noteworthy to mention that, according to Liu *et al.* (2009), there are reasons to suspect that there are other non-negligible natural estrogens that may also contribute to the estrogenicity in wastewater and should be the focus of future research.

Following metabolism, natural estrogens are excreted in conjugated form and during transport, fecal bacteria hydrolyze the conjugated estrogens back into their original bioactive form (D'ascenzo *et al.* 2003). Likewise, as glucurondasee activity increase from the sewers to the WWTPs, biologically active EE2 may be released (Desbrow *et al.* 1998). Overall, estrogenic activity is mainly associated with E2, its metabolites E1 and E3 and the oral contraceptive EE2.

4.1.2 Household laundering

In addition to excretion, laundering contribute significantly to the estrogenicity of wastewater effluent due to the release of nonylphenol ethoxylates (Soares *et al.* 2008). Ranging from 0.1% to as high as 25%, nonylphenol ethoxylates are not only found in laundering products, but in textiles, cosmetics and lubricants (US Department of Health and Human Services 2013). To put this in perspective, the European Union has forbid the use of NPEs at concentrations higher than 0.1% of the total product formulation since 2005 (Eurofins Product Testing 2012). In the US, due to the extensive use of NPEs and their incomplete degradation, high concentrations of

NPEs and NP, which is more persistent in the environment; reach WWTPs (Ahel *et al.* 1994; Johnson *et al.* 2000; Koh *et al.* 2008; Nakada *et al.* 2006; Shao *et al.* 2003). For example, Shao *et al.* (2003) measured a total of 49.31 ug/l of NPEs in the wastewater influent, of which 70% had already been partially transformed to NP within the sewer system.

4.2 Wastewater Treatment

Citizens of New York on average use approximately 100 gallons/day, this is twice compared to most Europeans cities and many places within the US (NYC Department of Environmental Protection 2011). To manage such an overwhelming usage of water, fourteen wastewater treatment plants throughout the five boroughs of New York City are responsible for treating a capacity of 1,805 millions gallons daily of dry weather flows of wastewater (Fig. 2). Two WWTPs in the Bronx, two in Staten Island, three in Queens, five in Brooklyn and one in Manhattan.

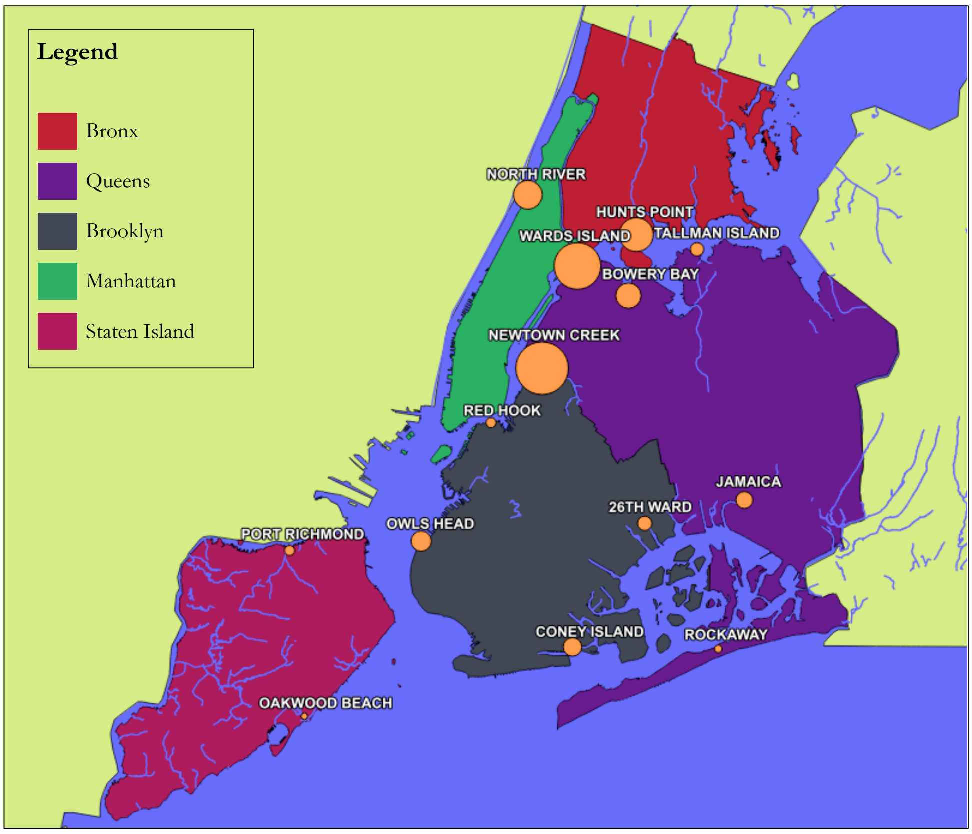


Fig. 2. The location and size of New York City wastewater treatment plants. Data source: NYC Department of Environmental Protection 2011.

Table 2. Capacity of NYC Facilities. Data source: NYC Department of Environmental Protection 2011 (with amendments).

Size	Capacity (Mgd)	Facility Name	Borough
Large:	310	Newtown Creek	Brooklyn
	275	Wards Island	Bronx
	200	Hunts Point	Bronx
Medium:	170	North River	Manhattan
	150	Bowery Bay	Queens
	120	Owls Head	Brooklyn
	110	Coney Island	Brooklyn
	100	Jamaica	Queens
Small:	85	26th Ward	Brooklyn
	80	Tallman Island	Queens
	60	Port Richmond	Staten Island
	60	Red Hook	Brooklyn
	45	Rockaway	Queens
	40	Oakwood Beach	Staten Island

The Newtown Creek is the largest WWTP and is located in Brooklyn, followed by Wards Island and Hunts Point WWTPs located in the Bronx (Table 2).

4.2.1 Wastewater influent

There have been numerous studies on the concentration of estrogens and estrogen mimics in wastewater influent however there is great variation between the values measured (Table 3). For example, estrone was measured at 44 ng/l by Baronti *et al.* (2000), not detected or at low concentrations such as 18 ng/l by Tan *et al.* (2007). This was also found to be true for E2 and E3. (Tan *et al.* 2007) measured E2 between 3 and 226 ng/l whereas, both (Baronti *et al.* 2000; Servos *et al.* 2005) reported E2 concentrations between 2 and 26 ng/l. Estriol was detected at much high concentrations (57 and 72 ng/l) by Johnson *et al.* (2000) and D'ascenzo *el al.* (2003) respectively. As mentioned in Section 4.1, there are variations in estrogen excretion between individuals however, it is most likely that the differences in techniques used to measure estrogen concentrations has contributed to this variation and can be the limiting factor for detection capabilities. As for EE2 and NP, there are few studies that have measured concentrations in the influent.

Table 3. Mean influent to effluent percent reduction averages of estrogenic hormones at WWTPs with activated sludge treatment. Source: Hamid and Eskicioglu 2012, Teske and Arnold 2008 (with amendments).

Compound	Influent (ng/l)	Effluent (ng/l)	% Reduction	Study
E1	44	17	61%	(D'ascenzo *et al.* 2003)
	19 – 78	1 – 96	-62 – 98%	(Servos *et al.* 2005)
	25 – 132	2.5 – 8.2	61%	(Baronti *et al.* 2000)
	42	6.7*	74%	(Johnson *et al.* 2000)
	40, 27	6.8*, 27*	83%, 0%	(Ternes *et al.* 1999b)
	n.d. – 18	–	-233 – 100%	(Tan *et al.* 2007)
E2	11	1.6	85%	(D'ascenzo *et al.* 2003)
	2.4 – 26	0.2 – 14.7	-18.5 – 97.8%	(Servos *et al.* 2005)
	4.0 – 25	0.35 – 3.5	87%	(Baronti *et al.* 2000)
	12	1.4*	88%	(Johnson *et al.* 2000)
	21, 15	0.02*, 5.4*	99.9%, 64%	(Ternes *et al.* 1999b)
	3 – 226	–	90 – 100%	(Tan *et al.* 2007)
	(45)	15*	67% (median)	(Nasu *et al.* 2001)
E3	72	2.3	97%	(D'ascenzo *et al.* 2003)
	24 – 188	0.43 – 18	95%	(Baronti *et al.* 2000)
	57	13*	77%	(Johnson *et al.* 2000)
	n.d. – 185	n.d.	100%	(Tan *et al.* 2007)
EE2	0.40 – 13	n.d. – 1.7	85%	(Baronti *et al.* 2000)
	6	1.3*	78%	(Ternes *et al.* 1999b)
NP	110–430 nMol/l	–	65%	(Ahel *et al.* 1994)
	199 µg/l	–	-623 – 95%	(Solé *et al.* 2000)
	49.31 ug/l			(Shao *et al.* 2003)

* Calculated using % reduction average
n.d. No detection

Most notably, NP is an order of magnitude greater in concentration compared to the estrogenic hormones. This does not suggest that higher concentrations have stronger effects. In recent years it has been shown that dose-response relationships can vary between compounds; low doses do not necessarily cause weaker effects compared to high doses (Vogel 2005). This is the principle behind the montonic dose-response relationship of classic toxicology, which does not hold true for EDCs (Vogel 2004).

Current wastewater treatment plants do not have appropriate facilities to remove all organic contaminants (i.e. steroids, pharmaceuticals, surfactants, etc) thus, residual concentrations are found in both the effluent and the biosolids in North America and Europe. Unfortunately, these facilities are in compliance with State and Federal regulations.

Known removal pathways for estrogens and estrogen mimics during conventional wastewater treatment consists of volatilization, biodegradation, adsorption onto solids and abiotic degradation (Hamid and Eskicioglu 2012). Depending on the physical, chemical and biological conditions (i.e. temperature, presence of oxygen, pH, etc) for each stage of wastewater treatment, various removal pathways occur.

In New York City, most WWTPs have activated sludge treatment and a select few have advanced nitrogen removal. Currently, specific data on the individual wastewater treatment plants' removal efficiencies are not available. Thus, conventional wastewater treatment will be discussed to demonstrate the average removal efficiencies and the uncertainties at each stage.

4.2.2 Preliminary treatment

The purpose of preliminary treatment is to remove large objects by passing the raw sewage through bar screens. During this physical process, little organic matter is removed and therefore most remains suspended and in dissolved form . Therefore, little to no hydrophobic compounds are removed during preliminary treatment (Khanal *et al.* 2006).

4.2.3 Primary treatment

By gravitational force, primary treatment removes organic solids. First, the influent is pumped into the primary settling tank where fats, oils, grease and/or primary sludge partition from the water phase (Water Environment Federation 2008). As a result, solids are removed from the aqueous phase and defined as primary sludge.

Being a predominately physical process, primary treatment is mainly governed by particle density. Therefore, considering that steroid estrogens and NPEs have a tendency to sorb to particulates, removal takes place through both flotation and sedimentation (Ahel *et al.* 1994; Khanal *et al.* 2006). According to Teske and Arnold (2008), 10% of estrogenic compounds is predicted to be removed as a result of sedimentation. However, to make estimates of estrogen removal, equilibrium between the solid and aqueous phase must be assumed. Therefore, this may result in the overestimation of primary treatment removal rates (Hamid and Eskicioglu 2012). As for NPEs, concentrations are significantly reduced via adsorption onto primary sludge due to their hydrophobic properties (Ahel *et al.* 1994). Adsorption is the principle route of removal in WWTPs. Up to 90% of removed NPEs are associated with sludge solids (Scrimshaw and Lester 2003; Shao *et al.* 2003).

After primary settling, the primary sludge is passed through a grit removal compartment known as the cyclone degritter in order to remove grit-like particles from damaging downstream process equipment and piping (Water Environment Federation 2008). Minimal removal of steroid estrogens and NP occurs due to the large particle size of the grit and the small surface area to volume ratio for adsorption.

4.2.4 Activated sludge treatment

From the primary settling tank, the supernatant, consisting of lighter particulate matter, is transferred in the aqueous phase to the aeration chamber to promote aerobic biodegradation. The supernatant is "the liquid remaining above a sediment or precipitate after sedimentation"(Water Environment Federation 2008). Aerobic digestion by sewage bacteria requires oxygen to facilitate the stabilization and reduction of the total organic waste mass. Also, volatile solids are eliminated thereby reducing the odor of both the activated sludge and the remaining supernatant (Water Environment Federation 2008). The volatility of a substance can be predicted by the Henry's law constant (H) which indicates the ratio of the substance dissolved in water to air. Compared to volatile organic compounds which have values in the range of 10^3, both natural and synthetic estrogenic compounds have low H values that range from 6.3×10^{-7} to 2.0×10^{-11} (Lai *et al.* 2002). Therefore yielding minimal removal of estrogens due to volatilization (Estrada-Arriaga and Mijaylova 2010; Hamid and Eskicioglu 2012; Khanal *et al.* 2006). Meanwhile, NP is a semi-volatile compound with an H value of 11.02 (European Union 2002) and can be removed during biological treatment.

The reduction of organic waste mass depends on present bacteria to oxidize organic wastes through the uptake of nutrients and oxygen resulting in the respiration of carbon dioxide, water, sulphates and phosphates. This oxidation reaction causes the 'biological mass' to grow and form flocs. During activated sludge treatment, adsorption plays a key role in the removal and biodegradation of lipophilic compounds such as estrogens and NPEs (Ahel *et al.* 1994; Khanal *et al.* 2006). Yet on the contrary, from primary and secondary sludge to the anaerobic digestors, NP concentrations have been observed to increase as a result of the degradation of NPEs to NP along with the concentration effect caused by decrease in organic matter (González *et al.* 2010). Lastly, after a standard time period, the wastewater is pumped into the final settling tank where the flocs, also known as activated sludge, are removed. A fraction of the activated sludge is recycled back into the aeration chamber to replenish the bacteria population that is gradually lost.

In WWTPs with activated sludge treatment, the influent to effluent % reduction averages for estrogenic hormones and NPEs are highly variable (Table 3) and not well understood (Teske and Arnold 2008). Specifically for EE2 and NPEs, few studies have estimated the percent reduction average during wastewater treatment (Ahel *et al.* 1994; Baronti *et al.* 2000; Ternes *et al.* 1999a; Ternes *et al.* 1999b).

Some studies have shown that the removal of hydrophobic EDCs, such as estrogens, during activated sludge treatment is highly dependent on several factors:

(1) Redox conditions (Joss *et al.* 2004)

(2) Hydraulic retention time (HRT) (Svenson *et al.* 2003)

(3) Solids retention time (SRT) (Holbrook *et al.* 2002; Johnson and Sumpter 2001)

(4) Partition coefficient of compound between the water phase and activated sludge (Khanal *et al.* 2006).

Redox conditions refer to the degree of the oxiding or reducing condition, which can facilitate either anaerobic or aerobic degradation with the presence of microbes. Hydraulic retention time is the time of retention of the aqueous supernatant in a biological wastewater treatment system whereas the solids retention time refers to the time of retention of suspended solids in a biological wastewater treatment system (Water Environment Federation 2008).

Thus, emphasizing the importance of site specific parameters to control the estrogenic activity in wastewater effluent (Hamid and Eskicioglu 2012; Teske and Arnold 2008). However, this is mostly in references to steroid estrogens. Biodegradation played a minor role in eliminating NP during activated sludge treatment (Ahel *et al.* 1994). The key factors that were observed to affect the removal of nonylphenol were temperature and aeration (Tanghe *et al.* 1998). While such factors may enhance the removal of NPs during biological treatment, most NPs are removed during sedimentation via primary and secondary sludge (Ahel *et al.* 1994).

4.2.5 Disinfection

The final treatment process before wastewater effluent is discharged into the aquatic environment is disinfection. On contact, chlorine oxidizes cellular material which leads to the destruction of cellular proteins. Chlorination involves the application of chlorine gas, liquid hypochlorites and/or chlorine dioxide and results in hydrolysis. Chlorine is the most widely used disinfectant at WWTPs due to high chlorine production in the US (Water Environment

Federation 2008). According to Lee *et al.* (2004), chlorine is an active agent that reduces the estrogenicity, yet the formation of chlorination by-products such as chloro-phenol is a major disadvantage that should taken into consideration. For example, 4-chloro-E2 has been shown to elicit strong estrogenic activity nearly equivalent to estrone (Hu *et al.* 2003). More studies should be conducted to further understand the matrix interferences and the risk associated with the by-products formed during chlorination.

4.2.6 Sludge stabilization

Both the primary and activated sludge are channeled together to a sludge gravity thickener where the sludge is concentrated and physically separated from the fluids by sedimentation (Water Environment Federation 2008). The overflow of sludge is re-channeled back to the primary settling tank where it is treated for a second time, while the remaining thickened sludge collected from the bottom is sent to anaerobic digesters for stabilization.

Anaerobic digestion occurs as a three-stage process (Water Environment Federation 2008). First, complex organic compounds are broken down by extracellular enzymes into simple organics. Then, acetogenic bacteria transforms the simple organics into long-chain fatty acids. In the final stage, different bacteria convert organic matter, hydrogen, carbon dioxide and acetate to methane and bicarbonate. These methane-forming bacteria are particularly sensitive to environmental conditions, reproduce slowly and therefore are the limiting factor in anaerobic digestion. Following stabilization, all digested sludge is sent to storage tanks before it is moved onsite or transported offsite by boat to the closest dewatering facilities.

Few studies have investigated the fate of estrogenic compounds during anaerobic digestion. According to Holbrook et al. (2002), estrogenicity increases through the anaerobic digestion process as a result of metabolite formation. Likewise, (Andersen *et al.* 2005) measured a notable increase of estrogen concentrations: 7 to 25.2 ng/g of E1, 1.7 to 5.1 ng/g of E2, and 3 to no detection of EE2 during sludge stabilization at 33 °C and 20-day solids retention time (SRT). However, some studies found lower E1 and E2 concentrations after anaerobic digestion (Fernandez *et al.* 2009; Ternes *et al.* 2002), while others Zhang *et al.* (2011) found increases in E1 and EE2 by 30.2% and 5.3%, respectively. This was thought to be caused by either the cleavage of conjugated estrogens by sludge bacteria or the desorption processes from the sludge. Carballa *et al.* (2006) found that parameters such as SRT or thermal pretreatment did not enhance the removal of EDCs. Mesophilic conditions compared to thermophilic slightly improved the removal of EE2 from 75% to 85%, yet had no effect on E1 and E2. Mesophilic refers to temperatures between 20 and 45 degrees C and thermophilic refers to temperatures between 45 and 120 degrees C.

During anaerobic digestion, nonylphenol ethoxylates are converted to nonylphenol, thus increasing the concentration of NP (Maguire 1999). Compared to aerobically digested sludges, Ginger *et al.* (1984) observed that anaerobically digested sludges had 4-5 times more NP. This accumulation of nonylphenolic compounds during anaerobic digestion causes concern about the land application of biosolids and the trace contaminants present (Teske and Arnold 2008).

4.3 Release to the Environment

Steroid estrogens concentrations in effluents are variable, and have been extensively studied compared to NP. E1, E2 and E3 influent concentrations have been observed as follows, respectively: n.d. – 132 ng/l, 2.4 – 226 ng/l, and n.d. – 188 ng/l. Depending on the parameters and dynamics discussed earlier, estrogen removal rates fluctuate drastically between studies. Maximum E1, E2 and E3 concentrations observed in effluent were 96 ng/l, 15 ng/l, and 18 ng/l respectively. Meanwhile, the range of EE2 concentrations found influent are much lower (0.40-6 ng/l) and has been measured in the effluent at 1.7 ng/l. Most concentrations of estrogens discharged to the aquatic environment lie approximately within the range of 1 and 20 ng/l. Of the nonylphenolic compounds that reach the WWTP, 60-65% are discharged to the aquatic environment. Wastewater discharge typically consists of 25% nonylphenol, 19% nonylphenol carboxylates, 11% short nonylphenol ethoxylates and 8% untreated compounds (Ahel *et al.* 1994). Even with removal efficiencies greater than 90% NPEs have been measured at high concentrations and have been shown to persist in the aquatic environment (Lee Ferguson and Brownawell 2003).

In New York City, WWTP discharge wastewater effluent to five waterbodies: the Hudson River, Jamaica Bay, NY Bay, East River and Kill Van Kull tidal strait (Table 4). Of these waterbodies, the Jamaica Bay and the East River receive the the highest discharge rates with maximum daily discharges of 340 and 800 million gallons per day (Mgd), respectively.

Table 4. Maximum daily discharges into NYC waterbodies. Source: NYC Department of Environmental Protection 2010.

NYC Waterbody	Maximum Daily Discharge (Mgd)
Hudson River	
North River	170
TOTAL	**170**
Jamaica Bay	
Coney Island	110
Jamaica	100
26th Ward	85
Rockaway	45
TOTAL	**340**
NY Bay	
Owls Head	120
Oakwood Beach	40
TOTAL	**160**
East River	
Newtown Creek	310
Hunts Point	200
Bowery Bay	150
Tallman Island	80
Red Hook	60
TOTAL	**800**
Kill Van Kull	
Port Richmond	60
TOTAL	**60**

4.3.1 Partitioning factors

The impacts of estrogenic hormones on the local environment due to wastewater discharge varies depending on many parameters. Firstly, the physical and chemical properties associated with an estrogenic compound and its form (i.e. free versus conjugated) set the conditions which control the transportation, degradation and to a larger extent, the fate of estrogens within the aquatic environment.

Both vapor pressure and solubility are saturation properties which measure the maximum capacity of a solvent (air and water) for a dissolved compound (i.e. estrogens). Considering that all estrogens have low vapor pressures (Table 5), it can be interpreted that estrogen concentrations in the air pose little threat to air pollution and/or the transport of estrogens. Meanwhile, volatilization is an important factor for the transport of NP due to its relatively high vapor pressure (Ney 1990). As for the solubilities of estrogenic compounds, there is greater variance. The solubility of natural estrogens is much higher (13 mg/l) than that of EE2 (4.8 mg/l) and NP (6.2 mg/l). This suggests that in comparison to EE2 and NP, natural estrogens will dissolve at higher concentrations in water.

Table 5. Physical-chemical properties of estrogens. Source: Hamid and Eskicioglu 2012 (with amendments).

Chemical Name	Molecular weight (g)	Vapor pressure (Pa)	Solubility ($mg\ l^{-1}$) a	Henry's Constant ($Pa\ m^3\ mol^{-1}$) b	log K_{ow}
Estrone	270.4	3×10^{-8}	13	6.20×10^{-7}	3.13
Estradiol	272.4	3×10^{-8}	13	6.30×10^{-7}	4.01
Estriol	288.4	9×10^{-13}	13	2.00×10^{-11}	2.45
Ethinylestradiol	296.4	6×10^{-9}	4.8	3.80×10^{-7}	3.67
Nonylphenol	220.3	4.5×10^{-3} [c]	6.2 [c]	11.02 [d]	4.48 [e]

[a] Liu *et al.* 2009
[b] Lai *et al.* 2002
[c] US Environmental Protection Agency 2005
[d] European Union 2002
[e] Ahel and Giger 1993

Similar to solubility and vapor pressure, Henry's constant provides an estimate of the air-water partitioning tendency and is preferably measured directly when vapor pressure and solubility are very low. Henry's constant is the ratio of partial pressure in air (Pa) to the concentration in water (mol/m3). Comparing Henry's constants, estriol has the lowest value mostly due to its low vapor pressure, meaning that it concentrates more in the water phase compared to the air phase, whereas NP has a higher value, which suggests that the exchange between the air and water phase is likely (Ney 1990).

Lastly, the octanol-water partition coefficient (K_{ow}) represents the partitioning between water and organic matter such lipids, waxes, humin and humic acid found in soil and sediment. In Table 5, all compounds have a log K_{ow} value greater than 3; this mean that they are hydrophobic and tend to accumulate in soils and sediments rather than remain in the water phase. According to Lai *et al.* (2000), synthetic estrogens, including EE2 tend to partition to the sediment more than natural estrogens (E1, E3). With a log K_{ow} of 4.48, NP as well as estradiol with a log K_{ow} of 3.94 partition mostly to organic matter. In addition to having a high partion coefficient, NP has low mobility in sediments (Barber *et al.* 1988).

In NYC's Jamaica Bay, E1, E2 and NPEs were detected in the sediment. Reddy and Brownawell 2005 measured E1 and E2 at low-ng/g concentrations, however the predicted estrogenic activity was two times greater than the NPEs. However, in this environment, E1, E2 as well as NPEs remain stable to further degradation and transformation. Synergistic effects and uncharacterized estrogenic compounds are expected to contribute to the estrogenic activity, however further research is needed to fully understand these relationships (Reddy and Brownawell 2005).

4.3.2 Water characteristics

Besides physical-chemical properties, environmental conditions play an important role in the transport and biological effects of contaminants in both the water column and sediment. In aquatic environments, salinity, temperature, and pH have the potential to affect the solubility and consequently the K_{ow} of contaminants. This suggests that contaminant transport and biological mechanisms are also affected by such variables. In the case of wastewater discharge to saline environments such as oceans, estuaries, and bays, mixing of freshwater and saltwater is common and can help serve as an effluent tracer (Ferguson *et al.* 2001). Research has shown that as a result of an increase in NaCl (salinity), estrogen sorption to sediment increases (Lai *et al.* 2000). In a recent study, sorption and persistence of the EDC Bisphenol-A in sediments was observed with increasing salinity, decreasing temperature and increasing pH (Borrirukwisitsak *et al.* 2012). Likewise, according to Marschner (1999), an increasing pH caused higher sorption rates. This was thought to be caused by pH induced solid organic carbon swelling that increased the surface area of particles, in turn facilitating higher sorption rates due to the increase in available binding sites. According to Li *et al.* (2004), higher water temperatures in warmer seasons facilitate the microbial degradation of NP in rivers. As for the biological implications, temperature has been shown to have an effect on the production of vitellogenin in rainbow trout (Purdom *et al.* 1994). Little research has been focused on the biological effects (i.e. uptake, elimination) of salinity or pH.

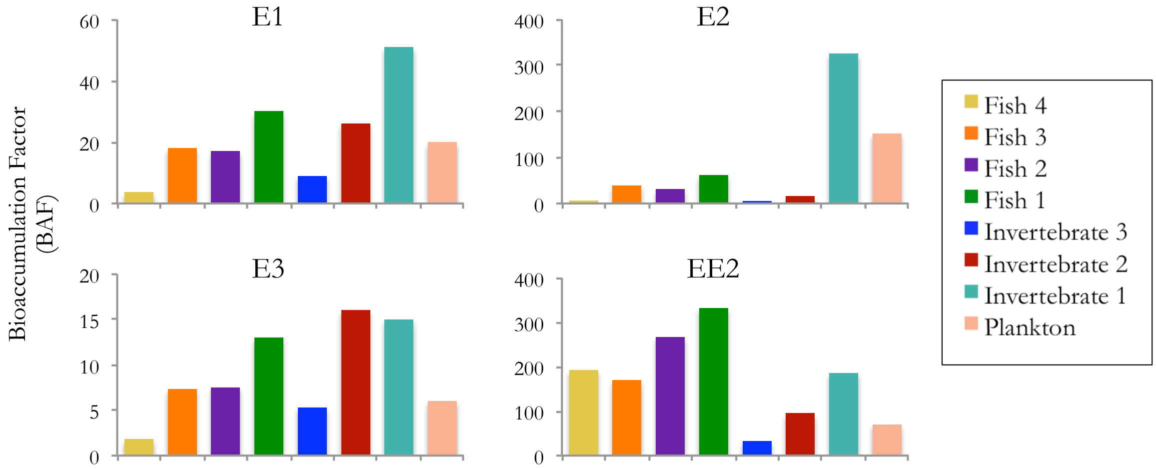
4.3.3 Bioaccumulation

As steroidal estrogens and NPs accumulate in sediments and remain in the water column, as a result of discharge or storm-surge events, potential for biota to be exposed to estrogens becomes a significant environmental and health concern. Depending on the aquatic organisms present, predator-prey relationships, and persistence of the chemical, bioaccumulation may also occur.

Bioaccumulation refers to the net amount of a chemical found in an organism after uptake, metabolism and elimination and the two main routes of uptake are respiration and food; whereas, bioconcentration is the specific bioaccumulation process that causes the concentration of a chemical to be higher in an organisms compared to its surroundings (air or water) (Arnot and Gobas 2006). The main difference being that bioaccumulation includes feeding and bioconcentration does not.

Bioaccumulation factors (BAF) are used to quantify the rate of accumulation and are based on the metabolic rate, log K_{ow} and concentration of the pollutant (Lai *et al.* 2002). The slower an organism's metabolism is the longer it take to eliminate the compound compared to the uptake. The more hydrophobic the chemical is, the larger the log K_{ow}, the more the chemical bioaccumulates in the fatty tissues of fish and other organisms.

According to Lai *et al.* (2002), although estrogens are biodegradable, bioaccumulation is likely to occur. A model was used to predict the BAFs for all estrogenic compounds in various organisms with a given predator-prey relationship (Fig. 3). Fish 4 represents a fish species at the highest trophic level and its diet consists of 50% from Fish 2, 40% from Fish 3, and 10% from Fish 1. Fish 1 and 2 preys solely on Invertebrate 1 and 2, yet at varying ratios. Invetebrate 1 differs from invetebrate 2 such that it preys on the other as well as plankton, whereas Vertebrate 2 lives feeds on the sediment. Resulting from this study, bioaccumulation occurred in all organisms and invertebrates exhibited the highest BAF for natural estrogens. However, for synthetic estrogen EE2, Fish 1 and 2 accumulated the most compared to invertebrates. Estradiol (E2) accumulated mostly in Invertebrate 1 with little accumulation in other organisms while, estrone (E1) likewise accumulated in Invertebrate 1 and to a lesser extent, in other organisms (Lai *et al.* 2002).



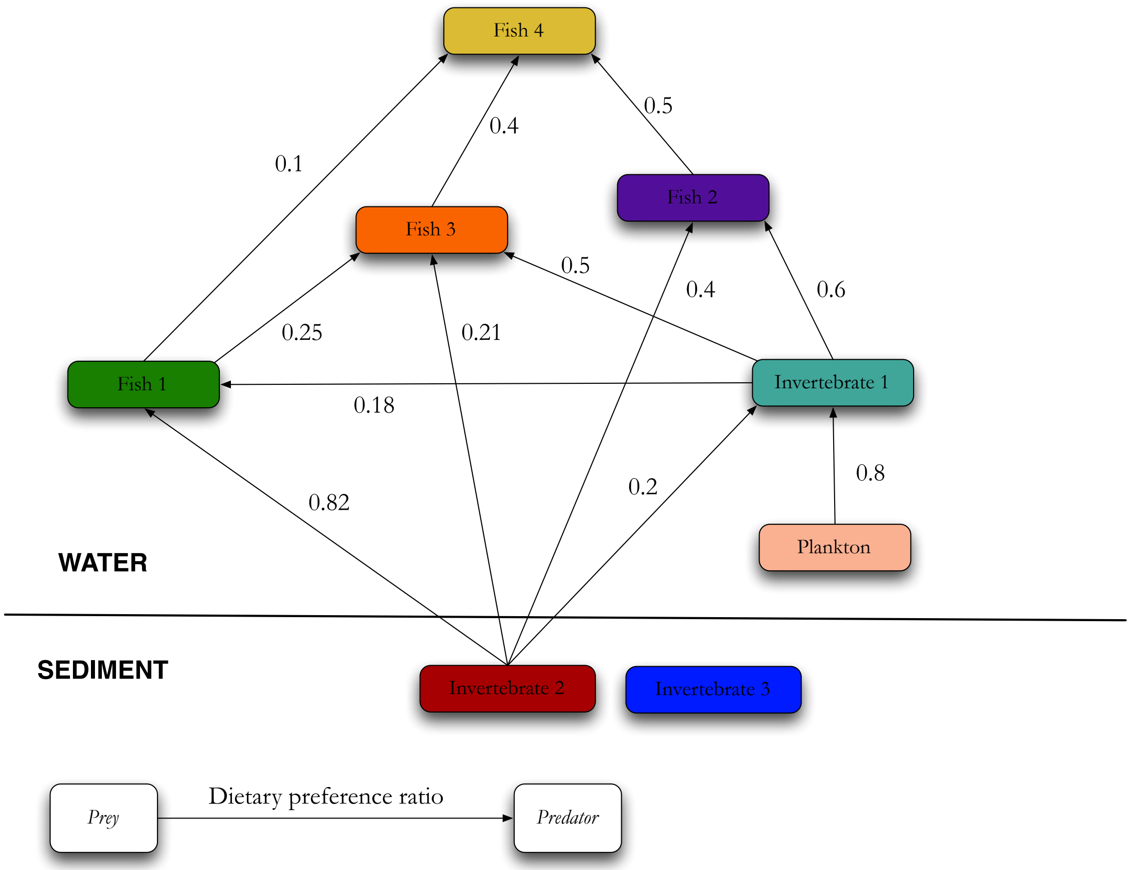


Fig. 3. Uptake of estrogens throughout the food chain. Data source: Lai *et al.* 2002.

Similarly to natural and synthetic estrogens, NP has been observed in algae fish and aquatic birds nearby contaminated waterbodies (Ahel *et al.* 1993; Snyder *et al.* 2001). According to Ahel *et al.* (1993), high concentrations between 1.5 and 38 mg/kg of NP were found in algae with bioconcentration factors ranging from 200 and 10,000, whereas fish had significantly lower concentrations between 0.03 and 1.59 mg/kg with bioconcentration factors ranging from 13 to 408. In another study, fathead minnows *Pimephales promelas* exposed to low concentrations of NP (0.33 - 2.36 μg/l) lead to bioaccumulation with a bioconcentration factor between 245-380 (Snyder *et al.* 2001). Not only has it been suggested that low concentration exposure to NP can cause accumulation in marine organisms (Ekelund *et al.* 1990), NP has been found in numerous foods items, which may very well pose a threat to human health (Guenther *et al.* 2002).

4.3.4 Complex mixtures & matrix effects

As wastewater is discharged to the water bodies, many other compounds besides estrogens are present causing largely variable and seemingly unpredictable effects. Such effects of numerous chemical present in wastewater effluent is largely unknown and is therefore difficult to model. However, observations were made that biological responses differed when EE2 was in a complex mixture or alone (Filby *et al.* 2007). Effluent with EE2 caused a stronger biological response compared to EE2 alone, which resulted in no immuno-response, suggestion that there is an interactive effect between present compounds. Filby *et al.* 2007 refered to this observation as paradoxical and hypothesized that coexposure may have effected the absorpotion, distribution metabolism, and/or signaling which could have facilitated other biological actions of immunitoxic chemicals present or vice versa.

> *"The results cast doubt on the accuracy of chemical safety testing regimes that rely solely on testing individual chemicals instead of mixtures, which is how exposure occurs in the environment" (Orlando and Hessle 2007).*

Comparing to other endocrine disruptors, the BAF of estrogens is orders of magnitude smaller than the well-studied pesticide DDT, mostly due to its high hydrophobicity (log K_{ow} = 6.91) (Arnot and Gobas 2006). However, adverse effects on the development, growth and reproduction of organisms have been caused by estrogenic compounds (Jobling *et al.* 1998; Matozzo *et al.* 2008; Wright-Walters and Volz 2009). Research continues to better understand the chemical and biological effects of multiple pollutants in hopes to better understand the risks to the environment and human health.

4.3.5 Aquatic environmental impacts

Estrogenic effects in aquatic organism has been elicited by both natural and synthetic estrogens as well as the biodegradation products of NP (Kinnberg *et al.* 2000b; Tyler *et al.* 1998). As previously discussed, vitellogenin (vtg) is a biomarker used to detect fish feminization. In male fish, the production of vtg can cause kidney and thyroid disfunction (Wester and Canton 1986), and decrease metabolic expenditure for growth and spermatogenesis (Herman and Kincaid 1988). In female fish, an increase in vtg concentrations can lead to a feedback mechanism that reduces the concentration of estradiol (Reis-Henriques *et al.* 1997), which may reduce egg quality (Vethaak *et al.* 2002).

The synthesis of vtg was induced in rainbow trout *Oncorhynchus mykiss* and medaka fish *Oryzias latipes*, at NP concentrations of 20.3 mg/l, and 0.1 mg/l respectively (Jobling *et al.* 2006; Tabata *et al.* 2001). In addition, the platyfish *Xiphophorus maculates* produced vtg at concentrations ≥0.96 mg/l and its testis morphology and male fertility were negatively affected after just 4 weeks of exposure (Kinnberg *et al.* 2000a). As for EE2, vtg production was induced in male zebrafish *Danio rerio*, Japanese Medaka *Oryzias latipes* and rare minnow *Gobiocypris rarus* after exposure to concentrations between 0.2 and 10 ng/l (Ma *et al.* 2007; Xu *et al.* 2008; Zha *et al.* 2008). Not only have EDCs been shown to cause effects individually, the combination of numerous EDCs can be additive or synergistic, even at low concentrations (Kwak *et al.* 2001; Rajapakse *et al.* 2002; Silva *et al.* 2002).

In New York City, recreational and, to a lesser extent, commercial fishing takes place throughout the 9 local bodies of water such as: Jamaica Bay, Flushing Bay, Flushing Creek, Bronx River, Westchester Creek, Newtown Creek, Alley Creek, Coney Island Creek and Gowanus Canal . Within the NYC waters, there are two superfund sites: the Gowanus Canal and Newtown Creek. Unfortunately, fishing is not prohibited and "the fish caught there are used as food" (US Environmental Protection Agency 2013a).

According to DEC (n.d.), the following species are of most important species for recreational fishing and consequently consumption: striped bass, winter flounder, summer flounder, bluefish, weakfish, tautog, porgy, black sea bass, striped sea robin, american eel, little skate, and spiny dogfish (Fig. 4).

Fig. 4. Fish species in New York Harbor. Data source: Don Flescher (illustrations).

Water quality tests are performed by the DEP and regulated by the DEC, however EE2 and NP are not measured. During heavy rains due to combined sewer overflows water quality has decreased. "In the first quarter of Fiscal 2013 New York City waters met the swimmable standard in 56 percent of the samples surveys, as compared to 64 percent during the same period the previous year" (City of New York 2013b).

Considering that organic contaminants tend to accumulate in sediments, benthic organisms and bottom-feeders are most affected by pollution due to their sedentary lives constantly in contact or are frequently exposed to the sediment. Therefore, species such as winter flounder *Pseudopleuronectes americanus* and fluke *Paralichthy dentatus* are indicative test species which are used to measure the biological effects associated with exposure to EDCs in Jamaica Bay.

Over the past decade, attention has been drawn to winter flounder, a very important fish stock for commercial fisheries, due to stock decline in the northeast of the US (Frisk *et al.* 2013). Within the NYC area, Jamaica Bay is a very important spawning ground for winter flounder. Up to 85% of freshwater input to the bay is from wastewater discharges that contain estrogens and estrogen mimics (McElroy 2006). Thus, exposure to endocrine disruptors was thought to affect population level throughout the region by skewing the sex ratio and/or causing adverse reproductive effects. Resulting from studies to investigate this problem, elevated vtg concentrations were measured in winter flounder from Jamaica Bay and estrogens (E1, E2) and NPs were detectible in the sediment, ranging up to 3.08 ng/g and 50.0 ug/g respectively (Ferguson *et al.* 2001; Reddy and Brownawell 2005). Now, it is clear that WWTPs are discharging estrogenic effluent and winter flounder are being affected (Anne McElroy & Bruce Brownawell pers.comm.). These results also suggest that it is likely that the animals within the NYC area are being affected (New York Sea Grant 2006).

4.3.6 Land application of biosolids

In addition to effluent discharge to surface waters, risks are associated with biosolids land application as soil amendments. Throughout the US, as well as in Europe, biosolids are used as fertilizers or soil conditioners that are spread on farmland, cemeteries, parkland, and golf courses (National Research Council 2002; US Environmental Protection Agency 2000). As biosolids are applied to lands, there is concern over contaminants such as NP present and their environmental and human toxicity (Pryor *et al.* 2002). However, land-applied biosolids vary in composition and imply different risks to the environment compared to wastewater discharge to rivers, bays and estuaries. Seepage into groundwater, runoff to surface waters as well as uptake by organisms are the potential risks that harmful compounds in biosolids, such as EDCs, pose on the environment (Andaluri *et al.* 2012; Sabourin *et al.* 2012).

Steroidal hormones found in land-applied waste are likely to persist and may potentially impact the water quality of runoff (Pedersen *et al.* 2005; Yang *et al.* 2012). The persistence of steroidal compounds is mostly a result of the hydophobic properties (log K_{ow}). Some experiments have shown that estrogens affinity for soil is high and is controlled by organic matter (Lai *et al.* 2000). However, E2 has been found in runoff at 3 ng/l (Pedersen *et al.* 2005). (Stumpe and Marschner 2010) explored the effects of dissolved organic carbon (DOC) on sorption and mineralization of estrogens by comparing sewage sludge and cattle manure and found that DOC has a considerable effect on the behavior of estrogens in soil, however more research is needed to fully understand the mechanisms. Likewise, very little is known of the impacts of municipal biosolid application yet some studies on land-applied manure and poultry litter have shown that estrogens can be mobilized during rainfall (Jenkins *et al.* 2009; Kjær *et al.* 2007).

The main pathway for NPs in WWTPs is sorption to sludge. Studies have shown that up to 90% of NP released into the environment is associated with sludge (Scrimshaw and Lester 2003; Shao *et al.* 2003). Concentrations of NP measured in biosolids from Europe and Canada have ranged between 22 and 4000 mg/kg (Bennie 1999). However, a more extensive study on Canadian sludge concluded that the mean concentration of NP was 330 mg/kg for WWTPs that utilize activated sludge treatment with anaerobic sludge digestion (Bennie *et al.* 1998).

Although it is not covered in this paper, animal manure is a significant source of steroidal hormones on agricultural lands (Shore and Shemesh 2003) and should not be under-emphasized. Most importantly, more research is needed to assess the potential for estrogen transport during various agricultural practices (Yang *et al.* 2012), since organic pollutants such as hormones, though at low concentrations, may pose a threat to the environment and the health of living organisms (Lu *et al.* 2012).

Due to the volume of New York City's biosolids, they are processed in a multitude of ways, depending on the City's contracts (NYC Department of Environmental Protection 2011). Within New York State, biosolids in the are disposed in landfills (52%), alkaline treated (14%), incinerated (17%), composted (12%), and directly applied to land (4%) (NYS Department of Environmental Conservation 2011). NYC Biosolids for land application are transported and directly spread on corn crops, wheat and grazing land in Virginia and Colorado as a nutrient source and to allow for further degradation (NYC Department of Environmental Protection 2011). Biosolids that are sold as mulch or soil conditioner to gold courses, gardens, lawns and nurseries are mixed with a bulking agent (i.e. wood chips) and left to degrade for a period of time. The composting facility for NYC biosolids is in Pennsylvania (NYC Department of Environmental Protection 2011). Alkaline treated biosolids were treated with lime or Portland cement to be used as an liming agent on agricultural lands. The facility that performs the alkaline treatment is in New Jersey (NYC Department of Environmental Protection 2011).

4.4 Current Regulations & Programs

4.4.1 Wastewater discharge

There are currently no federal regulations on estrogenic hormones in wastewater effluent. However, there are Federal Acts that give EPA the power to do so under various circumstances. According to the the Clean Water Act (CWA), regulation on wastewater effluent discharge is implemented through the National Pollutant Discharge Elimination System (NPDES) (US Environmental Protection Agency 2009). This is carried out by issuing permits that include limits for any person discharging pollutants to any body of water. In most cases, States are given jurisdiction to directly oversee the wastewater systems within their borders as long as the standards are equivalent or stricter than the federal standard established by the EPA (US Environmental Protection Agency 1989). New York, along with many other states, has opted to self-regulate its wastewater effluent discharges. Yet, the New York State Department of Environmental Conservation (DEC) has not established additional effluent discharge limits on harmful compounds. There are four state-wide standards that limit the concentrations of the biological oxygen demand (BOD), total suspended solids, pH, and the removal of BOD and TSS in wastewater effluent. While, the concentrations of harmful substances in the wastewater effluent discharge are regulated on an individual WWTP basis. Water quality is tested routinely and regulated by the Ambient Water Quality Standards. If concentrations exceed the established limits for water quality, the effluent discharge is then regulated through the permits issued by the NPDES (US Environmental Protection Agency 1989). However, estrogens and estrogen mimics are not among the compounds routinely monitored.

4.4.2 Biosolids

Biosolids, another source of estrogenic compounds, are regulated by the Federal and State governments as Class A and Class B biosolids. The difference is in the degree of pathogen reduction. Class A biosolids required to be treated by "processes to further reduce pathogens" such as composting, pasteurization, drying or heating treatment, alkaline treatment whereas Class B biosolids are treated with "processes to significantly reduce pathogens" such as aerobic digestion, anaerobic digestion, air drying and lime stabilization (US Environmental Protection Agency 2000). Neither Class A or Class B biosolids require testing under federal regulations for organic pollutants because "the organic chemicals of potential concern have been banned or restricted for use in the United States, are no longer manufactured in the United States, are present at low levels in biosolids based on data from a national survey, or because the limit for an organic pollutant based on a risk assessment is not expected to be exceeded in biosolids" (NYS Department of Environmental Conservation 1999). Tests and limits only apply for nutrients and metals such as nitrogen, phosphorus and mercury, arsenic, lead, cadmium, etc (NYS Department of Environmental Conservation 2011).

4.4.3 Endocrine Disruption Screening Program

Addressing harmful exposure to endocrine disruptors, the EDSP aides to regulate harmful hormone mimics that may cause risk to human health and the environment. Once a compound has been screened and tested through the EDSP, it must then be approved by one of four acts in order to be regulated at the federal level. Considering the end-points, the risks involved for estrogenic hormones and nonylphenol, the SDWA and the TSCA are currently the most relevant acts that can approve their federal regulation.

The SDWA gives the EPA power "to set legal limits on the levels of certain contaminants in drinking water". These legal limits are established to protect human health by using the best available technology as well as establishing water monitoring schedules. This is carried out by requiring the EPA to issue a list of no more than 30 unregulated contaminants every five years to monitor their concentrations in public water systems. Recently, in May of 2012, the Unregulated

Contaminant Monitoring Rule 3 list was submitted and included E1, E2, E3 and EE2 a part of its List 2 Screening Survey. This will result in monitoring from January 2013 to December 2015 and then a report upon its completion. The SDWA allows states to set and enforce their own standards for drinking water just as the CWA does for wastewater effluent.

The TSCA has the power to regulate the "production, importation, use, and disposal of organic and inorganic chemical substances and mixtures, both synthetic and naturally occurring" excluding food, drugs, cosmetics and pesticides (US Environmental Protection Agency 2013b). However, since its enactment, TSCA has not lived up to its expectation to protect public health and the environment (Safer Chemicals Healthier Families 2013). Once the law was in effect, over 60,000 chemicals were approved without testing and have remained grandfathered into the inventory list. Currently, there are more than 84,000 chemicals on the TSCA's inventory list (US Environmental Protection Agency 2011), of which only 200 have been tested and just 5 were restricted (Safer Chemicals Healthier Families 2013).

4.4.4 Chemical safety

A part of the Environmental Protection Agency, the Office of Pollution Prevention and Toxics (OPPT) was created as a result of the TSCA. The responsibilities of the OPPT is to assure that "chemicals manufactured, imported, processed, or distributed in commerce, or used or disposed of in the United States do not pose any unreasonable risks to human health or the environment". OPPT carries out this responsibility by reviewing new and existing chemicals. If a chemical is shown to pose "unreasonable risk" as a result of research findings, the EPA may "ban the manufacture or distribution in commerce, limit use, require labeling, or place other restrictions on chemicals" (US Environmental Protection Agency 2008). Unreasonable risk is a standard that must consider the benefits, risks and costs of regulating a chemical. For new chemicals, manufacturers or importers must submit a pre-manufacture notification (PMN) to the OPPT 90 days prior to manufacturing or importing. Within this time frame, the OPPT must determine whether regulatory action is necessary. Each year, the OPPT receives 1,500 PMNs that contain limited information; "67% have no test data and 85% include no health data" and half of the total received PMNs are approved (US Environmental Protection Agency 2008). Thus, the OPPT must make quick decisions about the risks associated with new chemicals.

4.4.5 Drug approval & monitoring

The Office of New Drugs (OND) is a management body within the FDA Center for Drug Evaluation and Research. Its responsibilities are to oversee investigational studies during the drug development process, make decisions on how drugs can be marketed and to monitor FDA-approved drugs (U.S. Food and Drug Administration 2013). This is carried out by reviewing the data submitted by a pharmaceutical company, which should demonstrate a drug's effectiveness, define its risks and describe its intended use. The OND also is responsible for monitoring and reevaluating previously approved drugs for unexpected health risks as well drug information and advertising.

CH 5: THE APPLICATION OF SYSTEMS DYNAMICS

Systems such as the lifecycle of estrogenic compounds are complex and the mechanisms that control their flow are even more so. Systems dynamics is a tool that can be applied to overcome such complexity by providing a comprehensive visual representation of a system to better understands its functionality. This chapter will discuss the flows of estrogenic compounds and the associated monetary flows that contribute to estrogenicity as well as the Actors and their roles within the system.

5.1 Present Estrogenic System in NYC

5.1.1 Estrogenic flows

In Fig. 5, starting from *Humans*, there are two main inputs to the body and one in greywater that will inevitably become the *Wastewater Influent* at the wastewater treatment facility. In terms of natural estrogens, *Foods* that contain cholesterol are consumed and broken down by the body and the cholesterol is used to synthesize hormones such as E1, E2, and E3. Whereas pharmaceuticals such as *EE2* are manufactured, formulated to *Oral Contraceptives* and *Hormone Replacement Therapies*, distributed to *Pharmacies* and then sold to patients.

Then, as a result of excretion, the synthetic and natural estrogens in the sewage are piped to the network of *Sewers*. The third source, *Nonylphenol Ethoxylates*, synthesized from *Crude Oil*, are dissolved in greywater from laundering and then piped to the *Sewers* where they are mixed in with the sewage. Once the sewage reaches the wastewater treatment plant as *Wastewater Influent*, it is passed through bar screens where is passes through to the *Primary Settling* tank. All particles separated by the bars screens are sent to the *Landfills*. During *Primary Settling*, the fats, oils, grease and sludge are partitioned from the aqueous *Supernatant*. Then, the *Primary Sludge* (fats, oils, grease and sludge) is sent to the *Degritter* where more particulate matter is sent to the landfill

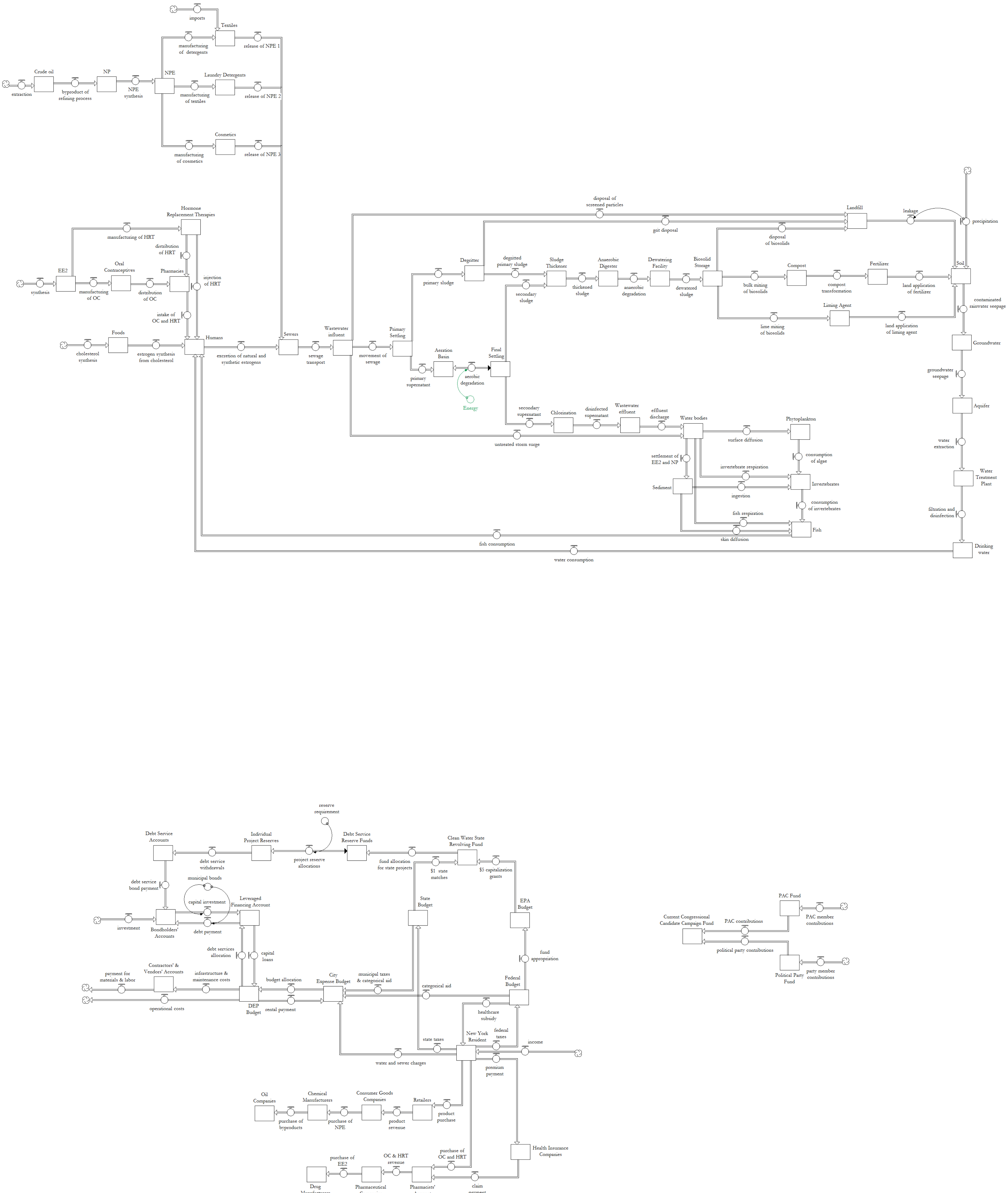


Fig. 5. Model of the current estrogenic system.

while the remaining sludge plus secondary sludge (from *Final Settling*, which will discussed further) enters the *Sludge Thickener* where the sludge is thickening by gravity. After, the sludge is sent to the *Anaerobic Digester* where anaerobic degradation occurs, to the *Dewatering Facility* where water is removed and finally to the *Biosolid Storage* where it remains until sent to the *Landfill*, or further processed for land application.

As for the primary supernatant that resulted from primary settling, it is first sent to the *Aeration* chamber where aerobic degradation occurs and then to the *Final Settling* where the secondary sludge is removed. The resulting secondary supernatant is then disinfected, by *Chlorination* and is then discharged to the local *Water Bodies*.

The two main paths in which wastewater contaminants can reach the environment are via land application of *Fertilizers* and *Liming Agents* and discharge of *Wastewater Effluent*. As a result of land application, biosolid contaminants have the potential to seep into the *Groundwater* during heavy rainfall and could contaminate a nearby *Aquifer*[2]. Then the contaminated water in the *Aquifer* would then be pumped to the local *Water Treatment Plant* where it is then treated. If such treatment processes are not aimed at removing wastewater contaminants such as estrogens and nonylphenols, then trace amounts of these contaminants may be taken up by the body from *Drinking Water*.

In the aquatic environment, *Wastewater Effluent* is discharged to local water bodies, which affects both aquatic organisms and plant life. Partitioning of contaminants between the *Water Column* and *Sediment* occurs and this determines the pathway for potential exposure. *Phytoplankton* uptake contaminants in the water column via diffusion whereas *Fish* and *Invertebrates* bioaccumulate contaminants in the aqueous phase via respiration through the gills. Due to close contact with

2. This is not the case for New York City considering that the source of drinking water is from the Catskills Mountains. However this externality should be considered, regardless of the fact that it falls outside the New York City boundary.

contaminated *Sediment*, Benthic *Fish* may bioaccumulate contaminants. *Fish* who prey on other *Fish* or *Invertebrates* that have previously bioaccumulated contaminants will bioaccumulate more contaminants. Other organisms that are dependent on *Fish*, *Invertebrates* and *Phytoplankton* may be directly and indirectly affected due to food chain dynamics. In the case that *Humans* eat the fish exposed to contaminated waters and sediments, they would too bioaccumulate harmful contaminants. As a result, *Humans* may recycle contaminants into the wastewater system again via excretion.

5.1.2 Monetary flows

Similar to all American cities, New York City residents pay taxes to the City in return for its public services and based on their *income* (Fig. 5). However, taxes are not directly paid to the City. *Federal taxes* and *State taxes* are collected and the State is responsible for allocating appropriate funds to each municipality such as New York City. In Fiscal Year (FY) 2012, the City-funded revenue amounted to $49.4 billion, with an additional $18.1 billion granted by the *Federal* and *State budget* as *categorical aid* to assist various departments with their annual expenditures (City of New York 2013a). There are two main streams of revenue that the City gains from NYC residents: municipal tax revenue and non-tax revenue. *Municipal taxes* are allocated via the State and consist mainly of monies collected based on *income* and property, whereas non-tax revenue are fees and charges based on services such as *water and sewer (charges)*, housing, and general government are directly paid to the City. Among the non-tax revenues, an estimated $1.37 billion was collected in FY 2012 for water & sewer services and the metered water rate was $3.17 per one hundred cubic feet (approximately 748 gallons) (NYC Water Board 2011). *Sewer* (and wastewater) *charges* are 159% of the charges for the water supplied to any property. In addition to the metered charges, there are frontage rates applied to each household/building that have access to the water and sewer network.

Combining both sources of revenues, there are $67.5 billion for the 2012 *City Expense Budget* (City of New York 2012). Considering that the City is known as being an economic hub of the US, it's not surprising that the budget for New York City is bigger than most states (City of New York 2009). Of the $67.5 billion generated from the City's revenues, the *budget allocation* for the services provided by the Department of Environmental Protection was 1.5%, totaling slightly more than $1 billion (City of New York 2013a). In addition to this sum, New York State and the Federal government provided $4.9 million and $26.9 million as *categorical aid*, respectively. Therefore, *DEP Budget* for 2012 consisting of City, State and Federal funding totaled $1.046 billion (City of New York 2013a). *Wastewater Treatment Facilities* rely on the DEP Budget to pay for the *operational & maintenance costs* due to high energy demanding processes such as aeration and heating. Money directed to the *NYC Leveraged Financing Account* for debt service accounts for 46% of the budget, operations and maintenance for 34% and the rental payment made to the City for 6% (NYC Water Board 2012). However, this is not representative of all funds allocated for public services. Continual *capital investment* in sewer & water infrastructure are necessary to ensure that operations are running properly and in compliance with regulations.

Among *Taxpayers* are *Consumers*. *Consumers* make purchases from *Retailers* and *Pharmacies* for products such as detergents, textiles and cosmetics and oral contraceptives and hormone replacement therapies respectively. *Retailers* pay for detergents, textiles and cosmetics from *Detergent Textile & Cosmetics Companies*, and *Pharmacies* pay for oral contraceptives and hormone replacement therapies. For each medication purchase a *Consumer* makes, depending on the deductible (i.e. minimum amount spent), a claim is made by *Pharmacies* to *Health Insurance Companies* for repayment of the intermediated discount during the purchase. Both streams of consumption must pay the *Manufacturers* of their respective active ingredients, such as nonylphenol ethoxylates (NPE) and ethinylestradiol (EE2). Unlike EE2, which is synthesized in a laboratory, NPE is derived from crude oil. *NPE Manufacturers* purchase byproducts such as

NP from the *Oil Companies* and manufacturers NPEs.

The *Clean Water State Revolving Fund* (CWSRF), is a program that is co-funded by *State (revenue)* and *EPA (budget)* to help municipalities receive financial support for projects that help keep water clean. Wastewater and water treatment facilities are both eligible for such support. In order to continue to receive such federal grants, the State must allocate $1 for every $5 granted by the EPA (Environmental Facilities Corporation 2012). The sources of funds for the program are federal capitalization grants, matching State funds, and a series of circulatory recycled monies from de-allocated reserves, bond proceeds and financing payments. The funds are then pooled into the *Debt Service Reserve Funds* that are then allocated for *Individual Project (reserves*). For each project that is funded by the Clean Water State Revolving Fund, *municipal bonds* are issued to investors who provide *capital investment* money in exchange for a stable return on investment. The *municipal bonds* issued under the CWSRF program are senior bonds and are categorized as general obligations backed by the Authority, the City and the State, ultimately backed by the *Taxpayers*. 30% of the *municipal bond* must be set aside using to *Debt Service Reserve Funds* (Environmental Facilities Corporation 2012). Over time, *capital expense payments* are made to *Contractors & Vendors* meanwhile, *debt payments* are made to investors from the *Leveraged Financing Account*.

5.2 Actors, Roles and Influential Responsibilities

Within any social system, there are actors. An actor, defined as "a participants in an action or process", are a part of a system by having role, the "function assumed or part played by a person or thing in a particular situation" (Corliss 2013). Roles directly or indirectly control the flow of money or materials. This section will outline the roles of the most essential Actors in the current system and what influence they have on the the present estrogenic system and its pattern of behavior (Fig. 6).

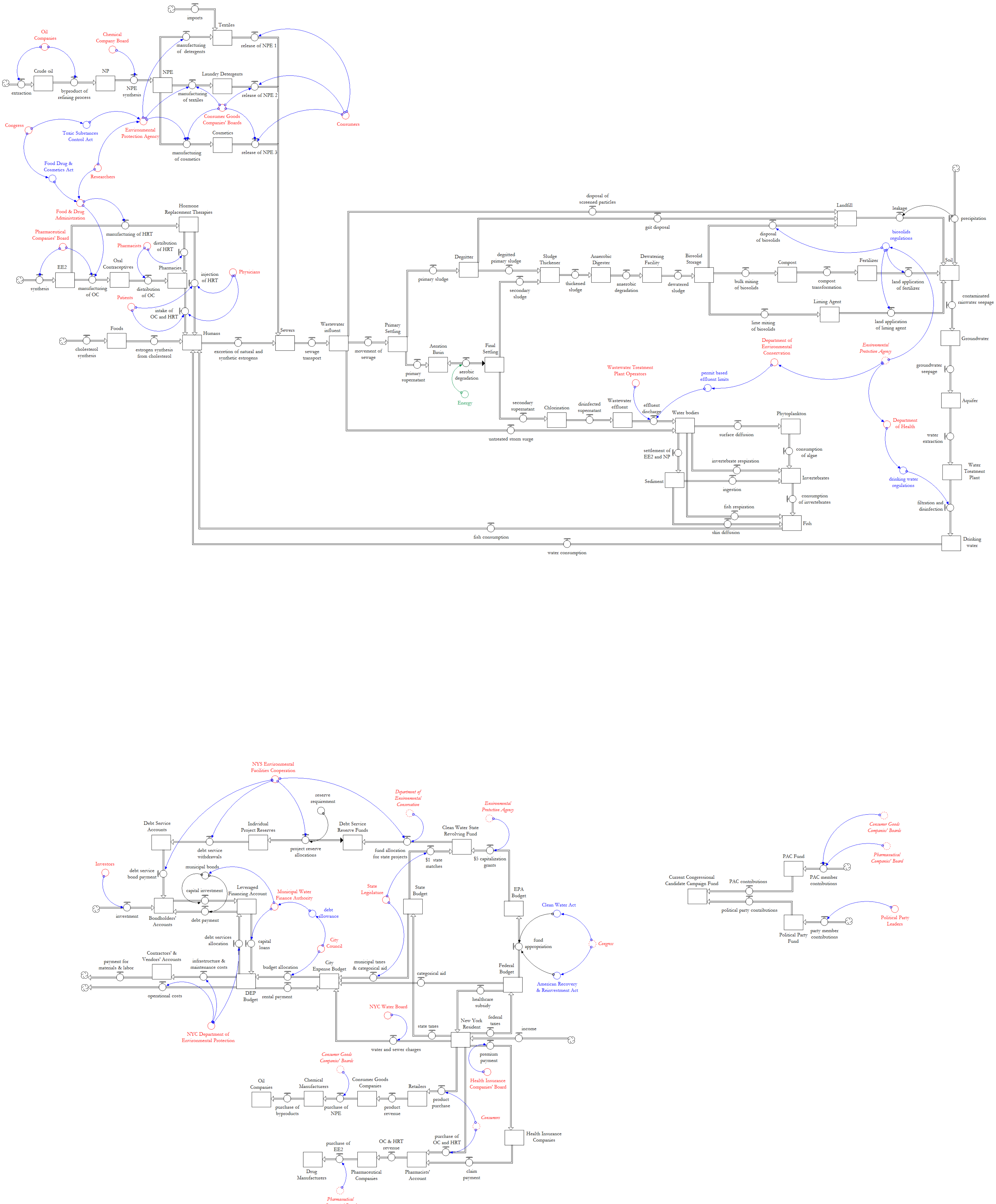


Fig. 6. Model of the current estrogenic system with actors.

5.2.1 NYC Resident

NYC residents have two important roles within the present estrogenic system: consumer and voter. As a consumer, a NYC residents make the decision to purchase products that contain the nonylphenol ethoxylates and ethinylestradiol, which are a washed into the sewers and contribute to the estrogenicity in the City's WWTPs. Textiles, cosmetics, and laundry detergents are the most commonly purchased products that contain NPEs and oral contraceptives and hormone replacement therapies are widely prescribed drugs that contain ethinylestradiol. Thus, NYC residents as consumers control the flow of estrogenic compounds into the sewers by choosing to consume or not consume such products. As a voter, a resident votes to elect local (Mayor, Comptroller, City Council members, Borough Presidents), state (Governor, Comptroller, Senators, Assembly members) and federal (President, Vice President, Senators, members of the House of Representatives) officials (City of New York 2013c).

5.2.2 FDA Office of New Drugs: Directors (and Staff)

The role of the directors in the Office of New Drugs (OND) is to oversee activities and direct the outcomes. This involves the responsibilities such as signing off on new drug applications, attending review meetings, writing decisional memorandum on applications, reviewing labeling, directing review teams and reevaluating previously approved drugs. As directors, these individuals affect the number of drugs that are passed annually and how they are labeled for the consumer (NYC resident). This includes oral contraceptives and hormone replacement therapies that contain EE2, thus affecting the flow of EE2 onto the market and how the consumer perceives these drugs.

5.2.3 EPA Office of Pollution Prevention and Toxics: Directors (and Staff)

Similarly to the directors in the OND, the role of the directors in the Office of Pollution Prevention and Toxics (OPPT) are to manage activities and direct outcomes. Some responsibilities of these directors are to review priority chemicals for harm, regulate the manufacturing of harmful chemicals, and run pollution prevention programs. These directors affect the number of chemicals regulated on the market and ultimately where they end up in the environment. The more scrutiny involved in the review process, the safer the chemicals on the market will be.

Resulting from a petition filled in 2007, the OPPT is taking action to regulate NPE by initiating a voluntary phase out in its 2010 action plan (US Environmental Protection Agency 2007; US Environmental Protection Agency 2010). In 2013, the voluntary phase out will begin with laundry detergents along with new regulatory rules for the premanufacture notification process.

5.2.4 Pharmaceutical Companies: Board Members

The role of board members of pharmaceutical companies are to manage various aspects of the business by forming committees to make decisions on financial, regulatory, health, technical and other issues. Based on these decisions, the price is determined for pharmacies and consequently, for consumers. This affects the affordability and likelihood of consumers' choosing to purchase OCs and HRTs. Johnson & Johnson, Merck & Co, Inc., Pfizer, Inc. are three important pharmaceutical companies (or parent companies) in the US that markets OCs and HRTs along with many other drugs.

5.2.5 Chemical Companies: Board Members

Chemical manufacturer board members have the role of making decisions about the production process of chemicals. Just like all boards, forming committees is the way in which they organize themselves to discuss important issues. Due to the close ties between chemical companies and oil companies, the petrochemicals produced are highly dependent on the negotiations made between these two parties, which are an important topic discussed at board meetings. The leading chemical company with the highest production volume of NPEs in the US is Dow Chemicals.

5.2.6 Consumer Goods Companies: Board Members

Likewise for pharmaceutical and chemical companies, board members of consumer goods companies form committees to decide on important finance, regulatory, technical, and public policy matters and other concerns for the business. The results of this decision-making process controls the flow of chemicals into various consumer products like laundry detergents and cosmetics. Labeling is an important aspect of how such products are marketed. Since under current regulation, little to no information about active ingredients needs to be labeled on the product, the consumer is completely unaware that they are purchasing products that contain NPEs. Therefore, the consumer goods companies have immense control over the flow of NPEs in their products as well as to the environment. Procter & Gamble is the biggest US consumer goods company, which produce a big variety of products such as cosmetics, laundry detergents, household cleaners and more.

5.2.7 Researchers

Researchers have the role to create new knowledge by establishing facts and reaching new conclusions. Researchers can be affiliated with universities, non-governmental organizations, governmental organizations, institutes, companies and more. The knowledge that researchers provide can be used by decision makers such as government officials and board members of companies. Integrity is an important characteristic that researchers should have in order to provide fair and honest information. Without integrity, researchers aide in false information and possibly the improper regulation of drugs and chemicals.

5.2.8 The Mayor (and staff)

Acting as the chief executive of the City, the Mayor's role is to give suggestions of plans, actions and laws and putting them into effect. Such responsibilities are to develop annual proposals for the allocation of the City's expenses, capital investments and revenues. Financial proposals are submitted to the City Council where it is negotiated between its members.

5.2.9 City Council Members

The role of the City Council members are to serve as representatives of the people to make and pass laws. This involves negotiating, reviewing and modifying city legislations and submitted proposals for the City's revenue and expenditures. The most common topics of discussion at City Council meetings are the expenses for operations, programs, services and capital projects.

5.2.10 Water Board Members (and Staff)

The Water Board was created along side the Municipal Water Finance Authority in order to capitalize the funding for public water systems. The Water Board members' role are to make decisions about levy water and wastewater rates and charges for the City. Rates and charges set by the Water Board members provide revenues for its services, and consequently influences the consumption of water throughout the City.

5.2.11 DEP Bureau of Engineering Design and Construction: Commissioners

The Bureau of Engineering Design and Construction Comissioners have the role of making decisions about the capital investment projects that are beneficial to NYC residents and the City. Decisions about the design and construction of wastewater treatment plant upgrades are a few examples of the responsibilities that the commissioners have.

5.2.12 DEP Bureau of Wastewater Treatment: Commissioners

Functioning as a management body within DEP, the Bureau of Wastewater Treatment (BWT) carries out the maintenance of the NY Harbor, by managing its sustainable use and monitoring the health of the aquatic environment. The roles of the BWT commissioners are to set policies that serve both the City and the NYC resident's interests. The responsibilities consist of overseeing wastewater treatment plants operators and allocating appropriate funds to individuals plants. Managing operators has some influence on the quality of the operations at WWTPs and its ability to remove EE2 and NP before it is discharged in to the waterways.

5.2.13 Municipal Water Finance Authority: Directors (and Staff)

The NYC Municipal Water Finance Authority (MWFA) is a public benefit corporation that manage the funding for capital projects for the water system. The role of board members of the WFA and the committees that they form is to make decisions about the funding of water projects by issuing of debt (bonds, commercial paper and other obligations) to finance capital investments. Such capital investments are typically infrastructure upgrades required to maintain operations in compliance with regulations set by the State and Federal government. Capital investments are predominately financed according to the State Revolving Funds (SRF) program which is administered by the Environmental Facilities Corporation (Environmental Facilities Corporation 2012).

5.2.14 Environmental Facilities Corporation: Directors (and Staff)

The New York State Environmental Facilities Corporation (EFC) was created by the State and it's role is to administer the Clean Water State Revolving Fund and the Drinking Water State Revolving Fund mandated by Congress to eligible Municipalities via States. Even though the EFC's responsibility is to facilitate State and Municipal projects, it remains a public corporate entity, separate from the State (Environmental Facilities Corporation 2012).

5.2.15 DEC Division of Water: Directors

The role of directors working for the Division of Water (DOW), within the NY State Department of Environmental Conservation, is to oversee programs and activities, issue permits and make decisions about the enforcement of State and Federal regulations regarding New York's water. Uses the New York State Pollution Discharge System, the DOW issues permits to municipal wastewater treatment plants, which are reissued every five years after the water quality data for the surrounding waters has been evaluated. Permits serve as the tool to influence the pollutants in wastewater discharge however, EE2 and NP are not among the selected pollutants monitored.

5.2.16 NY State Legislature: Assembly Members & Senators

The New York State Legislature consists of the Senate and the Assembly. Senators and Assembly members have the role of legislators, which requires that they review, negotiate and pass proposed laws. The laws that are passed by the assembly members and senators affected the Department of Environmental Conservation (e.g. the New York State Water Pollution Control Revolving Fund regulations).

5.2.17 Congress Members

Acting as the federal legislative branch, the United States Congress is made up of two houses: the Senate and the House of Representatives. The role of both houses are to review, negotiate and pass federal laws. Both the Environmental Protection Agency and the Food and Drug Administration are affected by acts mandated by congress by giving them the power to regulate chemicals and drugs in different ways.

CH 6: FUTURE VISION

And now we transport ourselves into a future vision of what can be -- Today, New York City is an urban agriculture hotspot where most households and buildings manage their organic end-products by the simple process of composting. "Humanure", also known as composted human excreta, is used to sustain rooftop gardens and parks throughout New York City. Humanure is viewed as a very valuable product that sustains the City's urban agriculture, and and therefore is no longer disposed of in landfills or spread on fields far away. Composting toilets are inexpensive, low maintenance and very beneficial to the City. Due to the decentralization and redesign of the waste system, the widespread use of close-loop composting systems was made possible.

People see wastewater treatment plants as landmarks of the overly complicated and linear thinking from the past. The remaining infrastructure of the wastewater treatment facilities serve to treat only minimal volumes of overflow greywater and there is a future plan in effect to phase them out entirely. There have been many great improvements to the City as a result of this urban-ecological movement. Stormwater is no longer a problem because high porosity is a part of the standard design requirement for paving the City's streets. Rooftop gardens intercept rainfall and the plants return it to the atmosphere by transpiration. This advancement in systems thinking reduced the pressure on wastewater treatment facilities and the costs to the taxpayers by simply allowing water to seep down naturally into the soil.

Toxic and persistent compounds have long been outdated. Pharmaceutical companies were incentivized to develop green chemistry due to the changes in chemical policy. Past reforms were made that required manufacturers and companies to prove harm prior to production and to pay compensation fees for the damages and costs incurred for removing toxic substances in the wastewater systems. These actions helped remove the taxpayers' financial burden of removing persistent chemicals and reduced the City's debt.

This paradigm co-evolved with holistic approaches to the City's services, health and well-being. People are much more aware of causal relationships. The past model of masking symptoms for indefinite periods of time was rejected and prevention became the underlying philosophy of medical practice. The normalization of holistic problem-solving helped empower the health revolution in which the drug approval process was reconstructed.

Today, water is understood as the most precious resource and is rigorously protected. There are simply no non-biodegradable compounds produced. Many efforts were made to clean up old toxic sites, leaving once highly polluted areas clean and available for public use. During this restoration period, waterbodies such as Jamaica Bay were remediated extensively and became important ecological reserves for natural wildlife where New Yorkers spend their weekends relaxing and enjoying the outdoors. Local estuaries are a healthy spawning ground and a safe haven for aquatic life as well as a biologically productive ecosystem for migratory birds, mammals, and other wildlife. This was not always the case. Fish populations were previously depleted due to poor water quality and overfishing. Fortunately, estuaries have rebounded to a healthier state and are well protected. Water pollution is seen as unimaginable and frightening now.

Every person has access to a natural environment because it's integrated within the City's infrastructure. People reflect on the environmental movement as the catalyst to the enlightenment period that brought society closer to responsible long-term thinking. With cleaner waters and the spread of garden projects throughout the City, healthier living spaces became a priority for New Yorkers. These changes led to the public increased sense of awareness of their relationship with nature, in terms of water, food and what was previously known as "waste". New Yorkers understand how they depend on eco-services and are conscious of the relationship that exists between their well-being and the environment.

CH 7: TRANSFORMATION

7.1 Unsustainable Dynamics

Resulting from the estrogenic system and its pattern of behavior, there are serious threats to the New York City wildlife and human health. This undesirable outcome is the manifestation action by past and present Actors that have influenced the system by acting on its flows. This section will describe the unsustainable dynamics that need to be changed.

7.1.1 Risky chemicals and drugs on the market

An overwhelming number of chemicals and drugs are placed on the market each year without being appropriately tested for risks or proven beneficial to human health and the environment. TSCA-regulated chemicals (excluding drugs, cosmetics and food), such as nonylphenol, are evaluated based on their benefits, risks to human health and environment and the costs associated with regulating them. At first, this may seem rational. However, this is severely problematic and unsustainable because (1) generally, limited data is provided by manufacturers (2) few studies on chemicals compared the total number of chemicals on the market and (3) the OPPT's responsibility to prove harm. Before the OPPT can restrict the use of a chemical, it must be able to identify some risks to human health or the environment. This is nearly impossible to do where there are over 1,000 chemicals approved annually and each are expected to start manufacturing after 90 days of the notification date. Drugs, on the other hand, are approved by assessing the risks and benefits to human health, excluding environmental harm as a risk. This is also problematic because it is assumed that there is no reason for drugs to be tested for environmental risks.

Risk to the environment is a risk to human health. Classifying environmental risks separate from human beings and our health is illogical. Existing drugs and chemicals have already been proven to be endocrine disrupting compounds and have severe consequences for livings things. The more compounds that are release into the environment, the more possible combinations of substances and reactions can occur and the heavier the burden to prove harm weights. In addition, even proving environmental harm is complex. As a result of the many chemicals released into the environment, the mixture effects have become nearly impossible to measure, yet alone understand.

7.1.2 Corporate lobbying

The corporate interest of pharmaceutical and chemical companies (and many more) dominates US policy. As Lessig (2011) puts it, "The great threat today .... is the economy of influence now transparent to all, which has normalized a process that draws our democracy away from the will of the people ... We have created an engine of influence ... that seeks simply to make those most connected rich." By forming lobby groups, industry influences Congress through campaign funding. Lobbying groups such as the American Chemistry Council (ACC), representing chemical companies, and the Pharmaceutical Research and Manufacturers of America (PhRMA), representing pharmaceutical companies, express their interest in current and future regulations to congressional candidates (and staff) while at the same, giving financial contributions to their campaigns. In some cases, lobbyists draft legislation. This "quid pro quo corruption" allows for corporate influence to seep into Congress and US policy through the intent to repay the gift of campaign contributions (Lessig 2011).

The largest US manufacturer of NPEs, Dow Chemicals, and the largest US consumer goods company, Procter & Gamble, are both members of the ACC (American Chemistry Council 2013). On issues such as the Endocrine Disruptor Screening Program, Toxic Substances Control Act (TSCA) Modernization, Confidential Business Information Disclosures under TSCA and TSCA Inventory Update Rule, the ACC lobbied with over $9 million in 2012 (Secretary of the Senate 2012). Large pharmaceutical companies such as Pfizer, Merck & Co., and Johnson &

Johnson are members of PhRMA (Pharmaceutical Research and Manufacturers of America 2013). In 2012, over $18 million were spent by PhRMA on lobbying activities.

The line between bribery and lobbying is thin and complex. Bribery is the practice of exchanging money or favors in order to influence a decision or the judgement of a decision. This is clearly unethical and unacceptable. Unfortunately, lobbying is not considered bribery because the exchange is not explicit. This is problematic because cognitive psychologists have suggested that intent to repay a gift may be completely subconscious; thus, the receiver of a gift (e.g. member of Congress) may not be aware of their intent to reciprocate the gesture (Lessig 2011).

7.1.3 Perpetual upgrades to wastewater treatment plants

Wastewater treatments in NYC and throughout the US face the problem of not having the resources to remove persistent contaminants. This resource deficiency is increasing due to the enormous capital investment and maintenance costs linked to removing the contaminants such as EDCs present from the wastewater influent. Simply, the more chemicals and pharmaceuticals that are approved and used, the harder it becomes to remove them due to mixture effects and synergies. Currently, there are EDCs in the NYC waterways that affect aquatic life and are not addressed by current effluent limits.

If business as usual prevails, upgrades will be continually needed along with the funds and debt to invest in such capital infrastructure. Furthermore, most WWTPs are compliance focused and have little interest in measuring pollutants that are not regulated by the DEC or the EPA. This trend is also attributed to the slow process of determining harm that is placed on the government. As previously discussed, the EDSP, which involves first screening, then testing and finally regulating EDCs, is exceptionally slow. This is not unimaginable, considering that there are around 87,000 potential EDCs: 75,000 on the TSCA list 8,000 regulated by FDA and 3,400 pesticides (US Environmental Protection Agency 2012a).

7.2 Intervention Points

In order to transform the present unsustainable system to the future sustainable model, Actors' roles must change. The essential 'intervention points' where change should be initiated is defined by where the most unsustainable practices occur and what Actors influence them. This section will discuss these intervention points and how the dynamics of the current system will become more sustainable (Fig. 6).

7.2.1 Chemical regulation and drug approval

Today, chemicals are regulated by EPA's OPPT and drugs are approved by FDA's OND. To make chemicals and pharmaceuticals safer, the regulation and approval process needs to change. By intervening at these points, the OPPT and OND would be required to ban chemicals and pharmaceuticals that simply have insufficient proof of zero-harm and those that are persistent in the environment. By only producing compounds that are safe for the environment, we, human beings that are a part of the environment, will also be protected. The fewer chemicals and drugs that reach the wastewater treatment plants, the cheaper the costs are to ensure that discharged effluent and land-applied biosolids are safe.

7.2.2 Corporate financial externalities

Both the chemical and pharmaceutical companies have externalized the costs associated with the removal of their products in the aquatic environment. These costs need be internalized by intervening where the money accumulates and collecting appropriate compensation for damages and costs that municipalities have incurred. More funds for remediating polluted sites and operational costs for removing harmful compounds in wastewater means fewer municipal bonds needed and less debt allocated for the City's wastewater services. Currently, municipal bonds help cover the enormous costs placed on the taxpayer by accumulating debt backed by the public through a semi-independent and non-transparent financial system.

7.2.3 Develop green waste management

Faced with the current problem of persistent compounds in wastewater, DEP is already in progress of upgrading its largest WWTPs with nitrogen removal and plans in the works for the rest of the City's WWTPs. By increasing the removal efficiency of these facilities, lower concentration of pollutants enter and persist in the environment. These improvements and the City's newest innovative Gycerol Facility at the 26th Ward just after its first year of operation have already helped to decrease the nutrient loading. This addition was completed in March 2013 and is a result of the City's research to use glycerol as a part of its nitrogen removal scheme.

Nonetheless, even with appropriate upgrades to the WWTPs, it is undeniable that the centralized treatment of human solid waste is inefficient. "It is more cost-effective to treat waste on-site than it is to build and maintain a central sewer system to which waste will need to be transported" (US Environmental Protection Agency 1999). The City and DEP should take action to explore alternative waste management practices to decrease costs and maximize use of materials. Transforming the way we manage organic waste is a great opportunity to create a useful product rather than just disposing of waste expected to serve no purpose. This would remove the unsustainable act of discharging pollutants into the water and create many benefits associated with recycling.

7.2.4 Create a positive vision of the future

In a world where environmental problems are nothing new, we need to stay positive to create the possibility of a better future for ourselves and future generations. Negative thoughts perpetuate negative situations by consuming one's mind when it could instead be dreaming up solutions and planning action. By giving people a positive vision of the future and feasible solutions to get there, possibilities are created to change the current pattern of behavior. We ourselves as individuals are a part of the transformation to a sustainable system.

CH 8: ACTION PLAN

8.1 Changing the Normal Patterns of Behavior

To transform the current unsustainable estrogenic system into the future model, this section will discuss how to change the normal patterns of behavior by first identifying the actors that need to change and then giving feasible actions that can be carried out to transform the estrogenic system (Fig. 7).

8.1.1 Initiate the Rootstrikers project

To remove the corporate interest from Congress, the simplest solution would be to make sure that campaign contributions come from the people. Lessig (2010) proposes that "democracy vouchers" worth $50 could be allocated by taxpayers to a candidate of their choice and up to $100 extras as a supplement (if desired). This would make candidates responsible to their funders, the people, rather than their political parties or corporate interests which fund their campaigns. This funding would be voluntary and would be competitive to the current funding scheme because it would produce at least $3 billion per year, more than the $2.8 billion spent in 2010 by the two major political parties (Lessig 2010). If candidates were to make decisions based on the interest of the people, then there would be less resistance to change that would benefit people, regardless of political views.

8.1.2 Impose a wastewater pollution tax in New York

A tax on "wastewater polluters" for damages should be imposed to help to relieve the present financial burden carried by the taxpayer for the remediation of polluted sites and WWTP upgrades to remove pollutants. A wastewater polluter would be defined as a producer of a product that contains a compound that is not removed by conventional activated sludge treatment. The fund created from this tax revenue would be set aside for not only conventional

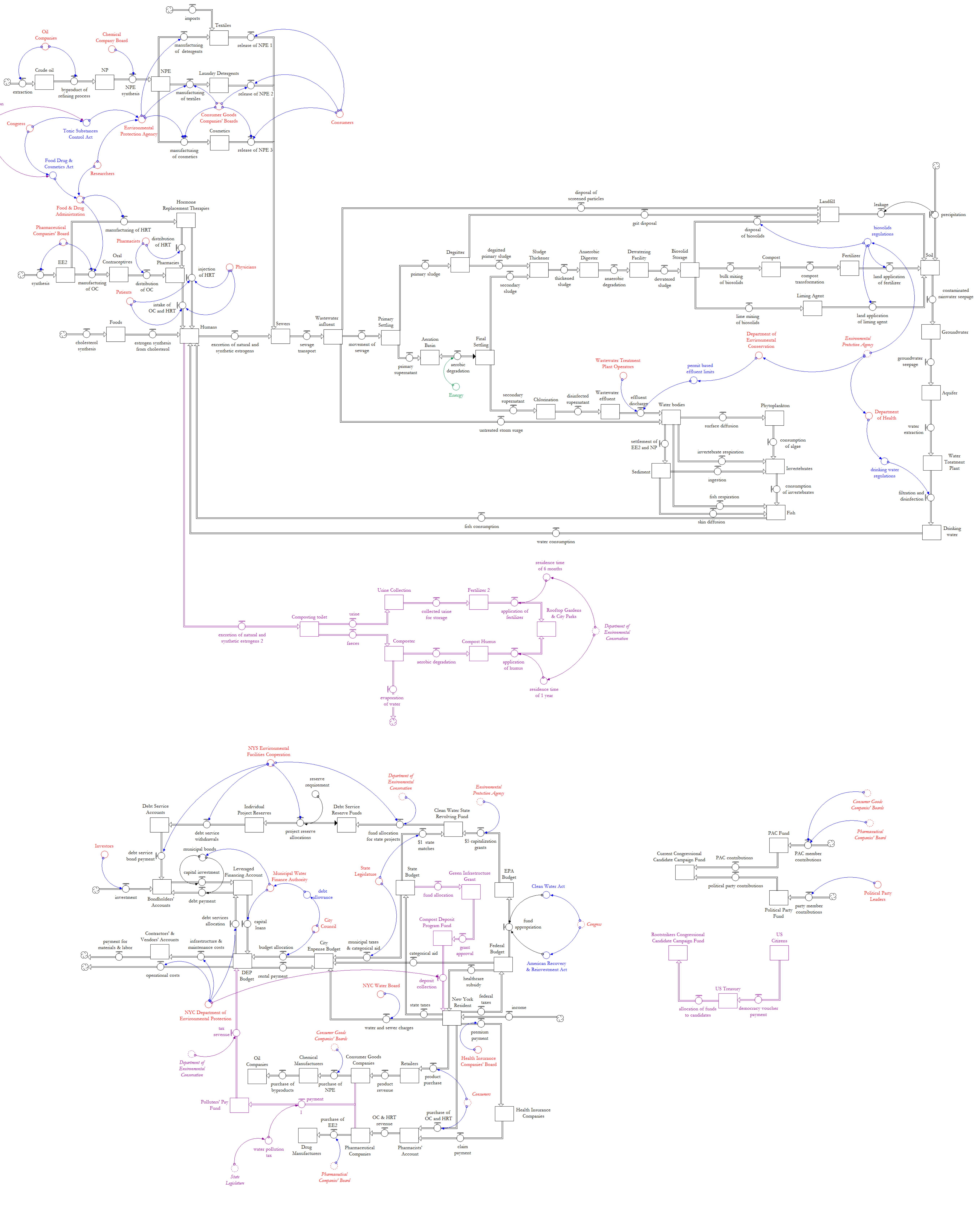


Fig. 7. Model of the transformation of the current estrogenic system.

infrastructure but for alternative and new technologies such as composting systems. In cooperation with EPA's green chemistry programs, this tax would give manufacturers incentives and the resources to explore sustainable and readily biodegradable alternatives. (Imports: In order to reduce NPEs in textiles, regulations must be placed on imported textiles as well.)

8.1.3 Modify the chemical approval process

Congress should propose and pass a modification of the TSCA that gives EPA's Office of Pollution Prevention and Toxics the power to regulate all chemicals on the market including cosmetics, pesticides and drugs. In addition, OPPT would be mandated to ban chemicals that are unable to prove zero-harm and non-persistence in the environment. The burden of proof must be placed on the manufacturer of both existing and new chemicals to fund the research necessary to support its candidacy. This modification Act should not remove the power to approve drugs from FDA's Office of New Drugs, but rather create a two-step process for approving pharmaceutical drugs. By requiring that all compounds go through the OPPT, fewer and safer drugs will reach the OND and reduce the number of unnecessary animals experiments and clinical trials. Also, data on all chemicals should be complied into a centralized database for all governmental office to use.

8.1.4 Create an ecological sanitation system

Ecological sanitation represents a shift in human thinking about human excreta. By moving away from a linear to a circular flow of nutrients, human excreta can be recycled and used as a resource. There are two main types of ecological sanitation systems: urine-diversion and composting. Urinie diversion toilets are designed to separate urine and faeces by a dividing wall and collected into two different containers. Composting toilets process urine and faeces together in a composter, where it is composted. Both types of systems allows for human excreta to be treated on site with a long retention time (1 year) until pathogens and non-persistent compounds (e.g. estrogens) are completed removed. The risk of persistent compounds not being degraded is worth considering, however composted humanure has more time to degrade compared to conventional wastewater treatment.

Benefits to ecological sanitation are that it requires little to no water (6 oz. water per flush), creates a nutrient-rich product, prevents water pollution and is economically viable. Having a system that uses less water and practices land recycling, contaminants are restricted from entering waterbodies. This prevents the transport of contaminants and their interactions within the environment, thereby protecting ecosystem (wildlife and human) health. Other benefits to using humanure are improved soil structure through increased water capacity and fertility.

In New York City, ecological sanitation would reduce the costs for treating waste, reduce water consumption, and encourage community gardens by recycling low cost nutrient-rich "humanure". Ecological sanitation systems would support the City's 2010 Green Infrastructure Plan to capture the first inch of rainfall on 10% of impervious areas in the next 20 years by providing green roofs, parks and gardens with a inexpensive supply of humus, the organic component of soil. Funds to make this shift are already available. In 2013, there will be up to $6 million in grants through Green Infrastructure Grant Program for blue roofs, green roofs and porous pavement (in combined sewered areas). There are also New York State Green Project Reserves available annually to develop green infrastructure from the Clean Water State Revolving Fund. In 2012, the Green Reserves amounted to $15 million for New York State.

Fortunately, composting in NYC is already on the rise. Ecological sanitation system such as composting toilets have already been installed in public spaces such as the Bronx Zoo, the Queens Botanical Garden, and the Hollenback Community Garden in Brooklyn. These projects have been initated to engage NYC residents in the discussion of recycling organic matter of all sorts. There are many manufacturers that install systems throughout the US such as BioLet, ez-Loo, Sun-Mar, Envirolet, Clivus Multrum, Sun Frost, Phoenix. The price of an ecological sanitation system depending on the type ranges up to $5,000 (Clivus Multrum). There is little in the way of installing composting toilets in any building regardless of the height. All that it required is a well-designed plumbing network that uses gravitational force to transport human excreta to the composter (Pete Septoff pers.comm.). Volume is also not a problem for large scale projects because evaporation removes up to 90% of volume of human excreta. Therefore, just 31 kg of compost are produced per capita per year.

8.1.5 Create subsidies for sustainable waste treatment and deposit system

An important detail that should be considered when setting up a large scale ecological sanitation system is that the participant will play a bigger role in the system compared to today's conventional system where things are "out of sight, out of mind". In order to encourage responsible actions, incentives must be made. This could be done by creating (1) a subsidy program to encourage the installation of ecological sanitation systems and (2) a deposit system that gives users an incentive to recycle the compost properly back to the City. These incentives would allow for composting system to become affordable for all New Yorkers and ensure that illegal dumping does not occur.

8.1.6 Use art installations and media art to spread the positive vision

Using my passion for sculpture and communicative art, I will gladly take on this project as my personal action plan to create change. By associating natural processes such as humanure and composting with images of life and benefits rather than foul smells and disease, perceptions can change. Once this positive image is created and the taboos are removed, the transformation will begin to manifest. From one person to another and through personal experiences, individuals will begin to see the benefits to recycling and take part in spreading the same vision that sparked them to change.

8.2 Stability of the Future System

The new system will resist returning to the old unsustainable pattern of behavior because it is a low-cost system that produces a high-demand product (Fig. 8). Compared to the astronomical capital and maintenance costs that the MWFA pays using bonds backed by NYC taxypayers, ecological sanitation systems are cheap. Composting toilets have little to no maintenance costs and require small capital investments (prices range from $10 to. $5,000 per household). There will be few incentives for individuals to go back to the conventional system once it is installed. Also, the City would benefit greatly to the new system because it would create a steady supply of fertilizer and humus for its parks and roof-top gardens that are already growing in number. This would also help the urban agriculture movement increase its food production since the limiting factor is quality soil (Cohen *et al.* 2012). The City's food production could also benefit from inexpensive fertilizers in order to keep the use of synthetic fertilizers to a minimum. Another factor that will help the new system persist is that as the surface area of parks and gardens increases, the volume of stormwater captured will also increase. This is essential for cities on the water such as New York City that combat storm surges regularly. Therefore, once the City makes the transformation towards an ecological sanitation system, there will more benefits than consequences to its stabilization and thus, resistance will be minimal.

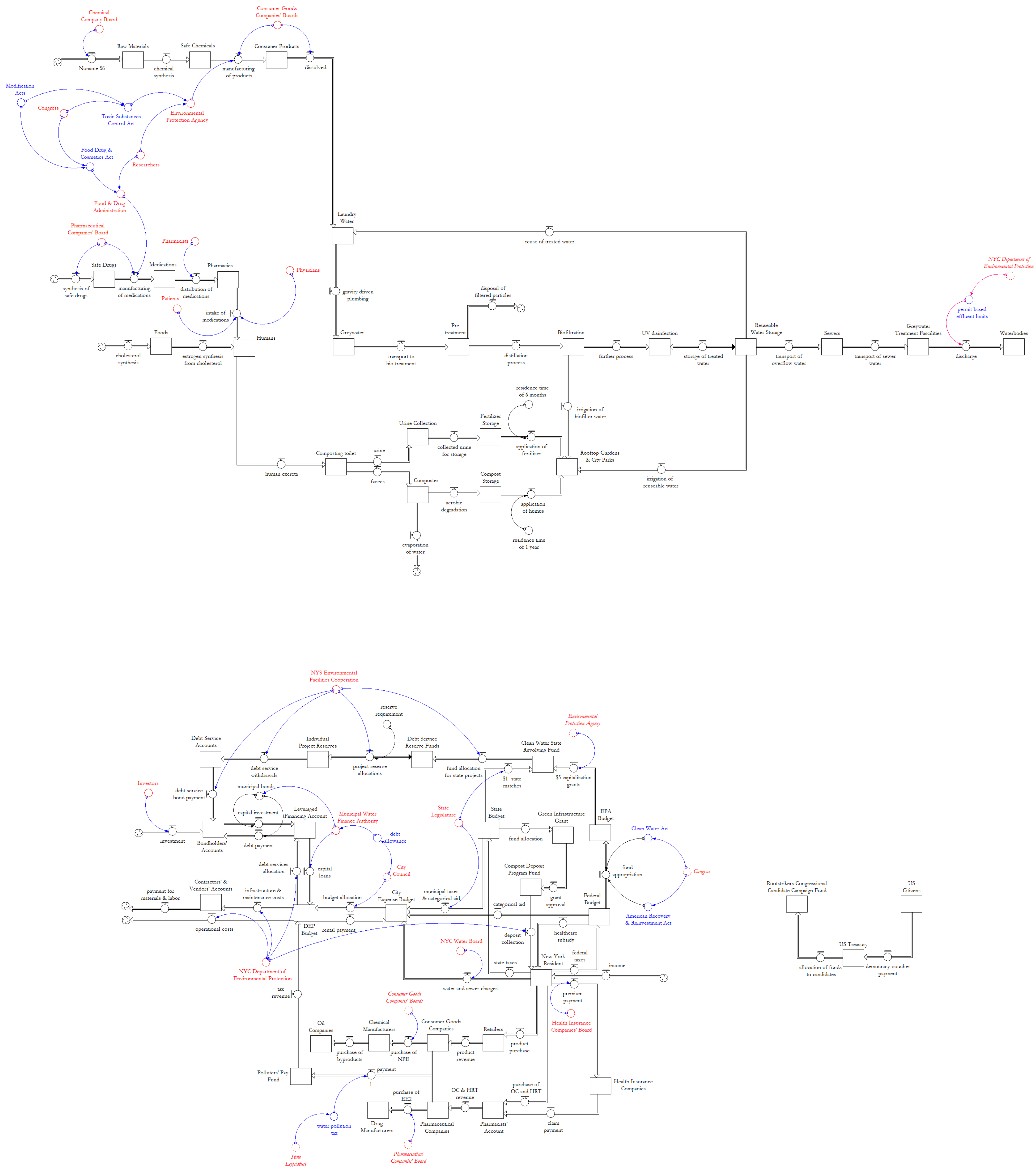


Fig. 8. Model of the future estrogenic system.

CH 9: CONCLUSION

Preventing endocrine disruption from occurring in the aquatic environment and consequently in humans is possible today. Environmental pollution due to the release of endocrine distributing compounds is becoming an unmanageable disaster for both fish and humans with incalculable consequences. Fish feminization and decreased fertility in humans are few examples of known effects caused by increased estrogenicity in water, both of which are unacceptable and should be eradicated. By shifting the linear thinking, which led to the way human excreta is treated and chemicals are approved to a cyclical one, harmful compounds can be restricted from reaching the NYC waterways.

As a result of mapping out the current estrogenic system from source to release including: the flows, the influential actors and the feedbacks that sustain its present state, the system is shown in totality. With this informative diagram, the intervention points are clear and actions for change can be constructed. First, the influence of chemical and pharmaceutical lobby groups on Congress needs to be removed. Second, governmental bodies need to have stricter regulations of chemical and pharmaceutical drugs that include proving no harm to environment or health prior to manufacturing. Third, states, municipalities or Congress need to create incentives to explore sustainable approaches to wastewater treatment.

Unfortunately, there are many hurdles to overcome in order to create change at these intervention points. Chemical and pharmaceutical companies have great power over Congress and will resist changes that involve stricter regulations. Additionally, the taboos associated with human excreta prevent the exploration of alternative approaches to waste management, which involves recycling nutrient-rich humanure. However, this resistance can be mitigated by creating incentives and informing the public of better alternatives that can create the solution for eliminating aquatic pollution and health concerns that everyone seeks.

Guided by a positive vision of the future, the proposed plan of action for transforming the unsustainable estrogenic system involves: building congressional candidate campaign funds that citizens can contribute to, reforming chemical and drug regulations to require proving no environmental harm, and establishing NYC ecological sanitation systems that supply the City's parks and gardens with inexpensive humus and fertilizers. Once people feel that they help to create the space that they live in, rather it be politically or environmentally, they are interested.

More and more individuals seek to remove corporate influence on decisions made by the US government. This has led to movements that reject corporate interest and seek for solutions that benefit the people. The 2010 Green Infrastructure Plan supports these movements by making steps to secure the City's sustainability through green roofs, blue roofs, porous payments and more. This shift in thinking supports the idea of ecological sanitation systems but is waiting for the taboo of recycling human excreta to be removed.

Once this happens, there are many benefits to be had from recycling organic matter. With an abundant and local source of humus and fertilizers, there would be lower humus and fertilizer costs, allowing for the expansion of the urban agriculture in New York City. There would also be less water consumed since little to no water is needed for an ecological sanitation system and more importantly, as a result of recycling human excreta, aquatic pollution would be greatly reduced as well as the needed investments to upgrade and maintain the infrastructure to treat the wastewater. Finally, the best benefit of all, all of these benefits come to no costs to the people.

To put this plan into action, future research is needed to develop strategies to make ecological systems a part of New York City's services, to reform current chemical and pharmaceutical regulations and to mitigate resistance that will occur. Indeed, this will require much effort but well worth it, so that individuals and future generations can live in a world free of endocrine disruption, free of unnecessary waste and full of creative possibilities.

References

AECOM. 2013. *The New York City Municipal Water Finance Authority: Fiscal Year 2013 Consulting Engineer's Report.* New York: City of New York.

Ahel, M., Giger, W., and Koch, M. 1994. Behaviour of alkylphenol polyethoxylate surfactants in the aquatic environment—I. Occurrence and transformation in sewage treatment. *Water Research* 28(5): 1131-42.

Ahel, M., McEvoy, J., and Giger, W. 1993. Bioaccumulation of the lipophilic metabolites of nonionic surfactants in freshwater organisms. *Environmental Pollution* 79(3): 243-48.

Ahlborg, U. G., Lipworth, L., Titus-Ernstoff, L., Hsieh, C. C., Hanberg, A., Baron, J., Trichopoulos, D., and Adami, H. O. 1995. Organochlorine compounds in relation to breast cancer, endometrial cancer, and endometriosis: an assessment of the biological and epidemiological evidence. *CRC Critical Reviews in Toxicology* 25: 463-531.

American Chemistry Council. 2013. Member Companies. URL: http://www.americanchemistry.com/Membership/MemberCompanies. [consulted 02 May 2013].

Andaluri, G., Suri, R. P. S., and Kumar, K. 2012. Occurrence of estrogen hormones in biosolids, animal manure and mushroom compost. *Environmental Monitoring & Assessment* 184(2): 1197-205.

Andersen, H. R., Hansen, M., Kjølholt, J., Stuer-Lauridsen, F., Ternes, T., and Halling-Sørensen, B. 2005. Assessment of the importance of sorption for steroid estrogens removal during activated sludge treatment. *Chemosphere* 61(1): 139-46.

Andersson, A. M., and Skakkebæk, N. E. 1999. Exposure to exogenous estrogens in food: possible impact on human development and health. *European Journal of Endocrinology* 140: 477-85.

Arnot, J. A., and Gobas, F. A. P. C. 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Reviews* 14(4): 257-97.

Ashby, J. 1997. A hierarchical approach to the evaluation of chemicals for estrogenic and other endocrine-disrupting properties. *Environmental Toxicology & Pharmacology* 3: 87-90.

Barber, L. B., Thurman, E. M., Schroeder, M. P., and LeBlanc, D. R. 1988. Long-term fate of organic micropollutants in sewage-contaminated groundwater. *Environmental Science & Technology* 22(2): 205-11.

Baronti, C., Curini, R., D'Ascenzo, G., Di Corcia, A., Gentili, A., and Samperi, R. 2000. Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water. *Environmental Science & Technology* 34(24): 5059-66.

Bateson, G. 1979. *Mind and Nature: A Necessary Unity.:* Dutton New York.

Bennie, D. T. 1999. Review of the environmental occurrence of alkylphenols and alkylphenol ethoxylates. *Water Quality Research Journal of Canada* 34(1): 79-122.

Bennie, D. T., Sullivan, C. A., Lee, H.-B., and Maguire, R. J. 1998. Alkylphenol polyethoxylate metabolites in Canadian sewage treatment plant waste streams. *Water Quality Research Journal of Canada* 33(2): 231-52.

Borrirukwisitsak, S., Keenan, H. E., and Gauchotte-Lindsay, C. 2012. Effects of salinity, pH and temperature on the octanol-water partition coefficient of bisphenol A. *International Journal of Environmental Science & Development* 3(5): 460-64.

Brett, K. M., and Chong, Y. 2001. *Hormone Replacement Therapy: Knowledge and Use in the United States.*

Brigden, K., Santillo, D., and Johnston, P. 2012. *Technical Report: Nonylphenol ethoxylates (NPEs) in textile products, and their release through laundering*. Exeter, UK: Greenpeace Research Laboratories.

Carballa, M., Omil, F., Alder, A. C., and Lema, J. M. 2006. Comparison between the conventional anaerobic digestion of sewage sludge and its combination with a chemical or thermal pre-treatment concerning the removal of pharmaceuticals and personal care products. *Water Science & Technology* 53(8): 109-18.

Carlsen, E., Giwercman, A., Keiding, N., and Skakkebaek, N. E. 1995. Declining semen quality and increasing incidence of testicular cancer: is there a common cause? *Environmental Health Perspectives* 103: 137.

City of New York. 2009. *Understanding New York City's Budget: A Guide.*

———. 2012. *Comprehensive Annual Financial Reports for FY 2012*. New York.

———. 2013a. Fiscal History. URL: http://www.ibo.nyc.ny.us/fiscalHistory.html. [consulted 02 May 2013].

———. 2013b. *Hearing on the Fiscal 2014 Preliminary Budget & the Fiscal 2013 Preliminary Mayor's Management Report: Department of Environmental Protection*. New York.

———. 2013c. Public Offices That Appears on New York City Ballots. URL: http://www.vote.nyc.ny.us/html/voters/guide.shtml. [consulted 02 May 2013].

Clayden, J., and Greeves, N. 2001. *Organic Chemistry*. Oxford: Oxford University Press.

Cohen, N., Reynolds, K., and Sanghvi, R. 2012. *Five Borough Farm: Seeding the Future of Urban Agriculture in New York City*. New York: Design Trust for Public Space.

Colborn, T. 2013. The Endocrine Disruption Exchange (TEDX). URL: http://www.endocrinedisruption.com. [consulted 02 May 2013].

Colborn, T., vom Saal, F. S., and Soto, A. M. 1993. Developmental effects of endocrine-disrupting chemicals in wildlife and humans. *Environmental Health Perspectives* 101(5): 378.

Colman, J. R., Baldwin, D., Johnson, L. L., and Scholz, N. L. 2009. Effects of the synthetic estrogen, 17α-ethinylestradiol, on aggression and courtship behavior in male zebra fish (*Danio rerio*). *Aquatic Toxicology* 91: 346-54.

Corliss, J. B. 2013. The Systems Dynamics of the Transformation to Sustainability. URL: http://www.collectivedynamics.org/. [consulted 1 Feb 2013].

D'ascenzo, G., Di Corcia, A., Gentili, A., Mancini, R., Mastropasqua, R., Nazzari, M., and Samperi, R. 2003. Fate of natural estrogen conjugates in municipal sewage transport and treatment facilities. *Science of the Total Environment* 302(1): 199-209.

de Mes, T., Zeeman, G., and Lettinga, G. 2005. Occurrence and fate of estrone, 17β-estradiol and 17α-ethynylestradiol in STPs for domestic wastewater. *Reviews in Environmental Science and Biotechnology* 4: 275-311.

Desbrow, C. E. J. R., Routledge, E. J., Brighty, G. C., Sumpter, J. P., and Waldock, M. 1998. Identification of estrogenic chemicals in STW effluent. 1. Chemical fractionation and in vitro biological screening. *Environmental Science & Technology* 32(11): 1549-58.

Diamanti-Kandarakis, E., Bourguignon, J. P., Giudice, L. C., Hauser, R., Prins, G. S., Soto, A. M., Zoeller, R. T., and Gore, A. C. 2009. Endocrine-Disrupting Chemicals: An Endocrine Society Scientific Statement. *Endocrine Reviews* 30: 293-342.

Ekelund, R., Bergman, Å., Granmo, Å., and Berggren, M. 1990. Bioaccumulation of 4-nonylphenol in marine animals—A re-evaluation. *Environmental Pollution* 64(2): 107-20.

Environmental Facilities Corporation. 2012. *Annual Report 2012-2013*. Albany, NY.

Estrada-Arriaga, E. B., and Mijaylova, N. P. 2010. A comparison of biodegradation kinetic models applied to estrogen removal with nitrifying activated sludge. *Water science and technology* 62(9): 2183.

Eurofins Product Testing. 2012. *Alkylphenol ethoxylates (APEO) in textiles.:* Eurofin Inc.

European Union. 2002. *Risk Assessment: 4-Nonylphenol (Branched) and Nonylphenol*. Luxembourg.

Ferguson, P. L., Iden, C. R., and Brownawell, B. J. 2001. Distribution and fate of neutral alkylphenol ethoxylate metabolites in a sewage-impacted urban estuary. *Environmental Science & Technology* 35(12): 2428-35.

Fernandez, M. P., Noguerol, T.-N., Lacorte, S., Buchanan, I., and Piña, B. 2009. Toxicity identification fractionation of environmental estrogens in waste water and sludge using gas and liquid chromatography coupled to mass spectrometry and recombinant yeast assay. *Analytical & Bioanalytical Chemistry* 393(3): 957-68.

Filby, A. L., Neuparth, T., Thorpe, K. L., Owen, R., Galloway, T. S., and Tyler, C. R. 2007. Health impacts of estrogens in the environment, considering complex mixture effects. *Environmental Health Perspectives* 115(12): 1704.

Forrester, J. W. 1971. Counterintuitive Behavior of Social Systems. *Technology Review* 73(3): 52-68.

———. 2000. *System dynamics: the foundation under systems thinking*. Cambridge, MA: Sloan School of Management. Massachussetts Institute of Technology.

———. 2007. System dynamics, the next fifty years. *System Dynamics Review* 23: 359-70.

Frisk, M. G., Jordaan, A., and Miller, T. J. 2013. Moving beyond the current paradigm in marine population connectivity: are adults the missing link? *Fish & Fisheries* : 1-13.

Galilei, G. 1623. *Il Saggiatore (the Assayer)*. In *Controversy on the Comets of 1618*, Rome: Giacomo Mascardi.

Gillesby, B. E., and Zacharewski, T. R. 1998. Exoestrogens: Mechanisms of action and strategies for identification and assessment. *Environmental Toxicology & Chemistry* 17: 3-14.

González, M. M., Martín, J., Santos, J. L., Aparicio, I., and Alonso, E. 2010. Occurrence and risk assessment of nonylphenol and nonylphenol ethoxylates in sewage sludge from different conventional treatment processes. *Science of the Total Environment* 408(3): 563-70.

Guenther, K., Heinke, V., Thiele, B., Kleist, E., Prast, H., and Raecker, T. 2002. Endocrine disrupting nonylphenols are ubiquitous in food. *Environmental Science & Technology* 36(8): 1676-80.

Hamid, H., and Eskicioglu, C. 2012. Fate of estrogenic hormones in wastewater and sludge treatment: A review of properties and analytical detection techniques in sludge matrix. *Water Research* 46: 5813-33.

Heath, D., and Greene, R. 2013. *EPA Contaminated By Conflict of Interest.*

Herman, R. L., and Kincaid, H. L. 1988. Pathological effects of orally administered estradiol to rainbow trout. *Aquaculture* 72(1): 165-72.

Holbrook, R. D., Novak, J. T., Grizzard, T. J., and Love, N. G. 2002. Estrogen receptor agonist fate during wastewater and biosolids treatment processes: A mass balance analysis. *Environmental science & technology* 36(21): 4533-39.

Hu, J., Cheng, S., Aizawa, T., Terao, Y., and Kunikane, S. 2003. Products of aqueous chlorination of 17β-estradiol and their estrogenic activities. *Environmental Science & Technology* 37(24): 5665-70.

Jenkins, M. B., Endale, D. M., Schomberg, H. H., Hartel, P. G., and Cabrera, M. L. 2009. 17β-Estradiol and testosterone in drainage and runoff from poultry litter applications to tilled and no-till crop land under irrigation. *Journal of Environmental Management* 90(8): 2659-64.

Jobling, S., Casey, D., Rodgers-Gray, T., Oehlmann, J., Schulte-Oehlmann, U., Pawlowski, S., Baunbeck, T., Turner, A. P., and Tyler, C. R. 2003. Comparative responses of molluscs and fish to environmental estrogens and an estrogenic effluent. *Aquatic Toxicology* 65(2): 205-20.

Jobling, S., Nolan, M., Tyler, C. R., Brighty, G., and Sumpter, J. P. 1998. Widespread Sexual Disruption in Wild Fish. *Environmental Science & Technology* 32: 2498-506.

Jobling, S., Williams, R., Johnson, A., Taylor, A., Gross-Sorokin, M., Nolan, M., Tyler, C. R., van Aerle, R., Santos, E., and Brighty, G. 2006. Predicted exposures to steroid estrogens in UK rivers correlate with widespread sexual disruption in wild fish populations. *Environmental Health Perspectives* 114(S-1): 32.

Johnson, A. C., Belfroid, A., and Di Corcia, A. 2000. Estimating steroid oestrogen inputs into activated sludge treatment works and observations on their removal from the effluent. *Science of The Total Environment* 256: 163-73.

Johnson, A. C., and Sumpter, J. P. 2001. Removal of endocrine-disrupting chemicals in activated sludge treatment works. *Environmental Science & Technology* 35: 4697-703.

Johnson, A. C., and Williams, R. J. 2004. A Model To Estimate Influent and Effluent Concentrations of Estradiol, Estrone, and Ethinylestradiol at Sewage Treatment Works. *Environmental Science & Technology* 38: 3649-58.

Joss, A., Andersen, H., Ternes, T., Richle, P. R., and Siegrist, H. 2004. Removal of estrogens in municipal wastewater treatment under aerobic and anaerobic conditions: consequences for plant optimization. *Environmental Science & Technology* 38(11): 3047-55.

Khanal, S. K., Xie, B., Thompson, M. L., Sung, S., Ong, S.-K., and Leeuwen, J. H. v. 2006. Fate, transport, and biodegradation of natural estrogens in the environment and engineered systems. *Environmental Science & Technology* 40(21): 6537-46.

Kidd, K. A., Blanchfield, P. J., Mills, K. H., Palace, V. P., Evans, R. E., Lazorchak, J. M., and Flick, R. W. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences* 104: 8897-901.

Kinnberg, K., Korsgaard, B., and Bjerregaard, P. 2000a. Concentration-dependent effects of nonylphenol on testis structure in adult platyfish *Xiphophorus maculatus*. *Marine Environmental Research* 50(1): 169-73.

Kinnberg, K., Korsgaard, B., Bjerregaard, P., and Jespersen, A. 2000b. Effects of nonylphenol and 17beta-estradiol on vitellogenin synthesis and testis morphology in male platyfish Xiphophorus maculatus. *Journal of Experimental Biology* 203(2): 171-81.

Kjær, J., Olsen, P., Bach, K., Barlebo, H. C., Ingerslev, F., Hansen, M., and Sørensen, B. H. 2007. Leaching of estrogenic hormones from manure-treated structured soils. *Environmental Science & Technology* 41(11): 3911-17.

Koh, Y. K., Chiu, T. Y., Boobis, A., Cartmell, E., Scrimshaw, M. D., and Lester, J. N. 2008. Treatment and removal strategies for estrogens from wastewater. *Environmental Technology* 29(3): 245-67.

Kolpin, D. W., Furlong, E. T., Meyer, M. T., Thurman, E. M., Zaugg, S. D., Barber, L. B., and Buxton, H. T. 2002. Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance. *Environmental Science & Technology* 36: 1202-11.

Krishnan, V., and Safe, S. 1993. Polychlorinated Biphenyls (PCBs), Dibenzodioxins (PCDDs), and Dibenzofurans (PCDFs) as Antiestrogens in MCF-7 Human Breast Cancer Cells: Quantitative Structure-Activity Relationships. *Toxicology & Applied Pharmacology* 120: 55-61.

Kuhnz, W., Heuner, A., Hümpel, M., Seifert, W., and Michaelis, K. 1997. In vivo conversion of norethisterone and norethisterone acetate to ethinyl etradiol in postmenopausal women. *Contraception* 56: 379-85.

Kwak, H., Bae, M., Lee, M., Lee, Y., Lee, B., Kang, K., Chae, C., Sung, H., Shin, J., and Kim, J. 2001. Effects of nonylphenol, bisphenol A, and their mixture on the viviparous swordtail fish (Xiphophorus helleri). *Environmental Toxicology & Chemistry* 20(4): 787-95.

Lai, K. M., Johnson, K. L., Scrimshaw, M. D., and Lester, J. N. 2000. Binding of waterborne steroid estrogens to solid phases in river and estuarine systems. *Environmental Science & Technology* 34(18): 3890-94.

Lai, K. M., Scrimshaw, M. D., and Lester, J. N. 2002. Prediction of the bioaccumulation factors and body burden of natural and synthetic estrogens in aquatic organisms in the river systems. *Science of the Total Environment* 289(1): 159-68.

Larsson, D. G. J., Adolfsson-Erici, M., Parkkonen, J., Pettersson, M., Berg, A. H., Olsson, P. E., and Forlin, L. 1999. Ethinyloestradiol, an undesired fish contraceptive? *Aquatic Toxicology* 45: 91-97.

Lee Ferguson, P., and Brownawell, B. J. 2003. Degradation of nonylphenol ethoxylates in estuarine sediment under aerobic and anaerobic conditions. *Environmental Toxicology & Chemistry* 22(6): 1189-99.

Lee, B.-C., Kamata, M., Akatsuka, Y., Takeda, M., Ohno, K., Kamei, T., and Magara, Y. 2004. Effects of chlorine on the decrease of estrogenic chemicals. *Water Research* 38(3): 733-39.

Lee, H. J., Chattopadhyay, S., Gong, E.-Y., Ahn, R. S., and Lee, K. 2003. Antiandrogenic effects of bisphenol A and nonylphenol on the function of androgen receptor. *Toxicological Sciences* 75(1): 40-46.

Lee, P.-C., and Lee, C. 1996. In vivo estrogenic action of nonylphenol in immature female rats. *Bulletin of Environmental Contamination & Toxicology* 57(3): 341-48.

Lessig, L. 2011. *Republic, Lost: How Money Corrupts Congress--and a Plan to Stop it*. New York: Twelve Hachette Book Group.

Li, D., Kim, M., Shim, W. J., Yim, U. H., Oh, J.-R., and Kwon, Y.-J. 2004. Seasonal flux of nonylphenol in Han River, Korea. *Chemosphere* 56(1): 1-6.

Lu, Q., He, Z. L., and Stoffella, P. J. 2012. Land Application of Biosolids in the USA: A Review. *Applied & Environmental Soil Science* 2012: 1-11.

Ma, T., Wang, Z., and Gong, S. 2007. Comparative sensitivity in Chinese rare minnow (Gobiocypris rarus) and Japanese Medaka (Oryzias latipes) exposed to ethinylestradiol. *Journal of Environmental Science & Health, Part A* 42(7): 889-94.

Maguire, R. J. 1999. Review of the persistence of nonylphenol and nonylphenol ethoxylates in aquatic environments. *Water Quality Research Journal of Canada* 34(1): 37-78.

Matozzo, V., Gagné, F., Marin, M. G., Ricciardi, F., and Blaise, C. 2008. Vitellogenin as a biomarker of exposure to estrogenic compounds in aquatic invertebrates: A review. *Environment International* 34: 531-45.

McElroy, A. E. 2006. Endocrine Disruptors in Jamaica Bay. Presentation to Jamaica Bay Watershed Protection Plan Advisory Committee, New York:

Meadows, D. 1996. Envisioning a sustainable world. *Getting Down to Earth: Practical Applications of Ecological Economics* : 117-26.

Meendering, J. R., Torgrimson, B. N., Miller, N. P., Kaplan, P. F., and Minson, C. T. 2009. Ethinyl estradiol-to-desogestrel ratio impacts endothelial function in young women. *Contraception* 79: 41-49.

Nakada, N., Tanishima, T., Shinohara, H., Kiri, K., and Takada, H. 2006. Pharmaceutical chemicals and endocrine disrupters in municipal wastewater in Tokyo and their removal during activated sludge treatment. *Water Research* 40: 3297-303.

Nash, J. P., Kime, D. E., Van der Ven, L. T. M., Wester, P. W., Brion, F., Maack, G., Stahlschmidt-Allner, P., and Tyler, C. R. 2004. Long-Term Exposure to Environmental Concentrations of the Pharmaceutical Ethynylestradiol Causes Reproductive Failure in Fish. *Environmental Health Perspectives* 112: 1725-33.

Nasu, M., Goto, M., Kato, H., Oshima, Y., and Tanaka, H. 2001. Study on endocrine disrupting chemicals in wastewater treatment plants. *Water Science & Technology* 43(2): 101.

National Research Council. 2002. *Biosolids Applied to Land: Advancing Standards and Practices*. Washington, D.C.: National Academy Press.

New York Sea Grant. 2006. Estrogenic compounds in urban waterways: Interview with Anne McElroy. *Coastlines* spring): 6-14.

Ney, R. E. 1990. *Where Did That Chemical Go? A Practical Guide to Chemical Fate and Transport in the Environment*. New York: Van Nostrand Reinhold.

Norris, D.O. 2007. Xenoestrogen Actions on Reproduction: Implications for Health of Wildlife and Humans. AWRA Summer Specialty Conference, Vail, Colorado:

NYC Department of Environmental Protection. 2011. *New York City's Wastewater Treatment System. Cleaning the Water We Use, Protecting the Environment We Live In*. New York.

NYC Water Board. 2011. *Water and Wastewater Rate Schedule*. New York.

———. 2012. *Minutes of a Meeting of the New York City Water Board*. New York.

NYS Department of Environmental Conservation. State Pollutant Discharge Elimination System (SPDES). URL: http://www.dec.ny.gov/permits/6054.html. [consulted 2 May 2013].

———. 1999. *Solid Waste Factsheet*. Albany, NY.

———. 2011. *Biosolids Management in New York State*. Albany, NY.

Orlando, E., and Hessle, W. 2007. Ecosystems At Risk When Estrogens Mix With Other Chemicals. URL: http://www.enn.com/ecosystems/article/22932. [consulted 2 May 2013].

Pedersen, J. A., Soliman, M., and Suffet, I. H. 2005. Human pharmaceuticals, hormones, and personal care product ingredients in runoff from agricultural fields irrigated with treated wastewater. *Journal of Agricultural & Food Chemistry* 53(5): 1625-32.

Pharmaceutical Research and Manufacturers of America. 2013. Member Companies. URL: http://www.phrma.org/about/member-companies. [consulted 02 May 2013].

Pryor, S. W., Hay, A. G., and Walker, L. P. 2002. Nonylphenol in anaerobically digested sewage sludge from New York State. *Environmental Science & Technology* 36(17): 3678-82.

Purdom, C. E., Hardiman, P. A., Bye, V. V. J., Eno, N. C., Tyler, C. R., and Sumpter, J. P. 1994. Estrogenic effects of effluents from sewage treatment works. *Chemistry & Ecology* 8(4): 275-85.

Rajapakse, N., Silva, E., and Kortenkamp, A. 2002. Combining xenoestrogens at levels below individual no-observed-effect concentrations dramatically enhances steroid hormone action. *Environmental Health Perspectives* 110(9): 917.

Reddy, S., and Brownawell, B. 2005. Analysis of estrogens in sediment from a sewage-impacted urban estuary using high-performance liquid chromatography/time-of-flight mass spectrometry. *Environmental Toxicology & Chemistry,* 24(5): 1041–47.

Reis-Henriques, M. A., Cruz, M. M., and Pereira, J. O. 1997. The modulating effect of vitellogenin on the synthesis of 17β-estradiol by rainbow trout (*Oncorhynchus mykiss*) ovary. *Fish Physiology & Biochemistry* 16(3): 181-86.

Reproductive Health Technologies Project. 2000. *Facts about Fertility*. Washington, D.C.: Reproductive Health Technologies Project.

Rivera, R., Yacobson, I., and Grimes, D. 1991. The mechnism of action of hormonal contraceptives an intrauterine contraceptive devices. *American Journal Obstet Gynecology* 181: 1263-69.

Rosendaal, F. R., and Reitsma, P. H. 2009. Genetics of venous thrombosis. *Journal of Thrombosis & Haemostasis* 7: 301-04.

Routledge, E. J., Sheahan, D., Desbrow, C., Brighty, G. C., Waldock, M., and Sumpter, J. P. 1998. Identification of Estrogenic Chemicals in STW Effluent. 2. In Vivo Responses in Trout and Roach. *Environmental Science & Technology* 32: 1559-65.

Sabourin, L., Duenk, P., Bonte-Gelok, S., Payne, M., Lapen, D. R., and Topp, E. 2012. Uptake of pharmaceuticals, hormones and parabens into vegetables grown in soil fertilized with municipal biosolids. *Science of the Total Environment* 431: 233-36.

Safer Chemicals Healthier Families. 2013. What is TSCA? URL: http://www.saferchemicals.org/resources/tsca.html. [consulted 02 May 2013].

Scrimshaw, M. D., and Lester, J. N. 2003. *Fate and Behaviour of Endocrine Disrupters in Sludge Treatment and Disposal*. In *Endocrine Disrupters in Wastewater and Sludge Treatment Processes*, London, UK: CRC Press LLC and IWA Publishing.

Secretary of the Senate. 2012. Lobbying Report filed by the American Chemistry Council. URL: http://soprweb.senate.gov/index.cfm?event=getFilingDetails&filingID=27E8684A-3F3A-4525-A30B-FFF7C285E17D&filingTypeID=60. [consulted 2 May 2012].

Servos, M. R., Bennie, D. T., Burnison, B. K., Jurkovic, A., McInnis, R., Neheli, T., Schnell, A., Seto, P., Smyth, S. A., and Ternes, T. A. 2005. Distribution of estrogens, 17β-estradiol and estrone, in Canadian municipal wastewater treatment plants. *Science of the Total Environment* 336(1): 155-70.

Shao, B., Hu, J., and Yang, M. 2003. Nonylphenol ethoxylates and their biodegradation intermediates in water and sludge of a sewage treatment plant. *Bulletin of Environmental Contamination & Toxicology* 70(3): 0527-0532.

Sharpe, R. M., and Skakkebaek, N. E. 1993. Are oestrogens involved in falling sperm counts and disorders of the male reproductive tract? *The Lancet* 341: 1392-96.

Shore, L. S., and Shemesh, M. 2003. Naturally produced steroid hormones and their release into the environment. *Pure & Applied Chemistry* 75(11): 1859-71.

Sierra Club. 2005. A Safer Alternative Exists to This Toxic Cleaning Agent. URL: http://www.sierraclub.org/toxics/factsheets/. [consulted 02 May 2013].

Silva, E., Rajapakse, N., and Kortenkamp, A. 2002. Something from "nothing"-eight weak estrogenic chemicals combined at concentrations below NOECs produce significant mixture effects. *Environmental Science & Technology* 36(8): 1751-56.

Simons, S. S. 2008. Steroid Hormones. URL: http://onlinelibrary.wiley.com/doi/10.1002/9780470048672.wecb563/full. [consulted 02 May 2013].

Snyder, S., Westerhoff, P., Yoon, Y., and Sedlak, D. L. 2003. Pharmaceuticals Personal Care Products and Endocrine Disruptors in Water- Implications for the Water Industry. *Environmental Engineering Science* 20: 449-69.

Snyder, S. A., Keith, T. L., Pierens, S. L., Snyder, E. M., and Giesy, J. P. 2001. Bioconcentration of nonylphenol in fathead minnows (*Pimephales promelas*). *Chemosphere* 44(8): 1697-702.

Soares, A., Guieysse, B., Jefferson, B., Cartmell, E., and Lester, J. N. 2008. Nonylphenol in the environment: a critical review on occurrence, fate, toxicity and treatment in wastewaters. *Environment International* 34(7): 1033.

Solé, M., López de Alda, M. J., Castillo, M., Porte, C., Ladegaard-Pedersen, K., and Barceló, D. 2000. Estrogenicity determination in sewage treatment plants and surface waters from the Catalonian area (NE Spain). *Environmental Science & Technology* 34(24): 5076-83.

Stone, R. 1994. Environmental Estrogens Stir Debate. *Science* 265: 308-10.

Stumpe, B., and Marschner, B. 2010. Dissolved organic carbon from sewage sludge and manure can affect estrogen sorption and mineralization in soils. *Environmental Pollution* 158(1): 148-54.

Svenson, A., Allard, A.-S., and Ek, M. 2003. Removal of estrogenicity in Swedish municipal sewage treatment plants. *Water Research* 37(18): 4433-43.

Tabata, A., Kashiwada, S., Ohnishi, Y., Ishikawa, H., Miyamoto, N., Itoh, M., and Magara, Y. 2001. Estrogenic influences of estradiol-17 beta, p-nonylphenol and bis-phenol-A on Japanese medaka (*Oryzias latipes*) at detected environmental concentrations. *Water Science & Technology* 43(2): 109.

Tan, B. L. L., Hawker, D. W., Müller, J. F., Leusch, F. D. L., Tremblay, L. A., and Chapman, H. F. 2007. Comprehensive study of endocrine disrupting compounds using grab and passive sampling at selected wastewater treatment plants in South East Queensland, Australia. *Environment International* 33(5): 654-69.

Tanghe, T., Devriese, G., and Verstraete, W. 1998. Nonylphenol degradation in lab scale activated sludge units is temperature dependent. *Water Research* 32(10): 2889-96.

Ternes, T. A., Kreckel, P., and Mueller, J. 1999a. Behavior and occurrence of estrogens in municipal sewage treatment plants – II. Aerobic batch experiments with activated sludge. *Science of The Total Environment* 225: 91-99.

Ternes, T. A., Stumpf, M., Mueller, J., Haberer, K., Wilken, R. D., and Servos, M. 1999b. Behavior and occurrence of estrogens in municipal sewage treatment plants – I. Investigations in Germany, Canada and Brazil. *Science of The Total Environment* 225: 81-90.

Ternes, T. A., Andersen, H., Gilberg, D., and Bonerz, M. 2002. Determination of estrogens in sludge and sediments by liquid extraction and GC/MS/MS. *Analytical Chemistry* 74(14): 3498-504.

Teske, S. S., and Arnold, R. G. 2008. Removal of natural and xeno-estrogens during conventional wastewater treatment. *Reviews in Environmental Science & Biotechnology* 7(2): 107-24.

The Dow Chemical Company. 2013. Dow surfactants. URL: http://www.dow.com/surfactants/products/nonylph.htm. [consulted 2 May 2013].

Todorov, J. R., Elskus, A. A., Schlenk, D., Ferguson, P. L., Brownawell, B. J., and McElroy, A. E. 2002. Estrogenic responses of larval sunshine bass (M*orone saxatilis x M. Chrysops*) exposed to New York City sewage effluent. *Marine Environmental Research* 54: 691-95.

Tyler, C. R., Jobling, S., and Sumpter, J. P. 1998. Endocrine disruption in wildlife: a critical review of the evidence. *CRC Critical Reviews in Toxicology* 28(4): 319-61.

U.S. Food and Drug Administration. 2013. Office of New Drugs. URL: http://www.fda.gov/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDER/ucm184426.htm. [consulted 02 May 2013].

US Census Bureau. 2011. *State and County QuickFacts*. New York City.

US Department of Health and Human Services. 2002. *Facts About Menopausal Hormone Therapy*.

———. 2013. Nonylphenol ethoxylate - CAS: 127087-87-0. URL: http://householdproducts.nlm.nih.gov/cgi-bin/household/brands?tbl=chem&id=1639&query=nonylphenol+ethoxylate&searchas=TblChemicals1&prodcat=all. [consulted 02 May 2013].

US Environmental Protection Agency. 1989. *Overview of Selected EPA Regulations and Guidance Affecting Potw Management*. Washington, DC.

———. 1997. *Special Report on Endocrine Disruption*. Washington, D.C.

———. 1999. *Water Efficiency Technology Fact Sheet Composting Toilets*. Washington, D.C.

———. 2000. *Guide to Field Storage of Biosolids*. Washington, D.C.

———. 2005. *Aquatic Life Ambient Water Quality Criteria B Nonylphenol*. Washington, D.C.

———. 2007. TSCA Section 21 Petition on Nonylphenol and Nonylphenol Ethoxylates; Response to Citizens' Petition. URL: http://www.epa.gov/fedrgstr/EPA-TOX/2007/September/Day-05/t17542.htm. [consulted 2 May 2013].

———. 2008. *Overview of Oppt Laws and Programs*. Washington, D.C.

———. 2009. National Pollutant Discharge Elimination System (NPDES). URL: http://cfpub.epa.gov/npdes/. [consulted 02 May 2013].

———. 2010. *Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan*. Washington D.C.

———. 2011. EPA's Toxic Substances Control Act (TSCA) Inventory Homepage. URL: http://www.epa.gov/oppt/existingchemicals/pubs/tscainventory/. [consulted 02 May 2013].

———. 2012a. *Endocrine Disrupting Screening Program: Universe of Chemicals and General Validation Principles*. Washington, D.C.

———. 2012b. *U.S. Environmental Protection Agency Endocrine Disruptor Screening Program Comprehensive Management Plan*. Washington D.C.

———. 2013a. *Gowanus Canal*. Washington D.C.

———. 2013b. Summary of the Toxic Substances Control Act. URL: http://www2.epa.gov/laws-regulations/summary-toxic-substances-control-act/. [consulted 02 May 2013].

US Government Accountability Office. 2009. *Observations on Improving the Toxic Substances Control Act*. Washington, D.C.

Vader, J. S., Van Ginkel, C. G., Sperling, F. M. G. M., De Jong, J., De Boer, W., De Graaf, J. S., Van Der Most, M., and Stokman, P. G. W. 2000. Degradation of ethinyl estradiol by nitrifying activated sludge. *Chemosphere* 41(8): 1239-43.

Vajda, A. M., Barber, L. B., Gray, J. L., Lopez, E. M., Woodling, J. D., and Norris, D. O. 2008. Reproductive disruption in fish downstream from an estrogenic wastewater effluent. *Environmental Science & Technology* 42: 3407-14.

Vandenbroucke, J. P., Rosing, J., Bloemenkamp, K. W. M., Middeldorp, S., Helmerhorst, F. M., Bouma, B. N., and Rosendaal, F. R. 2001. Oral contraceptives and the risk of venous thrombosis. *New England Journal of Medicine* 344: 1527-35.

Vethaak, A. D., Belfroid, A. C., and Gray, M. 2002. *Estrogens and xeno-estrogens in the aquatic environment of The Netherlands: occurrence, potency and biological effects.:* Dutch National Institute of Inland Water Management and Waste Water Treatment (RIZA) and the Dutch National Institute for Coastal and Marine Management (RIKZ).

Vogel, J. 2004. Tunnel Vision: The Regulation of Endocrine Disruptors. *Policy Sciences* 37(3/4): 277-303.

Vogel, J. M. 2005. Perils of paradigm: Complexity, policy design, and the Endocrine Disruptor Screening Program. *Environmental Health: a Global Access Science Source* 4: 2.

Water Environment Federation. 2008. *Operation of Municipal Wastewater Treatment Plants.*

Wester, P. W., and Canton, J. H. 1986. Histopathological study of *Oryzias latipes* (medaka) after long-term β-hexachlorocyclohexane exposure. *Aquatic Toxicology* 9(1): 21-45.

White, R., Jobling, S., Hoare, S. A., Sumpter, J. P., and Parker, M. G. 1994. Environmentally persistent alkylphenolic compounds are estrogenic. *Endocrinology* 135(1): 175-82.

Willmer, P., Stone, G., and Johnston, I. 2009. *Environmental Physiology of Animals*. 2 ed. Hoboken, New Jersey: Wiley-Blackwell.

Wise, A., O'Brien, K., and Woodruff, T. 2011. Are Oral Contraceptives a Significant Contributor to the Estrogenicity of Drinking Water? *Environmental Science & Technology* 45: 51-60.

Wright-Walters, Maxine, and Volz, Conrad. 2009. Municipal Wastewater Concentrations of Pharmaceutical and Xeno-Estrogens: Wildlife and Human Health Implications. 2007 National Conference on Environmental Science and Technology, 103-13. Greensboro, North Carolina: Springer.

Xu, H., Yang, J., Wang, Y., Jiang, Q., Chen, H., and Song, H. 2008. Exposure to 17α-ethynylestradiol impairs reproductive functions of both male and female zebrafish (*Danio rerio*). *Aquatic Toxicology* 88(1): 1-8.

Yang, Y.-Y., Gray, J. L., Furlong, E. T., Davis, J. G., ReVello, R. C., and Borch, T. 2012. Steroid hormone runoff from agricultural test plots applied with municipal biosolids. *Environmental Science & Technology* 46(5): 2746-54.

Zha, J., Sun, L., Zhou, Y., Spear, P. A., Ma, M., and Wang, Z. 2008. Assessment of 17α-ethinylestradiol effects and underlying mechanisms in a continuous, multigeneration exposure of the Chinese rare minnow (*Gobiocypris rarus*). *Toxicology & Applied Pharmacology* 226(3): 298-308.

Zhang, Z., Feng, Y., Gao, P., Wang, C., and Ren, N. 2011. Occurrence and removal efficiencies of eight EDCs and estrogenicity in a STP. *Journal of Environmental Monitoring* 13(5): 1366-73.

Zhou, J., Zhu, X., and Cai, Z. 2008. Endocrine disruptors: an overview and discussion on issues surrounding their impact on marine animals. *Journal of Marine Animals & Their Ecology* 2: 7-17.

Zulkosky, A. M., Ferguson, P. L., and McElroy, A. E. 2002. Effects of sewage-impacted sediment on reproduction in the benthic crustacean *Leptocheirus plumulosus*. *Marine Environmental Research* 54(3): 615-19.

Personal Communications

Brownawell, B. Professor at Stony Brook University, Stony Brook, NY. Informal Interview. 29 April 2013

McElroy, A. Professor at Stony Brook University, Stony Brook, NY. Informal Interview. 29 April 2013

Septoff, P. Representative of Clivus Northeast, Inc. Phone Interview. 02 May 2013