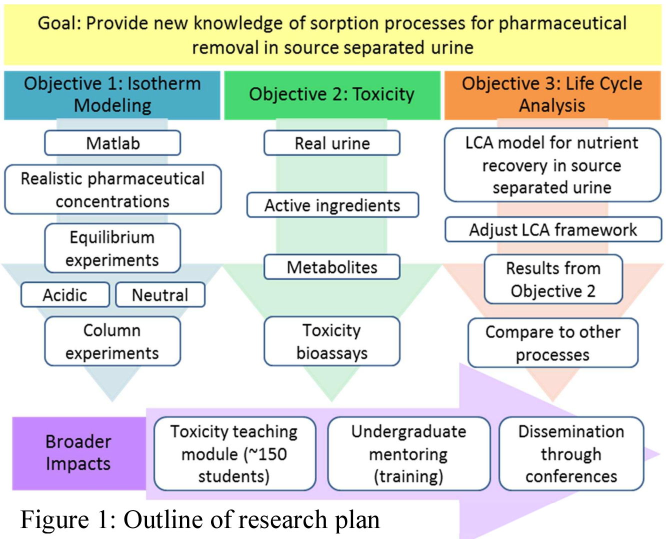

Figure 1: Outline of research plan

Introduction: Approximately 70% of consumed pharmaceuticals are excreted in urine, and are subsequently subject to inadequate removal during conventional wastewater treatment. As a result, pharmaceuticals and associated metabolites are discharged into the environment [1]. However, urine contributes ~1% of the volumetric flow to municipal wastewater treatment thus source separation and treatment of urine has been proposed to create high concentrations of pharmaceuticals in a small volume for effective removal [2]. The additional benefit of source separated urine is recovery of phosphorus and nitrogen for reuse as a urine-derived fertilizer [3]. Accordingly, my graduate research plan consists of three objectives to generate new knowledge of pharmaceutical removal in source separated urine to produce a contaminant free nutrient product through (i) sorption experiments and modeling, (ii) toxicity bioassays, and (iii) life cycle assessment (LCA) (see Figure 1). This research is *novel* because sorption processes have the potential to specifically target pharmaceuticals of concern and separate them from recoverable resources

Intellectual Merit: The results of this work will *advance knowledge within environmental engineering* by providing new insight on pharmaceutical removal in wastewater. Furthermore, it will contribute to the research area of urine source separation as well as a more detailed understanding of pharmaceutical removal by sorption. This work will *advance knowledge across fields* by contributing to pharmaceutical drug-delivery by sorption. This research could also be applied to human health monitoring through the application of ion-exchange resins in hospital toilets for patient monitoring through collection of urine metabolites.

Objectives: The first objective is to conduct non-linear isotherm modeling to understand the equilibrium sorption of various acidic and neutral pharmaceuticals. Non-linear modeling of data from my previous research [4] was used to estimate resin requirements to remove diclofenac at more relevant concentrations in urine [1, 5-7]. Dowex 22 anion exchange resin was determined to have the highest affinity for diclofenac removal and will be used for the remaining experiments in Objective 1. Batch equilibrium experiments of widely consumed acidic pharmaceuticals, individually and as a mixture, will be conducted in synthetic ureolyzed urine. A comparison of the removal of individual pharmaceuticals and the mixture will determine whether removal of acidic pharmaceuticals is additive. Newly developed isotherms will be used to design a column for practical application. The working hypothesis is that the removal of the pharmaceutical mixture will be additive and individual isotherms can be used to predict how removal of various pharmaceutical mixtures will behave. Additionally, the chemical properties of pharmaceuticals can be used to predict removal.

The second objective is to investigate pharmaceutical removal under more realistic operating conditions by using real ureolyzed human urine in which natural urine metabolites are present. Acidic, basic, and neutral pharmaceuticals as well as at least one metabolite of each will be investigated. In addition to anion exchange resins, cation exchange resins, adsorbents, and potentially low-cost materials such as biochar will be investigated. Toxicity bioassays will be conducted to determine the ecotoxicity potential of parent compounds and metabolites before and after treatment to assess acute and chronic toxicity following Method 1002.0 and Method 1003.0 [8]. The results of this objective will show the potential for sorption of pharmaceuticals in source separated urine to reduce ecotoxicity. The working hypothesis is that the metabolites of parent compounds will be effectively removed through sorption because they contain carboxyl and hydroxyl groups that can participate in hydrogen bonding and electrostatic interactions with ion-exchange resins.

The third objective is a life cycle assessment (LCA) of pharmaceutical removal in source separated urine. The results from Objective 2 will be added to an LCA framework developed to model urine source separation for nutrient recovery at the university scale. Results of the LCA will provide information regarding the true environmental impacts of pharmaceutical removal in source separated urine using sorption. A comparison of previous pharmaceutical removal/destruction processes in source separated urine will also be conducted to determine the best advanced treatment option.

Broader Impacts: The completion of this research will provide new knowledge on pharmaceutical removal in source separated urine, which is of great significance to *society and the environment*. Efficient removal of pharmaceuticals from source separated urine would decrease the loading in the environment and may decrease the potential ecotoxocity and presence in our drinking water [9]. To *promote teaching and learning*, a teaching module will be developed for Dr. Boyer's environmental organic chemistry course that will model the ecotoxicity of pharmaceuticals on aquatic life. This class is taught each spring semester to 50 students so over the course of 3 years it will reach 150 students. I also intend to mentor at least one undergraduate student each year, focusing on *training* in the laboratory, and *teaching* new concepts not learned in the classroom. This will be a *learning* experience for me as well by developing my abilities to convey ideas in a constructive manner. Finally, I plan on *disseminating* my research through publishing in peer-reviewed journals and at various regional and national conferences through poster and oral presentations. I will attend at least one national conference each year, such as American Chemical Society (ACS), Association of Environmental Engineering and Science Professors (AEESP), and Water Environment Federation Technical Exhibition and Conference (WEFTEC).

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Motivation: Growing up in Florida, a fundamental part of our science education involved learning about our most precious resource, the Floridan Aquifer. I always understood and appreciated the significant ecosystem services and beauty provided by the aquifer, so protecting the environment became an interest of mine. My parents claim that they predicted my pursuit of engineering long before my days at the University of Florida. These claims are typically accompanied by them reminiscing about how I would disassemble toys as a child simply to see how they worked, and then proceed to put them back together again. In accordance with my previous interest and successes in math and science, I pursued engineering as an undergraduate student. Initially, I declared my major as a mechanical engineering, but I soon found my passion for this specialty to be lacking. There appeared to be a disconnect between the information I was learning and how it could be used to not only serve this generation, but also to protect future generations and the environment in which they would thrive. My passion for providing society with its essential services while remaining respectful of our natural resources became increasingly apparent the summer in which I took Introduction to Engineering at the University of Florida, a semester course where we learned about a new area of engineering each week. I immediately changed my major to environmental engineering upon hearing a short lecture on water reuse for NASA space stations given by Dr. David Mazyck and participating in a simple water filtration experiment. I was inspired, motivated, and truly excited about my change in career path. Through my undergraduate research supported by NSF CAREER grant number CBET-1150790 studying urine source separation and treatment, as well as educational and community outreach, I was able to hone in on precisely what would become the basis for my future studies and career in environmental engineering.
Intellectual Merit: To expand my knowledge beyond the requisite coursework, I joined Dr. Treavor Boyer's research group the summer before my junior year. Under the mentorship of another student, I investigated the effects of anion exchange water treatment processes on the corrosion potential of water distribution systems [1]. Along with another undergraduate student, we *worked as a team executing bench-scale experiments and analytical work in the laboratory*. The following semester, I began an *independent* research project, which served as the basis for my undergraduate Honors thesis, investigating the efficacy of diclofenac removal from synthetic urine using anion exchange resins. The goal of this research was to remove pharmaceuticals, i.e., diclofenac, from source separated urine that was diverted from the general waste stream for treatment. Although the treatment of urine as a separate waste stream may initially seem unconventional, it becomes significantly less so when one recognizes that urine contributes ~1% of the volumetric flow to a typical wastewater stream, yet ~50% of the phosphorus and ~80% of the nitrogen present in the wastewater originates from urine [2]. This fact coupled with the energy demand of nutrient removal from large volumes of water and the importance of nutrient recovery for reuse in agriculture continually motivates my work. However, pharmaceutical contamination of source separated urine poses an issue, as recovery and reuse of nutrients with pharmaceuticals represents a human health and ecotoxicity concern [3]. The removal of pharmaceuticals from source separated urine prior to nutrient recovery is necessary not only to produce a contaminant free nutrient product, but also to ultimately reduce the discharge of pharmaceuticals into the environment. Previous research of urine source separation treatment processes for the removal/destruction of pharmaceuticals has shown to be lacking in their ability to produce a contaminant free nutrient product [4, 5].

Anion exchange treatment shows promise as an effective method of pharmaceutical removal from urine. Many pharmaceuticals, such as diclofenac, ibuprofen, and other non-steroidal antiinflammatory drugs (NSAID), contain carboxylic acid functional groups that may deprotonate in urine, resulting in an overall negative charge. Additionally, non-electrostatic interactions between the aromatic benzene ring structure of the pharmaceuticals and polymer structure of the resin may increase selectivity. Through *bench scale kinetic and equilibrium testing* it was determined that polystyrene anion exchange resins can successfully remove >90% of diclofenac in both synthetic fresh and aged urine which indicates that treatment would not need to adhere to a strict timeline. Furthermore, *collaboration* with a colleague provided additional insight into pharmaceutical separation from nutrients. It was determined that hybrid anion exchange resin impregnated with ferric oxide was successful at removing >90% phosphate, as well as >90% diclofenac [6]. However, minimal removal of phosphate by the polystyrene anion exchange resin was observed. This indicates that polystyrene resin could be used for successful pretreatment of urine to selectively remove pharmaceuticals prior to application as a nutrient product. Over the course of this research, I became a huge advocate for this other type of "liquid gold" and I wanted to help facilitate a shift from the view that urine is a waste product to a valuable resource. Although this research helped to shed light on the efficacy of pharmaceutical removal in urine through sorption, many research questions remain. My desire to pursue a doctoral degree at the University of Florida stems from the need to further explore the technical challenges of urine source separation.

Acknowledging the need to disseminate one's work and learn from the expertise of others, I presented a research poster at the 2013 Association of Environmental Engineering and Science Professors 50th Anniversary Conference in Golden, Colorado. Out of 216 posters, I was awarded 1st place in the competition. I attribute this honor to the dedication I took in preparing a clear and concise poster as well as my experience presenting at various on-campus poster symposiums. Additionally, I gave an oral presentation at the 2013 Water Environment Federation/International Water Association Nutrient Removal and Recovery in Vancouver, Canada this past July. Speaking to an international audience proved to be especially rewarding, as I was able to get feedback from professionals from all over the world. My undergraduate research experience eased my transition into graduate school because I have developed a strong foundation in research methods to build upon. From these experiences, I have strengthened my ability to communicate research through oral presentations, papers, and posters. At the conclusion of my undergraduate career, I successfully published an original research article in *Water Research* [7], which was an invaluable learning experience of the academic writing and publishing process. My abilities to critically review scientific literature, design and execute experiments, and apply the fundamental science that drives my research have undergone significant development and I look forward to future growth as a PhD student.

I attribute a large portion of my success to the building blocks I developed while working as an executive assistant at a law firm throughout high school and college. During my employment I developed a strong work ethic based on dedication, self-discipline and self-motivation which I believe are all integral tools necessary for graduate school. I frequently displayed *leadership* through my ability to train new employees and streamline procedures to ensure the office ran efficiently.

Broader Impact: This past year, I was selected to participate in the 2013 EPA P3 Design Competition for Sustainability. Through this EPA funded project, a four person team was formed to design and build a pilot size column treatment system to separate pharmaceuticals, phosphorus, and nitrogen in urine, thus resulting in a contaminant free nutrient product. My knowledge of pharmaceutical removal by ion-exchange resins was integral to the design process.

In addition to addressing technical challenges, a large component of this project pertained to societal impact. We *collaborated* with two Alachua County schools to *teach* students ranging from 2nd–7th grade the concepts of sustainability and wastewater treatment. Through lectures and hands-on activities, we introduced the idea of urine source separation in terms of water conservation and nutrient cycling. At the end of the project, our work was *broadly disseminated* to the public at an exposition at the National Mall in Washington D.C. I found this to be the most fulfilling part of the project because we were able to present our work to the general public. I was determined to communicate the motivation and scientific content of our project to the public in a manner that was both accurate and easy to understand. I believe that public interest and understanding is an integral part of improving society through science.

Community outreach is very worthwhile and I am confident that it can have significant impacts on students and the general public. A few years ago, as a member of Dr. Boyer's research group, I participated in the Summer Science Institute, an event that *enhances diversity* by developing and presenting science activities for middle school teachers from under resourced schools in Florida. During the program, I developed an activity with three other students that highlighted the advantages of recovering a resource from a concentrated waste stream, as opposed to a mixed, diluted waste stream. I also prepared an environmental engineering session, including a presentation and accompanying hands-on activities, for Introduce a Girl to Engineering Day, an annual event directed towards middle school girls that exposes them to different engineering majors. This event is a great tool for increasing diversity in a predominantly male field. Outreach opportunities such as these have a *broader impact* on society by exposing diverse groups of students at a young age to ways they can contribute to solving critical real-world problems. Throughout my graduate career, I will continue participating in outreach activities to increase student excitement and competence in STEM fields.

Future Goals: As the need for environmental protection through policy becomes increasingly apparent, contaminants such as pharmaceuticals will be at the forefront for regulation. I expect that my research will provide new knowledge on which to control and minimize the release of pharmaceuticals to the environment. Furthermore, I aspire to become a leader in the advanced wastewater treatment field, and couple this technical knowledge with an appreciation for the three pillars of sustainability. I will achieve this goal by pursuing a career as an environmental engineering consultant, at a firm that embraces challenging projects and maintains a culture centered around sustainability and protecting the environment and human health.

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