Each full proposal shall consist of the following 20 elements.
Items numbered 1 through 12 need to be completed and will be entered by TWRI into a Web form.

1. Title. Effects of Salinity on DOC Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems

2. Project Type. Research

3. Focus Categories. WQL, TRT, SW (Attachment C)

4. Research Category. Water Quality

5. Keywords. Salinity, Dissolved Organic Carbon, Biological pretreatment, Reverse Osmosis

6. Start Date. 3/1/2017

7. End Date. 2/28/2018

8. Principal investigator(s). Asef Mohammad Redwan

9. Congressional District TX-019

10. Abstract. Reverse osmosis (RO) is one of the most practiced technologies used for salinity removal and is necessary for areas such as West Texas where surface waters are rich in salts. Membrane fouling is a major drawback of RO and results in increased operating costs. This can be mitigated in wastewater systems by pretreating water with biological activated carbon, but it is unknown whether biological activated carbon (BAC) is an appropriate pretreatment strategy for partially saline surface waters intended for RO and potable use. We propose a combined BAC-RO system to study: i) the effects of varying salinity concentrations on DOC removal in BAC and ii) how BAC permeate influences membrane flux and organic fouling in downstream RO systems. We will evaluate BAC using small-scale glass columns packed with activated carbon and will measure influent/effluent organic carbon concentration and size distribution. BAC permeate will be filtered through RO membranes, and fouling will be analyzed using SEM imaging. Both synthetic and actual West Texas surface water will be used for these studies and will allow for a better understanding of how salinity influences BAC-RO system performance.

11. Budget Breakdown, see Attachment A for template.

12. Budget Justification, see Attachment B for template.

Note: Items 13 through 20 are in a different one file document.

13. <u>Title</u>. Effects of Salinity on Dissolved Organic Carbon (DOC) Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems.

14. <u>Statement of Regional or State Water Problem</u>.

Surface water is a significant water resource within the State of Texas. Use of surface water is expected to increase as groundwater resources are depleted, and the Texas Water Development Board (TWDB) estimates that surface water will comprise ~45 % of total water supplies in the state by year 2070 (State Water Plan, 2017). Waters in West Texas can be partially saline, with sulfate (SO_4^{2-}) present as the dominant anion (Forsberg, 1996). The extent of salinity in water determines its application (*e.g.* drinking water, livestock, industrial usage, irrigation, etc.). Most of the cities situated in the far western Texas (*e.g.* El Paso) are facing continual drawdown and salinity intrusion problems in their aquifers and hence, switching to surface water resources for potable purposes. For example, the Rio Grande water usage is transferring from agricultural to municipal. But high salinity during winter season due to minimal precipitation is enforcing introduction of desalination treatments for water use (Turner et. al., 2002). As surface water usage in West Texas increases, so will issues associated with salinity. Additionally, surface waters are likely to contain high levels of dissolved organic carbon (DOC).

Salinity is roughly equivalent to total dissolved solids (TDS). The Texas Commission on Environmental Quality (TCEQ) has established a secondary drinking water standard for TDS of 1,000 mg/L, which is higher than EPA's (500 mg/L). This reflects the higher saline waters typical of Texas. Several rivers in Texas exceed these limits, including the upper portions of the Red, Wichita, Colorado, Brazos, and Rio Grande, located in the western part of the state (TDS = 5,000 mg /L or more). These regions have recommended water management strategies to address salinity issues (TWDB Final Report, 2015).

Reverse osmosis (RO) is a high-pressure filtration process that removes minerals, monovalent and divalent salts, pathogens, and organic contaminants. It is the most common technique for salt removal, but organic fouling of the membranes is still a major issue, limiting its efficiency. Fouling is usually due to accumulation or adsorption of organic matter in the membrane micropores and surfaces, which results in declining flux, increasing operating pressures, and increasing energy costs. Fouling is problematic for RO systems treating West Texas surface water, because these waters are high in both TDS (requiring RO treatment) and DOC (responsible for RO fouling).

A current research priority of the TWDB is to minimize fouling by implementing pretreatment strategies before RO. One proposed treatment, biological activated carbon (BAC), is a low energy pretreatment strategy applied upstream of RO units that removes DOC via microbial oxidation. BAC has excellent removal efficiency in wastewater treatment systems, mitigating membrane fouling (Pramanik *et al.*, 2014), but it is unknown how salinity may affect DOC oxidation in waters intended for potable use. **This study will evaluate the impact of salinity upon DOC removal and RO fouling in combined BAC-RO systems treating West Texas surface water.**

15. <u>Statement of Results or Benefits</u>.

Turner *et al.* (2002) investigated performance of dual microfiltration-nanofiltration membrane system for combined total organic carbon (TOC) and salinity removal through a pilot study on

the Rio Grande River. Effective TOC removal of up to less than 1% was observed in nanofiltration in the microfiltration permeate (Turner *et al.*, 2002). However, the purpose of my work is to determine whether or not BAC is a viable RO pretreatment strategy for waters containing both salts and DOC. The results will demonstrate co-relationships between salinity and DOC levels on the performances of BAC and RO separately, and also as a combined system. I expect to see an initial "shock" in BAC at the highest tested salinity level where less DOC is removed, followed by a shift in the microbial community over time as they adjust to the high sulfate concentrations. After the culture adjusts – you will again see transformation of NOM due to development of osmotic stress in microbial community. So, I believe BAC can be an effective pretreatment option for no/low saline waters with minimal effect on the microbial structure in BAC. I aim to i) identify the extent to which a shift in salinity affects transformation of NOM in a BAC filter, ii) characterize the effects of a shift in alkalinity on downstream RO fouling, and iii) determine whether fouling can be minimized by upstream BAC filter. If the results show minimal effects of salinity upon DOC removal and membrane fouling over a range of relevant sulfate concentrations, this combined system may be an appropriate treatment option for potable water in West Texas. This would be particularly encouraging, as BAC is less energy intensive than membrane pretreatment (ultra- or microfiltration) and is more cost effective. Results from this study will be disseminated to academics and water treatment industry through peer-reviewed journal articles (*e.g.*, Journal of Water Reuse and Desalination) and conference (*e.g.*, AWWA Membrane Technology Conference and Exposition) proceedings.

16. <u>Nature, Scope, and Objectives of the Project, including a Timeline of Activities</u>.

Multiple studies have suggested BAC as an effective option for treating DOC in wastewater systems, and also improving RO flux in sea water systems. BAC process combined with pre-oxidation by UV/H_2O_2 process showed DOC removal of approximately 60% for a high salinity (TDS 10 g/L) municipal wastewater RO concentrate (Lu, 2013). Chinu *et al.* (2009) showed reduction in normalized flux decline with BAC pretreatment for sea water with TDS of 35 g/L. In the acclimation phase of BAC (2-3 months), DOC adsorption and biological degradation processes occur simultaneously with the rate of biological degradation increases, but the physical adsorption ceases to decline. Then slowly biological degradation becomes predominant over the adsorption process for DOC removal reaching a steady state. The DOC removal of 15-45% was observed during the steady state period in ozonated water (Korotta, 2015). In a bench scale experiment with BAC run for 18 months, salinity level of 1 g Cl^-/L was showed no adverse impact on microbial growth and total organic carbon (TOC) removal (Sozanski, 1995).

Carlson and Amy (2000) showed that microorganisms releasing organic compounds, called soluble microbial products (SMP), along with substrate utilization can underestimate DOC removal efficiency in biofiltration system. It can be defined as soluble cellular components derived from substrate metabolism during biomass synthesis and released during cell lysis. They are further divided into two classes: a) substrate-utilization-associated products (UAP) formed directly during substrate metabolism, and b) biomass-associated products (BAP) produced from biomass as part of decay. SMPs are important because they are ubiquitous in nature, usually attribute to the effluent oxygen demand (COD/BOD) and possess toxic effect on biomass activity in the system (Laspidou and Rittman, 2002).

The rate and extent of fouling is governed by the quality of water/permeate to the membranes. Fouling may result from the retention of constituents or the rapid and substantial biofilm growth

in the membranes or the combination of both. Problems associated with chemical treatments for minimizing RO fouling are cost, byproduct formation and membrane-sensitivity at times. On the other hand, though conventional treatment systems (nano- and ultrafiltration) can remove dissolved organic material in the presence of activated carbon and coagulant chemicals only, they were also found to promote microbial growth in the treated water. None of the above mentioned treatment approaches worked efficiently and sustainably alone in fouling mitigation. So, I am proposing BAC as an effective upstream treatment method for low-nutient waters containing no, low, and high levels of salinity.

RO treatment of water containing high DOC levels is prone to rapid membrane fouling and flux declination, as DOC is utilized as a substrate by the bacteria. While there is no regulatory level specified for DOC level in water, RO membrane manufacturers suggest restricting DOC levels to less than 3 mg/L (Paterson et al, 2007). This limits use of RO membranes for raw water with high organic carbon content. Still, RO was successfully combined with biological pretreatment in the study conducted by Paterson *et al.* (2007). Hence, I propose to reduce membrane fouling by pretreating feed water using BAC. BAC will reduce foulants like DOC by promoting bacterial activity. The proposed system will complement the experiences of the drinking water industry, where biological filtration is often practiced for reducing natural organic matter, disinfectant demand, and downstream foulants of the distribution system.

My approach will be to test a combined BAC-RO system at varying salinity levels for stabilizing and improving water quality and thus, prolonging membrane performance. This proposal is based on the belief that the deliberate encouragement of biological growth within BAC will substantially reduce the undesirable growth on RO membranes, particularly for low salinity level of the feed water. This study is divided into three tasks. The first task is setup. The second two tasks test my hypothesis and will be conducted simultaneously:

Task 1: Practice protocols and inoculate BAC columns. Suwannee River Natural Organic Matter (SRNOM) will be purchased, size fractions to < 3 kDa, dissolved in water, and analyzed using size exclusion chromatography. Resulting chromatograms will be compared against those available in the literature to establish a baseline. Lubbock surface water intended for column experiments will be collected and analyzed for relevant water quality parameters (*e.g.* pH, DOC, NOM, salinity, NH_4^+, etc.); these values will be compared against published values. Eight glass columns will be packed with GAC and empty bed contact time estimated using bromide as a tracer. Lubbock surface water will be allowed to pass through the columns for one month, allowing for adequate biofilm development prior to experimentation.

Task 2: Evaluate the effects of salinity on DOC removal in small-scale BAC column experiments. Water of varying salinity levels will be passed through the BAC filters. Artificial and natural water sources will be evaluated. Influent and BAC permeate waters will be collected and analyzed for quantity and size distribution of natural organic matter (NOM). The proposed hypotheses on BAC performance are:

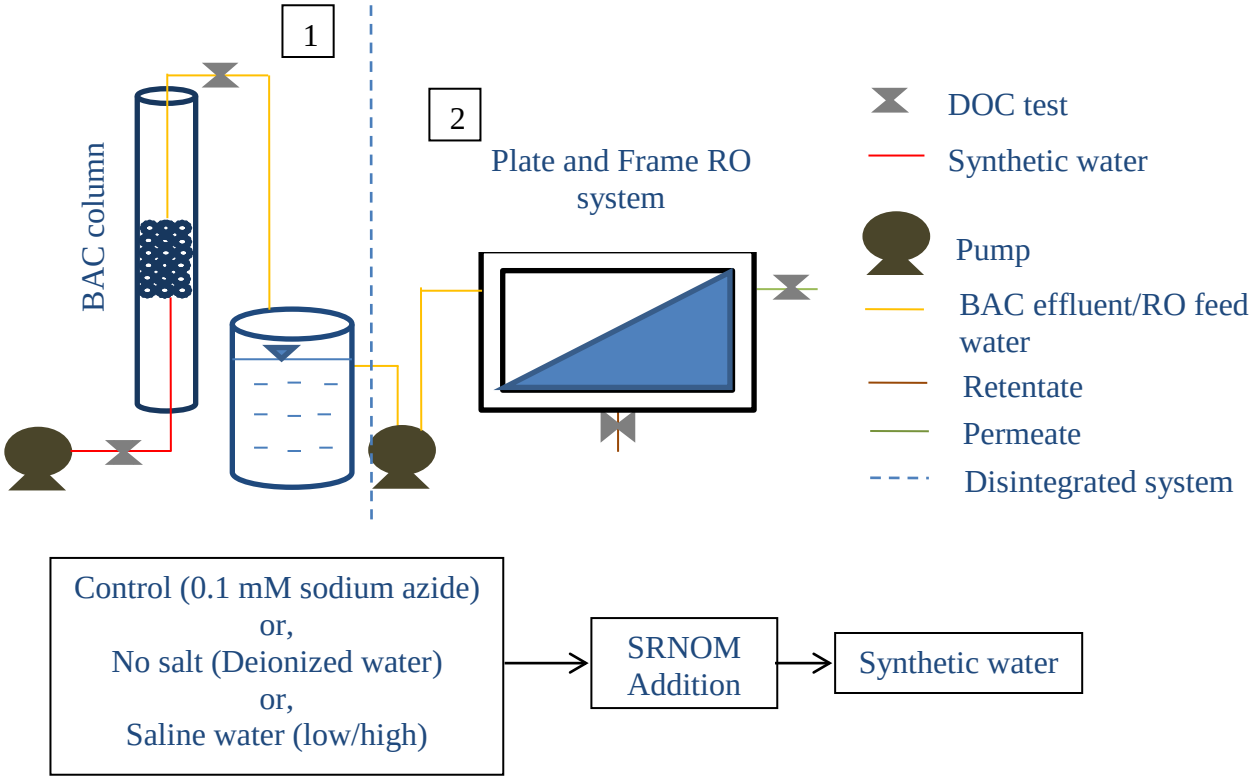
> *Hypothesis 1: Low/no salt samples will remove more DOC (< 3 kDa).* This hypothesis is based on the belief that high salinity level in the system will adversely impact biomass (excluding salt-tolerant microbes) of the BAC columns. So, I expect to see slightly greater removal of DOC under low or no salt conditions. How *et al.* (2005) demonstrated that the DOC removal efficiency reduced from 96% to 86% when NaCl concentration elevated from 0 to 60 g/L in a sequencing batch reactor, though the range of tested salinity is very high in

comparison to this study (0-8g/L). This hypothesis also follows study of Pradhan *et al.* (2016), where sequential UV/H_2O_2 and BAC treatment for the RO concentrate from municipal wastewater reclamation process of various salinity levels (7, 10 and 16 g/L) showed very slightly disproportionate DOC removal ranging 45 to 49%.

Hypothesis 2: NOM size distribution of BAC effluent will be slightly more consistent for high salinity sample. Carlson and Amy (2000) demonstrated that SMPs can underestimate the actual DOC removal efficiency by up to 33% for a drinking water ozone-biofiltration combined process. This impact was attributed to BAPs, rather than UAPs. With low/no salinity sample, more biomass growth in the BAC columns will occur due to minimal salt toxicity, so will BAPs. So, I am expecting to see spikes in the NOM size distribution for those samples, but more stable graphs for the high salinity with low biomass.

Task 3: Evaluate the fouling potential of permeate from columns in RO systems: BAC permeate will be collected from BAC columns and stored at 4 °C until a sufficient volume has been collected. Following collection, BAC permeate will be treated via a GE Osmotics Plate and Frame RO which employs flat sheet membranes, and flow rates will be measured to evaluate flux. RO membrane fouling will be visualized through microscopy, and biofilm thickness will be calculated. My proposed hypotheses on RO performance are:

Hypothesis 3: Latest samples will show more flux decline in comparison to earlier points. BAC effluent can contain organic matters such as non-biodegradable portion of NOM, dead cells and EPS released by microbes (Korotta, 2015). With time, these fractions will increase, so will the RO membrane clogging. Thus, a reasonable assumption is that RO flux may show declination before reaching pseudo steady-state condition.



Hypothesis 4: High saline samples will cause slightly more membrane fouling. This hypothesis compliments Hypothesis 1. Higher salt concentration will interrupt biomass structure, formation and concentration. With slightly less DOC removal in upstream BAC, slightly more biomass growth will be initiated in the downstream RO membrane assay. So, I am expecting to see slightly more and faster membrane fouling in case of high saline samples.

Schematic diagram of proposed BAC-RO combined system: The flow rate through each BAC column will be maintained individually with a stainless steel needle valve. Flows will be maintained between 1-2 mL min^{-1}.

Timeline of Activities (3/1/2017 to 2/28/2018):

- *March to April 2017:* Protocols will be practiced and tested. West Texas surface water will be collected and analyzed for relevant water quality parameters (pH, DOC, salinity, etc.).
- *May 2017:* Glass columns will be packed, and Lubbock surface water will be allowed to pass through the columns for one month, allowing for biofilm growth.
- *June to November 2017:* Columns will operate continuously for 6 months. BAC influent and permeate will be analyzed for DOC and NOM size distribution [testing hypotheses 1 and 2]. BAC permeate from select columns will be utilized in membrane fouling experiments [testing hypotheses 3 and 4]. RO system fouling experiments will utilize BAC permeate collected by the end of June (1st month), August (3rd month), and November (6th month of column experiments).
- *December 2017*: Final testing and sample analysis will be performed.
- *January to February 2018:* Results will be summarized in a final report.

17. Methods, Procedures, and Facilities.

Bench top experiments will be conducted in Dr. Millerick's environmental microbiology laboratory using glass columns and Dr. Morse's RO membrane setup. Methods and procedures are described below. Identified equipment is operational and available.

Water Quality Analysis: Lubbock surface water will be collected, run through a glass fiber filter, and analyzed for standard water quality parameters (pH, total suspended solids, total dissolved solids, carbon content, nitrogen content, SUVA, and alkalinity) using methods described in *Standard Methods for Examination of Water and Wastewater*. Water will also be analyzed for DOC, sulfate, and NOM using methods described later in this section. When not in use, all natural waters will be stored at 4 °C.

Biological Activated Carbon (BAC) Columns: Borosilicate glass columns (ID of 25mm, length of 150 mm; 73.63 mL total volume) will be used for BAC experiments. Columns will be sealed with glide fit end caps but no inlet/outlet filters. All tubing will be Masterflex silicone or Tygon tubing. Columns will be packed with granular activated carbon (BPL® 4x10, Calgon Carbon) prior to setup. Water will be continuously passed through the columns in an upflow direction using a Masterflex L/S peristaltic pump. Flow will be adjusted to maintain an empty bed contact

time (EBCT) of 20 min; use of bromide (tracer) will facilitate EBCT estimations. Eight (8) columns will be operated in parallel.

Inoculation: After column packing and tracer analysis, Lubbock surface water will be filtered through a glass fiber filter (to prevent clogging) and pumped through columns for one month, allowing for adequate biofilm development prior to experimentation. Identical feed water will be used for this one-month inoculation step.

BAC Experiments: Following inoculation, each column will be fed water from different reservoirs. These reservoirs will contain *artificial* or *local* waters, with amendments. *Artificial water* will be synthesized in the lab in a similar method as described in Reinaeur *et al.*, but will be adapted to better mimic the local Lubbock water collected and analyzed in Task 1. *Local water* will consist of West Texas surface water prefiltered through a both glass fiber filter (to prevent clogging) and a 3 kDa ultrafiltration membrane (to remove bacteria and large NOM). Local water may be supplemented with additional NOM or nitrogen if concentrations of these are deemed too low, since collection will occur in winter (low organics/nutrients expected). Eight BAC columns will be operated; four for each water type. Feed waters for each of the 4 column types are described below. Sulfate will be amended as the K_2SO_4 salt.

- **Control (no salt)**: Water is amended with sodium azide (0.1 mM), inhibiting microbial growth and activity
- **No salt:** Water is run through columns "as is" and is not amended with salt beyond what is naturally present in local Lubbock waters
- **Low salt:** Water is amended with 2 g/L SO_4^{2-} (low salinity)
- **High salt:** Water is amended with 8 g/L SO_4^{2-} (high salinity)

Suwannee River Natural Organic Matter (SRNOM, filtered to < 3 kDa in size) will be used as DOC in artificial water. SRNOM is a widely used and commercially available source of natural organic matter (NOM). It is well characterized and has been utilized as reference material in multiple investigations related to drinking water treatment. Filtered SRNOM will be amended to a final concentration of 0.5 mg/L in artificial water and may additionally be used to supplement local waters if existing DOC (< 3 kDa) is deemed too low. 0.5 mg/L is low for surface water DOC in general, but I am only considering NOM that is < 3 kDa in size, which is usually only a small fraction of total DOC.

Influent and permeate from BAC columns will be analyzed for DOC and NOM size distribution Permeate from BAC systems will be collected and stored in the refrigerator at 4°C until 10 L has been collected; this will then be used for RO experimentation. Because of the length of time required for RO experiments, only samples (RO permeate) deemed of interest (either significantly different or representative based on SUVA and DOC measurements) will be assessed during RO experiments.

Specific Analytical Methods. Dissolved Organic Carbon (DOC) will be analyzed using a Vario TOC Select (Elementar). Water will be filtered through a 0.2 µm PTFE filter prior to analysis. To remove inorganic carbon, samples will titrated with hydrochloric acid (37%) until acidified ($pH \leq 2$), converting all inorganic carbon into carbonic acid. This will be removed via purging.

After acidification, triplicate samples will be analyzed. DDI blanks and standards (prepared with potassium hydrogen phthalate and DDI) will be used, and specific tests will be conducted during Task 1 to ensure the instrument can accurately detect DOC at low levels. If not, DOC will be concentrated via reverse osmosis prior to analysis. Changes in natural organic matter size and composition will be quantified with high performance size exclusion chromatography using an HPLC (Agilent 1200) equipped with a UV-Diode array detector and a size exclusion column. Reference standards (1 kDa, 3 kDa, and 10 kDa) will be purchased for size quantification. Samples may need to be concentrated via reverse osmosis prior to SEC analysis. Salinity will be measured as TDS using a TDS probe (HACH) and ion chromatography (Dionex UltiMate 3000) using an AS-14A column with a carbonate mobile phase (8 mM .Na_2CO_3/1 mM $NaHCO_3$; 1 mL min^{-1}); sulfate standards will be prepared in DDI water using a concentrated stock solution of K_2SO_4.

RO system specifications: All polyamide composite RO membranes (Type PA-AK) (19 cm x 14 cm), spacers (medium foullant; 47 mm thickness) and permeate carriers will be used in all the experiments. All membranes, spacers and permeate carriers will be purchased from GE Osmonics (Minnetonka, MN). The GE SEPA™ CF II Med/High Foulant system consists of a cell body (made from grade 316 stainless steel), an anodized aluminum cell body holder, a concentrate flow control valve, a centrifugal pump (Wanner Engineering, Inc. Hydra-Cell), and a media reservoir, which is connected using ¼" (6.35 mm) tubing. Permeate will be collected in ⅛" (3.18 mm) in size tubing. The centrifugal pump supplies media to the flow cell at an approximate flow rate of 1.9 L/min. System pressure is increased to the required operating pressures using a hydraulic hand pump. Pressure in the system will be measured by analog pressure gauges.

RO flux calculations: The RO experimental setup consists of an in-line membrane holder containing 47 mm RO membrane swatches. A pump at constant pressure (200-250 kPa) will maintain flow across the membrane. Flux through the membrane will be measured periodically to determine the flux reduction as the fouling layer develops. Flux measurement will be determined by collecting the flux effluent from the membrane assay for a known time and then measuring the collected volume. After the final day of the experimental run, the assays will be dismantled and the membrane removed for biofouling analysis.

SEM fouling layer assessment: Total biomass and average biofilm thickness will be visualized and quantified using confocal laser scanning microscope (CLSM) and a LIVE/DEAD BacLight™ Bacterial Viability Kit for microscopy assays. The viability kit employs cell membrane integrity to estimate the live and dead bacterial populations Cells with a compromised membrane that are considered to be dead or dying stained red, whereas cells with an intact membrane stained green; results of bacterial cells intact (dyed green) are reported. I will randomly select samples three locations on the RO membrane surface and aggregate data to estimate biofilm thickness and viability. CLSM images will be obtained for using a Nikon Eclipse Ni-E upright microscope with a 10X optical lens, and NIS-Elements Imaging Software at the WCOE Materials Characterization Center. Data files were generated for each z-slice of biofilm collected by CLSM within the Nikon microscope's software, and the biofilms were quantified using the COMSTAT program module. Values for the total specific biomass concentration ($\mu m^3/\mu m^2$) and average biofilm thickness (μm) will be generated using COMSTAT (Monaco *et al.* in review).

Membrane sterilization before tests: Effluent from BAC systems will be collected and stored in the refrigerator at 4^{o}C until 10 L has been collected. Once this occurs, the RO system will be sterilized and experiments will be conducted following the procedures outlined below.

The RO system will be sanitized using the procedure outlined in Low *et al.* (2010) to remove impurities and microorganisms in the system. The sterilization process begins with one two-hour cycle of 0.5% sodium hypochlorite (NaOCl), two ten-minute flush cycles with nanopure water, one thirty-minute cycle of 5mM ethylenediamintetraacetic acid (EDTA) (pH 11), two ten-minute flush cycles with nanopure water, one thirty-minute cycle of sodium dodecyl sulfate (SDS) (pH 11), two ten-minute flush cycles with nanopure water, one one-hour cycle of 90% ethanol, and finalized with three ten-minute flush cycles with nanopure water. The RO membranes will be sterilized by exposing each side of the membrane to 254 nm UV light for 30 minutes. The sterilized membrane will be placed in the SEPA flow cell unit and the unit will be pressured. The membrane will be compressed using DI water for approximately 24 hours at 300 psi. After completing the compression process, the operating pressure will be lowered to 180 psi and the system will be operated until achieving a constant flux for a one-hour period. Once reaching a constant flux, the DI water in the system will be drained and the feed tank emptied and refilled with the BAC effluent. Upon 90% flux reduction, the RO system will be shut down, and the membrane extracted from the flow cell body will be divided into 4 pieces before conducting the live-dead stain analysis with CLSM and BacLight^{TM} kit.

18. Related research.

BAC as pretreatment for controlling fouling: Pramanik *et al.* (2014) investigated the performance of BAC as a pre-treatment for reducing organic fouling in microfiltration in the biologically treated secondary effluent. BAC showed 30% reduced in high molecular substances like bioploymers and humic substances by biodegradation and adsorption, and also higher flux in comparison to GAC controls. Characteristics of the organic molecules rather than DOC concentration alone, were attributed to membrane fouling. Hu *et al.* (2004) investigated biofouling of RO membrane with and without the biofiltration system. They found almost five times increase in the operational length before getting effected significantly by biofouling in the system, when biofiltration was used as pretreatment. Simon *et al.* (2013) found approximately 94% reduction in biofilm formation when they conducted comparative study on biofiltered and non-biofiltered seawater. Flux improvement was also observed in ultrafiltration membrane with permeate from BAC filtration after efficient reduction of suspended particles from activated sludge through ozonation (Nguyen and Roddick, 2010).

Advisor Expertise

Dr. Millerick's research explores interactions between microbes and granular activated carbon for enhanced micropollutant removal. She has studied biologically active GAC in flow-through systems (Reinauer, 2014), in batch systems with pure cultures (Millerick, 2013) and is currently working with biological colonization of GAC-amended sediment caps (in progress). She has previous experience monitoring NOM in drinking water sources using the methods described in this text for SUVA, DOC quantification, and NOM size speciation.

Dr. Morse's research has explored membrane biofouling for more than 7 years by exploring the impact of biologically treated graywater on biofouling production (Crawley *et al.*, 2012), the impact of organo-selenium coatings and organo-selenium feed spacers on biofouling production (Monaco et al, in review; Vercellino *et al.*, 2013a; Vercellino *et al.*, 2013b; Vercellino *et al.*, 2013c; Low *et al.*, 2011) and the ability to use polysolfulone with polyaniline and silver nanoparticples to prevent biofouling (Zhao *et al.*, in review).

19. <u>Training potential</u>. This project will provide lots of training opportunities in new laboratory techniques for me. I am very keen to learn more, continue my research, and take my training on membrane fouling through this project to a more advanced level during my Ph.D.

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20. <u>Investigator's qualifications</u>. Resume(s) of the (co-) principal investigator(s) are attached.

Attachment A –BUDGET BREAKDOWN

Cost Category	Federal	Non-Federal	Total
1. Salaries and Wages - Principal Investigator(s) - Graduate Student(s) Asef Redwan - Undergraduate Student(s) - Others Total Salaries and Wages	$0	$5,019	$5,019
2. Fringe Benefits - Principal Investigator(s) - Graduate Student(s) - Undergraduate Student(s) - Others Total Fringe Benefits	$0	$50	$50
3. Tuition - Graduate Student(s) - Undergraduate Student(s) Total Tuition	$0	$0	$0
4. Supplies	$5,000	$0	$5,000
5. Equipment	$0	$0	$0
6. Services or Consultants	$0	$0	$0
7. Travel	$0	$0	$0
8. Other direct costs	$0	$0	$0
9. Total direct costs	$5,000	$5,069	$10,069
10a. Indirect costs on federal share	XXXXXXXX XXXXXXXX	$2,450	$2,450
10b. Indirect costs on non-federal share	XXXXXXXX XXXXXXXX	$2,484	$2,484
11. Total estimated costs	$5,000	$10,003	$15,003
Total Costs at Campus of the University on which the Institute or Center is located.	$5,000	$10,003	$15,003
Total Costs at other University Campus Name of University:	$0	$0	$0

Attachment B – BUDGET JUSTIFICATION

Salaries and Wages for PIs. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.
Salaries and Wages for Graduate Students. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)
Graduate student leading the project will be compensated at an annual rate of $27,500 for 2.19 months (~189.8 hours). These funds will be provided by the faculty advisor's start-up funds.
Salaries and Wages for Undergraduate Students. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)
Salaries and Wages for Others. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.
Fringe Benefits for PIs. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.
Fringe Benefits for Graduate Students. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable.
Calculated as a direct cost at 18% of salary plus average health insurance costs for graduate students. These funds will be provided by the faculty advisor's start-up funds.
Fringe Benefits for Undergraduate Students. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable
Fringe Benefits for Others. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.
Tuition for Graduate Students.
Tuition for Undergraduate Students
Supplies. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies. Provide a breakdown of the supplies in each category.
Funds are requested for consumable items ($2,600) and an 8 channel masterflex pump ($2,400).
Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items. A detailed breakdown is required.
Services or Consultants. Identify the specific tasks for which these services, consultants, or subcontracts would be used. Provide a detailed breakdown of the services or consultants to include personnel, time, salary, supplies, travel, etc.
Travel. Provide purpose and estimated costs for all travel. A breakdown should be provided to include location, number of personnel, number of days, per diem rate, lodging rate, mileage and mileage rate, airfare (whatever is applicable).
Other Direct Costs. Itemize costs not included elsewhere, including publication costs. Costs for services and consultants should be included and justified under "Services or Consultants (above). Please provide a breakdown for costs listed under this category.
Indirect Costs. Provide negotiated indirect ("Facilities and Administration") cost rate.