Supplemental Information

Ozone-UV net-zero water wash station for remote emergency response healthcare units: Design, operation, and results

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Table S1. Organic Content as mg of TOC and pH of Selected Shampoo, Soap, and Conditioner.

Soap Brand	mg TOC per g of Soap	pH
African Black Soap Body Wash	326.6	4.81
Bar Soaps[1]	850-950	10-12
Campsuds	112.5	7.05
25% Campsuds with 0.747 M Soda Ash	37.50	10.66
Garnier Fructis Biodegradable Conditioner	219.0	7.25
Garnier Fructis Biodegradable Shampoo	166.9	6.47
Garnier Fructis Daily 2 in 1	236.4	6.24
Garnier Fructis Orange Conditioner	192.3	5.70
Garnier Fructis Orange Shampoo	212.6	5.82
Garnier Fructis Triple Nutrition Conditioner	189.7	6.00
Head and Shoulders 2 in 1	267.5	6.26
Suave 3 in 1	177.4	4.68
Trader Joe's Tea Tree Body Wash	110.7	3.78
Trader Joe's Tea Tree Conditioner	124.3	6.22
Trader Joe's Tea Tree Shampoo	138.1	6.36
Tresame Conditioner	112.9	7.05

[1]African Black Soap, Dove White Beauty Bar, Lever 2000 Soap, Trader Joe's Green Tea Soap, Trader Joe's Tea Tree Oil Soap, and Homemade Lye Soap (Great Smoky Mountains Association)

S1. Sampling

Samples for experimental runs were taken as described in the Section 2.2, Experiments, in 500 mL high-density polyethylene (HDPE) wide-mouth laboratory bottles, and analyzed for pH, conductivity, dissolved oxygen (DO), turbidity, temperature, and hydrogen peroxide, and measures of total organics depending on the experiment including chemical oxygen demand (COD), total organic carbon (TOC), and UV254 absorbance. *E. coli* was measured during each experiment, in treated water during showers and after treatment. These microbiological samples were collected in 500 mL HDPE wide mouth laboratory bottles, sterilized by autoclave at 115°C for 15 minutes.

Samples were collected for analysis by a certified external laboratory (Florida Spectrum Environmental Services, Inc., Fort Lauderdale, FL, USA) for compliance with all U. S. federal and Florida drinking water standards, during two scenarios in the fed batch system, when a point-of-use GAC filter was in use on the showerhead for additional treatment (June 8, 2016), and when the system had operated without the point-of-use GAC filter for one week (June 15, 2016). All samples were collected after the system had been used for at least 48 showers in fed batch mode with 15% water replacement as described previously. These samples were preserved according to their respective standard methods in containers provided by Florida Spectrum, and maintained at 4°C until analysis.

Three tests to determine the kinetics of microbial inactivation were conducted by spiking the reactor influent with bacteriophage and spores, on March 9, 2016, and March 11, 2016, as follows. Concentrated bacteriophage and spores, including PhiX174, MS2, Phi6, and *Bacillus atrophaeus* were sent to the site on dry ice by the U. S. Environmental Protection

Agency (USEPA), Cincinnati, OH, and bacteriophage were preserved at -78^{o}C and spores at 4^{o}C until use. Microbes were then defrosted, diluted into 10 L of treated net-zero water in a sterile container sterilized with a 12,800 mg/L free chlorine solution, followed by five rinses with the treated water, and three samples were taken from this mixture in 50 mL sterilized centrifuge vials to enumerate the concentration of microbes entering the treatment system. The four types of microbes were then injected together into the vacuum side of the ozone-UV treatment system using a hose sterilized with a 12,800 mg/L free chlorine solution, and then rinsed with running treated water for 10 minutes. The microbes were injected at a point immediately preceding the strainer and approximately 12 ft prior to the ozone injector, and subjected to a single pass through treatment. The effluent was fully collected into a separate container sterilized as described previously, from a port directly after the 5 µm filter, using a separate hose also sterilized as described previously. Full collection of the effluent by this procedure was verified by dye test.

After greywater collection, three sub-samples were taken in sterilized 50 mL centrifuge vials, and the remaining full effluent volume was filtered through Rexeed 25S ultrafilters using a peristaltic pump. Flow rate was maintained at 1.8 LPM and recorded. Tubing was disinfected prior to each sample using a concentrated chlorine solution (12,800 mg/L free chlorine) and rinsed for 10 minutes with the treated net-zero water before attaching to the filter. The full volume of effluent filtered was recorded, to quantify total microbe inactivation. Filters and samples were placed in a Ziploc bag in a cooler with ice packs and shipped overnight for morning delivery to USEPA for analysis.

To test the organic loading per person per shower, including in particular the organic content washed off from the human body, experiments were performed using the amounts of soap and conditioner described previously and collecting the full shower drainage volume in a container. The full volume of each shower was collected in an 80 L container, and samples were taken from that container in 500 mL HDPE bottles. These raw greywater samples were analyzed for COD or TOC or both. In total, 25 samples were collected, from showers taken by 12 males and 13 females.

Samples of treated water and greywater from six showers were collected in 500 mL HDPE bottles to determine the sources and distribution of nitrogen species. Three samples of RO source and effluent water were also taken. To analyze nitrogen species in the Campsuds and Garnier Fructis conditioner, solutions of both were prepared and diluted as appropriate with deionized water to fall within the detection limit of the nitrogen tests. Samples to determine bromate inputs to the system were collected for analysis in 1000 mL and 500 mL HDPE bottles, from the same six sources as the nitrogen samples. These samples were bubbled with ozone at 3 g/hr in a vertical three-foot by two-inch diameter PVC pipe, for a minimum of eight hours, to convert bromide to bromate, for trace bromate analysis. In the case of the soap solution, hydrogen peroxide was first added to prevent excess foaming during ozonation. Ozonated samples were then analyzed by certified external lab (Florida Spectrum).

Simulated shower tests were conducted using a gender-averaged soap and conditioner loading for each shower, i.e., 17.5 mL of the soap mixture, 3.5 mL of conditioner, and 2.43 mL soybean oil to simulate body organics.

S2. Initial System Design – Continuous Flow and Batch Design

A two-tank continuous-flow system was initially designed and built based on results of pseudo-first order kinetic modeling (Figure 1). A 40-gallon working-volume treated water tank supplied the 1 gpm showerhead and the sink. Used water drained directly to the 175-

gallon working-volume greywater tank underlying the wash station, which was made-up with 15% RO-treated water and continuously ozonated to maintain disinfection. Both tanks contained an ozone vent, to allow ozone gas to vent to an outside courtyard. Water in the treated water tank was blended with 10% water from the greywater tank, adjustable by valves as shown, for continuous recirculation through the ozone-UV reactor, which included a 16 mesh high capacity stainless steel polypropylene-housed t-strainer (McMaster-Carr, Elmhurst, IL) and ozone injection by venturi, followed immediately by flow through three high-efficiency, low-pressure UV reactors with total 596 W of UV power (NeoTech D338 and NeoTech D438, NeoTech Aqua Solutions, San Diego, CA). After ozone-UV advanced oxidation, the water passed to a 5 μm fiberglass filter (Graver Stratum, Graver Technologies, Glasgow, DE). Hence, all treated water was passed through advanced oxidation and filtration treatment at least once prior to use.

The energy consumption of individual unit processes of the system tested are estimated as follows: 200 W for continuous 25 g/hr ozone generation, 550 W for the oxygen concentrator, 470 W for continuous venturi ozone injection and water recirculation by 0.5-0.75 hp pump, and 700 W for the UV reactors and controllers. The energy consumption of other system components, such as the tank mixer and shower pump, were negligible in comparison. Due to the subtropical Miami climate and UV heating, the shower was run continuously for evaporative cooling, to maintain a comfortable shower temperature. The system operated at an 85% recycle rate across all experiments, with 15% makeup water provided by an RO-treated county water (StealthRO200, Hydrologic Purification Systems, CA, USA) and disposal to sewer of excess water remaining after 3-8% evaporative loss. In particular, water was not replaced between experiments.

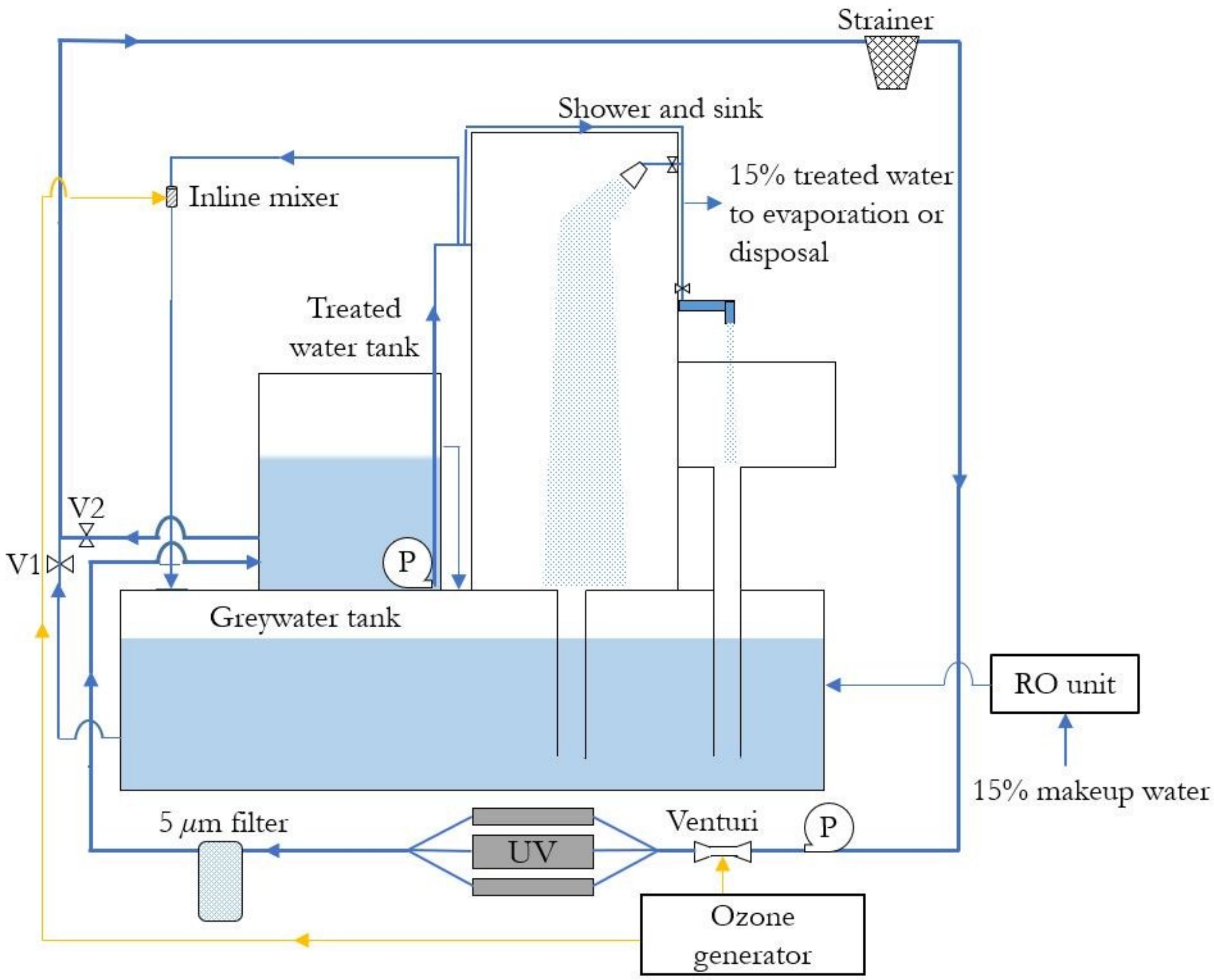

Figure S1. Schematic for the continuous flow wash station.

Following continuous flow reactor testing, a batch reactor design was tested for kinetics of organics mineralization. However, the ozone-UV reaction system involves initial competition between organics and ozone for UV absorption and, subsequently, competition between UV and ozone for reaction with the hydrogen peroxide produced initially from ozone. Apparently as a result, the observed rates of oxidative degradation were much lower than were projected by modeling for the continuous flow design.

Kinetic tests of the continuous flow system comprised 8 showers per day, or 16 with the simulated mixture (using a timer to dispense the mixture over 16 hours) to better analyze steady state, one shower every hour, on Mondays, Wednesdays, and Fridays over a period of four months. Samples were taken for the full period of actual showers, but only for the final 8 hours of simulated showers, due to the first portion of the run occurring overnight.

S3. Continuous-flow system organics mineralization

Results of shower tests of the continuous-flow system, representing two scenarios, with six runs of each scenario: 8 actual, and 16 simulated, showers taken at equal intervals over a period of 8 and 16 hours, respectively, are presented in Figures S2 and S3. TOC in the treated water tank over the test period appeared to reach steady state in terms of TOC concentration at approximately 1 mg/L, higher than the anticipated 0.5 mg/L goal. Results suggest that a pseudo first order model is not appropriate for the ozone-UV process under the experimental conditions of this study. That is, it appears that ozone was photolyzed much more slowly than expected due to competing ozone cyclic decay reactions and scavenging for example by hydroxyl radical, which proved significant at the UV and ozone doses used in the experiment (Gassie and Englehardt, 2018). Moreover, hydroxyl radical concentration was changing during treatment due to the change in TOC and UV light availability for reaction with ozone and hydrogen peroxide, invalidating the first-order approximation (Glaze and Kang, 1998; Kang and Lee, 1997). Hence, a second order kinetic model was developed as presented elsewhere (Gassie and Englehardt, 2018). In the County Water, ammonia added to nitrate tested significantly higher than total nitrogen. This can be attributed to possible interference from turbidity or color in the water, which can cause high value errors, which would be more noticeable at the low levels of measured ammonia in this water.

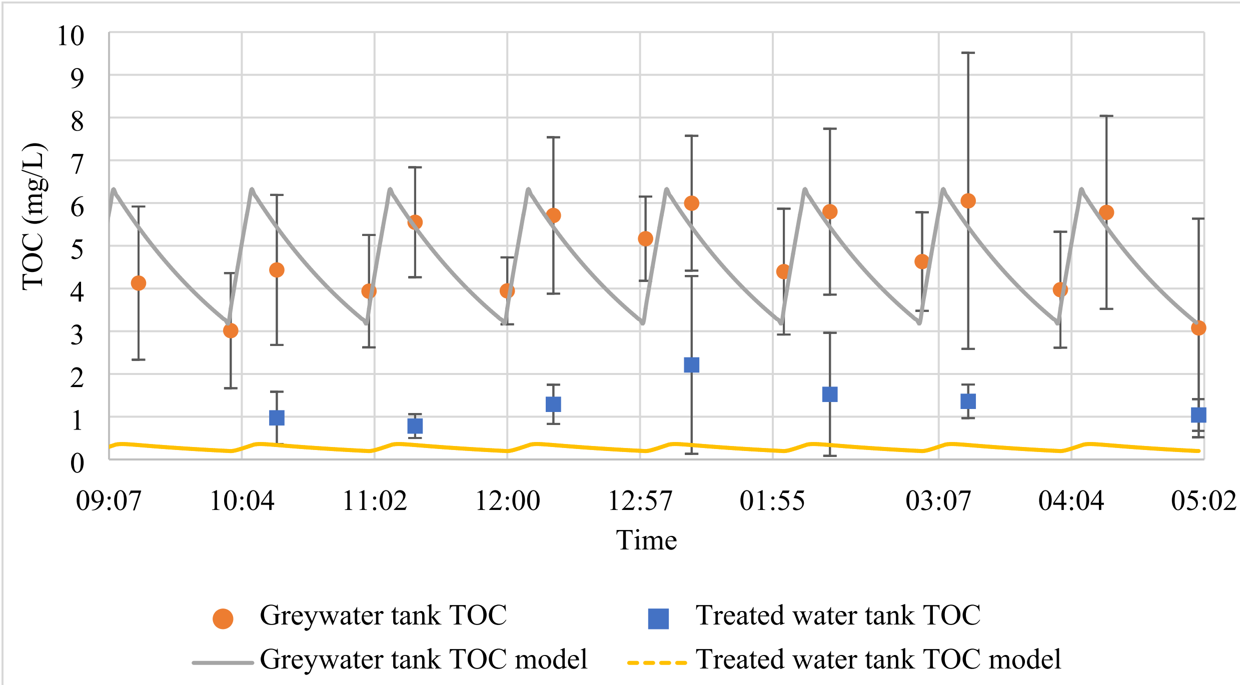

Figure S2. Results of simulated shower tests of the continuous-flow system. [Conditions: 1 shower per hour, pH = 7.1, TDS = 190 mg/L, 25 mL 25% Campsuds with 0.747 M soda ash, 2.43 mL soybean oil, and 5 mL conditioner per shower, 9:00 sample is shower 9 of 16]

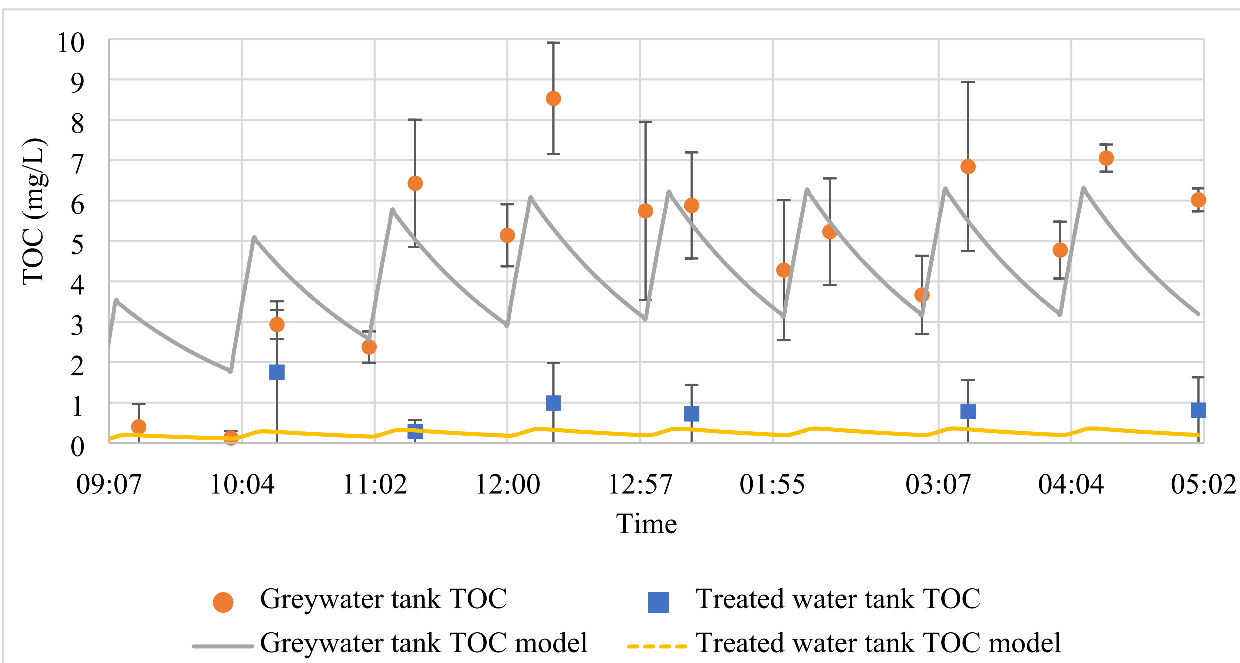

Figure S3. Results of real shower testing using the continuous-flow system. [Conditions: 1 shower per hour, pH = 7, TDS = 200 mg/L, 25 mL 25% Campsuds with 0.747 M soda ash and 5 mL conditioner per shower, 9:00 sample is shower 1 of 8]

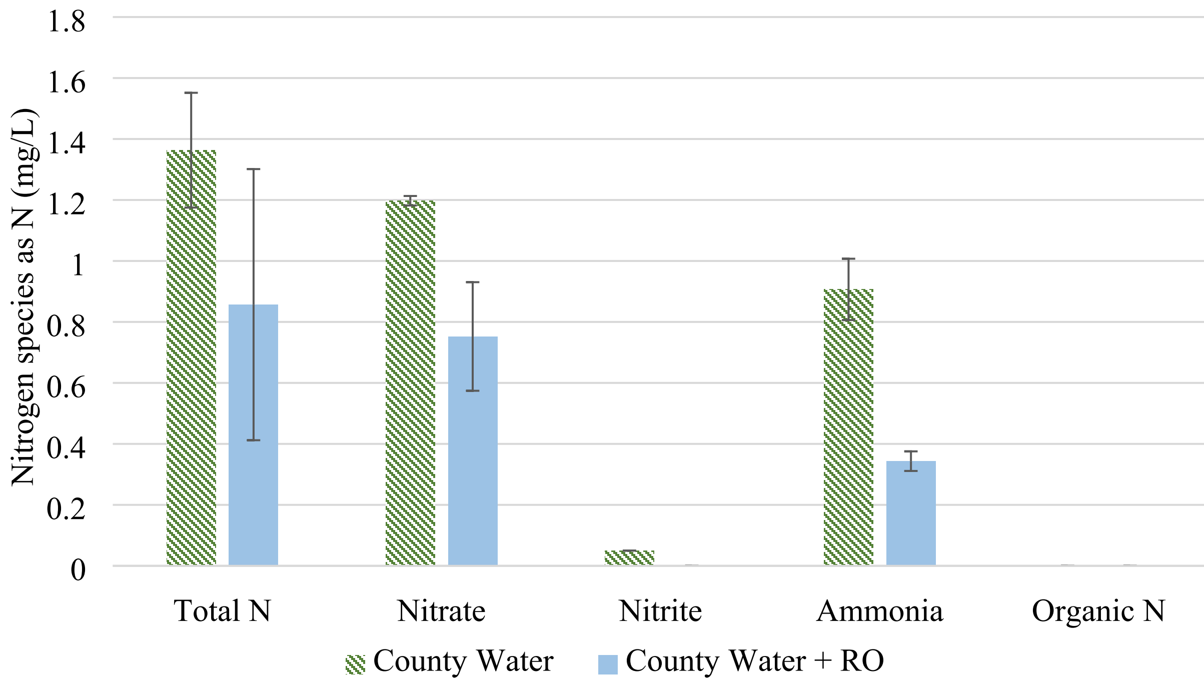

Figure S4. Comparison of nitrogen species in the RO source water and effluent. [Conditions: 28°C, influent TDS = 151 mg/L, effluent TDS = 13.3 mg/L]

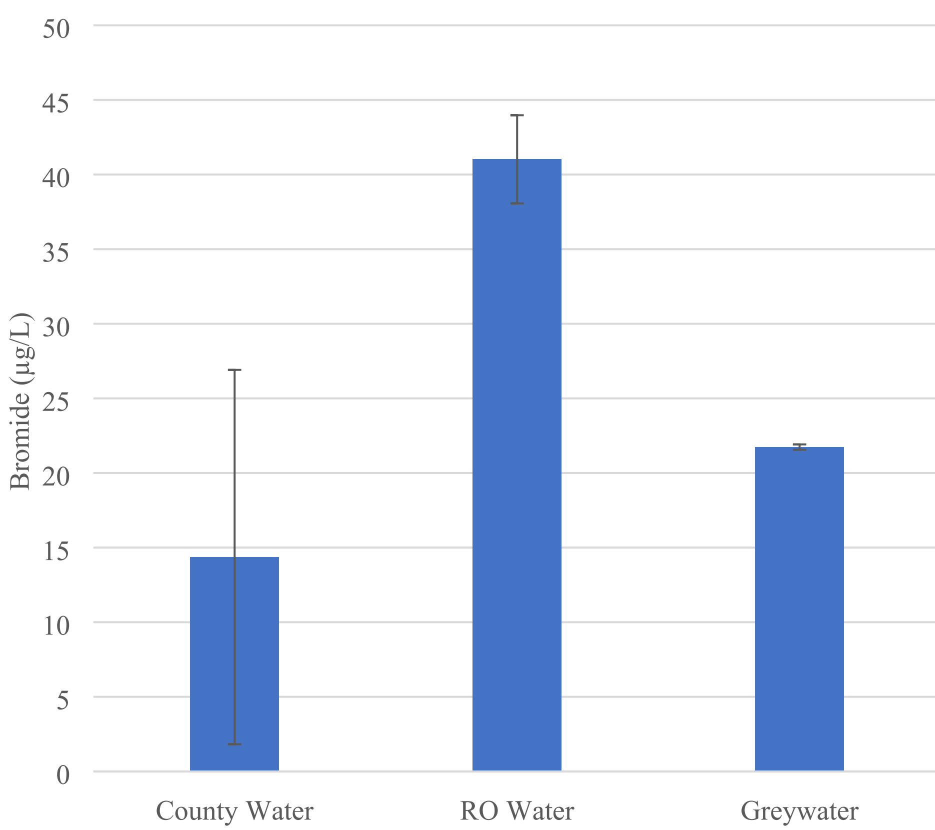

Figure S5. Bromide inputs to the system.