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A taxonomy of *chemicals of emerging concern* based on observed fate at water resource recovery facilities

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HIGHLIGHTS

- Primary and secondary effluents were analyzed for three WRRFs under dry conditions in Texas and Oklahoma for a suite of 95 CECs.
- For the study set of 95 CECs, 82 were detected above the corresponding minimum reporting limit (MRL) in the primary effluent.
- 14 CECs were not detected in any WRRF samples.
- 18 of the studied 95 CECs were fully (100%) removed by full-scale WRRF biological treatment.
- 64 of the 95 studied CECs were found to exist in the secondary effluent at residual concentrations above MRL.

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ABSTRACT

As reuse of municipal water resource recovery facility (WRRF) effluent becomes vital to augment diminishing fresh drinking water resources, concern exists that conventional barriers may prove deficient, and the upcycling of *chemicals of emerging concern* (CECs) could prove harmful to human health and aquatic species if more effective and robust treatment barriers are not in place. A multiple month survey, of both primary and secondary effluents, from three (3) WRRFs, for 95 CECs was conducted in 2014 to classify CECs by their persistence through conventional water reclamation processes. By sampling the participating WRRF process trains at their peak performance (as determined by measured bulk organics and particulates removal), a short-list of recalcitrant CECs that warrant monitoring to assess treatment performance at advanced water reclamation and production facilities. The list of identified CECs for potable water reclamation (indirect or direct potable reuse) include a herbicide and its degradants, prescription pharmaceuticals and antibiotics, a female hormone, an artificial sweetener, and chlorinated flame retardants.

1. Introduction

Record drought, shrinking water supply alternatives, and growing water demand from population centers across the West, South Central and Southeast United States (US) have combined to push municipal wastewater potable reuse to the forefront as a vital solution to augment public water supplies (Tisdale, 2015). Capital expenditures for potable reuse infrastructure are anticipated to exceed $11 billion over the next decade. As reuse of treated municipal wastewater becomes vital to augment diminishing fresh drinking water resources, both State and Federal agencies in the U.S. have cataloged the presence of *chemicals of emerging concern* (CECs) in publicly-owned treatment works (POTW) discharges and receiving streams, as well as reclaimed water for beneficial use (EPA, 2014; Ferrey, 2013).

CECs are predominantly water soluble contaminants of anthropogenic origin. CECs in water resource recovery facility (WRRF) effluent include pharmaceuticals and personal care products such as hormones, antibiotics, stimulants, surfactants, as well as preservatives, artificial sweeteners, and caffeine. While the focus

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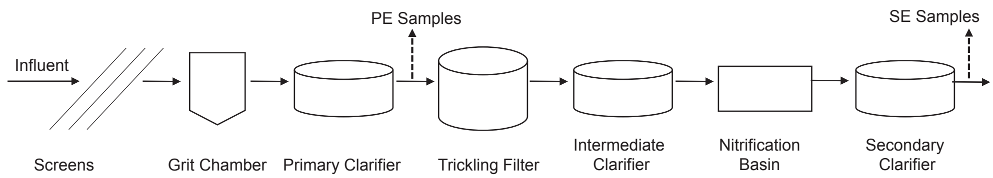

Fig. 1. Process flow diagram (PFD) for the sampled TF/AS plants (Lawton, OK and Garland, TX).

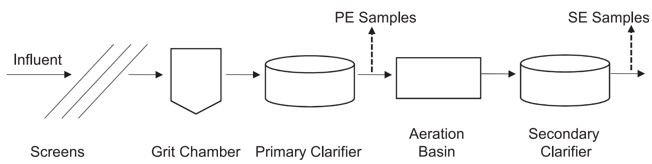

Fig. 2. Process flow diagram (PFD) for the Norman WRRF, OK.

of engineered treatment systems for potable reuse projects begins with minimizing the risk associated with wastewater pathogens, non-regulated trace organic contaminants have become important considerations for treatment system design (Dickenson and Drewes, 2008; Gerrity et al., 2013; Tchobanoglous et al., 2015). Municipal WRRF primary and secondary effluents have been found to contain trace levels of CECs (Purdom et al., 1994; Drewes, 2006; Behera et al., 2011; Luo et al., 2014). Often-cited studies have linked, in certain aquatic species, the presence of CECs in POTW discharges and specific bioactivity, including estrogenic activity (Purdom et al., 1994; Folmar et al., 1996; Rodgers-Gray et al., 2000).

While multiple studies have attempted to catalog the presence and concentration of CECs in municipal wastewater effluents, due to the complexity and cost of trace CEC sampling and analysis, few have utilized sampling plans for a broad spectrum of wastewater CECs (by class or intended use) over multiple weeks when municipal wastewater treatment facilities (or WRRF) are considered to be operating under optimum conditions. This research program was designed to conduct CEC sampling in both primary and secondary effluents from three (3) WRRFs (all located in the South-Central U.S.) at the peak of biological treatment process efficiency (dry conditions in summer months). By doing so, the resulting CEC occurrence data can be used to identify the anthropogenic organic compounds that are recalcitrant in municipal wastewater, even during *ideal* WRRF operating conditions (for biological oxidation). Two (2) of the three (3) sampled WRRFs are identical in treatment regime - trickling filters followed by nitrification — while a third sampled WRRF employed conventional activated sludge. However, the sampled treatment facilities were representative of conventional, secondary wastewater treatment, and as such provided an important screening tool for identification of CECs resistant to state-of-the-art biological treatment. The resulting list of recalcitrant CECs can be used in the development of monitoring protocols for CECs in reclaimed waters receiving advanced treatment, and for additional screening of both potential public and aquatic health effects.

2. Materials and methods

2.1. Water resource recovery facilities

The City of Garland, Texas, owns and operates two tertiary WRRFs (Rowlett Creek and Duck Creek) to treat flows from their Dallas/Fort Worth suburban population of 235,000 residents. Primary effluent (PE) and secondary effluent (SE) for this research was collected from the Rowlett Creek WRRF, a fixed-film trickling filter and suspended-growth activated sludge (TF/AS) facility, permitted to treat 24 MGD. The Texas Commission for Environmental Quality (TCEQ) administers a Texas Pollutant Discharge Elimination System (TPDES) permit which dictates the monthly average effluent limits from Rowlett Creek for carbonaceous biochemical oxygen demand (cBOD) of 10 mg/L, total suspended solids (TSS) of 15 mg/L, and seasonal ammonia nitrogen limits of 5 mg/L (December through March) and 2 mg/L (April through November). Effluent is discharged from this facility to the East Fork of the Trinity River.

The City of Lawton, Oklahoma, also owns and operates a tertiary TF/AS plant to treat sanitary sewer flows from their southwest Oklahoma population of 85,872 residents. PE and SE samples were collected from the Lawton WRRF, which currently treats an average daily flow of 10 MGD with average daily effluent water quality of 3 mg/L cBOD, 9 mg/L TSS, and 0.2 mg/L ammonia nitrogen. Effluent is discharged to Nine Mile Creek in the Red River watershed; however, up to 5 MGD is dedicated for reuse by the Public Service Company of Oklahoma (PSO) for their industrial cooling towers. Fig. 2 presents a simplified process flow diagram of treatment at the Lawton and Garland WRRFs, as well as the locations of PE and SE sample collection in the process train.

The City of Norman, Oklahoma, owns and operates a WRRF to treat flows from their Oklahoma City suburban and research university population of over 100,000 residents. Samples were collected for this study from the conventional, suspended-growth, activated sludge (AS) facility; permitted to treat 17 MGD. Monthly average effluent limits from the WRRF are cBOD of 13 mg/L, TSS of 30 mg/L, and ammonia nitrogen limits of 4.1 mg/L. Effluent is discharged to the Canadian River in the Arkansas River watershed. The Norman WRRF provides seasonal reuse to the University of Oklahoma for irrigation of the Jimmie Austin Golf Course. Fig. 2 presents a simplified process flow diagram of the Norman WRRF, and the locations of PE and SE sample collection in the process train.

2.2. Effluent sampling

Two (2) sampling locations were identified per WRRF. The sample locations included the influent to the biological reactor(s) and the effluent of the final (or secondary) clarifiers. Samples collected on the influent side of the biological reactor were always prior to being combined with the return activated sludge (RAS) flow. The sampling location of the secondary clarifier effluent, at each WRRF, was after all clarifier effluents had been combined, but prior to any tertiary treatment or disinfection. Sampling was performed in August and September of 2014, with one sample event per week. Table 1 lists the number of discrete sample events during

Table 1
Sampling events and WRRF flow treated during sampling in August/September 2014.

WRRF	No. of sample events	Avg. flow treated (MGD)
Norman (OK)	4	9.6
Lawton (OK)	4	11
Garland (TX)	3	12.7