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DROUGHT TIP

Use of Treated Wastewater for Crop Production

Overview

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Increased competition for water supplies and the increased availability of treated (secondary-treated wastewater) and recycled or reclaimed water (tertiary-treated wastewater) present an opportunity to develop this resource for agricultural production, especially during drought periods when regular water supplies are limited or nonexistent. Treated and recycled water use for landscaping and agricultural production has been practiced around the world for several decades (Pescod 1992; Wu et al. 2009; USEPA 2012), but its use in agriculture has been affected by adverse public perception. This perception has been associated with possible crop contamination [e.g., by bacteria or accumulation of contaminants of emerging concern (CECs) such as commonly used pharmaceutical and personal care products (PPCPs)], as well as growers' concern about the possibility of long-term physical and chemical deterioration (e.g., salinization) of the soil root zone from long-term use of treated or recycled wastewater.

The use of treated municipal wastewater for irrigating crops has increased dramatically in California over the past decade and is expected to expand exponentially in the next few decades. Today, California's water agencies recycle about 669,000 acre-feet per year (CA SWRCB 2009). The environmental benefits of using treated or recycled water for agricultural and landscaping water needs include decreased groundwater pumping and limiting wastewater discharge into natural waterways, which helps preserve potable water supplies for human consumption (municipal use). The California Department of Water Resources (CA DWR) estimated a potential of 0.9 to 1.4 million acre-feet per year of additional water supply from recycled water by the year 2030 (CA DWR 2005).

Use of treated or recycled water for crop production is controlled by the recently updated (July 2014) restrictions of the California Administrative Code Title 22 that consider treated wastewater quality. Such restrictions continue to be revised worldwide (e.g., Blumenthal et al. 2000; Al-Jasser et al. 2011), and interested growers should contact their local water agencies for assistance in evaluating the possibility of using recycled water for landscape or crop irrigation.

Definitions

- *Recycled water* means water that, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource [CA Water Code Section 13050(n), CA SWRCB 2016].
- *Reclaimed water* means effluent derived in any part from sewage from a wastewater treatment system that has been adequately and reliably treated, so that as a result of such treatment it is suitable for a beneficial use or a controlled use that would not otherwise occur and is no longer considered wastewater [WA Statute – RCW 90.46.020, Washington State Legislature].

Characteristics of Treated and Recycled (Reclaimed) Water

The quality of treated or recycled water depends on the original potable source water from which it was derived and the various unit operations (treatment processes, see fig. 1) employed by the wastewater treatment plant (WWTP). During the past few decades in California, there has been a progression toward greater wastewater treatment. In many locations, originally developed secondary treatment processes such as clarification (fig. 2, and see fig. 1) are being followed by additional treatment through biological filtration and disinfection and a variety of other tertiary treatment processes (e.g., constructed wetlands). As an example, fig. 2 illustrates the recycled water treatment steps outlined by the Santa Rosa Regional WWTP.

The various WWTP unit operations remove nutrients, pathogens, bacteria, and other dietary or health-related pollutants at varying rates (USEPA 2010). Table 1 summarizes typical treated wastewater quality (domestic water source) following each level of treatment. For example, activated sludge treatment removal efficiencies ranged from 22 percent for carbamazepine to 94 percent for caffeine; activated carbon adsorption removal ranged from 3.6

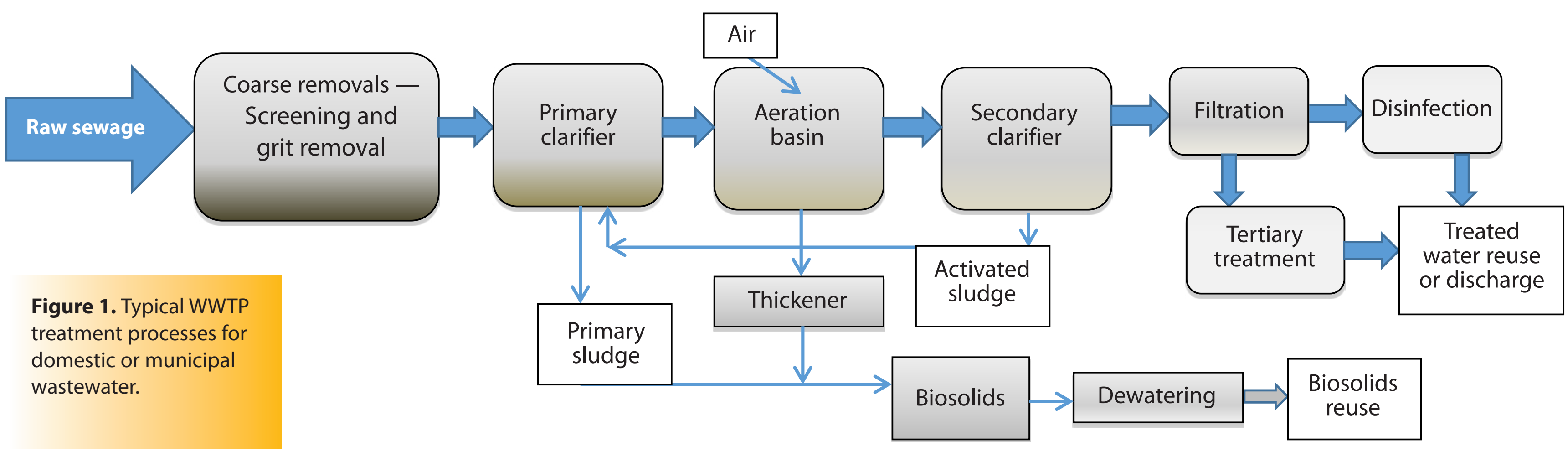

Figure 1. Typical WWTP treatment processes for domestic or municipal wastewater.

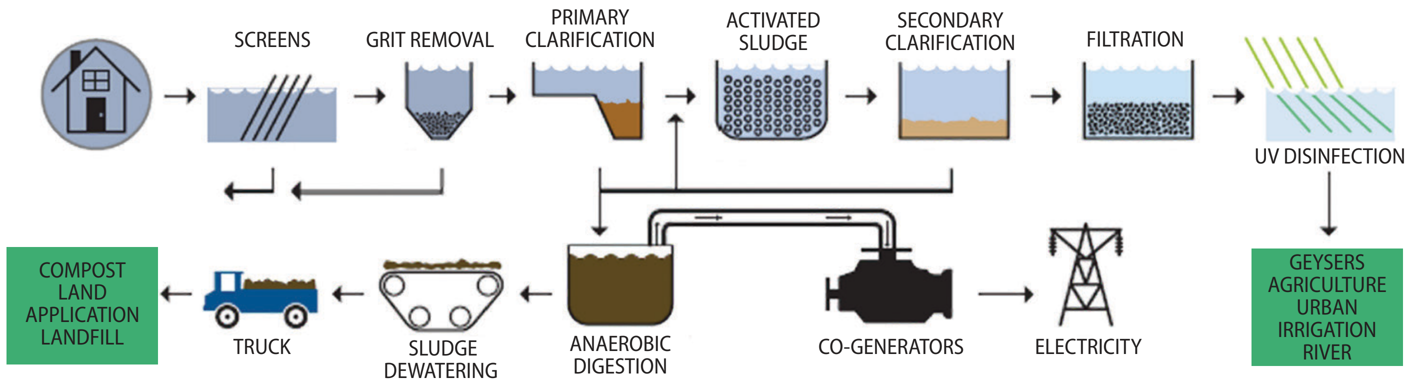

Figure 2. Santa Rosa Regional WWTP treatment processes for developing recycled water. *Source:* Courtesy of Santa Rosa Regional wastewater treatment plant.

Table 1. Typical range of effluent quality after secondary treatment

		Range of effluent quality after indicated treatment						
Constituents	**Unit**	**Untreated wastewater**	**Conventional activated sludge**	**Conventional activated sludge with filtration**	**Activated sludge with BNR***	**Activated sludge with BNR* and filtration**	**Membrane bioreactor**	**Activated sludge with microfiltration and reverse osmosis**
total suspended solids (TSS)	mg/L	120–400	5–25	2–8	5–20	1–4	≤2	≤1
colloidal solids	mg/L	—	5–25	5–20	5–10	1–5	≤1	≤1
biochemical oxygen demand (BOD)	mg/L	110–350	5–25	< 5–20	5–15	1–5	< 1–5	≤1
chemical oxygen demand (COD)	mg/L	250–800	40–80	30–70	20–40	20–30	< 10–30	≤2–10
total organic carbon (TOC)	mg/L	80–260	10–40	8–30	8–20	1–5	0.5–5	0.1–1
ammonia nitrogen	mg N/L	12–45	1–10	1–6	1–3	1–2	< 1–5	≤0.1
nitrate nitrogen	mg N/L	0–trace	10–30	10–30	2–8	1–5	< 10	≤1
nitrite nitrogen	mg N/L	0–trace	0–trace	0–trace	0–trace	0–trace	0–trace	0–trace
total nitrogen	mg N/L	20–70	15–35	15–35	3–8	2–5	< 10	≤1
total phosphorus	mg P/L	4–12	4–10	4–8	1–2	≤2	< 0.3–5	≤0.5
turbidity	NTU	10–1,000	2–15	0.5–4	2–8	0.3–2	≤ 1	0.01–1
volatile organic compounds (VOCs)	µg/L	100–400	10–40	10–40	10–20	10–20	10–20	≤ 1
metals	mg/L	1.5–2.5	1–1.5	1–1.4	1–1.5	1–1.5	trace	trace
surfactants	mg/L	4–10	0.5–2	0.5–1.5	0.1–1	0.1–1	0.1–0.5	≤ 1
total dissolved solids (TDS)	mg/L	270–860	500–700	500–700	500–700	500–700	500–700	≤ 5–40
trace constituents	µg/L	10–50	5–40	5–30	5–30	5–30	0.5–20	≤0.1
total coliform	No./100 mL	10^6–10^9	10^4–10^5	10^3–10^5	10^4–10^5	10^4–10^5	< 100	~0
protozoan cysts and oocysts	No./100 mL	10^1–10^4	10^1–10^2	0–10	0–10	0–1	0–1	~0
viruses	PFU/100 mL	10^1–10^4	10^1–10^3	10^1–10^3	10^1–10^3	10^1–10^3	10^0–10^3	~0

Source: Asano et al. 2007.
*BNR = biological nutrient removal (removal of nitrogen and phosphorus by biological treatment).

percent for naproxen to 63 percent for DEET; chlorine treatment alone removed 98 percent of caffeine; and UV-disinfection removed 33 percent of sulfamethoxazole to 97 percent for caffeine and naproxen. Generally, with secondary- or tertiary-treated wastewater, overall salinity (electrical conductivity, EC) as well as trace element concentrations not specifically targeted for removal (e.g., boron, arsenic, selenium, and some metals) are greater than that found in the source water.

In contrast to water supplies that are subject to water rights restrictions, treated or recycled water discharge is regulated by state and federal permit or regulatory restrictions that direct where and how much treated wastewater can be discharged. That is, the relative availability of this water for landscaping and agricultural use depends on the specific WWTP discharge permits issued by the National Pollution Discharge Elimination System (NPDES) and the California Department of Water Resources (CA DWR). On the other hand, treated wastewater is generated at predictable monthly or annual supply rates associated with the WWTP operations [e.g., a typical 10-million-gallon-per-day (mgd) WWTP produces about 30 ac-ft/day of treated water], which may decrease during drought periods as urban water users adopt water conservation technologies. Nonetheless, during drought periods treated or recycled water may provide an alternative reliable water supply for irrigation to supplement traditional sources. Depending on location and available pumping or piping infrastructure across the state, the cost of treated or recycled water varies. It may be obtained relatively inexpensively (e.g., nearly free from the Santa Rosa Regional WWTP) and brought to areas having sufficient infrastructure, such that only those costs required for pumping to the field sites are involved. Or it may be quite expensive in those regions lacking piping infrastructure needed to deliver water to agricultural fields. In some cases, WWTPs incur substantial treated wastewater disposal costs associated with pipeline infrastructure and pumping costs (e.g., Santa Rosa Regional WWTP discharge to the geysers) and are receptive to more opportunities for possible discharge. Interested growers should inquire with their local water agency for the possibility of obtaining treated or recycled water, as well as information about the monthly average water quality (often such information is required as part of the WWTP permitting), particularly the recycled water salinity (EC) and major anion/cation concentrations (SAR, or sodium adsorption ratio). (See ANR publications 8554 and 8562 in the "Drought Tips" series, by Grismer and Bali 2015 and Grattan 2016, respectively, considering saline water use for irrigation). This latter information is critical toward irrigation and root zone salinity management using recycled water.

Considerations for Irrigation with Treated or Recycled Water

Use of treated or recycled water for irrigated crop production is controlled in part by state and federal regulations that govern the treated water quality (USEPA 2012). Table 2 summarizes the primary treatment factors controlling use of recycled water for crop irrigation in California; lesser standards are required for forage crops or landscaping irrigation compared with those for food crops. For example, treated water from secondary-treatment WWTP processes are generally effective in removing several typical wastewater pollutants and can be used for irrigation of forage crops only, while disinfected secondary-treated water can be used for irrigation of nonedible portions of some food crops (e.g., surface irrigation of nut trees).

Recent, multi-year (decade) studies of the use of recycled water for strawberry and cole crop production in the Salinas Valley (Platts and Grismer 2014a; 2014b), as well as vineyard irrigation in the Napa-Carneros region (Weber et al. 2014), indicated that leaching by winter rains of as little as 12 to 15 inches per year appear to be sufficient to maintain soil salinity, sodium (Na), and chlorine (Cl) levels within acceptable ranges for even moderately salt-sensitive crop production. Similar observations have been made in southern California avocado orchard production, and these results suggest that during drought periods, some crops may be successfully irrigated using recycled water for extended periods, providing that some winter rainfall leaching of the root zone occurs.

In the Salinas Valley, 40 to 90 percent blends of recycled water and on-farm well water was used for irrigation to assess the relative impacts of various blend ratios on soil salinity parameters and crop production. Overall, the average soil salinity parameters (ECe, Na,

Table 2. Treatment requirements for recycled water use for irrigation

Crop type	Treatment	Constituents	Requirements or limits
food crop including edible root crops, where recycled water comes into contact with the edible portion of the crop	disinfected tertiary recycled water: oxidization, coagulation, filtering, and disinfection	chlorine dosage	cell residence time > 450 mg-minutes per liter
			90 minutes modal contact time based on peak dry weather flow
		bacteria indicators	total coliform: < 2.2 MPN/100mL (7 day mean); < 23 MPN/100 mL (not more than one sample exceeds this value in 30 days); max of 240 MPN/100mL in any sample
		turbidity (measured using Nephelometric Turbidity Units, NTUs)	< 2 NTU (avg) within a 24-hr period*
			< 5 NTU more than 5% of the time within a 24-hr period*
			< 10 NTU at any time*
			< 0.2 NTU more than 5% of the time within 24-hr period†
			< 0.5 NTU at any time†
food crops where the edible portion is produced above ground and not contacted by the recycled water	disinfected secondary recycled water: oxidization, and disinfection	bacteria indicators	total coliform: < 2.2 MPN/100mL (7 day mean); < 23 MPN/100 mL (not more than one sample exceeds this value in 30 days)
ornamental nursery stock, sod farms, pasture for animals producing milk for human consumption, any nonedible vegetation	disinfected secondary recycled water: oxidization and disinfection	bacteria indicators	total coliform: < 23 MPN/100mL (7 day mean); < 240 MPN/100ml (not more than one sample exceeds this value in 30 days)
orchards, vineyards, non-food-bearing trees, fodder and fiber crops, pasture for animals not producing milk for human consumption, seed crops not eaten by humans, food crops that must undergo commercial pathogen-destroying processing before being consumed by humans, and ornamental nursery stock and sod farms	undisinfected secondary recycled water: oxidization	not specified	

Source: California Chapter 4, Article 3 of Title 22.
* Undisturbed soil or bed of filter media (at a rate < 5 gal/min/ft^2 of surface area in mono, dual, or mixed media gravity, upflow, or pressure filtration system or < 2 gal/min/ft^2 of surface area in traveling bridge automatic backwash filters).
† Microfiltration, ultrafiltration, or reverse osmosis membrane.

Cl, and SAR) at the test sites were highly correlated with the average blended irrigation water quality values. At the same time, with the exception of two sites, the average soil-salinity-parameter values remained roughly constant from one year to the next, suggesting the possibility of relatively steady-state leaching of the soil profile to a soil depth of 36 inches. Assuming that strawberry production is the most sensitive to soil chlorine concentrations, the irrigation leaching requirement predicted from salt-balance considerations using the full-strength recycled water (Cl at 7 meq/L) for irrigation was about 23 percent compared with about 5 percent for pure well water, with chlorine at about 1.5 milliequivalents per liter (meq/L). Determining which soil-water hydrologic factor (i.e., rainfall or fresh water irrigation) is controlling this apparent steady-state leaching situation (Grismer 1990) is critical toward developing long-term sustainable recycled water use strategies in any region.

More recently, however, several studies as well as changes in Title 22 have been directed at using recycled water for managed aquifer recharge for later availability as an irrigation water supply. This aquifer recharge provides a storage opportunity for the steady recycled water supply, as well as an additional "polishing" treatment associated with natural degradation processes that occur as the water percolates through the soil and into the aquifer. Such recharge of groundwater aquifers that are often overdrafted during drought periods may be critical toward maintaining irrigated agricultural production when regular surface water supplies are unavailable. However, increasing use of recycled water for managed aquifer recharge will require special permitting by the state and federal regulatory agencies. Finally, the water quality of aquifer recharge that occurs using fracking wastewater remains relatively unknown, and growers should sample pumped groundwater subject to fracking wastewater recharge for suitability for crop irrigation. Nonetheless, during drought periods, aquifers recharged with recycled water would augment groundwater supplies, thereby decreasing possible aquifer overdraft and subsidence problems associated with groundwater pumping for irrigation.

Contaminants of Emerging Concern (CECs)

Detection of trace concentrations of a variety of chemicals, such as those associated with industrial and agricultural activity, CECs, and PPCPs in the nation's waterways (USEPA 2010), has raised public awareness about the potential human health risks associated with chronic exposure to such chemicals at very low concentrations. Few unit operations currently used at WWTPs completely remove PPCPs and CECs at such trace concentrations, and they are likely present in recycled water. Recent studies suggest that the residual concentrations of CECs on the edible portions of the crops appear to be quite small (Valdés et al. 2011; Wu et al. 2014) and likely not significant to human health when limited to the anticipated exposure (e.g., rates of food consumption). This research is ongoing and requires additional verification; however, the results thus far suggest that there is very limited uptake of CECs by the crops studied. Use of recycled water on forage crops appears to be of little concern, and growers need only consider the salinity and major ion effects on the root zone soil. Similarly, recycled water use for drip irrigation of vegetable, tree, and vine crops in which CEC uptake appears to be very limited is also likely acceptable. Use of treated (disinfected) or recycled water directly on root and edible leaf crops may require additional monitoring associated with possible CEC uptake and direct irrigation contact with edible plant parts.

Conclusions and Recommendations

Treated or recycled water available from WWTPs is a viable and possibly steady water source for irrigation and agricultural production in California, and it is particularly significant during drought periods. In most cases, there is little concern about application of treated water to forage crops beyond that of root zone salinity or boron management, while use of recycled water for irrigation of food crops requires additional careful consideration associated with human health risk. But concentrations of CECs in the tertiary-treated wastewater and in plant tissues irrigated with reclaimed water are very low, and this concern is addressed in part by the CA Title 22 restrictions mentioned above for recycled water. Long-term studies using reclaimed water for irrigation of various crops have indicated that it can be successfully used in maintaining crop production if the growers carefully manage root zone soil conditions (see ANR Publications 8554 and 8562 in the "Drought Tips" series). Growers interested in obtaining and using reclaimed water for crop production should do the following:

- Contact local water agencies or wastewater treatment plants to obtain information on treated water availability, average monthly water quality, and anticipated costs for use. (Locate your local source of reclaimed water on the Google Maps website, https://maps.google.com/maps/ms?msid=209954178860641865140.0004e506d6ab731978d98&msa=0&dg=feature.)
- Determine the average root zone (depth crop dependent; suggest soil sampling at 6-, 12-, 24-, and 36-inch depths) soil salinity at the end of the summer irrigation season (prior to the rainy weather) and after the rainy season to assess root zone specific ion concentrations (e.g., Na) and salinity levels.
- Consider the possibility of blending reclaimed water with available groundwater or surface water to manage applied water salinity.
- Monitor soil sodium and salinity levels at least annually (at the end of the summer irrigation season), preferably twice per year, to ensure that root zone soil conditions are acceptable
- Consider submitting crop tissue samples for analysis of CECs to provide customer assurance of the limited exposure to these chemicals prior to consumption.

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