Wastewater Irrigation on Farms Contaminates Food

The use of recycled wastewater in agricultural fields has implications for human health and the environment

by Nikita Naik

The use of recycled wastewater, an increasingly attractive option in face of growing water shortages and droughts in the U.S. and abroad for uses such as agriculture, landscaping, and drinking water, raises serious questions about dietary exposure to toxic chemicals such as antibacterial pesticides. Concerns about chemical exposure through the food supply are being raised just as water recycling is being advanced as a sound environmental alternative that reduces strain on water resources and vulnerable ecosystems, decreases wastewater discharge, and cuts down on pollution.

Recycled wastewater presents a risk to human health and the environment due to contaminants of emerging concern (CECs) that are not removed even by high level water treatment processes, and can persist in the water for long periods of time, especially when used for agricultural irrigation. Residues of pesticides, pharmaceutical drugs, and other chemicals in irrigation water can end up on plant surfaces, be taken up by crops, or contaminate the soil, thus increasing human exposure risk and environmental contamination, as evidenced by a recent study conducted in Irvine, California. The study, "Treated Wastewater Irrigation: Uptake of Pharmaceutical and Personal Care Products by Common Vegetables under Field Conditions," published in *Environmental Science & Technology* (2014), found that 64% of vegetables irrigated with treated wastewater contained traces of CECs, including DEET (a repellent) and triclosan (an antibacterial).[1] Wastewater recycling, which is typically regulated at the state level in the U.S., lacks specific criteria governing the presence of these CECs in agricultural irrigation and on crops due to significant data gaps, such as lack of information on the chronic effects of CEC exposure on human health, their persistence in and effects on the environment, the effectiveness of various treatments in removing these contaminants from wastewater effluents, lack of analytical detection methods, and more. Additionally, the cost of decontamination, if technologically feasible, is typically left to taxpayers and local water and sewage authorities.

Background

The U.S. Environmental Protection Agency (EPA) describes the recycling of wastewater or "water recycling" as "reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin."[2] While the terms "water recycling" and "water reuse" may seem redundant since all water is reused in one way or another within the water cycle, the distinction suggests the use of technology to hasten the reuse process or multiple use before returning to the natural water cycle.

The practice of reusing wastewater in the U.S. has been established for nearly 100 years. The earliest history of large-volume water reuse involved applications like pasture irrigation near wastewater treatment plants (WWTP) that did not require high-quality effluent. In 1912, the first small urban reuse system was the irrigation of Golden Gate Park in San Francisco. By the 1960s, landscape irrigation had become a major use for wastewater recycling. As urban populations grew, so did municipal reuse systems. In 1977, St. Petersburg, Florida built the first large-scale urban reuse system in the country. Over the years, other countries followed suit, including Israel, Japan, and Spain.[3] Now, as water shortages increase due to growing populations and climate change, cities are beginning

Table 1: Categories of trace chemical constituents (natural and synthetic) potentially detectable in reclaimed water and illustrative example chemicals

End use category	Examples
Industrial chemicals	1,4-Dioxane, perflurooctanoic acid, methyl tertiary butyl ether, tetrachloroethane
Pesticides, biocides , and herbicides	Atrazine, lindane, diuron, fipronil
Natural chemicals	Hormones (17β-estradiol), phytoestrogens, geosmin, 2-methylisoborneol
Pharmaceuticals and metabolites	Antibacterials (sulfamethoxazole), analgesics (acetominophen, ibuprofin), beta-blockers (atenolol), antiepileptics (phenytoin, carbamazepine), veterinary and human antibiotics (azithromycin), oral contraceptives (ethinyl estradiol)
Personal care products	Triclosan, sunscreen ingredients, fragrances, pigments
Household chemicals and food additivies	Sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perflourooctane sulfonate)
Transformation products	NDMA, HAAs, and THMs

From EPA's Guidelines for Water Reuse (2012)

to view wastewater reuse as a viable option for everything from agricultural irrigation to drinking water.

Implications for Health and the Environment

While wastewater recycling has many benefits, there are a host of issues that must be addressed, chief among them being contaminants of emerging concern. Contaminants of emerging concern are chemicals that typically have not been monitored in the environment, but have only recently been detected in waterways and municipal wastewater and include chemicals like flame retardants, personal care products, pharmaceuticals, and pesticides. CECs can enter municipal wastewater through bathing, cleaning, and the disposal of human waste and unused pharmaceuticals. Although they typically exist at extremely minute concentrations, there is a growing concern regarding their impact on public health and ecology. Table 1 contains examples of trace chemical constituents that are potentially detectable in recycled wastewater.

The uptake of contaminants by crops treated with recycled wastewater present a serious human exposure risk. The recent Irvine, California study measured levels of 19 commonly occurring pharmaceutical and personal care products (PPCPs) in eight types of vegetables irrigated with treated wastewater under field conditions. The analytes studied included 16 pharmaceuticals (e.g., acetaminophen, caffeine, meprobamate, atenolol, trimethoprim, carbamazepine, diazepam, gemfibrozil, and primidone) and three personal care pesticide products (DEET, triclosan, and triclocarban). The vegetable species, such as lettuce, carrots, and tomatoes, include those often consumed raw by people and are among the most important cash crops in arid and semi-arid regions, such as southern California, where there has been a rapid increase in irrigation with treated wastewater. The study finds that 64% of the edible portions of vegetables grown with treated wastewater have at least one PPCP detected, while fortified water-irrigated vegetables, in which treated wastewater was deliberately spiked with 15 PPCPS, have a detection frequency of 91%. In treated wastewater-irrigated vegetables, meprobamate (31%) and carbamazepine (31%) are the most frequently detected compounds. In fortified water-irrigated vegetables, the detection frequencies of carbamazepine, dilantin, and primidone significantly increased to 89%, 57%, and 39%, respectively.

The study's researchers found that, based on their results, the greatest annual exposure due to the consumption of contaminated vegetables is caffeine, followed by the antibacterial pesticide triclosan, then carbamazepine, while meprobamate is the lowest. Triclosan is a toxic antimicrobial pesticide that contains the contaminant dioxin and is associated with a range of adverse effects, from skin irritation, endocrine disruption, bacterial and compounded antibiotic resistance, to the contamination of water and its negative impact on fragile aquatic ecosystems. The Centers for Disease Control and Prevention (CDC) reports

The Deer Island Massachusetts wastewater plant and surrounding park area. Photo by Fletcher6.

document triclosan in the urine of 75% of the U.S. population, with the most recent 2010 update finding that the levels of triclosan in the U.S. population continue to increase.[4] The researchers in the California study also note that caffeine and triclosan are mostly detected in carrots, while carbamazepine is detected widely in all vegetables. The study also finds that some PPCPs display a higher tendency for accumulation in plants than others, which may have harmful implications for vulnerable human populations like pregnant women. For example, carbamazepine, an anticonvulsant and antidepressant drug used to treat epilepsy, bipolar disorder, and other conditions, is detected consistently in all plant samples, including roots, leaves, and fruits. According to the study, the chemical is known to be immune to wastewater treatment processes and is found ubiquitously in wastewater treatment plant effluents. There is evidence that pregnant women's exposure to carbamazepine may result in congenital malformations in offspring.[5]

The use of recycled wastewater in agriculture may have indirect health effects resulting from antibiotic resistance in soil bacteria. Samples taken and archived in the Netherlands between 1940 (when antibiotic use began increasing) and 2008 supported evidence that resistance to antibiotics is increasing in both pathogenic and nonpathogenic bacteria.[6] Wastewater effluent from hospitals, which contain major discharge of chemicals that are difficult to remove in WWTPs, may also result in the contamination of soils by trace levels of antibiotics.[7]

Certain pharmaceuticals have been shown to be phytotoxic (e.g., plant growth inhibition) to various wild and cultivated plant species, but these effects are still not fully understood.[8]

Regulations Governing Wastewater Recycling

According to EPA's *Guidelines for Water Reuse* (2012), wastewater recycling standards are the responsibility of state and local agencies. The majority of states have regulations governing quality for recycling of reclaimed water from centralized treatment facilities, and these can vary considerably according to region. As of 2012, 30 states and one territory have adopted regulations, and 15 states have guidelines or design standards. A few states have no specific regulations, but may permit programs with approval on a case-by-case basis. *Guidelines for Water Reuse* serves as a resource for states that desire to develop new regulations and guidelines for wastewater reuse. The guidelines also exist to inform and supplement state regulations and guidelines by providing technical information and outlining key implementation considerations.

State regulations for wastewater recycling must be consistent with and, in some cases, function within the boundaries imposed by other federal and state laws, regulations, rules, and policies. State regulatory programs are affected or superseded by federal water laws where reuse affects international boundaries, Native American rights, multiple states with a claim on limited water supplies, or instream flow requirements to support threatened or endangered fisheries under the *Endangered Species Act.* Federal and state agencies have jurisdiction over the quantity and quality of wastewater discharge into U.S. public waterways. The primary federal law is the *Clean Water Act* (CWA) for water quality management designed to ensure that all surface waters are "fishable and swimmable." CWA requires states to set water quality standards, establishing the right to manage the pollution that comes from wastewater treatment plants, as long as the standards, at minimum, meet federal rules. Another federal standard regulating recycled wastewater end use is the *Safe Drinking Water Act* (SDWA) for water diverted to potable use.

Standards governing recycled wastewater irrigation on crops can differ in stringency by state. For example, California's *Water Recycling Criteria* requires some of the most stringent water quality standards for disinfection. Some states ban the practice altogether, by prohibiting the use of recycled wastewater on food crop irrigation or allowing it only if the food is to be processed or not eaten raw. Florida, Nevada, and Virginia require that recycled wastewater does not come in contact with the crop or that the crop is to be peeled or heated before eating. While California does not have these requirements, the state does have stringent, near-potable quality standards for food crop irrigation. For other states that allow food crop irrigation with treated wastewater, treatment

The Future of Recycled Wastewater Use in Agricultural Irrigation in California

California has been at the forefront of wastewater reuse, propelled by necessity due to frequent water shortages in the state. The Recycled Water Policy, adopted in 2009, establishes a set of goals to help move California toward more sustainable management of surface waters and groundwater, along with water conservation, water reuse, and the use of storm water. One of these goals include the increase in use of recycled water over 2002 levels by at least one million acre-feet per year (afy) by 2020 and by at least two million afy by 2030, as well as the substitution of as much recycled water for potable water as possible by 2030. The State Water Board has mandated the increase in use of recycled water by 200,000 afy by 2020 and by an additional 300,000 by 2030.[9]

In California, water reuse for agricultural purposes makes up a hefty chunk of total recycled water use at approximately 37% (roughly 240,000 afy). Future demand is estimated to increase agricultural reuse by a factor of 3.2 to 3.5 times current reuse levels by 2030.[10] California's Department of Public Health requires varying levels of water treatment requirements depending on purpose of use: orchards and vineyards for which there is no contact with edible crops (undisinfected secondary treatment); food crops with edible portion above ground, no contact (disinfected secondary); and food crops, parks and playgrounds, golf courses (disinfected tertiary).[11]

Table 2: Reclaimed water quality and treatment requirements for irrigation on food crops

		Arizona	California	Florida[1]	Hawaii	Nevada
	Unit processes	Secondary treatment, filtration, disinfection	Oxidized, coagulated, filtered, disinfected	Secondary treatment, filtration, high-level disinfection	Oxidized, filtered, disinfected	NP
	UV dose, if UV disinfection used	NS	NWRI UV Guidelines	NWRI UV Guidelines enforced, variance allowed	NWRI UV Guidelines	NP
	Chlorine disinfection requirements, if used	NS	CrT > 450 mg min/L; 90 minutes modal contact time at peak dry weather flow	TRC > 1 mg/L; 15 minutes contact time at peak hr flow[2]	Min residual > 5mg/L, actual modal contact time of 90 minutes	NP

From EPA's Guidelines for Water Reuse (2012)
NS = not specified by the state's reuse regulation
TR = monitoring is not required but virus removal rates are prescribed by treatment requirement
NP = not permitted by the state
NWRI = National Water Research Institute

[1]In Texas and Florida, spray irrigation (i.e. direct contact) is not permitted on foods that may be consumed raw (except Florida makes an exception for citrus and tobacco), and only irrigation types that avoid reclaimed water contact with edible portions of food crops (such as drip irrigation) are acceptable.

[2]In Florida when chlorine disinfection is used, the product of the total chlo-

requirements can range from secondary treatment and disinfection, to oxidation, coagulation, filtration, and high level disinfection. See Table 2 for more information on state requirements regarding the treatment of wastewater for agricultural irrigation.

Guidelines for Water Reuse recommends that as human exposure levels increase, so should the level of treatment. For example, for non-food crop irrigation, wetlands, wildlife habitat, and stream augmentation, and industrial cooling processes, EPA suggests both primary (sedimentation) with secondary (biological oxidation, disinfection) treatment. For landscape and golf course irrigation, toilet flushing, and food crop irrigation, EPA suggests primary, secondary, and tertiary/advanced (chemical coagulation, filtration, disinfection) treatment.[12]

Additional Concerns

Lack of Treatment Technology. Nearly all wastewater treatment plants provide a minimum of secondary treatment as a result of CWA requirements. Treatment levels beyond secondary are called advanced treatment and can include physical-chemical separation techniques such as adsorption, flocculation/precipitation, membranes for advanced filtration, ion exchange, and reverse osmosis.[13] In 2008, only 37 percent of municipal facilities produced and discharged effluent at advanced levels of treatment that were

Table 3: Indicative percent removals of organic chemicals during various stages of wastewater treatment

Treatment	Percent Removal							
	Antibiotics[1]	Pharmaceuticals					Hormones	
		DZP	CBZ	DCF	IBP	PCT	Steroid[2]	Anabolic[3]
Secondary (activated sludge)	10–50	nd	–	10–50	>90	nd	>90	nd
Soil aquifer treatment	nd	nd	25–50	>90	>90	>90	>90	nd
Aquifer sotrage	50–90	10–50	–	50–90	50–90	nd	>90	nd
Microfiltration	<20	<20	<20	<20	<20	<20	<20	nd
Ultrafiltration/powdered activated carbon (PAC)	>90	>90	>90	>90	>90	nd	>90	nd
Nanofiltration	50–80	50–80	50–80	50–80	50–80	50–80	50–80	50–80
Reverse osmosis	>95	>95	>95	>95	>95	>95	>95	>95
PAC	20–>80	50–80	50–80	20–50	<20	50–80	50–80	50–80
Granular activated carbon	>90	>90	>90	>90	>90		>90	
Ozonation	>95	50–80	50–80	>95	50–80	>95	>95	>80
Advanced oxidation	50–80	50–80	>80	>80	>80	>80	>80	>80
High-level ultraviolet	20–>80	<20	20–50	>80	20–50	>80	>80	20–50
Chlorination	>80	20–50	–<20	>80	<20	>80	>80	<20
Chloramination	<20	<20	<20	50–80	<20	>80	>80	<20

From EPA's Guidelines for Water Reuse (2012)

CBZ = carbamazepine
DBP = disinfection by-product
DCF = diclofenac
DZP = diazepam
IBP = ibuprofen
nd = no data
PAC = powdered activated carbon
PCT = paracetamol

[1]erythromycin, sulfamethoxazole, triclosan, trimethoprim
[2]ethynylestradiol; estrone, estradiol and estriol
[3]progesterone, testosterone

New Jersey	North Carolina		Texas[1]	Virginia[3]	Washington
	Processed Foods[4]	Unprocessed Foods[5]			
Filtration, high-level disinfection	Filtration (or equivalent)	Filtration, dual UV/chlorination (or equivalent)	NS	Secondary treatment, filtration, high-level disinfection	Oxidized, coagulated, filtered, disinfected
100 mJ/cm² at max day flow	NS	Dual UV/chlorination (or equivalent)	NS	NS	NWRI UV Guidelines
Min residual > 1 mg/L; 15 minutes contact at peak hr flow	NS	Dual UV/chlorination (or equivalent)	NS	TRC CAT > 1 mg/L; 30 minutes contact time at avg flow or 20 minutes at peak flow	Chlorine residual > 1; 30 minutes contact time

rine residual and contact time (CrT) at peak hour flow is specified for three levels of fecal coliform as measured prior to disinfection. If the concentration of fecal coliform prior to disinfection: is ≤ 1,000 cfu per 100 mL, the CrT shall be 25 mg min/L; is 1,000 to 10,000 cfu per 100 mL the CrT shall be 40 mg min/L; and is ≥ 10,000 cfu per 100 mL the CrT shall be 120 mg min/L.

[3]The requirements presented for Virginia are for food crops eaten raw.

[4] Processed foods include those that will be peeled, skinned, cooked or thermally processed before consumption.

[5]Unprocessed food refers to crops that will not be peeled, skinned, cooked or thermally processed before consumption.

higher than the federal minimum.[14]

Currently, there is no single treatment process that can provide a complete barrier to all chemicals (see Table 3) and most municipal wastewater treatment plants are not specifically designed to remove these types of contaminants from wastewater due to barriers such as cost and lack of research and data.

Data and Regulatory Gaps. In addition to the presence of CECs in treated wastewater, these contaminants have been shown to occur in natural bodies of water as well, which indicates lack of sufficient wastewater treatment technology. A major study published in 2002 as a part of the U.S. Geological Survey discovered the presence of numerous pharmaceuticals and organic wastewater contaminants (OWCs) in 139 streams located across 30 states. Eighty-two (out of 95) OWCs were detected at least once in the study, with 80% of the streams sampled containing one or more OWC. Compounds included steroids, insect repellents, disinfectants, and detergent metabolites. While the majority of the compounds rarely exceeded drinking water guidelines, many did not have any guidelines.[15] The lack of regulatory standards, data on metabolites and potential synergistic effects, and other sources of incomplete data on these chemicals show a failure in the regulatory framework.

Conclusion

Contaminants of emerging concerns (CECs) in recycled wastewater present a risk to both human health and the environment. However, their presence in natural bodies of water as well as recycled wastewater points to a much larger problem, most notably lapses within federal laws, including the *Toxic Substances Control Act*, *Federal Insecticide, Fungicide, and Rodenticide Act*, *Clean Water Act*, and others that govern both the introduction and use of toxic materials in commerce without an adequate assessment of their life-cycle (from manufacture, use, to disposal) effects. The *Organic Foods Production Act* establishes a model for analyzing life cycle impacts of synthetic chemicals that should be used when determining allowances of any synthetic chemical – thus prohibiting materials not eliminated by wastewater treatment. Until that happens, contaminated wastewater presents a serious challenge across all agricultural production where it is used.

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Who should pay for the removal of CECs?

Widespread water contamination with the herbicide atrazine, used to control broadleaf weeds and annual grasses in crops, golf courses, and residential lawns, has been found across the U.S. Atrazine is used extensively for broadleaf weed control in corn. The herbicide does not cling to soil particles, but washes into surface water or leaches into groundwater, and then finds its way into municipal drinking water. It is the most commonly detected pesticide in rivers, streams and wells, with an estimated 76.4 million pounds of atrazine applied in the U.S. annually. It has been linked to a myriad of environmental concerns and health problems in humans, including disruption of hormone activity, birth defects, and cancer, as well as effects on human reproductive systems.

A class action settlement, *City of Greenville v. Syngenta Crop Protection, Inc.*, between plaintiffs and the manufacturer of atrazine, Syngenta, paid out $105 million in 2013 to settle this nearly eight-year-old lawsuit and help reimburse community water systems (CWS) in 45 states that have had to filter the toxic chemical from its drinking water. It provided financial recoveries for costs that have been borne for decades by more than 1,887 CWSs that provide drinking water to more than one in six Americans.[16]

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