Trace elements in wastewater

Beneficial use of water always results in degradation of its quality. Among impurities added to municipal wastewaters, trace elements have attracted the attention of many researchers in recent years. The term "trace element" includes a number of chemical elements that occur in natural systems in small concentrations. They are utilized by organisms in minute quantities, and most are essential to growth. When present in high enough concentrations, trace elements may become toxic.

Boron (B), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn), widely used in industrial processing and in manufacturing of consumer goods, are the most common trace elements in municipal wastewaters (table 1). Small amounts are always present, and consistently high concentrations usually indicate waste discharge into the collection system by certain industries. The actual concentrations of trace elements in wastewater, therefore, vary considerably with the nature of the communities.

In a conventional, two-stage wastewater treatment system consisting of primary settling, secondary bio-adsorption, and other auxiliary processes, the treated wastewater is separated into the effluent stream and the sludges. During the treatment, essentially all impurities in the wastewater except dissolved minerals can be effectively removed or eliminated from the effluent and concentrated into sludges. Results of observations of several southern California wastewater treatment facilities are summarized in tables 2 and 3. The wide variations of trace element levels in wastewater and their concentrating into sludges are clearly demonstrated. Data from other sources indicate that concentration variations in the same order of magnitude can also be anticipated elsewhere in the United States.

TABLE 1. Sources of Trace Elements in Wastewater

Element	Sources
As	Glass, ceramics, textiles, paints, pesticides
Ba	Fabrics (printing and dyeing), paper manufacturing, rubber
Be	Plating, organic chemical catalyst
Bi	Electrical fuse, solders, dental works, pharmaceutics
B	Detergents, cleansing agents, glue
Cd	Plating, battery cell, pesticides, contaminants in Zn
Cr	Plating, tanning
Cu	Plating, pickling, synthetic fabric, utensils
Pb	Battery, paints, gasolines
Hg	Paints, medical uses
Mo	Ceramic glaze, lubricants
Ni	Plating, dyes, inks, electrodes
Se	Photography, rubber, insecticides
Ag	Photography, plating
V	Medical use, metal alloy
Zn	Plating, galvanizing, rubber, synthetic fabrics

TABLE 2. Concentration of Trace Elements in Wastewater vs. Water Quality Criteria

Element	Wastewater effluent		Water quality criteria		
			Public water supply	Irrigation water	
	Range	Median		Continuous use*	Short-term use†
	mg/l	mg/l	mg/l	mg/l	mg/l
As	<0.005-0.023	<0.005	0.1	0.1	2.0
B	0.3-2.5	0.7	·	0.75	2.0
Cd	<0.005-0.22	<0.005	0.01	0.01	0.05
Cn	<0.001-0.1	0.001	0.05	0.1	1.0
Cu	0.006-0.053	0.018	1.0	0.2	5.0
Hg	<0.0002-0.001	0.0002	0.002	·	·
Mo	0.001-0.018	0.007	·	0.01	0.15
Ni	0.003-0.60	0.004	·	0.20	2.0
Pb	0.003-0.35	0.008	0.05	5.0	10.0
Se	·	·	·	0.02	0.02
Zn	0.004-0.35	0.04	0.05	2.0	10.0

*For water used continuously on all soils

†For use up to 20 years on fine texture soils of pH 6.0 to 8.5

Wastewater effluents

Quality criteria applicable to various water uses, recommended by a National Academy of Science and National Academy of Engineering Joint Committee in 1972, are shown in table 2. Most waste effluents could meet these recommended trace-element requirements for both public water supply and crop irrigation. Among elements likely to exceed the upper limits, lead and cadmium are closely related to industrial wastes. Another, boron, is found commonly in household cleaning products.

TABLE 3. Trace Elements in Sludges and Their Possible Input in Land Disposal

Element	Sludges		Possible input in 20 years		
	Range	Median	Sludge @ 10 metric tn/ha/yr*	Irrigation @ 1.2 m/yr†	
				Continuous use	Short-term use
	mg/ha	mg/ha	kg/ha	kg/ha	kg/ha
As	1.6-18	6.5	1.3	24	480
B	74-680	440	88	180	480
Cd	1.0-140	6.5	1.3	2.4	12
Cr	60-400	216	43	24	240
Cu	200-1,050	320	64	48	1,200
Hg	0.4-56	3.4	0.7	–	–
Mo	2-25	6.5	1.3	2.4	12
Ni	10-2,140	75	15	48	480
Pb	15-1,700	446	89	1,200	2,400
Se	–	8.7	1.7	4.8	4.8
Zn	265-1,200	775	155	480	2,400

*Assuming median trace-element concentrations in the sludge.

†Irrigation water contains maximum allowable concentration of trace elements recommended by Water Quality Criteria.

TABLE 4. Trace Elements in Lettuce Grown on Sludge-Amended Soils

Sludge applied	Plant tissue (µg/g)		
	Zn	Cu	Cd
metric tn/ha			
0	58.8	6.2	1.9
11.25	90.7	8.0	2.1
22.50	141.3	6.0	4.0
45.0	151.6	6.1	4.1

If treated wastewater effluents are routed directly to a public water supply, the process allows little margin for error in the treatment system and could expose consumers to acute or long-range health effects not yet fully documented. Therefore, direct reuse of wastewater for public water supply is not recommended by regulatory agencies and water supply utilities at present.

Considering the extreme variability of trace-element uptake and toxicity tolerance among plant species, as well as possible interactions with minerals and organics in soils, maximum acceptable trace-element concentrations in irrigation water may vary. However, the median concentrations shown in table 2 are clearly below the standards for continuous use. As indicated in the table, somewhat higher levels are suitable for short-term use (20 years) on certain soils. (Fine-textured soils remove a significant amount of trace elements from the soil solution, so more trace elements can be in the irrigation water without injury to crops grown on these soils.) In the case of effluents that do not meet recommended maximum concentrations, boron and cadmium are the most likely problem elements.

Sludges

Sewage sludges are generally considered a source of plant nutrients, but little is known about how they can be most effectively used to supplement the plant's nutrient needs. Since sludges are generally low in primary plant nutrients, applying them to satisfy the nitrogen or phosphorus requirements of plants may result in excessive trace elements in soils. Sludges are also used as organic soil amendments to bring about desired changes in physical properties of soils.

Most sludges, when used at reasonable rates, do not appear to produce phytotoxicity. Application of sludges with nominal trace-element concentrations over a 20-year period would add far lower amounts of trace elements than would irrigating with a water that meets only the quality criteria for short-term use on fine-textured soils. Assuming that trace elements—whether derived from sludge or irrigation water—are equally removed from soil solutions by soils, it appears that the trace-element content of sludge-treated soils should not reach levels that will become detrimental to plants. At the application rates listed in table 3, it would take at least 100 years of sludge application to accumulate the amount of trace elements that would be toxic to plants.

The chief concern about trace elements in use of sludge on cropland is centered on the potential danger to the human food chain. Plants are capable of translocating trace elements and concentrating them in plant tissues. Accumulated in the edible portion of the plants, they would pose a threat to consumers.

Experimental results from solution culture and greenhouse potted plants indicate that plant uptake usually increases with increased trace-element concentration in the growing medium. In some plant species, even at sub-phytotoxic concentrations, the accumulation in the plant tissue could become significant.

Data from an on-going sludge disposal experiment show the increased concentrations of certain trace elements in the tissue of a sensitive plant grown under field conditions (table 4). Under the same conditions, no increases in trace elements were found in barley, which is a non-sensitive plant.

Continuing experimentation is needed to project the long-range effects. It appears that the potential accumulation of trace elements in plant tissue can be minimized by proper selection of crop species, soil types, and sludge compositions. For sludges that are unusually high in trace elements, however, land disposal definitely would be detrimental to plant growth and the human food chain.

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Water quality requirements for floricultural operations

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Compared to most food crops, floricultural and ornamental greenhouse crops use large amounts of irrigation water per square foot of production area. This is because of shallow soils in containers and raised beds and because of high leaching requirements when nutrient solutions are added. As a result of the large amounts of water generally being leached and its high nutrient content when fertilizers are injected into the irrigation stream, there is increasing pressure to (1) conserve water in greenhouse operations and (2) avoid contamination of surface- and ground-water supplies by reusing nutrient solutions and runoff water that might otherwise move off the premises.

This growing need for recycling adds to the water quality problems faced by greenhouse operators. Unlike other types of agriculture, greenhouse production must be concerned with water quality not only because of its effect on the crop, but also because additional standards must be met for the water used in mist propagation, in greenhouse cooling, and in conditioning cut flowers before shipment.

The water quality standards listed as presenting "no problem" in the U.C. Guidelines for Interpretation of Water Quality for Agriculture generally apply to ornamental greenhouse crops also. Salinity less than 0.75 millimhos per centimeter, adjusted Sodium Absorption Ratio (SAR) less than 3, and chlorides less than 3 milliequivalents per liter (meq/l) (106 ppm) should be satisfactory for almost all crops, if drainage is good. Crop tolerances for dissolved salts vary widely: Chrysanthemums make satisfactory growth at electrical conductivity (EC) from 1.5 to 2.5, but certain azalea cultivars may show reduced growth or damage symptoms at EC 0.75.

In mist propagation, experience indicates that foliar problems probably can be avoided when both chloride and sodium concentrations are less than 3 meq/l. Carbonates and bicarbonates at more than 100 ppm (1.66 meq/l) can result in both foliar deposits and clogging of mist nozzle orifices. However, carbonates do not form unless the pH of the water is higher than 8.3, and acidification with phosphoric or sulfuric acid can solve the problem. A final pH of 6.5 is generally satisfactory.

Most greenhouses are cooled with evaporative fan and pad systems, which require passage of water over permeable fiber or cell pads from which the water is evaporated. The resulting concentration of salts eventually clogs the pads. Soluble salts like chlorides and sodium can be dissolved with high-pressure streams of water and washed away. Deposits from high-carbonate water will not respond to this treatment, and acidification of the cooling water may be necessary. To avoid concentration of salts in the recycled cooling water, "bleeding off" 10 to 20 percent of the returned water and replacing the water level in the sump with fresh water is a generally accepted and highly desirable practice.

Cut flowers are normally conditioned or "hardened" by placing the stems in water for a period before packing or shipping. Recent University of California experiments indicate that even small amounts of dissolved salts in the water used for conditioning can adversely affect the keeping quality or shelf life of the flowers. The effect becomes even more pronounced when chemicals or so-called flower preservatives are added to the water. In a number of experiments the shelf life of carnations and chrysanthemums was extended from .5 to 2.5 days when deionized water was used instead of tap water with an EC of 0.5 to 0.75. Because of the small amounts of water used in conditioning and because the conditioning solutions can be reused for some time, it is recommended that both growers and handlers of flowers install deionizing equipment.

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Dramatic differences in carnations seven days after harvest as a result of conditioning the cut blooms in deionized water. Blooms were conditioned in: left, deionized water; middle, a mixture of three-fourths tap water and one-fourth deionized water; right, undiluted tap water.