**Reuse
of
Sludge
and
Minor
Wastewater
Residuals**

Alice B. Outwater

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The land application of sludge is as old as agriculture. The Chinese have used human waste as a fertilizer for thousands of years. The Japanese called it nightsoil and carried it out of town under the cover of darkness to apply to their orchards and gardens. The special role of the Untouchable caste in India was to gather up human waste from the towns and transport it out to the countryside. Before the 1940s, land application of sludge was common in the United States. In those simpler, less squeamish times the “manurial” benefits of sludge were appreciated, and local farmers were glad to use wastewater residuals to improve crop yields. However, as soon as synthetic fertilizers became affordable and available, sludge was seen as a disposal problem rather than a resource.

After a hiatus of nearly 50 years, the amount of sludge that is applied to U.S. forests, crops, and disturbed land is steadily increasing. Seattle sprays sludge on forests to promote tree growth, Maryland sludge compost is used to enhance the turf on the White House lawn, Omaha spreads its sludge on nearby farmland, Pennsylvania rehabilitates strip-mined land with sludge compost, and Florida uses sludge from around the country to fertilize the orange groves. Nearly all of the major cities in the U.S., including Philadelphia, Chicago, Baltimore, Denver, Madison, Phoenix, Los Angeles, and Portland, are processing their municipal sludge into fertilizers and soil conditioners.

When sludge products are used judiciously, the risk to human health and the environment is negligible. There are rarely reports of harmful effects to humans, livestock, and pets or to the environment resulting from the land application of sludge products when recommended application rates and good management practices are followed, in spite of the fact that we live in a litigious society and sludge has been land applied for generations. With the promulgation of the U.S. Environmental Protection Agency (EPA) 40 CFR Part 503 regulations,¹ the beneficial reuse of sludge has become a viable alternative for almost all wastewater treatment plants in the U.S.

1.1 SLUDGE PRODUCTION IN THE UNITED STATES

There is a tremendous amount of sludge produced in this country. A typical family of four discharges 300 to 400 gal of wastewater per day, using 75 to 100 gal per person. Domestic wastewater contains material flushed into household drains from

sinks, toilets, and tubs. Components of domestic sewage include soaps, shampoo, human excrement, toilet paper, foodstuffs, detergents, pesticides, household hazardous waste, and oil and grease. Domestic wastewater may be treated (or partially treated) at its source in septic tanks, cesspools, or portable toilets or in publicly or privately owned treatment works. These treatment works may accept domestic wastewater alone or a combination of domestic and industrial wastewater.

Municipal wastewater treatment works may use one or more levels of treatment — primary, secondary, or tertiary — to clean this wastewater. Each level of treatment provides both a higher level of wastewater cleanup and a larger quantity of sewage sludge. Unprocessed sewage sludge contains from 93 to 99.5% water, as well as the solids and dissolved substances that were present in the wastewater or that were added or cultured by the wastewater treatment process.

Approximately 12,750 publicly owned treatment works (POTWs) generate 5.4 million dry metric tons of sludge annually, or 47 dry pounds of sewage sludge for every person in the U.S. This sewage sludge is commonly used or disposed of in a number of ways. Sludge is applied to agricultural and nonagricultural lands; it is sold or given away for use in home gardens, lawns, horticulture, and landscaping (often referred to as sludge distribution and marketing); it is disposed of in municipal landfills, sludge-only landfills (known as monofills), and surface disposal sites; and it is incinerated.

Table 1-1 shows the amount of sludge generated based on the size of the facility and on the amount of sewage sludge that is disposed of by a use or disposal practice. Table 1-2 shows the number of facilities employing a particular method of use or disposal. Only about one third of the sewage sludge generated in the U.S. is effectively reused by land application or is sold or given away for use in home gardens.² In comparison, Japan uses 42% of its sewage sludge for coastal reclamation and home gardening or farming uses, while the U.K. applies 51% of its sewage sludge to the land.

1.2 BENEFITS OF REUSING SEWAGE SLUDGE

Sludge reuse improves the productivity of the land by adding organic matter and nutrients to the soil. In addition, there are a number of indirect advantages to human health and the environment. Secondary benefits of sludge reuse include a reduction of the adverse health effects of incineration, a decreased dependence on chemical fertilizers, a reduction in the emissions associated with incineration that may contribute to the greenhouse effect, and a reduction in fuel or energy costs associated with incineration. EPA analyses show that the land application of sludge poses less carcinogenic risk than sludge incineration. The lifetime cancer risk to a highly exposed individual ranges from 6×10^{-4} for land application and surface disposal of sludge to 7×10^{-3} for incineration.

The organic and nutrient contents of sewage sludge are a valuable resource for improving marginal lands and as a supplement to fertilizers and soil conditioners. Sludge use as a fertilizer can both increase crop yields and decrease the farmer's costs for chemical fertilizers. Studies done across the country have shown that the benefits to farmers that reuse this resource extend beyond avoiding the costs of chemical

Table 1-1 Estimated Mass of Sludge Disposed Annually in the U.S.^a

Use or disposal practice	Reported flow rate (MGD) ^b				Total ^a
	>100	>10 to 100	>1 to 10	≤1	
Incineration	382.9	346.5	124.8	10.5	864.7
Land application: agricultural	203.0	400.8	423.9	143.2	1170.9
Land application: compost	22.4	65.3	31.7	30.8	150.2
Land application: forests	4.5	24.5	1.0	1.3	32.3
Land application: public contact	62.1	60.5	40.3	6.3	166.1
Land application: reclamation	52.6	9.8	2.4	1.0	65.8
Land application: sale	30.6	27.8	11.9	0.8	71.1
Land application: undefined	12.7	76.4	27.2	13.0	129.3
Co-disposal: landfill	518.6	674.0	495.6	110.4	1818.7
Surface disposal: dedicated site	34.2	124.9	63.2	36.5	258.8
Surface disposal: monofill	13.8	79.8	41.6	22.2	157.4
Surface disposal: other	31.5	60.0	17.4	28.5	137.5
Unknown: ocean ^c	166.1	157.9	8.0	3.4	335.5
Total	1532.0	2128.3	1284.1	407.7	5357.2

Source: U.S. EPA.²

^a Mass values are in dry metric tons $\times 10^3$.

^b MGD = millions of gallons per day.

^c This survey was conducted before the Ocean Dumping Ban Act of 1988, which generally prohibited the dumping of sewage sludge into the ocean after December 31, 1991. Ocean dumping of sewage sludge ended in June 1992. Numbers may not add up to 100% because of rounding.

Table 1-2 Number of POTWs and Sludge Quantities by Use or Disposal Practice

Use/disposal practice	POTWs use or disposal practice		Quantity of sludge disposed ^a	
	Number of POTWs	Percent of POTWs	Quantity ^b	Percent of sludge
Incineration	381	2.8	864.7	16.1
Land application	4,657	34.6	1,785.3	33.3
Codisposal: landfill	2,991	22.2	1,818.7	33.9
Surface disposal	1,351	10.0	553.7	10.3
Unknown: ocean disposal ^c	133	1.0	335.5	6.3
Unknown: other	3,920	29.1	0.0	0.0
Unknown: transfer	25	0.2	N/A	N/A
All POTWs	13,458	100.0	5,357.2	100.0

Source: U.S. EPA.²

^a N/A = not applicable.

^b In dry metric tons $\times 10^3$.

^c This survey was conducted before the Ocean Dumping Ban Act of 1988, which generally prohibited the dumping of sewage sludge into the ocean after December 31, 1991. Ocean dumping of sewage sludge ended in June 1992.

fertilizers. The increased organic content in sludge-amended soil improves water retention and drainage, lightens heavy soils, and enriches sandy soils. Depending on crop rotation, previous soil management practices, soil type, and the level of sludge application, farmers can enjoy substantial financial benefits from this resource. About two thirds of the sludge that is land applied in this country is used to improve the condition and the nutrient content of the soil for agricultural crops, including row and feed crops and pastures.

The beneficial uses of sludge are not restricted to agricultural lands; about 22% of the sludge that is land applied is used on nonagricultural sites. Sewage sludge is

used in silviculture to increase forest productivity and to revegetate and stabilize harvested forestland. The application of sludge to forestland shortens the wood production cycle by accelerating tree growth, particularly on marginal soils. Studies from the University of Washington have shown that trees grow twice as fast on sludge-amended soil. This means that trees that would typically be cut after 60 years could be cut after only 30 years, radically improving the economic forecasts for these projects. Forest soils are well suited to sludge application because they have high rates of infiltration to reduce ponding and runoff, large amounts of organic material to immobilize metals in the sludge, and perennial roots systems which allow year-round application in mild climates.

Sludge is used to stabilize and revegetate areas destroyed by natural disasters like forest fires or landslides and by human activities such as mining, dredging, and construction. Historically, land reclamation with sludge application has been very successful and somewhat less expensive than other methods of land reclamation. Philadelphia sludge has been used to reclaim over 3000 acres of strip-mined lands. In a strip-mined area in Fulton County, IL, reclamation with sewage sludge cost \$3660 an acre, while reclamation using commercial methods cost \$3395 to \$6290 an acre. Studies on Pennsylvania strip mines have shown that the microbial communities in sludge-reclaimed land revert to those of normal soils within 2 or 3 years, while the land reclaimed with conventional methods can take 10 to 15 years and even longer.

Sludge is used to fertilize highway median strips, cloverleaf exchanges, airports, parks, ball fields, cemeteries, and other public access sites and to cover closed landfills. Using sludge as an aid in establishing the final vegetative cover for municipal solid waste landfill takes advantage of the nutrient content and soil amendment characteristics of sewage sludge. The quick establishment of the final root zone can facilitate municipal solid waste closure plans.

Finally, sludge can be processed, packaged, and sold or given away for use in home gardens. About 12% of the sewage sludge generated in the U.S. is distributed and marketed as a soil amendment or fertilizer.

1.3 CONSTRAINTS FOR SEWAGE SLUDGE REUSE

To beneficially reuse sewage sludge, the standards laid out in the 40 CFR Part 503 regulations must be met. The benefits of using sludge to improve land productivity are substantial, but if the sludge contains high levels of pathogens or high concentrations of pollutants, land application could contaminate the soil, water, crops, livestock, fish, and shellfish. Virtually all sewage sludge contains nutrients such as nitrogen and phosphorus, but it also contains significant numbers of pathogens, including bacteria, viruses, protozoa, and eggs of parasitic worms. In addition, some sludges contain more than trace amounts of volatile and semivolatile organic compounds and heavy metals along with the organic constituents. The pollutants come from domestic wastewater, from the discharge of industrial wastewater to municipal sewers, and from combined sewers which collect the runoff from streets, parking lots, lawns, and fields where fertilizers and pesticides were applied incorrectly.

The major threats to human health and the environment in the land application of sludge are related to pathogens, metals, and persistent organic chemicals content. The 40 CFR Part 503 regulations are designed to prevent the contamination of soil and crops by pathogens. They also ensure that food and animal feed crops are not contaminated by inorganic chemicals in the sludge. The Part 503 regulations are based on a multimedia approach which ensures that the land application of sludge presents a negligible risk to human health and the environment.

1.3.1 Improving Sludge Quality

If the levels of pollutants in the sludge exceed the maximum standards provided by the Part 503 rule, sludge quality must be improved before it can be reused. The most cost-effective method of removing toxic contaminants from the sludge is to prevent them from entering the wastewater system in the first place. POTWs with capacities greater than 5 million gallons per day (MGD) are required to establish discharge limits for industrial dischargers to the wastewater system by 40 CFR 403, a regulation which was initially disregarded by many POTWs. In the last decade, pretreatment programs have sprung up around the country, and 2015 of the nation's POTWs currently have local pretreatment programs. While this is only about 15% of the total number of POTWs in the country, it includes all of the largest facilities and is estimated to be about 80% of the national wastewater flow. In many major cities, the level of industrial toxics discharged to the wastewater system has quietly decreased by tenfold or more in the past decade. In most cases, improving sludge quality is a relatively straightforward problem to resolve.

1.4 A GUIDE TO SLUDGE REUSE

This book is a guide to sludge reuse. It provides an overview of the production and characterization of sludge and minor residuals and presents a practical, least cost approach to improving sludge quality. Markets are paired with sludge products, and the problems and solutions of siting a sludge processing facility are explored. Moving from the simpler to the more complex sludge processing technologies, case histories give a practical view of the costs and the caveats of each sludge management option.

Starting with the land application of liquid sludge on agricultural land and forestland, we move to natural and mechanical dewatering methods and sludge cake application. Next, lime stabilization, pasteurization, and chemical fixation are discussed. Sludge composting processes from static pile to in-vessel composting are included, as are the odor control options for composting facilities and the markets for sludge compost. Sludge pelletization and some innovative technologies for sludge reuse are presented, as well as an analysis of the new EPA 40 CFR Part 503 regulations.

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