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Comparative Criteria: Land Application of Sewage Sludge and Ocean Disposal of Dredged Material

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That societal perceptions differ between use of the land and the ocean is exemplified by environmental regulations in the United States that allow much higher levels of chemical contamination in sewage sludge to be used on land than in dredged material to be dumped at sea. Criteria for sewage sludge acceptability for land application are bulk chemical concentrations. Criteria for acceptability of dredged material for disposal at sea focus upon biological testing for toxicity and bioaccumulation. The result is that sludge applied to land can have much higher levels of contamination than are commonly found even in sediments deemed unacceptable for disposal-at-sea. The inconsistencies between these criteria suggest re-evaluations of both.

Existing Criteria

In compliance with the 1988 Ocean Dumping Ban Act, no sewage sludge has been dumped into the ocean by United States municipalities since 1992. As a consequence, municipalities that once dumped at sea have joined other cities in making soil conditioner and fertilizer from sewage sludge (also called biosolids) for application to agricultural land and home gardens. To avoid undesirable effects, there are limits (Table 1) on concentrations of chemicals in sludge destined for land application which, in addition to farm and home use, includes rangeland, forests, public contact areas, and land reclamation areas. The limits were derived from a lengthy risk assessment (EPA, 1993a&b) that considered 14 pathways for chemicals to migrate from sludge-amended soil to plants, animals, and humans. The limiting concentrations for As, Cd, Pb, Hg, and Se are all based on preventing sickness among children directly ingesting sludge. For those elements, all other pathways to humans and all effects on plants or animals were calculated to result in higher limiting concentrations. The limiting concentrations for Cr, Cu, Ni, and Zn are all based on preventing toxicity to crops.

Limits for some organic chemicals were considered but were excluded for one or more of three reasons: the chemical has been banned for use in the United States; the chemical was detected in less than 5% of the sludges tested in the National Sewage Sludge Survey (EPA, 1993c) ; or based on the Survey results and assessments of exposure, concentrations would rarely exceed limits calculated to pose unacceptable risks. The chemicals considered and the limiting concentrations that would have applied are also listed in Table 1. For some organic compounds, the limiting concentration was based on direct ingestion by humans. For other organic compounds, the limit was based on human consumption of livestock grazing on sludge-amended land. For DDT, the limit was based on a runoff model and pre-existing water quality criteria.

Criteria for at-sea disposal of dredged material deem sediment unacceptable for ocean dumping if it fails prescribed toxicity tests or if chemicals of concern are accumulated in the tissues of test organisms in laboratory exposures (EPA/USACE, 1991). The chemicals of concern are Cd, Hg, organohalogens, petroleum hydrocarbons, as well as any other chemical presumed to be important in a specific instance.

Sediments not often found that exceed biosolids criteria

The last column in Table 1 shows frequencies by which elemental and organic compound concentration limits for sewage sludge have been exceeded in samples of coastal and estuarine sediment of the United States. The frequencies were calculated from concentration data collected in many different programs (Daskalakis and O'Connor, 1995). The exceedances are rare in terms of total samples, but even less common on an area-weighted basis. Comparisons based on dredged material deemed unacceptable for at-sea disposal (Table 2) reveal that maximum bulk concentrations observed even in individual samples are below the limits set for sewage sludge. Clearly, chemical concentrations in coastal sediments, including dredged material failing to meet ocean disposal criteria, very rarely exceed limits proscribed for sewage sludge application to land.

Differing assumptions for risk

Pathways of risk centering on bioaccumulation by biota and toxicity to biota apply to both sewage sludge and dredged material. For the transfer of a chemical from sludge to animals to humans the limiting concentration of a chemical is based on assuming that sludge is 1.5% of a grazing animal's total diet and that 10% of a person's diet could come from sludge-exposed animals. At-sea disposal is prohibited for a sediment if chemicals accumulate in test organisms to above U. S. Food and Drug Administration (FDA) action levels for the protection of human health. If there are no FDA action levels for a particular chemical or if it is accumulated to concentrations beyond those found in test organisms exposed to sediments from a reference area, case-specific decisions need to be reached and agreed to between high level officials of the U. S. Environmental Protection Agency and the U. S. Army Corps of Engineers.

For direct toxicity to biota, the sewage sludge assessment assumed that only copper posed any risk (EPA, 1985). Hartenstein *et al.*. (1980) observed that compost worms, *Eisenia foetida*, feeding for more than 4 months on sludge with up to 1500 ppm copper showed no toxic effect. Since 1500 ppm was already the limiting copper concentration (Table 1) based on crop toxicity, direct toxicity to fauna was judged non-existent. For toxicity to small feral animals (e.g. moles and shrews) that eat earthworms, only cadmium and lead were considered to pose a risk. Assumptions were made as to percentages of total diet from earthworms and assimilation efficiency and it was further assumed that small animals could safely ingest cadmium and lead at rates 10 and 5 times, respectively, those known to affect grazing livestock. At-sea disposal is prohibited for dredged material if it is more toxic than reference sediment to test organisms based on direct testing of a filter-feeding, a deposit feeding, and a burrowing organism. In practice, the tests measure survival upon 10-day exposures of mollusks (e.g. *Mercenaria mercenaria*), polychaetes (e.g. *Nereis virens*) and amphipods (e.g. *Ampelisca abdita*). Amphipod testing was introduced in the most recent version of dredged material criteria (EPA/USACE, 1991) and, in general, is more sensitive than the other two tests.

If comparable assessments of sewage sludge for land application were applied to dredged sediment for at-sea disposal, there would be no tests of toxicity or bioaccumulation. Sediments would be considered non-toxic unless chemical concentrations exceeded the highest values found not to be associated with biological effects. Bioaccumulation would be assumed to occur but would only be a reason for exclusion after accounting for the proportion of total human diets that could be from organisms exposed to dredged material.

Which assessment is correct?

One argument against defining toxic thresholds on the basis of chemical data is that toxicity determinations are method and species dependent. A large number of test species and endpoints have been employed to assess sediment toxicity. The corresponding database for sludge-amended soil is very small. EPA (1993b) states that the limiting concentration for toxicity to soil organisms is not based on the most sensitive species but rather on the only species for which there are relevant data. Even in that case, the observations are for the earthworm living in 100% sewage sludge. No account is taken that soil characteristics such as pH, texture, and water content may increase the availability and therefore the toxicity of chemicals added with sludge. Other species would show different sensitivities to sewage sludge and the chosen species, *E. foetida,* may be less sensitive than most because it is only found in places of high organic matter, such as compost and dung heaps (Kula, 1994). Just as sediment toxicity is tested with a variety of species, there are several other species of annelids, as well as different species of arthropods and mollusks, that have been used to test soil toxicity (Donker *et al*., 1994). If other species were used, it is very likely that lower limits would be found for sludge toxicity. Though, perhaps, not so low as to alter the criteria which are based on direct toxicity by human ingestion and toxicity to crops.

The major differences between the two criteria with regard to bioaccumulation are not only in how bioaccumulation is estimated but also in how the estimates are used. The dredged material criteria disallow dumping if calculated or measured body burdens exceed FDA limits and require high level consensus in cases where there is bioaccumulation above that in tests with reference sediment. The sewage sludge criteria, on the other hand, assume that bioaccumulation will occur. The limits are those that would result in harm to humans or animals after accounting for the portion of their total diets that would be from sludge-exposed plants or animals. A similar recognition that marine organisms and humans do not get all their seafood from a source exposed to dredged material would greatly alter present assessments of the hazard of bioaccumulation from dredged material.

The criteria for land application of sewage sludge are less stringent than those for application of dredged material to the sea floor. In the foreword of an EPA document written for the general user (EPA, 1994) it is stated that "The Part 503 rule creates incentives for beneficial use of biosolids. EPA believes that biosolids are an important resource that can and should be safely used..." Those drafting the dredged material criteria had no such incentive. The criteria do encourage beneficial uses of dredged material, such as beach replenishment and wetland creation, but dumping at sea is not among them. Nonetheless, while the benefits of dredging are only to marine commerce rather than the marine environment, the ocean disposal criteria can be considered overly protective.

Conclusion

If human exposure to chemicals from dredged material were to be calculated on the basis of reasonable assumptions about how much of a highly exposed human's diet actually came from sediment-exposed organisms, the dredged material criteria would be much less stringent. In this author's opinion, these realistic assumptions should apply to dredged material.

With regard to toxicity, it is not so easy to choose between the criteria. There is probably sufficient information already in hand on sediment toxicity to use bulk chemical concentrations, not as criteria, but as guidelines whose exceedance would force biological tests of toxicity. On the other hand, there is so little data on toxicity of sludge-amended soil that the criteria for land application cannot be taken as a model for basing estimates of toxicity on bulk chemistry alone.

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Table 1. Trace elements for which there are concentration (ppm-dry) limits in sewage sludge proposed for land application (EPA, 1993a) and organic chemicals (ppm-dry) which were excluded from sewage sludge criteria but for which limiting concentrations had been calculated (appendix page B-12 in (EPA, 1993b)). The totals and exceedances are total numbers of concentration determinations and exceedances of those concentrations in coastal sediment samples in the COSED database (Daskalakis and O'Connor, 1995) containing concentrations measured in more than 10,000 samples of sediment from the coastal United States (hexachlorobenzene, hexachlorobutadiene and N-nitrosodimethylamine data were not included in the compilation of COSED).

chemical	sludge limit	exceedances/total in coastal sediment
arsenic	41ppm-dry	119/6209
cadmium	39	21/6920
chromium	3000	3/8674
copper	1500	7/6251
lead	300	116/11995
mercury	17	15/9671
nickel	420	2/7150
selenium	100	7/2920
zinc	2800	10/9082
Aldrin/dieldrin	3.9	0/1643
benzo(a)pyrene	21.5	4/2272
chlordane	129	0/1970
DDT/DDE/DDD	171	0/2440
heptachlor	10.6	0/523
hexachlorobenzene	42	
hexachlorobutadiene	860	
lindane	126	0/682
N-nitrosodimethylamine	3.3	
PCBs	6.6	6/2441
toxaphene	15.1	0/35
trichloroethylene	14000	0/35

Table 2. Maximum bulk chemical concentrations (ppm-dry) measured in dredged materials from three harbor projects that were unacceptable for ocean-disposal (USACE 1990, 1994, and 1995).

chemical	Boston MA[a]	New York NY[a]	Oakland CA[a]
arsenic	27	16	29
cadmium	2.9	8.0	8.0
chromium	210	150	2150
copper	180	290	462
lead	210	220	497[b]
mercury	1.1	4.6	15
nickel	39	41	390
selenium	0.88	nd[d]	6.1
zinc	420	390	549
Aldrin/dieldrin	-[c]	-	0.015
benzo(a)pyrene	1.1	0.96	2.5
chlordane	-	-	nd
DDT/DDE/DDD	0.031	-	0.051
heptachlor	0.01	-	0.008
hexachlorobenzene	-	-	nd
hexachlorobutadiene	-	-	nd
lindane	0.029	-	0.002
N-nitrosodimethylamine	-	-	nd
PCBs	nd	0.28[e]	3.8[f]
toxaphene	-	-	nd
trichloroethylene	-	-	-

[a]Total numbers of samples: Boston, 6 (two each from the three portions of the project where sediment was deemed unsuitable for ocean disposal); New York, 4 composite samples for trace elements, two samples for organic chemicals; Oakland 88 samples (from entire project including portions with sediment deemed acceptable for ocean disposal)

[b]This is the sole maximum concentration above the sewage sludge limit. The second highest lead concentration among the Oakland samples was 216 ppm.

[c]A dash (-) indicates that chemical concentration was not measured

[d]nd indicates chemical measured but not detected in any sample

[e]PCB is Aroclor 1016

[f]PCB is the sum of eight aroclors