The health impacts of biosolids use on land

● Application of wastewater-derived biosolids to land offers considerable benefits, but debate continues as the what negative health impacts might arise from this practice. **PAUL DARVODELSKY** and **MARY FIEN** review current thinking.

Opinion about the safety of using biosolids in land application is polarised, particularly on land used for growing food or grazing stock. Those who are involved in finding appropriate disposal or reuse mechanisms for biosolids and many users tend to consider biosolids a very safe and effective alternative to inorganic fertilisers and a great benefit in land rehabilitation. Proponents point to the greater safety and sustainability of biosolids use compared to inorganic fertilisers and the merits of recycling. On the other hand, there is a group of consumers, neighbours and some primary producers who believe the safety of biosolids use is uncertain at best, and more likely a grave concern.

This article presents a review of evidence, scientific and anecdotal, regarding the potential health impacts of biosolids use, primarily for land application and assumes that biosolids will be used in accordance with relevant local regulations.

Background

Biosolids are generated as part of the sewage treatment process. Biosolids are of human origin and include anything households and industry discharge to sewer. Biosolids may contain organisms and substances which can cause an impact on human and environmental health if they occur above certain levels.

The organisms and substances of concern are pathogens, trace elements, especially heavy metals, and synthetic organic compounds.

Safegy of biosolids use – the case for

Industry and regulators have concluded that 'application of biosolids on agricultural land is safe, provided the guidelines are followed' (WEAO, 2001), and cite studies showing that there are no significant health effects from living on farms receiving biosolids. Further, biosolids are beneficial to soils in terms of structure, water holding and microbial population (Tenenbaum, 1997).

The US EPA concluded more cautiously that 'there is no documented scientific evidence that sewage sludge regulations have failed to protect public health' (USEPA, 2003). However, in response to concerns raised by the National Research Council, the EPA identified areas requiring further investigations and risk assessment, particularly regarding pathogens and a specific list of 15 chemicals (USEPA, 2003).

The case against

In contrast, various interest groups have made criticisms of biosolids application processes and claim that there are 'known potential health risks related to consuming food grown in sewage sludge-amended soils' (IATP, 1999). The IATP article does not explain what the health effects may be, referring instead to cadmium absorption by grazing animals and increased human intake of dioxin by eating animals grown on biosolids-applied soils. There is no distinction made between the contents of sewage, biosolids or the soil.

Whilst the risks of health impact are low, cadmium is a metal which the water industry needs to continue to monitor in biosolids applied agricultural land.

Others raise concerns that 'sewage sludge' applied to land contains lead, arsenic, PCBs, dioxins and 'additional polluting materials' (Williams, 2004). This article describes a 'sludge syndrome' with a range of symptoms,

apparently experienced by those living near land application sites. It further claims that Cornell University Waste Management Institute 'has received over 350 sludge-based complaints'.

There have been several reports of injuries or illness allegedly arising from contact with biosolids. In one, reported in the New York Times, a road construction worker claimed that hay 'tainted' by biosolids had made him and other workers ill. The article acknowledged the lack of 'conclusive scientific studies' to show a causal link between biosolids and health effects.

There has been at least one lawsuit related to human health effects of biosolids, when a neighbour of a farm using biosolids died in 2000 (USA Today). The case settled in 2003, with the plaintiff required to make a statement that the death was unrelated to biosolids application, as the science produced had shown no connection and the autopsy ruled out biosolids as the cause.

Pathogens

Different experts have drawn similar conclusions, that pathogens in biosolids do not pose a significant human health risk for biosolids treated and managed in accordance with a guideline such as the US EPA 40CFR part 503 regulation. Some conclusions from research are:

- Spray application of (liquid) biosolids does not represent a health threat for individuals more than

Close-up of sludge on a Deskins quick-dry filter bed.

Picture courtesy Paul Darvodelsky.

100m down wind of the application site. Organisms transported in aerosols are much more susceptible to inactivation than in soil due to solar radiation, desiccation and high temperature;
- Bacterial contamination of surface water is unlikely, as the survival time of enteric bacteria and viruses in soil is relatively short;
- Very few bacteria have been detected in groundwater from biosolids amended sites;
- There are no significant health risks to people and their domestic animals from living on farms that receive biosolids application.

Further it is noted that any health impacts should show up in workers who are in regular and often direct contact with biosolids well before it affects communities or people near application sites.

Regulated trace elements

The consensus of scientific research on the effect of these trace elements as derived from biosolids application is that there is 'sufficient credible scientific information to assure the public that the current agricultural land application programme/guidelines are adequate to protect the well beings of soils, crops, animals, human health, ground and surface water qualities.' WEAO, 2001.

It has however been suggested that the US guideline for cadmium is too generous because the average plant uptake used in risk modelling is much lower than the actual uptake for a range of leafy vegetables. In addition, the assumed human exposure is too low for those following a vegetarian or semi-vegetarian diet (McBride, 2003).

It is known that the cadmium content of grain is directly linked to soil cadmium level and soil pH; wheat grain takes up more cadmium than barley grain, for which the correlation is less accurate. One study endorsed the low EU limits for soil cadmium of <0.5 mg/kg for soil with a pH of 5-6, <1.0 mg/kg for pH 6-7, and <1.5 mg/kg for pH >7 (Adams, Zhao, McGrath, Nicholson and Chambers, 2004).

Whilst the risks of health impact are low cadmium is a metal which the water industry needs to continue to monitor in biosolids applied agricultural land.

Unregulated trace elements

Unregulated compounds include: aluminium, antimony, asbestos, barium, beryllium, boron, cyanide, fluoride, manganese, silver, thallium and tin. It is unlikely that these compounds will be present in biosolids at levels presenting any health risk, but if source control programmes are not effective in restricting such compounds from entering the sewerage system they may have to be examined on a case by case basis.

For the water industry an absence of data, albeit due to a very low risk profile for these compounds in biosolids, leaves an opening for some groups of the community to criticise the science behind beneficial use of biosolids in agriculture. Further research on these compounds is therefore prudent.

Synthetic organic compounds

A range of synthetic organic compounds may be present in biosolids. These compounds exist in the environment and are used in everyday products by the community. The compounds found in biosolids may be regulated or unregulated.

Regulated compounds vary around the world, but generally include DDT/DDD/DDE, aldrin, dieldrin, chlordane, heptachlor and heptachlor epoxide, hexachlorobenzene, lindane, benzene hexachloride and poly-chlorinated biphenyls (PCBs).

WEAO, 2001 concluded 'Trace Organics: which include VOCs, PAHs, pesticides, dioxins and furans, and LAS surfactants, are deemed to be Group I, due to their low concentrations in biosolids and/or rapid loss in the soil.' (Group I has sufficient information to assure safety, Group II needs further work).

The World Health Organisation (WHO) Working Group on the Risk to Health of Chemicals in Sewage Sludge Applied to Land has concluded that 'the total human intake of identified organic pollutants from sludge application to land is minor and is unlikely to cause adverse health effects'.

Unregulated compounds include surfactants (alklybenzene sulphonates), endocrine disruptors (alkylphenols and estrogenic hormones), dioxins and furans, pharmaceuticals, radionuclides and poly brominated fire retardants. Recent research with biosolids is strongly consistent with the conclusions of the WHO and WEAO, however it suggests that breakdown products from endocrine disrupting compounds persist in biosolids and may be of concern in terms of potential impact on wildlife. This area warrants further research.

Pharmaceuticals and radionuclides in biosolids are unlikely to pose any significant health risks; most pharmaceuticals are designed to be water-soluble, biodegradable and have short half-lives, and medically used radionuclides that may be discharged with human wastes are short-lived. WEAO 2001.

There is limited evidence and regulatory guidance for poly-brominated fire retardants to make an assessment for biosolids. An important point for this group of substances is that is that they are ubiquitous and human contact is likely through everyday use of computers and furnishings. Biosolids may be a contributing pathway, but is unlikely to be a major contributing pathway.

Most broad based reviews of scientific evidence make the same conclusion: 'there is no documented scientific evidence that sewage sludge regulations have failed to protect public health'. Criticism of biosolids use is often anecdotal and the majority of the papers reviewed by the authors opposing biosolids use were lacking in scientific rigour. Based on the information reviewed, use of biosolids on agricultural land in accordance with established management practices and regulations has very low to extremely low risk of creating a significant health impact.

A number of key compounds for further research are suggested by this review. Whilst it is likely that the potential risks associated with these compounds are very low it is considered important to demonstrate this with rigorous science. The key compounds are cadmium, endocrine disrupting compound by-products and poly-brominated fire retardants. ●

References

1. Adams, M.L., F.J. Zhao, S.P. McGrath, F.A. Nicholson & B.J. Chambers, *Predicting cadmium concentrations in wheat and barley grain using soil properties. Journal of Environmental Quality, 33 (2), 2004.*
2. Alvarez, E.A., M.C. Mochon, J.C.J. Sanchez & M.T. Rodriguez, *Heavy metal extractable forms in sludge from wastewater treatment plants. Chemosphere, 47 (7), 2002.*
3. Association of Metropolitan Sewerage Agencies, *The AMSA 2000/2001 Survey of Dioxin-like Compounds in Biosolids: Statistical Analyses. October 2001.*
4. Baran, S. & P. Oleszczuk, *Changes in the content of polycyclic aromatic hydrocarbons (PAHs) in light soil fertilized with sewage sludge. Journal of Environmental Science and Health, A38 (5), 2003.*
5. Brooks, J. P., C. P. Gerba, & I. L. Pepper, *Biological aerosol emission, fate, and transport from municipal and animal wastes. Water Science & Technology, 50(1), 2004.*
6. Brooks, J.P., B.D. Tanner, C. P. Gerba, C.N. Haas & I. L. Pepper, *Estimation of bioaerosol risk of infection to residents adjacent to a land applied biosolids site using an empirically derived transport model. Journal of Applied Microbiology, 98, 2005a.*
7. Brooks, J.P., B.D. Tanner, K.L. Josephson, C. P. Gerba, C.N. Haas & I. L. Pepper, *A national study on the residential impact of biological aerosols from the land application of biosolids. Journal of Applied Microbiology, 99, 2005b.*
8. Cintra, A.A.D., M.D. Revoredo, W.J. Melo & L. T. Braz, *Non-nutrient heavy metals in tomato plants cultivated in soil amended with biosolid and sugar-cane bagasse compost, ISHS Acta Horticulturae 638: XXVI International Horticultural Congress: Sustainability of Horticultural Systems in the 21st Century, 2004.*
9. Colucci, M.S. & E. Topp, *Dissipation of part-per-trillion concentrations of estrogenic hormones from agricultural soils. Canadian Journal of Soil Science, 82 (3), Aug 2002.*
10. Evanylo, G.K., *Risk of toxic nitrate accumulation in forages grown on biosolids-amended soils. Crop and Soil Environmental News, September 2002.*
11. Gale, P & G. Stanfield, *Towards a quantitative risk assessment for BSE in sewage sludge. Journal of Applied Microbiology, 91 (3), 2001.*
12. Hesselsoee, M., D. Jensen, K. Skals, T. Olesen, P. Moldrup, P. Roslev, G.K. Mortensen & K. Henriksen, *Degradation of 4-Nonylphenol in homogeneous and nonhomogeneous mixtures of soil and sewage sludge. Environmental Science & Technology, 35 (18), 2001.*
13. Institute for Agriculture and Trade Policy, *Sewage Sludge & Food Safety. September 1999.*
14. Jensen, J., H. Loekke, M. Holmstrup, P.H. Krogh & L. Elsgaard, *Effects and risk assessment of linear alkylbenzene sulfonates in agricultural soil. 5. Probabilistic risk assessment of linear alkylbenzene sulfonates in sludge-amended soils. Environmental Toxicology and Chemistry, 20 (8), 2001.*
15. Jjemba, P.K., *The effect of chloroquine, quinacrine and metronidazole on both soybean plants and soil microbiota. Chemosphere, 46, 2002.*
16. Johnson, A. P. & J.P. Sumpter, *Removal of endocrine-disrupting chemicals in activated sludge treatment works. Environmental Science and Technology, 35 (24), 2001.*
17. Kato, S., E. Fogarty, D.D. Bowman, *Effect of aerobic and anaerobic digestion on the viability of Cryptosporidium parvum oocysts and Ascaris suum eggs. International Journal of Environmental Health Research, 13 (2), 2003.*
18. Korboulewsky, N., S. Dupouyet, G. Bonin, *Environmental risks of applying sewage sludge compost to vineyards: Carbon, heavy metals, nitrogen, and phosphorus accumulation. Journal of Environmental Quality, 31 (5), 2002.*
19. La Guardia, M.J., R.C. Hale, E. Harvey and T.M. Mainor, *Alkylphenol ethoxylate degradation products in land-applied sewage sludge (biosolids). Environmental Science & Technology, 35 (24), 2001.*
20. Lee, J., *Sludge Spread on Fields Is Fodder for Lawsuits. The New York Times, June 26, 2003.*
21. Lee, N.-B. & T.E. Peart, *Organic contaminants in Canadian municipal sewage sludge. Part 1. Toxic or endocrine-disrupting phenolic compounds. Water Quality Research Journal of Canada, 37 (4), 2002.*
22. McBride, M.B., *Cadmium concentration limits in agricultural soils: Weaknesses in USEPA's risk assessment and the 503 Rule. Human and Ecological Risk Assessment, 9 (3), 2003.*
23. Potash and Phosphate Institute, *Enviro-Briefs No. 7: Crop Fertilization and Heavy Metal Accumulation in Soils.*
24. Ramachandran, V. & T.J. D'Souza, *Plant uptake of cadmium, zinc and manganese from four contrasting soils amended with Cd-enriched sewage sludge. Journal of Environmental Science and Health, A37 (7), 2002.*
25. Rate, A.W., K.M. Lee & P.A. French, *Application of biosolids in mineral sands mine rehabilitation: use of stockpiled topsoil decreases trace element uptake by plants. Bioresource Technology, 91 (3), 2004.*
26. Rhind, S.M., A. Smith, C.E. Kyle, G. Telfer, G. Martin, E. Duff & R.W. Mayes, *Phthalate and alkyl phenol concentrations in soil following applications of inorganic fertiliser or sewage sludge to pasture and potential rates of ingestion by grazing ruminants. Journal of Environmental Monitoring, 4 (1), 2002.*
27. Rideout, K., K. Teschke1 & S. Varughese, *Guidance document: Potential for exposure to polychlorinated dibenzo-p-dioxins and dibenzo-furans when recycling sewage biosolids on agricultural land. British Columbia Ministry of Water, Land and Air Protection, Environment Canada, 2002.*
28. Rusin, P.A., S.L. Maxwell, J.P. Brooks, C.P. Gerba & I.L. Pepper, *Evidence for the absence of Staphylococcus aureus in land applied biosolids, Environmental Science & Technology, 37 (18), 2003.*
29. Selvaratnam, S. & J.D. Kunberger, *Increased frequency of drug-resistant bacteria and fecal coliforms in an Indiana creek adjacent to farmland amended with treated sludge. Canadian Journal of Microbiology, 50 (8), 2004.*
30. Solinov Inc, *Prepared for the Quebec Ministry of Environment, Biosolids and bioaerosols: The current situation. September 2002*
31. Stevens, J.L. & K.C. Jones, *Quantification of PCDD/F concentrations in animal manure and comparison of the effects of the application of cattle manure and sewage sludge to agricultural land on human exposure to PCDD/Fs. Chemosphere, 50 (9), 2003.*
32. Tenenbaum, D., *The beauty of biosolids. Environmental Health Journal, 105(1), 1997.*
33. United States Environmental Protection Agency, Office of Water, *Use and Disposal of Biosolids (Sewage Sludge): Agency Final Response to the National Research Council Report on Biosolids Applied to Land and the Results of the Review of Existing Sewage Sludge Regulations. 4304T, EPA-822-F-03-010, December 2003*
34. Wang, Q., Y. Li, W Klassen, *Effects of Soil Amendments at a Heavy Loading Rate Associated with Cover Crops as Green Manures on the Leaching of Nutrients and Heavy Metals from a Calcareous Soil. Journal of Environmental Science and Health, B38 (6), 2003.*
35. The Water Environment Association of Ontario, *Fate and significance of selected contaminants in sewage biosolids applied to agricultural land through literature review and consultation with stakeholder groups. April 2001.*
36. Weltin, D. & B. Bilitewski, *Mobility of endocrine disrupters in soil after sewage sludge treatment. Wasser und Boden, 53 (1-2), 2001.*
37. Wilkinson, J.M., J. Hill, & J.P. Hillman, *The accumulation of potentially toxic elements in edible body tissues of lambs grazing after a single application of sewage sludge. Water Research, 37 (1), 2003.*
38. Williams, R.M., *EPA to label toxic sludge as organic compost. Townsend Letter for Doctors and Patients, May 2004.*
39. *Polybrominated Flame Retardants (PBFRs) – Priority Existing Chemical Assessment Report No 20 – NICNAS (National Industrial Chemicals Notification and Assessment Scheme June 2001.*
40. *Biosolids Applied to Land: Advancing Standards and Practices, National Research Council July 2002.*

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Chemical conditioning for sludge

● A new chemical treatment process that can reduce sludge volumes, achieve disinfection and control odours is being trialled around Europe. LIS STEDMAN reports.

Sludge conditioning is a topic of considerable interest around the world, with increasingly strict requirements for sludge application to land and the high costs of landfill providing a timely focus.

In this vein, Swedish company Kemira has brought out a sludge conditioning technology called Kemicond that is intended to reduce volumes, disinfect and control odours.

Kemicond is a three-step technology, beginning with acidification, moving to oxidation and then finally to flocculation. Sulphuric acid is added to the wastewater sludge to acidify it to a pH of below five – the pH of digested sludge is normally around seven. Carbon dioxide is released during acidification, ferrous phosphates, hydroxides and other salts are dissolved and water-retaining gel-like inorganic structures broken down. Acid consumption is lower for undigested sludge because of its lower alkalinity.

By adding a strong oxidising agent such as hydrogen peroxide (bleach), dissolved bivalent ferrous ions are oxidised to trivalent ions if soluble phosphate ions are present – as they are in wastewater sludges. An insoluble precipitate of ferric phosphate is formed – one of the key reactions in the process, which occurs if the molar ratio of iron to phosphate is roughly 1:1. With most sludges the amount of iron is somewhat higher, giving a ratio of around 3:2, which means the phosphate is still precipitated and the excess dissolved iron can be recycled as coagulant.

The precipitated ferric phosphate acts as a filtering enhancer, enabling the sludge to release water from a mainly-organic structure. Organic water-retentive structures are also partly destroyed or physically modified during this process.

Because hydrogen peroxide is so strongly oxidative in the presence of ferrous and ferric ions at low pH, most of the micro-organisms in the sludge, such as salmonella and other pathogens, are destroyed and organic micro-pollutants reduced. In addition, the sulphur compounds that cause unpleasant odours are oxidised or bound to the iron.

These processes completely change the structure of the sludge, which subsequently requires substantially less flocculation. This is undertaken with a specially-developed polymer, and followed by a mechanical dewatering step using a filter belt press, centrifuge, screw press or chamber filter press. If the pH level is too low (below three) an alkali may have to be added to facilitate dewatering.

Kemira says that the Kemicond system offers a 25% to 50% reduction in sludge volumes compared to untreated sludge, achieved both through increased dry solids (up to and above 40% TDS depending on the dewatering process) and a reduction in the suspended solids of 5 to 10% depending on sludge composition.

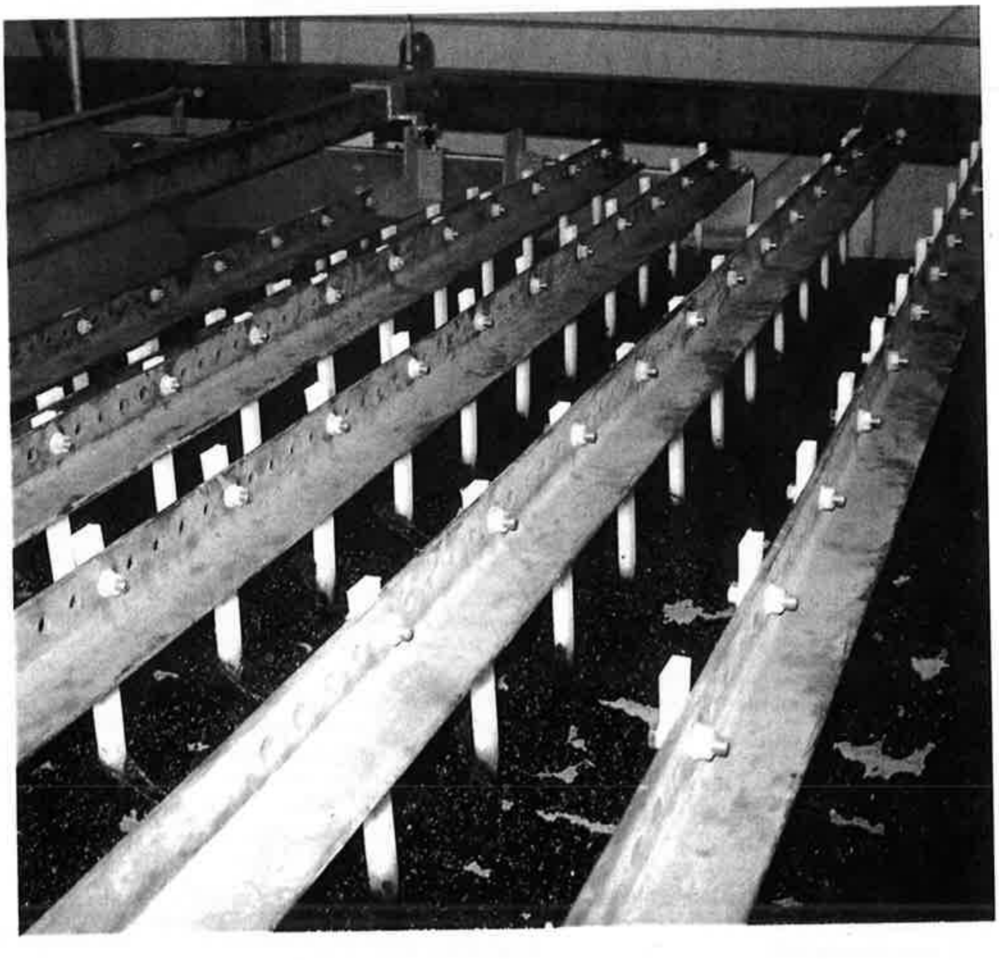
The sludge's structure and composition are radically changed by the process – from a sticky, smelly substance to an odourless, gravel-like one. This structure aids oxygenation, so composting is possible without the addition of peat or bark, Kemira says.

Analysis of results from using the conditioner at three wastewater treatment works showed reductions in polyaromatic hydrocarbons (PAH) of between 11% and 33%; DEHP (diethylhexylphthalate) reductions of 5% to 33%; NPE (nonylphenolethoxylate) reductions of 33% to 47%; and a reduction in PCB (polychlorinated biphenyls) of 25%.

Further tests showed that the reject waters contained more iron, calcium and sulphates, experienced a small increase in COD and nitrogen, but showed no change in phosphorus levels. It was also found that the reject water did not affect biological processes such as nitrification.

Full-scale tests

Kemira undertook full-scale tests of the conditioner in Denmark in the latter part of last year, first evaluating the sludge properties in a laboratory and then undertaking filtering tests on both untreated sludge and Kemicond-treated sludges at different chemical doses.



Stockholm's Kappala plant treats 7000 tonnes of dry sludge a year. The Kemicond process being installed there is due for start-up in March 2006.