Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

LINDANE
(Hexachlorocyclohexane)

Lindane, the γ isomer of hexachlorocyclohexane (HCH), and HCH itself are synthetic organochlorine pesticides that have been used in Canada since the early 1950s as a treatment for the control of a variety of insect pests. Lindane is currently registered under the Pest Control Products Act for restricted uses, including moth sprays, seed treatment, and control of domestic insects (IPCS 1991). The development of sediment quality guidelines for this substance is necessary because of concerns regarding its persistence, potential for bioaccumulation, and toxicity (Pest Management Regulatory Agency 1997, Ottawa, pers. com.).

Lindane enters aquatic systems mainly as surface runoff from treated lands, washoff from treated lumber and livestock, and deposition following volatilization and aerial transport. Due to its affinity for organic materials, lindane in aquatic systems tends to become associated with particulate matter and accumulate in bed sediments. Due to its relatively high water solubility, however, lindane accumulates in bed sediments to a lesser extent than many other organochlorines. Because a wide variety of organisms live in, or are in contact with, bed sediments, sediments act as an important route of exposure to aquatic organisms.

The interim sediment quality guidelines (ISQGs) and probable effect levels (PELs) for lindane were developed using a modification of the National Status and Trends Program approach as described in CCME (1995) (Table 1). The ISQGs and PELs refer to total concentrations of lindane in surficial sediments (i.e., top 5 cm), as quantified by extraction with an organic solvent (e.g., 1:1 acetone:hexane) followed with determination by a standard analytical protocol.

The majority of the data used to derive ISQGs and PELs for lindane are from studies on field-collected sediments that measured concentrations of lindane, along with concentrations of other chemicals, and associated biological effects. Biological effects associated with concentrations of lindane in sediments are compiled in the Biological Effects Database for Sediments (BEDS) (Environment Canada 1998). Both the freshwater and marine BEDS data sets for lindane are large, with the freshwater data set containing 22 effect entries and 279 no-effect entries and the marine data set containing 21 effect entries and 161 no-effect entries (Figures 1 and 2). Both data sets represent a wide range of concentrations of lindane, types of sediment, and mixtures of chemicals. Evaluation of the percentage of effect entries that are below the ISQGs, between the ISQGs and the PELs, and above the PELs for lindane (Figures 1 and 2) indicates that these values define three ranges of chemical concentrations: those that are rarely, occasionally, and frequently associated with adverse biological effects, respectively (Environment Canada 1998).

Toxicity

Adverse biological effects for lindane in the BEDS include decreased benthic invertebrate diversity, reduced abundance, increased mortality, and behavioural changes (Environment Canada 1998, Appendixes Xa and Xb). For example, low abundance of Amphipoda, Ephemeroptera, Plecoptera, and Trichoptera was observed in the Niagara River, New York, where the mean concentration of lindane in sediments was 2.63 $\mu g \cdot kg^{-1}$, which is above the freshwater PEL (Jaagumagi 1988; Jaagumagi et al. 1989). In contrast, higher abundance was observed at sites with a mean concentration of 0.5 $\mu g \cdot kg^{-1}$, which is below the freshwater ISQG (Jaagumagi 1988; Jaagumagi et al. 1989). Similarly, mortality was observed in the larvae of a bivalve in sediments from San Francisco Bay with a mean concentration of 0.47 $\mu g \cdot kg^{-1}$, which is above the marine ISQG (Long and Morgan 1990). No significant mortality was observed at a mean concentration of 0.1 $\mu g \cdot kg^{-1}$, which is below the marine ISQG (Long and Morgan 1990).

Spiked-sediment toxicity tests for lindane report the onset of toxicity to benthic organisms at higher concentrations than those observed in field studies. This is likely a result of the shorter exposure times of these laboratory studies, as well as exposure to lindane only as opposed to chemical mixtures containing lindane (Environment

Table 1. Interim sediment quality guidelines (ISQGs) and probable effect levels (PELs) for lindane ($\mu g \cdot kg^{-1}$ dw).

	Freshwater	Marine/estuarine
ISQG	0.94	0.32
PEL	1.38	0.99

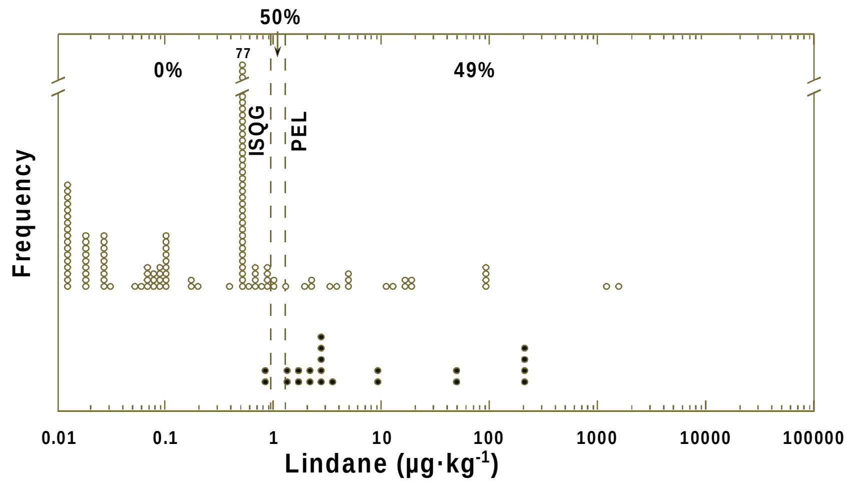

Figure 1. Distribution of lindane concentrations in freshwater sediments that are associated with adverse biological effects (●) and no adverse biological effects (○). Percentages indicate proportions of concentrations associated with effects in ranges below the ISQG, between the ISQG and the PEL, and above the PEL.

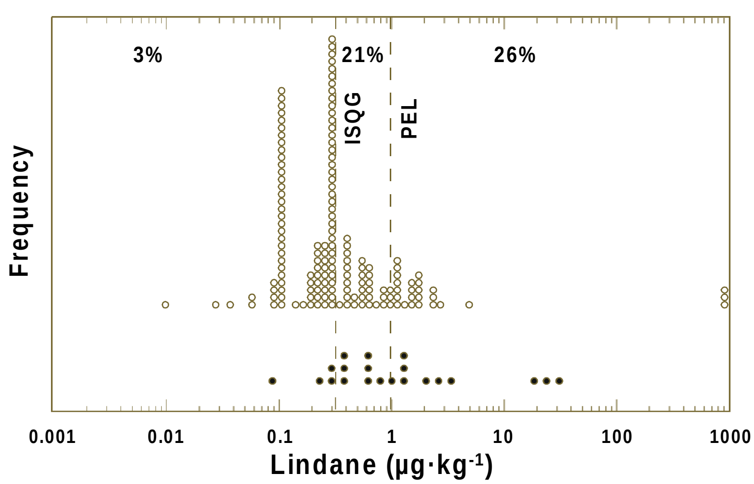

Figure 2. Distribution of lindane concentrations in marine and estuarine sediments that are associated with adverse biological effects (●) and no adverse biological effects (○). Percentages indicate proportions of concentrations associated with effects in ranges below the ISQG, between the ISQG and the PEL, and above the PEL.

Canada 1998). For example, Ciarelli et al. (1997) assessed the toxicity of lindane to *Corophium volutator*, an amphipod. Tests on different size classes yielded 10-d LC_{50}s of 1.31 $mg \cdot kg^{-1}$, 1.28 $mg \cdot kg^{-1}$, and 1.26 $mg \cdot kg^{-1}$ for organisms of 5-, 7-, and 8-mm lengths, respectively. Similarly, Hermsen (1994) exposed *Mytilus edulis*, a mussel, to marine suspended particulate matter that had been spiked with 150 $\mu g \cdot kg^{-1}$ lindane. After 7 d, the clearance rates of mussels exposed to the lindane-spiked sediments were significantly lower than controls.

The results of freshwater and marine spiked-sediment toxicity tests and field studies indicate that concentrations of lindane that are associated with adverse effects are consistently above the ISQGs, confirming that the guidelines adequately represent concentrations below which adverse biological effects will rarely occur. Further, these studies provide additional evidence that toxic levels of lindane in sediments are similar to, or greater than, the PELs, confirming that effects are more likely to be observed when concentrations of lindane exceed the PELs (Environment Canada 1998). The ISQGs and PELs for lindane are therefore expected to be valuable tools for assessing the ecotoxicological relevance of lindane in sediments.

Concentrations

Currently data on concentrations of lindane in Canadian freshwater and marine sediments are limited. In freshwater lake, river, and stream sediments, concentrations range from below detection to a maximum of 126 $\mu g \cdot kg^{-1}$ measured in Nova Scotia (Environment Canada 1998). In marine and estuarine sediments, concentrations range from below detection to 2.1 $\mu g \cdot kg^{-1}$ in sediments from the St. Lawrence estuary, Quebec (Environment Canada 1998). Lindane degrades slowly in aquatic sediments, therefore, the elimination of local sources should result in a gradual decrease in concentrations over time.

Additional Considerations

Regardless of the origin of lindane in sediments, aquatic organisms may be adversely affected by exposure to elevated levels. The occurrence of adverse biological effects cannot be precisely predicted from concentration data alone, particularly in the concentration ranges between the ISQGs and the PELs (Figures 1 and 2). The likelihood of adverse biological effects occurring in response to exposure to lindane at a particular site depends on the sensitivity of individual species and the endpoints examined, as well as a variety of physicochemical (e.g., temperature and pH), geochemical (e.g., sediment particle size and TOC), and biological (e.g., feeding behaviour and uptake rates) factors that affect the bioavailability of lindane (Environment Canada 1998).

Benthic organisms are exposed to both particulate and dissolved lindane in interstitial and overlying waters, as well as to sediment-bound lindane through surface contact and sediment ingestion. Lindane that is dissolved in the interstitial or overlying waters is believed to be the most bioavailable source for sediment-associated organisms and correlates well with toxicity (Adams et al. 1985; Di Toro et al. 1991). When different types of sediment with the same concentrations of total lindane are compared, less lindane is dissolved in the interstitial water of sediments with high TOC content (Karickhoff 1984; Shea 1988). Therefore, organic carbon may reduce the bioavailability and, hence, toxicity of sediment-associated lindane to benthic organisms. The physicochemical, geochemical, and biological factors that modify bioavailability should be considered when evaluating the potential biological impact of lindane in sediments (Environment Canada 1998).

Currently, the degree to which lindane will be bioavailable at particular sites cannot be predicted conclusively from the physicochemical characteristics of sediments or the attributes of endemic organisms (Environment Canada 1998). Nonetheless, an extensive review of the available data indicates that the incidence of adverse biological effects associated with exposure to lindane increases as concentrations increase in a range of sediment types (Figures 1 and 2). Therefore, the recommended Canadian ISQGs and PELs for lindane will be useful in assessing the ecotoxicological significance of lindane in sediments.

References

Adams, W.J., R.A. Kimerle, and R.G. Mosher. 1985. Aquatic safety assessment of chemicals sorbed to sediments. In: Aquatic toxicology and hazard assessment: Seventh symposium, R.D. Cardwell, R. Purdy, and R.C. Bahner, eds. American Society of Testing and Materials, Philadelphia.

CCME (Canadian Council of Ministers of the Environment). 1995. Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life. CCME EPC-98E. Prepared by Environment Canada, Guidelines Division, Technical Secretariat of the CCME Task Group on Water Quality Guidelines, Ottawa. [Reprinted in Canadian environmental quality guidelines, Chapter 6, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]

Ciarelli, S., A.P.M.A. Vonck, and N.M. van Straalen. 1997. Reproducibility of spiked sediment bioassays using the marine benthic amphipod, *Corophium volutator*. Mar. Environ. Res. 43:329–343.

Di Toro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin. 1991. Technical basis for establishing sediment quality criteria for non-ionic organic chemicals using equilibrium partitioning. Environ. Toxicol. Chem. 10:1541–1583.

Environment Canada. 1998. Canadian sediment quality guidelines for chlordane, dieldrin, endrin, heptachlor epoxide, and lindane: Supporting document. Environmental Conservation Service, Ecosystem Science Directorate, Science Policy and Environmental Quality Branch, Guidelines and Standards Division, Ottawa. Draft.

Hermsen, W. 1994. The bioavailability and toxicity to *Mytilus edulis* L. of two organochlorine pesticides adsorbed to suspended solids. Mar. Environ. Res. 38:61–70.

IPCS (International Programme on Chemical Safety). 1991. Lindane. Environmental Health Criteria 124. World Health Organization, Geneva.

Jaagumagi, R. 1988. The in-place pollutants program. Volume V, Part B. Benthic invertebrates studies results. Ontario Ministry of the Environment, Water Resources Branch, Aquatic Biology Section, Toronto.

Jaagumagi, R., D. Persaud, and T. Lomas. 1989. The in-place pollutants program. Volume V, Part A. A synthesis of benthic invertebrates studies. Ontario Ministry of the Environment, Water Resources Branch, Aquatic Biology Section, Toronto.

Karickhoff, S.W. 1984. Organic pollutant sorption in aquatic systems. J. Hydraul. Eng. 110:707–735.

Long, E.R., and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOS OMA 52. National Oceanic and Atmospheric Administration, Seattle, WA.

Shea, D. 1988. Developing national sediment quality criteria. Environ. Sci. Technol. 22(11):1256–1261.

Reference listing:

Canadian Council of Ministers of the Environment. 1999. Canadian sediment quality guidelines for the protection of aquatic life: Lindane (hexachlorocyclohexane). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

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