Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

CHLORDANE

Chlordane is a synthetic organochlorine pesticide that was used in Canada from the mid-1940s to the 1980s as a treatment for a variety of insect pests. Technical-grade chlordane is composed primarily of two isomeric forms (α-[cis] chlordane and γ-[trans] chlordane), along with small amounts of heptachlor and other stereoisomers of chlordane (Dearth and Hites 1991). The registration and use of chlordane under the Pest Control Products Act were discontinued as of January 1, 1991. Chlordane has also been identified as a Track 1 substance by Environment Canada as it is persistent, bioaccumulative, released primarily as a result of human activities, and considered "CEPA-toxic" under the Canadian Environmental Protection Act (Environment Canada 1997).

Chlordane has entered aquatic systems mainly as surface runoff from treated lands, spray drift, and deposition following volatilization and aerial transport. Because of its hydrophobicity and affinity for organic materials, chlordane in aquatic systems tends to become associated with particulate matter and accumulate in bed sediments. 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. Canadian interim sediment quality guidelines (ISQGs) and probable effect levels (PELs) for chlordane can be used to evaluate the degree to which adverse biological effects are likely to occur as a result of exposure to chlordane in sediments.

Canadian ISQGs and PELs for chlordane 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 chlordane (α and γ) 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 chlordane are from studies on field-collected sediments that measured concentrations of chlordane, along with concentrations of other chemicals, and associated biological effects. Biological effects associated with concentrations of chlordane in sediments are compiled in the Biological Effects Database for Sediments (BEDS) (Environment Canada 1998). Both the freshwater and marine BEDS data sets for chlordane are large, with the freshwater data set containing 50 effect entries and 263 no-effect entries and the marine data set containing 25 effect entries and 178 no-effect entries (Figures 1 and 2). Both data sets represent a wide range of concentrations of chlordane, 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 chlordane (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 chlordane in the BEDS include decreased benthic invertebrate diversity, reduced abundance, increased mortality, and behavioural changes (Environment Canada 1998, Appendixes VIa and VIb). For example, benthic species richness and chironomid abundance in Toronto Harbour, Lake Ontario, were low at locations with a mean concentration of 10.5 $\mu g \cdot kg^{-1}$ chlordane, which is above the freshwater PEL (Jaagumagi 1988; Jaagumagi et al. 1989). By comparison, benthic species richness and chironomid abundance were higher at sites with a mean concentration of 3 $\mu g \cdot kg^{-1}$, which is below the freshwater ISQG (Jaagumagi 1988; Jaagumagi et al. 1989). Similarly, a significant reduction in fertilization was observed in *Arbacia punctulata*, a sea urchin, in Tampa Bay, Florida, at a mean concentration of 5.37 $\mu g \cdot kg^{-1}$, which is above the marine PEL (Long and Morgan 1990). In contrast, no effect was observed in sediments with a mean concentration of 1.2 $\mu g \cdot kg^{-1}$, which is below the marine ISQG (Long and Morgan 1990).

Spiked-sediment toxicity tests for chlordane report the onset of toxicity to benthic organisms at higher

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

	Freshwater	Marine/estuarine
ISQG	4.50	2.26
PEL	8.87	4.79

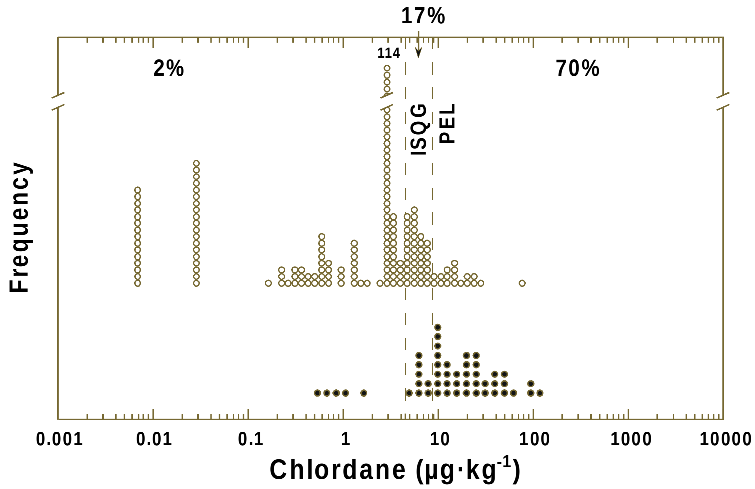

Figure 1. Distribution of chlordane concentrations in freshwater sediments that are associated with adverse biological effects (●) and no adverse biological effects (○). Percentages indicate proportions of concentrations associated with effects in ranges below the ISQG, between the ISQG and the PEL,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

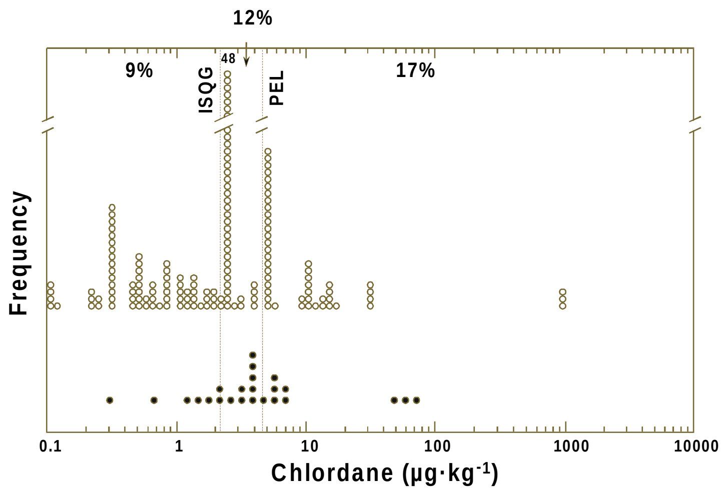

Figure 2. Distribution of chlordane concentrations in marine and estuarine sediments that are associated with adverse biological effects (●) and no adverse biological effects (○). Percentages indicate proportions of concentrations associated with effects in ranges below the ISQG, between the ISQG and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

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 chlordane only as opposed to chemical mixtures containing chlordane (Environment Canada 1998). For example, McLeese and Metcalfe (1980) reported a 96-h LC_{50} of 120 µg·kg^{-1} for *Crangon septemspinosa*, a marine shrimp. Similarly, Roper and Hickey (1994) observed a 10-d LC_{50} for technical grade chlordane to be 238 µg·kg^{-1} for *Macomona liliana*, a marine bivalve. However, in a sublethal test, they found that movement of the clams out of the dosed sediment was significantly inhibited at a concentration of 20 µg·kg^{-1}.

The results of freshwater and marine spiked-sediment toxicity tests and field studies indicate that concentrations of chlordane 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 chlordane in sediments are similar to or greater than the PELs, confirming that effects are more likely to be observed when concentrations of chlordane exceed the PELs (Environment Canada 1998). The ISQGs and PELs for chlordane are therefore expected to be valuable tools for assessing the ecotoxicological relevance of chlordane in sediments.

Concentrations

Currently, data on concentrations of chlordane in freshwater and marine sediments are limited. In Canada, freshwater lake, river, and stream sediments range from below detection to a maximum of 664 µg·kg^{-1} measured in Nova Scotia (Environment Canada 1998). In marine and estuarine sediments, concentrations range from below detection to 2.7 µg·kg^{-1} in sediments from the St. Lawrence estuary, Quebec (Environment Canada 1998). In both freshwater and marine systems, concentrations of α- and γ-chlordane are similar. In addition, chlordane degrades slowly in aquatic sediments (Eisler 1990); therefore, the elimination of local sources should result in a gradual decrease in concentrations over time.

Additional Considerations

Regardless of the origin of chlordane 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 chlordane at a particular site depends on the sensitivity of individual species and the endpoints examined, as well as a variety of physico-chemical (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 chlordane (Environment Canada 1998).

Benthic organisms are exposed to both particulate and dissolved chlordane in interstitial and overlying waters, as well as to sediment-bound chlordane through surface contact and sediment ingestion. Chlordane 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 sediments with the same concentrations of total chlordane are compared, less chlordane is dissolved in the interstitial water of sediments with high TOC content (Karickhoff 1984; Shea 1988). Therefore, TOC may reduce the bioavailability and, hence, the toxicity of sediment-associated chlordane to benthic organisms. The physicochemical, geochemical, and biological factors that modify bioavailability should be considered when evaluating the potential biological impact of chlordane in sediments (Environment Canada 1998).

Currently, the degree to which chlordane will be bioavailable at particular sites cannot be predicted conclusively from the physicochemical characteristics of the sediment 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 chlordane increases as concentrations increase in a range of sediment types (Figures 1 and 2). Therefore, the recommended Canadian ISQGs and PELs for chlordane will be useful in assessing the ecotoxicological significance of this substance in sediments.

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