Canadian Water Quality Guidelines for the Protection of Aquatic Life

BENZENE

Benzene (C_6H_6) is a clear, colourless to light yellow liquid that is highly volatile. A constituent (2%) of gasoline, benzene contributes to gasoline odour (Montgomery and Welcom 1990; WHO 1993). Synonyms for benzene include benzol, benzoline, and carbon oil (Montgomery and Welcom 1990). Benzene has a molecular weight of 78.11 $g \cdot mol^{-1}$, a melting point of 5.5°C, and a boiling point of 80.1°C (Howard 1990). The specific density of benzene ranges from 0.8765 to 0.878 95 at 20/4°C (Montgomery and Welcom 1990) and the water solubility is 1791 $mg \cdot L^{-1}$ (Howard 1990). Its vapour pressure is 12.69 kPa at 25°C and Henry's law constant is 5.43×10^{-3} $atm \cdot m^3 \cdot mol^{-1}$ (Howard 1990). The CAS registry number for benzene is 71-43-2 (Howard 1990; Montgomery and Welcom 1990).

Benzene is produced through coal tar distillation, coal processing, and coal coking at petroleum refineries and solvent recovery plants (Verschueren 1983). Natural sources of benzene are volcanoes, forest fires, volatile emissions from plants, as well as it being a constituent of crude oil (Howard 1990). Benzene is used in motor fuels, as a solvent for fats, inks, oils, greases, resins, and paints, and in the manufacture of plastics, synthetic rubber, detergents, explosives, textiles, packing materials, disinfectants, pesticides, pharmaceuticals, and dyestuffs (Sittig 1985; BUA 1992). In Canada, benzene is used primarily for the production of ethylbenzene, styrene, cumene, cyclohexane, and maleic anhydride (Environment Canada 1984).

Benzene may enter the environment from discharges or spills associated with its production, use, storage, or transportation (Buikema and Hendricks 1980; Fishbein 1984). Benzene also enters the environment from the combustion of gasoline, from its use as a solvent and an intermediate in the production of other chemicals, from its indirect production in coke ovens, from nonferrous metal manufacturing, ore mining, wood processing, coal mining and textile manufacturing, and from cigarette smoke (Howard 1990). Effluent discharges containing benzene may originate from municipal sewage treatment plants receiving industrial inputs, or from industries discharging directly to surface waters. Atmospheric emissions are expected from industries by way of process and fugitive emissions as well as evaporation from wastewater streams.

According to the 1995 National Pollutant Release Inventory, benzene was among the 25 highest releases by weight Canada-wide. Most releases were to air (96%), with only 6.665 t being released on site to water including direct discharges, spills, and leaks (NPRI 1998). Benzene has been detected in effluents of many industrial sectors including organic and inorganic chemical manufacturers, pulp and paper mills, and iron and steel manufacturers. In Ontario, average concentrations found in freshwater have been generally <0.001 $mg \cdot L^{-1}$, though inputs as high as 0.155 $mg \cdot L^{-1}$ occurred during 1990–91 in Hamilton Harbour, the St. Marys River, and the Ottawa River (Hamdy 1991). Benzene (mean of 0.38 $\mu g \cdot L^{-1}$) has been detected in only 95 measurements from Alberta's surface water monitoring program since 1984 (R.H. Tchir 1997, Alberta Environmental Protection, Edmonton, Alberta, pers. com.).

If released into water, environmental fate processes may result in rapid removal from the water column. Half-lives for evaporation and volatilization of benzene have been estimated to be 5 and 2.7 h, respectively (Mackay and Leinonen 1975; Thomas 1982). However, benzene may be relatively persistent in groundwater where volatilization is not a viable process (Howard 1990). Benzene can be degraded by a variety of aquatic microorganisms with rates depending on many factors including temperature and acclimation of the microbial community (Gibson and Subramanian 1984; Howard 1990). Half-lives range from 33 to 384 h for aerobic biodegradation, and 28 to 720 d for anaerobic biodegradation in water (Government of Canada 1993). Photolytic half-lives for benzene range from 17 d to 36.6 a and may be enhanced by the presence of humic acids (Hustert et al. 1981; Zepp et al. 1981; SRC 1989). Based on a log K_{ow} value of 2.1, benzene is not expected to concentrate in aquatic organisms or to significantly adsorb to sediments or soil (Hawker and Connell 1988; Howard 1990).

Table 1. Water quality guidelines for benzene for the protection of aquatic life (OMOE 1998).

Aquatic life	Guideline value ($\mu g \cdot L^{-1}$)
Freshwater	370*
Marine	110*

*Interim guideline.

Water Quality Guideline Derivation

The interim Canadian water quality guidelines for benzene for the protection of aquatic life were developed by the Ontario Ministry of the Environment (OMOE 1998) based on the CCME protocol (CCME 1991).

Freshwater Life

Estimates of acute toxicity (24- to 96-h LC_{50}) of benzene to freshwater fish range from 4.6 mg·L^{-1} for emergent fry of pink salmon *(Oncorhynchus gorbuscha)* to 476 mg·L^{-1} for eggs of coho salmon *(O. kisutch)* (Moles et al. 1979). Acute toxicity values (24- to 96-h LC_{50}) for invertebrates ranged from 10 mg·L^{-1} for *Ischnura elegans* to >320 mg·L^{-1} for *Erpobdella* and a mixed tubificid culture of *Limnodrilus* and *Tubifex* (Slooff 1983). Studies involving other organisms (plants, algae, bacteria) reported toxicity ranging from 29 mg·L^{-1}, which caused reduced growth in 72-h exposures in the alga *Selenastrum capricornutum,* to 740 mg·L^{-1}; the 1-h minimum lethal concentration for the aquatic plant *Elodea canadensis* (Galassi et al. 1988).

Very few chronic studies, partial or full life cycle, have been reported. Results ranged from a 9-d LC_{50} of 3.7 mg·L^{-1} for aquatic early life stages of the leopard frog *(Rana pipiens)* (Black et al. 1982) to a 32- to 33-d LOEC for survival of 23.4 mg·L^{-1} for the early life stages of the fathead minnow *(Pimephales promelas)* (Marchini et al. 1992).

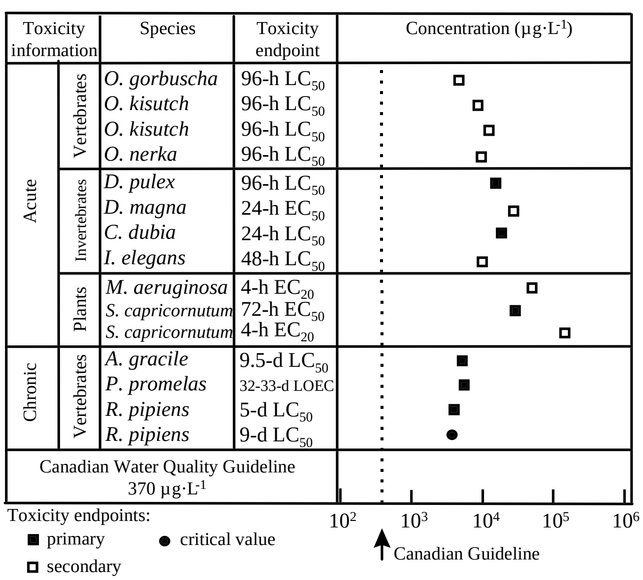

Figure 1. Select freshwater toxicity data for benzene.

The interim water quality guideline for benzene for the protection of freshwater life is 370 µg·L^{-1}. It was derived by multiplying the 9-d LC_{50} from fertilization to 4-d post-hatch of 3.7 mg·L^{-1} (Black et al. 1982) for the most sensitive organism to benzene, the leopard frog, by a safety factor of 0.1 (CCME 1991).

Marine Life

Estimates of acute toxicity for marine fish ranged from 0.7 mg·L^{-1}, which caused delayed mortality in herring *(Clupea harengus)* larvae at 17-d post-fertilization, to 40–50 mg·L^{-1}, which caused 50% mortality in herring eggs (Struhsaker et al. 1974; Struhsaker 1977). Acute toxicity levels (96-h LC_{50}) for invertebrates ranged from 27 mg·L^{-1} for shrimp *(Palaemonetes pugio)* (Tatem et al. 1978) to 196 mg·L^{-1} for the manila clam *(Tapes semidecussata)* (Nunes and Benville 1978). Developmental defects in sea urchin *(Paracentrotus lividus)* embryos were observed following 48-h exposure to 0.078 mg·L^{-1} (Pagano et al. 1988). Estimates involving other organisms (plants, algae, bacteria) ranged from a 48-h EC_{50} for sexual reproduction of <34.3 mg·L^{-1} for *Champia parvula* to 2-h 95% reduction in photosynthesis concentration of 525 mg·L^{-1} for *Acrosiphonia sonderi* (Kusk 1980; Thursby and Steele 1986).

Only one chronic study was found for marine fish. Korn et al. 1976 noted decreased dry weight in striped bass exposed to 5.3 mg·L^{-1} benzene. Similarly, there was only one chronic invertebrate toxicity test found. Caldwell et al. (1976) showed that 1.1 mg·L^{-1} benzene reduced survival of larval Dungeness crabs *(Cancer magister)* in exposures lasting up to 40 d.

Sufficient data exist to derive an interim water quality guideline for the protection of marine life. The lowest concentration reported for sea urchins was deemed unacceptable because only a single concentration was tested (Pagano et al. 1988). Other low concentrations had either unsuitable endpoints for guideline development (i.e., stress) (McFarlane and Benville 1986) or were difficult to interpret owing to delayed effects (Struhsaker 1977). Studies by Pagano et al. (1988) and Struhsaker (1977) suggest that benzene may exert some effect on egg fertilization, but data are not strong enough to be used as the critical data points for guideline development. The chronic toxicity threshold of 1.1 mg·L^{-1} for Dungeness crab larvae was chosen as the critical value to be used for deriving the guideline (Caldwell et al. 1976). Though not the lowest concentration reported, it is considered the most reliable despite probable loss of benzene from the

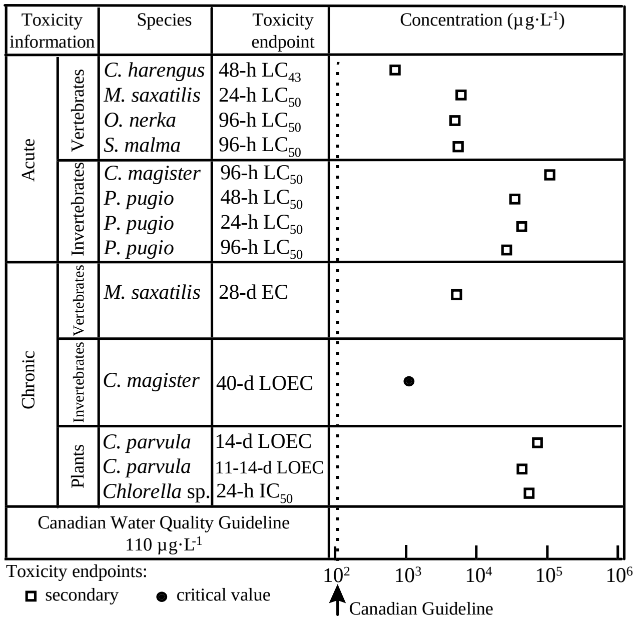

Figure 2. Select marine toxicity data for benzene.

test solution. The value of 1.1 mg·L^{-1} is multiplied by the safety factor of 0.1, yielding the interim water quality guideline for benzene for the protection of marine life of 110 µg·L^{-1}.

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Excerpt from Publication No. 1299; ISBN 1-896997-34-1

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