SCIENCE AND INFORMATION BRANCH
WATER STEWARDSHIP DIVISION
MINISTRY OF ENVIRONMENT

Ambient Water Quality Guidelines for Benzene

Overview Report

Prepared pursuant to Section 5(e) of the
Environmental Management Act, 2003

Approved: October 3, 2007 Fern Schultz
Date Director, Science and Information Branch
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Library and Archives Canada Cataloguing in Publication Data
Nagpal, N. K.
Ambient water quality guidelines for Benzene : overview report [electronic resource]

Available on the Internet.
Report by: Narender K. Nagpal. Cf. p.
This overview is based on a technical report prepared for the Canadian Council of Ministers of Environment (CCME) proposing water quality guidelines for benzene (CCME 1999a) and reviewed by Pommen Environmental Consulting under contract to B.C. Ministry of Environment. Cf. Summary.
ISBN 978-0-7726-5873-9

1. Benzene – Environmental aspects - British Columbia.
2. Water quality – Standards - British Columbia.
3. Aquatic organisms – Effect of water pollution on - British Columbia. I. British Columbia. Ministry of Environment. Water Stewardship Division. Science and Information Branch. II. Title. III. Title: Water quality guidelines for Benzene.

TD227.B7N33 2007 363.739’46209711 C2007-960223-1

SUMMARY

This document is one in a series that establishes ambient water quality guidelines for British Columbia. It is based on a technical report prepared for the Canadian Council of Ministers of Environment (CCME) proposing water quality guidelines for benzene (CCME 1999a) and reviewed by Pommen Environmental Consulting under contract to B.C. Ministry of Environment. This overview report assesses those guidelines for use in British Columbia, assesses more recent information, and makes amendments where appropriate to suit B.C. conditions. Guidelines are safe conditions or levels that have province-wide application and are set to protect various water uses. This report sets guidelines for benzene to protect source water used for drinking water and fresh and marine aquatic life. Based on this evaluation, the CCME guidelines were adopted for source water for drinking and marine aquatic life, while adjustments were deemed necessary to protect freshwater aquatic life.

A major use of the guidelines is to set ambient water quality objectives. The objectives are the guidelines modified or adopted to protect the most sensitive designated water use in a particular body of water. The objectives are used in the preparation of waste management plans, pollution prevention plans, waste management permits, orders or approvals. The latter three are the only documents that have legal status. The guidelines are also used for evaluating contaminated sites and determining remediation requirements.

The guidelines are summarized in Table 1.

Table 1: Summary of Recommended Water Quality Guidelines for Benzene

Water Use	Maximum Total Benzene
Raw Drinking Water	5 µg/L
Freshwater Aquatic Life	40 µg/L*
Marine and Estuarine Aquatic Life	110 µg/L**

* Revised interim B.C. guideline based on review of CCME water quality guidelines for benzene.

** Interim CCME guideline.

PREFACE

The Ministry of Environment develops province-wide ambient water quality guidelines for variables that are important in the surface waters of British Columbia. This work has the following goals:

1. To provide guidelines for the evaluation of data on water, sediment, and biota.
2. To provide guidelines for the establishment of site-specific ambient water quality objectives.

The definition adopted for a guideline is as follows:

> A maximum and/or a minimum value for a physical, chemical or biological characteristic of water, sediment or biota, which should not be exceeded to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions.

The guidelines are province-wide in application, use-specific, and developed for some or all of the following water uses:

- Source water for drinking, public water supply and food processing
- Aquatic life and wildlife
- Agriculture (livestock watering and irrigation)
- Recreation and aesthetics
- Industrial water supplies

The guidelines are set after considering the information in the scientific literature, guidelines from other jurisdictions, and general conditions in British Columbia. The scientific literature gives information on the effects of toxicants on various life forms.

This information is not always conclusive because it is usually based on laboratory tests, which at best only approximates field conditions. To compensate for this uncertainty, guidelines have built-in safety factors, which are conservative, but reflect the natural background conditions in the province.

Guidelines are subject to review and revision as new information becomes available, or as other circumstances dictate.

> The guidelines apply to the ambient source water before it is diverted or treated for domestic use.
>
> The Ministry of Health regulates the quality of water for domestic use after it is treated and delivered by a water purveyor.
>
> Guidelines relating to public health at bathing beaches are the same as those used by the Ministry of Health, which regulates the recreation and aesthetic use.

The site-specific water quality objectives are, in many cases, the same as the guidelines. However, in some cases, such as when natural background levels exceed the guidelines, the objectives could be less stringent than the guidelines. In relatively rare instances, for example, if the resource is unusually valuable or of special provincial significance, the safety factor could be increased by using objectives that are more stringent than the guidelines. Another approach in such special cases is to develop site-specific objectives by carrying out toxicity experiments in the field. This approach is costly and time-consuming and therefore seldom used.

Ambient water quality objectives for specific waterbodies will be based on the guidelines and also consider present and future water uses, waste discharges, hydrology, limnology,

or oceanography, and existing background water quality. The process for establishing water quality objectives is more fully outlined in *Principles for Preparing Water Quality Objectives in British Columbia* (*Ministry of Environment and Parks 1986*), copies of which are available from the Ministry of Environment.

Neither guidelines nor objectives that are derived from them have any legal standing. The objectives, however, can be used to calculate allowable limits or levels for contaminants in waste discharges. These limits are set out in waste management permits and thus have legal standing. The objectives are not usually incorporated as conditions of a permit.

INTRODUCTION

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. Benzene is produced through coal tar distillation, coal processing, and coal coking at petroleum refineries and solvent recovery plants. Natural sources of benzene are volcanoes, forest fires, volatile emissions from plants, as well as it being a constituent of crude oil. In Canada, benzene is primarily used for the production of ethylbezene, styrene, cumene, cyclohexane, and maleic anhydride.

Benzene may enter the environment from discharges or spills associated with its production, use, storage, or transportation. Benzene also enters the environment from a multitude of other sources: the combustion of gasoline; its use as a solvent; an intermediate in the production of other chemicals; its indirect production in coke ovens; nonferrous metal manufacturing; ore mining; wood processing; coal mining; textile manufacturing; and from cigarette smoke. In Canada, benzene has been detected in numerous industrial effluents and occasionally in freshwater in Ontario and Alberta.

If released into water, environmental fate processes may result in rapid removal from the water column by evaporation (half-life of five hours) and volatilization (half-life of 2.7 h). Benzene may be relatively persistent in groundwater, where volatilization is not a viable process. Benzene can be degraded by aerobic biodegradation (half-life of 33 to 384 h), anaerobic biodegradation (half-life of 28 to 720 d), and photolysis (half-life of 17 d to 36.6 years). With a log octanol-water partition coefficient (K_{ow}) of 2.1, benzene is not expected to concentrate in aquatic organisms or to significantly adsorb to sediments.

The CCME interim benzene guideline for freshwater aquatic life considered 15 toxicity studies, eight deemed to be secondary data and seven deemed to be primary data. The interim guideline was based on the primary data from a 9-d LC_{50} of 3700 µg/L for the early life stages (fertilization to 4 d post-hatch) of the leopard frog (*Rana pipiens*) reported by Black *et al*. (1982). The guideline of 370 µg/L was derived by multiplying

3700 µg/L by a safety factor of 0.1 in accordance with the CCME protocol (1999b). Black *et al.* (1982) reported an LC_{10} of 75.6 µg/L and stated that "reproduction of sensitive amphibian species may be appreciably impaired at benzene concentrations above 100 µg/L". However, Suter and Tsao (1996) note that Black *et al*. (1982) did not determine the LOEC and NOEC for benzene and did not generate standard chronic values.

For this assessment, the U.S. Environmental Protection Agency's Ecotoxicology Database (ECOTOX) was reviewed as of December 2, 2005. No new toxicity data with preferred toxicity endpoints that were more sensitive (lower) than used by the CCME were found. Four references (Pawlisz *et al*., 1995; Freitag *et al*., 1984; Eldridge *et al.* 1981; Maynard *et al*., 1981) not included by the CCME reported lower effect levels, but their toxicity endpoints were inconclusive and unacceptable.

Also assessed was a 2006 study by the Simon Fraser University (Kennedy, 2006) that was specifically designed to test the toxicity of benzene to the leopard frog (*R. pipiens*), under contract to the British Columbia Ministry of Environment. The intermittent flow-through bioassay system had a chemical delivery system designed to eliminate chemical loss through volatilization. Chemical stability tests showed that a single benzene concentration in the bioassay vessel averaged 95% of expected over 28 days, and that the measured concentration of benzene in the bioassays ranged from 93 to 100% of expected with a mean of 97.5%. The 7-d EC_{50} was 2470 µg/L compared to the 3700 µg/L 9-d LC_{50} reported by Black *et al.,* 1982. The Ministry of Environment results, although somewhat lower, confirm those found in the literature (Black *et al*., 1982). The Ministry of Environment data also reported a 7-d EC_{20} of 400 µg/L, which is the lowest-observable-adverse-effect-level (LOAEL).

RECOMMENDED GUIDELINES

These guidelines are based on a review of the technical background information used to prepare the CCME water quality guidelines for benzene (*CCME 1999a*), as well as more recent information from the literature and other sources. The guidelines have been revised where appropriate in light of new information, and are summarized in Table 1.

Source Water for Drinking

A maximum acceptable concentration of 5 μg/L for benzene in drinking water has been recommended by the Federal-Provincial Subcommittee on Drinking Water, Health Canada, 2004, and is adopted for ambient conditions.

The recommended concentration yields no objectionable taste or smell and no adverse health effects. Without treatment prior to entering a water distribution system, benzene concentrations would change little from ambient concentrations, especially if the time to use is short and there is no opportunity for volatilization or evaporation. Therefore, the recommended concentration for drinking water at the consumer's tap will be adopted as the raw drinking water quality guideline.

Freshwater Aquatic Life

The maximum concentration of benzene should not exceed 40 μg/L. This interim guideline has been reduced from the CCME interim guideline of 370 μg/L.

The recommended guideline of 40 μg/L was derived by multiplying the LOAEL, a 7-d LC_{20} of 400 μg/L, by the 0.1 safety factor recommended by CCME. The safety factor chosen was consistent with the CCME protocol and accounts for differences in sensitivity to a chemical variable due to differences in species, laboratory versus field conditions, and test endpoints. This guideline is below the 100 μg/L level that Black *et al.* (1982) reported as appreciably impairing amphibian reproduction and below the more subtle effects of benzene on freshwater organisms, such as accumulation, avoidance, and changes in feeding behavior and physiology reported above.

The recommended B.C. guideline would be deemed to be an interim guideline by CCME because the minimum aquatic toxicological data set requirements for full freshwater guidelines set by the CCME have not yet been attained. Additional primary toxicity studies using apparatus designed to eliminate the loss of benzene are needed to move to full guideline status.

Marine and Estuarine Aquatic Life

The maximum concentration of benzene should not exceed 110 μg/L. This interim guideline has been adopted from the CCME.

The interim benzene guideline published by CCME in 1999 was adopted since there does not appear to have been any more sensitive studies of the effects of benzene on saltwater organisms since then. The toxicity database available to the CCME was weak, with 12 of 13 studies deemed to be secondary, and the critical study from which the interim guideline was derived had a probable loss of benzene from the test solution. A complete set of studies on temperate marine species using apparatus designed to eliminate the loss of benzene would be needed to move to full guideline status (i.e., three fish species, including two chronic studies, two chronic studies on invertebrate species, and one study on a plant or algal species).

Crop Irrigation

No water quality guideline for this use is recommended, as there are insufficient data on the adverse effects of benzene in irrigation water.

Livestock Watering

No water quality guideline for this use is recommended, as there are insufficient data on the adverse effects of benzene in livestock water.

APPLICATION OF THE GUIDELINES

Care must be exercised when the water quality guidelines are applied to assess the impacts of benzene, because of the volatile nature of benzene. In turbulent, well-mixed waters the half-life of benzene could be only a few hours due to evaporation and volatilization. However, there may be situations where benzene concentrations are continuously renewed, such as in the discharge from an industrial operation, or with the potential for only a minimal amount of evaporation and volatilization, such as under ice cover, in quiescent waters, at depth in lakes and marine waters, or in groundwater. In general, a site-specific study should be conducted to determine the actual or predicted benzene persistence and concentrations (i.e., exposure).

SETTING WATER QUALITY OBJECTIVES

Benzene is a very volatile substance. The water quality guidelines recommended in this document are based on controlled laboratory bioassays that do not account for factors that may modify the toxicity of benzene in the aquatic environment. In many cases, water quality objectives will be the same as the guidelines. When concentrations of benzene in developed waterbodies are constantly maintained due to a continuous source, or an environment that prevents its degradation, or valuable species that have not been thoroughly tested (e.g., salmonids) are present, then water quality objectives that are more stringent than the recommended guidelines may be justified. In some cases, socioeconomic or other factors may justify objectives that are less stringent than the guidelines. Site-specific impact studies would be required in such cases.

Methods such as the water effects ratio, resident species toxicity in the field, etc. are available to adapt the recommended guidelines to a specific site. Where necessary, these methods can be employed to set site-specific water quality objectives, but because these methods are costly and time-consuming, they are seldom used.

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REFERENCES

Black, J.A., W.J. Birge, W.E. McDonnell, A.G. Westerman, B.A. Ramey, and D.M. Bruser. 1982. The Aquatic Toxicity of Organic Compounds to Embryo-Larval Stages of Fish and Amphibians. Univ. KY Water Resour. Res. Inst., Res. Rep. 133.

Canadian Council of Ministers of the Environment (CCME). 1999a. Canadian Water Quality Guidelines for the Protection of Aquatic Life – Benzene. Canadian Environmental Quality Guidelines, 2005 Update.

Canadian Council of Ministers of the Environment (CCME). 1999b. Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life. Canadian Environmental Quality Guidelines, 2005 Update.

Eldridge, M.B., P. Benville, and J.A. Whipple. 1981. Physiologic Responses of Striped Bass (*Morone saxatilis*) Embryos and Larvae to Low Sublethal Concentrations of the Aromatic Hydrocarbon Benzene. In: J.B. Hingman (Ed.), Proc. 33rd Annu. Meet. of the Gulf and Caribbean Fisheries Inst., Univ. of Miami, FL: 52-68.

Frietag, D., J.P. Lay, and F. Korte. 1984. Environmental Hazard Profile - Test Results as Related to Structures and Translation into the Environment. In: K.L.E. Kaiser (Ed.), QSAR in Environmental Toxicology, Proc. of the Workshop held at McMaster University, Hamilton, Ont., Aug. 16-18, 1983, D. Reidel Publ. Co., Dordrecht, Netherlands: 111-131.

Kennedy, C.J. 2006. Toxicological Assessment of Naphthalene, Benzene, Ethylbenzene, Toluene and Xylene to Embryo-Larval Stages of Fish (*Oncorhynchus mykiss*), Amphibians (*Rana Pipiens*) and Freshwater Invertebrates (*Daphnia magna*). Dept. of Biological Sciences, Simon Fraser University, Burnaby, B.C. (Draft).

Maynard, D.J., and D.D. Weber. 1981. Avoidance Reactions of Juvenile Coho Salmon (*Oncorhynchus kisutch*) to Monocyclic Aromatics. Can.J.Fish.Aquat.Sci. 38(7):772-778.

Pawlisz, A.V., and R.H. Peters. 1995. Effects of Sublethal Exposure on Lethal Body Burdens of Narcotic Organic Chemicals in *Daphnia magna*. 1995. Environ. Sci. Technol. 29(3):613-621.

Ministry of Environment and Parks. 1986. Principles for Preparing Water Quality Objectives in British Columbia. Water Management Branch, Resource Quality Section, Victoria, B.C.

Suter, G.W. II and C.L. Tsao. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. Risk assessment Program, Health Sciences Research Division, Oak ridge, Tennessee 37831.