Environment and Climate Change Canada	Environnement et Changement climatique Canada

# *Canadian Environmental Protection Act, 1999*

# Federal Environmental Quality Guidelines

# *Quinoline*

**Environment and Climate Change Canada**

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## Introduction

Federal Environmental Quality Guidelines (FEQGs) for water, sediment and biological tissue provide thresholds of acceptable quality of the ambient environment. In addition, FEQGs for soil and groundwater are intended to be used for assessing in-place contaminants in soil and groundwater and are developed as remediation values to protect the ecological function of various land uses. Irrespective of which media they represent, FEQGs are based solely on the toxicological effects or hazards of specific substances or groups of substances. FEQGs serve three functions: first, they can be an aid to prevent pollution by providing targets for acceptable environmental quality; second, they can assist in evaluating the significance of concentrations of chemical substances currently found in the environment (monitoring of water, sediment, soil and biological tissue); and third, they can serve as performance measures of the success of risk management activities. The use of FEQGs is voluntary unless prescribed in permits or other regulatory tools. The development of FEQGs is the responsibility of the federal Minister of the Environment and Climate Change Canada under the *Canadian Environmental Protection Act, 1999* (CEPA) (Government of Canada (GC) 1999). The intent is to develop FEQGs as an adjunct to the risk assessment/risk management of priority chemicals identified in the Chemicals Management Plan (CMP) or other federal initiatives.

Where data permit, FEQGs are derived following CCME protocols. FEQGs are developed where there is a federal need for a guideline (e.g., to support federal risk management or other monitoring activities) but where the CCME guidelines for the substance have not yet been developed or are not reasonably expected to be updated in the near future. More information on FEQGs is available at https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/federal-environmental-quality-guidelines.html.

This factsheet describes the Federal Water Quality Guideline (FWQG) for the protection of aquatic life from adverse effects of quinoline (Table 1). The FWQG applies to the ambient environment and is not an effluent limit or “never to be exceeded” value but may be used to derive effluent limits. The factsheet also describes Federal Groundwater Quality Guideline for protection of aquatic life ($FGWQG_{FL}$) (Table 1) and Federal Soil Quality Guidelines (FSQG) for Agricultural, Residential/Parkland, Commercial and Industrial land uses for quinoline (Table 2).

The quinoline FEQGs are based on toxicity data identified up to August 2015. No FEQGs have been developed for the biological tissue or sediment compartments at this time.

Table 1. Federal Environmental Quality Guidelines for Quinoline for Freshwater and Groundwater.

| **Freshwater (FWQG)[a] (µg/L)** | **Groundwater[b] ($FGWQG_{FL}$) (µg/L)** |
|---|---|
| **150** | **150** |

[a] Derived for protection of aquatic life. Not applicable to human health.
[b] Applies to groundwater in coarse and fine soils.

Table 2. Federal Soil Quality Guidelines (FSQG) for Quinoline.[a]

| **Pathway** | **Agricultural (mg/kg)** | **Residential/ Parkland (mg/kg)** | **Commercial (mg/kg)** | **Industrial (mg/kg)** |
|---|---|---|---|---|
| **Final Proposed Federal Soil Quality Guideline (FSQG)** | **1.6** | **1.6** | **Coarse: 3.9<br>Fine: 2.9** | **Coarse: 3.9<br>Fine: 2.9** |
| Soil Contact ($SQG_{SC}$)[b] | 1.6 | 1.6 | 9.9 | 9.9 |

| **Pathway** | **Agricultural (mg/kg)** | **Residential/ Parkland (mg/kg)** | **Commercial (mg/kg)** | **Industrial (mg/kg)** |
|---|---|---|---|---|
| Soil Ingestion: $1^{o}$ consumers ($SQG_{1C}$) | NC | NR[c] | NR | NR |
| Soil Ingestion: $2^{o}$ and $3^{o}$ consumers ($SQG_{2C}$, $SQG_{3C}$) | NR[b] | NR[c] | NR | NR |
| Agricultural (Livestock Watering – $SQG_{LW}$) | NC | NR | NR | NR |
| Soil Quality Guideline to Protect Freshwater Life ($SQG_{FL}$)[d] | Coarse: 3.9<br>Fine: 2.9 | Coarse: 3.9<br>Fine: 2.9 | Coarse: 3.9<br>Fine: 2.9 | Coarse: 3.9<br>Fine: 2.9 |
| Check Mechanisms: Nutrient and Energy Cycling ($SQG_{NEC}$) | NC | NC | NC | NC |
| Check Mechanisms: Offsite migration ($SQG_{OM-E}$)[e] | NR | NR | 23 | 23 |

NC = not calculated due to lack of data.
NR = not required; see CCME 2006.
SC = Soil contact; 1C = Primary consumer; 2C = Secondary consumer; 3C = Tertiary consumer; FL= Freshwater life; LW = Livestock watering; NEC = nutrient and energy cycling; OM-E = Off-site migration – environmental.

[a] Derived for protection of ecological health. Not applicable to human health.

[b] Soil contact guidelines are based on and applicable to coarse soil. If the soil contact guidelines are being applied to fine soil they will be considered provisional.

[c] Only applicable for biomagnifying substances. Quinoline is not expected to bioaccumulate or biomagnify (GC 2011).

[d] $FSQG_{FL}$ is the concentration in soil that is expected to protect against potential impacts on aquatic systems from quinoline originating in soil that may enter the groundwater and subsequently discharge to a surface water body. This pathway may be applicable under any land use category, where a surface water body sustaining aquatic life is present (i.e., within 10 kilometres of the site). Where the distance to the nearest surface water body is greater than 10 kilometres, application of the pathway should be evaluated on a case-by-case basis by considering the site-specific conditions.

[e] Soil quality guidelines for commercial and industrial sites consider receptors exposed to on-site soil. However, wind and water erosion of soil and subsequent deposition can transfer contaminated soil from one site to another. Therefore $SQG_{OM-E}$ pathway addresses the movement of soil from a commercial or industrial site to an adjacent, more sensitive site (e.g. agricultural property). Given the uncertainties surrounding the model used to generate the $SQG_{OM-E}$, it is considered to be a check mechanism and professional judgement should be used to determine whether the soil quality guideline should be modified by this pathway (see CCME 2006).

## Substance Identity

Quinoline (CAS No. 91-22-5; chemical formula $C_9H_7N$) belongs to the group of nitrogen heterocycles, also known as azaarenes. It is naturally associated with coal and coal-derived compounds and may be formed as a trace pollutant during incomplete combustion of nitrogen-containing substances (e.g., petroleum, coal). The Government of Canada (GC) (GC 2011) concluded that quinoline meets two of the criteria set out in section 64 of CEPA, namely that quinoline is entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity; and, on the basis of carcinogenicity, that constitute or may constitute a danger to human life or health in Canada. Additionally, it was concluded that quinoline meets the criteria for persistence for air and soil, but does not meet the criteria for bioaccumulation potential as set out in the *Persistence and Bioaccumulation Regulations* (GC 2000) under CEPA (GC 2011).

## Uses

Quinoline is naturally present in coal (Clemo 1973). Coal tar is produced from coal as a by-product of metallurgical coke production in Canada and is recovered and refined as an intermediate for industrial use and as an ingredient in several commercial/consumer products (GC 2011). Quinoline remains present in industrially-produced coal tar and its distillation products— coal tar oils and coal tar pitch. Coal tar oil is refined to produce creosote, used for wood preservation. Coal tar pitch is used in aluminum smelting, manufacture of graphite electrodes, carbon products and asphalt pavement sealers (GC 2011). Quinoline can be present to various extent in polycyclic aromatic hydrocarbon (PAH) mixtures (EC 1999; McNeil 1981). It was also identified as a component in fragrance mixtures (RIFM 2003). Public literature described quinoline being used as a solvent, chemical intermediate and corrosion inhibitor and in the manufacture of dyes and pharmaceuticals, although there is no evidence of these uses in Canada (Finley 1996; HSDB 2003).

In the year 2000, one or more companies in Canada reported manufacture or import of quinoline in excess of 20 000 kg in the form of mixtures which contained quinoline at a composition of less than 1%, however more recent data were not available (EC 2001; GC 2011). Release of quinoline in Canada in 2014 was reported to the National Pollutant Release Inventory (NPRI) by 11 facilities including manufacturers of chemical products, an iron and steel mill and ferro-alloy manufacturer, chemical and allied product wholesaler-distributors, a petroleum product wholesaler-distributor, oil sands processing plants and mines, and a manufacturer of petroleum and coal products (NPRI 2014). No on-site release to water was reported; only on-site releases to air, and on-site and off-site releases for disposal were reported (NPRI 2014). Sources of quinoline releases to the environment include coal tar distillate (creosote) facilities and wood impregnation plants, creosote-impregnated wood used in harbour docks, creosote-impregnated railroad frames used in support walls along shorelines, steel plants equipped with coke ovens, aluminum smelters and abandoned coal gasification plants (GC 2011).

## Fate, Behaviour and Partitioning in the Environment

Quinoline can enter the environment at sites where pure coal tar or creosote has leaked into the subsurface and formed a pool of pure non-aqueous phase liquid in soil. When a pool of coal tar or creosote is present in the subsurface, it is possible that quinoline can dissolve into groundwater and, subsequently, be transported to surface water and sediments at the groundwater-surface water interface (GC 2011).

The boiling point (237.7°C), melting point (-15.0°C), and vapour pressure (8 Pa at 25°C) of quinoline suggest it will be semivolatile under atmospheric conditions (Mackay et al. 1999; GC 2011). The $pK_a$ value (acid dissociation constant) of 4.9 indicates that at ambient pH, nearly all quinoline will be present in its un-ionized form (Mackay et al. 1999; GC 2011).

Quinoline is not persistent in surface water. It is removed through the process of photooxidation in water. The modeled half-life in surface water is 14 to 23 days (Smith et al. 1978; Kochany and Maguire 1994; Mackay et al. 1999). Based on fugacity modelling, if released to surface water, quinoline will remain for the most part in that compartment until it is degraded. Similarly, if released to soil, it will remain mostly in the soil (GC 2011). Quinoline is biodegradable in soil under conditions favouring microorganisms; however, field evidence suggests it is difficult to degrade by microorganisms living in deep soil and groundwater. The high water solubility of quinoline (6110 mg/L) (Mackay et al. 1999), as well as a moderate affinity for particulate organic carbon (log $K_{OC}$ of 3.26) suggest it will have moderate to high mobility in soil. Therefore, although quinoline is easily degraded in aerobic soil, it can move easily into deeper, anaerobic regions, where it may persist for long periods (GC 2011). In general these media offer poor conditions for biodegradation, such as low oxygen levels, low temperatures and few carbon sources (GC 2011). An absence of significant degradation of quinoline associated with the occurrence of coal tar in soils has been frequently observed (GC 2011).

Quinoline is expected to persist in air in winter, with half-life >99 hours (Mackay et al.1999). Based on fugacity modelling, if released to the atmosphere, due to its moderate volatility, 82% of quinoline will partition to soil and surface water, and the remainder will stay in air. Quinoline is predicted to be transported long distances (>1500 km) in water but not the atmosphere (GC 2011).

Quinoline has low potential to bioaccumulate. Two bioconcentration factor (BCF) values were available for quinoline in fish on a wet weight basis. Bean et al. (1985) determined a BCF of 8 for quinoline and its metabolites (the BCF for the non-metabolized quinoline molecule is therefore less than 8) and 158 was calculated by de Voogt et al. (1991). Additionally, the log $K_{OW}$ value for quinoline is 2.10 (Mackay et al. 1999). The low potential for quinoline to bioaccumulate indicates that FEQGs for soil for agricultural and residential/parkland uses should only consider exposure to primary-level food web organisms, and not secondary or tertiary consumers.

## Measured Concentrations

Quinoline is not routinely measured in any environmental medium in Canada, and limited data are available for ambient concentrations in Canada. In air, quinoline was not detected in samples from a residential area of Ottawa, Ontario sampled in 2002 and 2003 (Zhu et al. 2005). In street sediments, 12 cities sampled between 1979 and 1983 in the Canadian Great Lakes basin (Ontario) had a mean quinoline concentration of 0.53 mg/kg (Marsalek and Schroeter 1988). In sediments sampled from Ontario, including Hamilton Harbour and St. Mary's River, both industrial sites, quinoline concentrations ranged from 0.008 to 0.063 mg/kg dw and from not detected to 0.46 mg/kg dw, respectively (Onuska and Terry 1989; Kauss and Hamdy 1991). In sediments sampled in Eastern Canada, quinoline was not detected at Sydney Harbour, Nova Scotia sampled in 1986 (EC 1988), nor at St. Croix River estuary and Passamaquoddy Bay, New Brunswick (sampling date not reported) (Loring et al.1998). In surface water from the Rainy River, Ontario sampled in 1986, quinoline was not detected (Merriman 1988). For soils, eight agricultural fields sampled in Southern Ontario in 1992 had quinoline concentrations ranging from not detected to 0.06 mg/kg dw (Webber 1994). At two other sites in Ontario quinoline was not detected in soil (Golder Associates Ltd. 1987). Background soil sampled from 34 sites in Alberta, Newfoundland and British Columbia with no known contamination history had non-detectable levels of quinoline (<0.05 mg/kg) in all samples (Kelly-Hooper et al. 2014, author correspondence).

## Mode of Action

Limited information was available on the mode of action of quinoline. There is some support to indicate that quinoline does not act primarily through baseline toxicity (narcosis). Evidence indicates that quinoline toxicity may be associated with its conversion in organisms to a mutagenic molecule through metabolic activation (e.g., Talcott et al. 1976; Eisentraeger et al. 2008; Neuwoehner et al. 2009). Laboratory studies attribute a low to medium mutagenic potency to quinoline with regards to bacteria (Talcott et al. 1976). The proposed mode of action is the binding of a metabolic intermediate epoxide to nucleic acids, producing a deoxyribonucleic acid (DNA) adduct (GC 2011). This epoxide metabolite is possibly produced as well during the biotransformation of quinoline by rainbow trout (Bean et al. 1985).

## Aquatic Toxicity

All relevant aquatic toxicity data for quinoline were critically reviewed for acceptability for use in environmental quality guideline derivation. The data are current to August 2015. Acceptable long-term quinoline toxicity data ranged from 160 to 63000 µg/L, with fish and invertebrates demonstrating the greatest sensitivity and algal species demonstrating the least sensitivity (Table 3). Endpoints for fish ranged from a 27-day $LC_{10}$ of 160 µg/L for rainbow trout (*Oncorhynchus mykiss*) (calculated from Black et al.1983) to a 7-day $EC_{10}$ for biomass of 12800 µg/L for fathead minnow (*Pimephales promelas*) (Maxxam Analytics 2015). Black et al. (1983) reported $LC_{50}$ for largemouth bass of 7.5 mg/L compared to 11.0 mg/L for rainbow trout but didn't provide sufficient data to calculate an acceptable endpoint. Invertebrate sensitivity ranged from a 21-day NOEC for *Daphnia magna* reproduction of 800 µg/L (Kuhn et al. 1989) to a 17 to 22-day $LC_{10}$ of 22000 µg/L for the snail *Physa gyrina* (Millemann and Ehrenberg 1982). Three endpoints were available for algal species and ranged from 38000 to 63000 µg/L. There were no data available for amphibian species. Photo-enhanced toxicity of quinoline is not expected (Bleeker et al. 1998; 2002).

## Terrestrial Toxicity

All relevant terrestrial toxicity data for quinoline were critically reviewed for acceptability for use in environmental quality guideline derivation. Acceptable terrestrial toxicity values for direct soil exposure were available for six species of plants and invertebrates, including northern wheatgrass (*Elymus lanceolatus*), red clover (*Trifolium pretense*), *Enchytraeus crypticus*, nematode (*Caenorhabditis elegans*), springtail (*Folsomia candida*) and worm (*Eisenia fetida*). Long-term endpoints ranged from 1.36 to 1948 mg/kg with plants demonstrating greater sensitivity than invertebrates. At 1.36 mg/kg there was a 10% reduction in root dry mass in red clover during a 14-day exposure (Maxxam Analytics 2015), whereas at 1948 mg/kg there was 50% effect to reproduction in *E. fetida* following a 28-day exposure (Kobeticova et al. 2008). Long-term median lethal concentrations ($LC_{50}$) were available for *F. candida* (81.1-537 mg/kg), *E. crypticus* (526.1-2093 mg/kg) and *E. fetida* (1993 mg/kg) (Kobeticova et al. 2008; Droge et al. 2006) but were excluded from the dataset as they represent severe lethality at a high effect level (50% of tested organisms) and more preferred measurement endpoints were available. Short-term endpoints included an $LC_{10}$ and $LC_{50}$ value for *C. elegans*, 1122 and >2500 mg/kg, respectively (Sochova et al. 2007) but were not included in derivation of the FEQG since long-term data are required.

## Federal Environmental Quality Guidelines Derivation

### Federal Water Quality Guideline

Federal Water Quality Guidelines (FWQGs) are preferably developed using CCME (2007) protocols[1]. CCME has an interim Canadian Water Quality Guideline for quinoline of 3.4 µg/L based on lowest endpoint with application of a safety factor and the earlier CCME protocol (CCME 1999). ECCC commissioned aquatic toxicity testing for quinoline (Maxxam Analytics 2015) in order to fill data gaps and meet minimum CCME long-term data requirements for a Type A guideline. The revised value of this FWQG reflects new toxicity data and follows the latest CCME protocol for guideline derivation (CCME 2007). The FWQG identifies a guideline for aquatic ecosystems that is intended to protect all forms of aquatic life for indefinite exposure periods.

A model-averaged species sensitivity distribution (SSD) was fit to the long-term toxicity data (Figure 1 and Table 3) using the web application, ssdtools (version 0.0.3) (Dalgarno 2018). This web application fits toxicity data to multiple cumulative distribution functions (e.g. log-normal, log-logistic, log-gumbel, gamma, weibull) and constructs an average SSD and $HC_5$ estimate based on the relative goodness of fit of each respective model. More information on this approach can be obtained from CCME (2019). In the case of quinoline, the toxicity data fits the gamma distribution the best, followed by weibell, log-normal, log-logistic and log-gumbel, and the 5th percentile of the SSD plot is 150 µg/L (Figure 1).

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[1] CCME (2007) provides two approaches for developing water quality guidelines, depending on the availability and quality of the available data. The preferred approach is to use the statistical distribution of all acceptable data to develop Type A guidelines. The second approach is based on extrapolation from the lowest acceptable toxicity endpoint to develop Type B guidelines. For further detail on the minimum data requirements for CCME guidelines see CCME (2007).

Table 3. Long-term Toxicity Endpoints for Freshwater Aquatic Life Used in the Derivation of the Federal Water Quality Guideline for Quinoline.

| **Species** | **Group** | **Endpoint** | **Concentration in Water (µg/L)** | **Reference** |
|---|---|---|---|---|
| Rainbow trout<br>*(Oncorhynchus mykiss)* | ▲ | 27-d[a] $LC_{10}$ | 160 | Calculated from Black et al. 1983 |
| Cladoceran<br>(*Daphnia magna*) | 🟩 | 21-d NOEC<br>(reproduction) | 800 | Kühn et al. 1989 |
| Amphipod<br>(*Hyalella azteca*) | 🟩 | 14-d $EC_{20}$<br>(dry weight) | 840 | Maxxam Analytics 2015 |
| Bluegill sunfish<br>(*Lepomis macrochirus*) | ▲ | 21-d $LC_{10}$ | 1500 | Maxxam Analytics 2015 |
| Water flea<br>(*Ceriodaphnia dubia*) | 🟩 | 6-d $EC_{10}$<br>(reproduction) | 8200 | Maxxam Analytics 2015 |
| Fathead minnow<br>(*Pimephales promelas*) | ▲ | 7-d $EC_{10}$<br>(biomass) | 12800 | Maxxam Analytics 2015 |
| Snail<br>(*Physa gyrina*) | 🟩 | 17-22-d $LC_{10}$ | 22000 | Millemann and Ehrenberg 1982 |
| Algae<br>*(Scenedesmus subspicatus)* | 🔴 | 72-h $EC_{10}$<br>(biomass) | 38000 | Kühn and Pattard 1990 |
| Algae<br>(*Desmodesmus subspicatus*) | 🔴 | 72-h $EC_{50}$<br>(growth inhibition) | 60900 | Eisentraeger et al. 2008 |
| Algae<br>(*Chlorella pyrenoidosa*) | 🔴 | 72-h $EC_{10}$<br>(growth inhibition) | 63000 | Ramos et al. 1999 |

**Legend:** ▲ = Fish; 🟩 = Invertebrate; 🔴 = Plant/Algae

**Notes:** $LC_x$/ $EC_x$ = Concentration at which there is inhibition/ effect on X percent of the population; NOEC = No observable effect concentration.

[a] The 27-day exposure included 23 days as embryonic development and 4 days post-hatching.

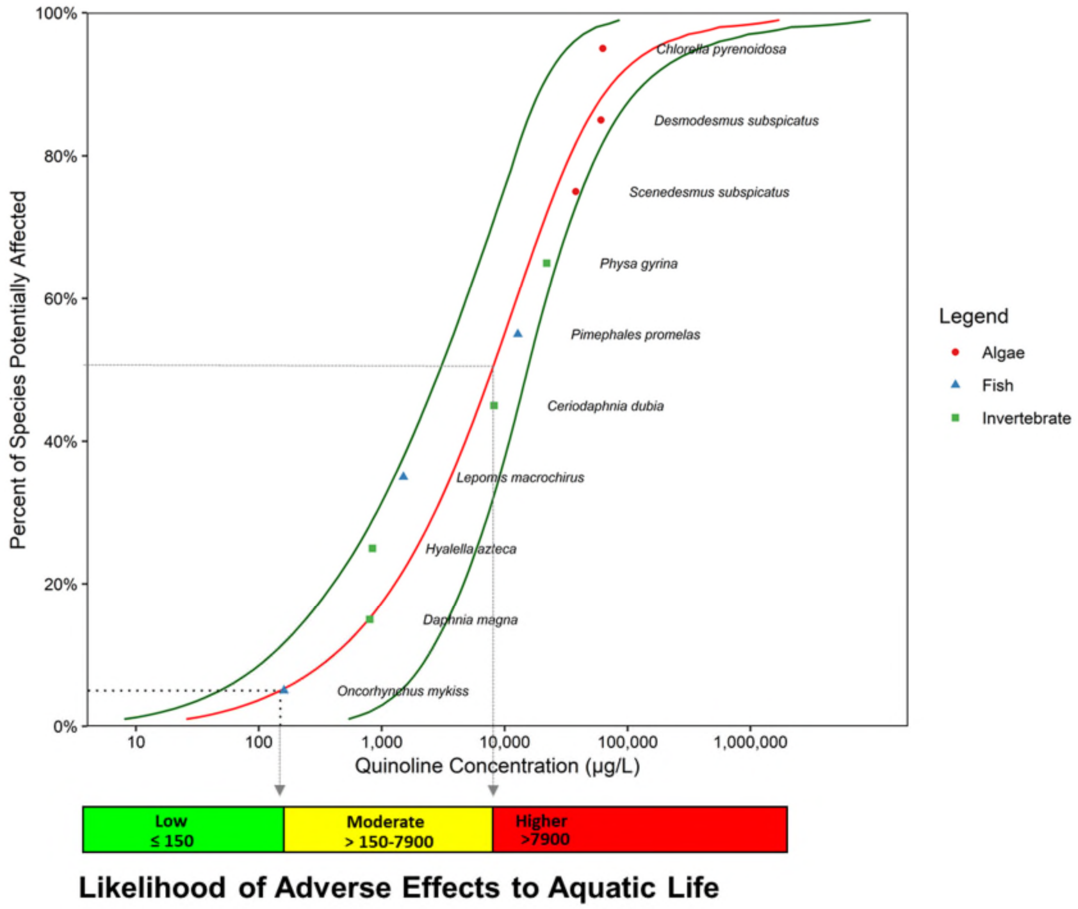

Figure 1. Species sensitivity distribution (SSD) for the chronic toxicity of quinoline and relative likelihood of adverse effects of quinoline to freshwater species.

The 5th percentile calculated from the SSD (150 µg/L), is the FWQG for protection of freshwater organisms (Figure 1). The guideline represents the concentration at or below which there would be no, or only a low likelihood of, adverse effects on aquatic life. In addition to this guideline, two other concentration ranges are provided for use in risk management. At concentrations between >5th percentile and the 50th percentile of the SSD (i.e., >150 to 7900 µg/L), there is a moderate likelihood of adverse effects to aquatic life. Concentrations greater than the 50th percentile (>7900 µg/L) have a higher likelihood of causing adverse effects. Risk managers may find these additional concentration ranges useful in defining short-term and or interim risk management objectives for a phased risk management plan. The moderate and higher concentration ranges may also be used in setting less protective interim targets for waters that are already highly degraded or where there are socio-economic considerations that preclude the ability to meet the FWQG.

## Federal Groundwater Quality Guideline

The methods used to derive the Federal Groundwater Quality Guideline for protection of freshwater life (FGWQG) at contaminated sites follow CCME (2006; 2015). The FGWQG derived here protects aquatic life in nearby surface water from indirect contact with contaminated groundwater that moves laterally and discharges to a downgradient surface water body. The groundwater quality guidelines for the protection of aquatic life are independent of the land use classification; however, guidelines are calculated separately for coarse and fine-grained soils to reflect the differences in groundwater transport between different soil types. The groundwater guideline for quinoline is calculated using the equations outlined in CCME (2006; 2015) with CCME default parameters (CCME 2006; 2015) as well as several chemical-specific input parameters for quinoline. A $K_{OC}$ value of 1819 was selected for quinoline

(GC 2011; Schuurmann et al. 2006). A long biodegradation half-life of >100 000 years was selected as a conservative assumption due to limited biodegradation data for quinoline. For the purpose of generic guidelines, it is assumed that the surface water body is located 10 m away from the contaminated groundwater (CCME 2015). By setting the surfacewater quality guideline equal to the FWQG and employing the models and default parameters from CCME (2006; 2015) as described above, the FGWQG for quinoline was calculated as 150 µg/L for both coarse and fine soil. The FWQG and FGWQG for fine and coarse soil are equal because of the assumption of a high biodegradation half-life in the absence of available data (i.e., no biodegradation will occur as groundwater moves 10 m to surface water, therefore the groundwater guidelines in both fine and coarse soil are equal to the surface water guideline).

## Federal Soil Quality Guidelines

The methods used to derive Federal Soil Quality Guidelines (FSQG) for quinoline follow CCME (2006). CCME has an Interim Remediation Criteria for soil for quinoline of 0.1 mg/kg for the agricultural land use only (CCME 1991). The FSQG presented in this factsheet reflects new toxicity data and the latest CCME protocol (CCME 2006). Soil guidelines are derived for the protection of key ecological function for four different land uses: agricultural, residential/parkland, commercial and industrial. A variety of exposure pathways described in CCME (2006) were considered based on the physical-chemical properties of the substance as shown in Table 2. The most sensitive pathway (the lowest value) is used as the basis for the final guideline for a given land use. Given its physical and chemical properties, the FSQGs for quinoline considered direct soil contact, protection of primary consumers via soil and food ingestion, protection of freshwater life, protection of livestock watering and irrigation, protection of adjacent sites via off-site migration and nutrient and energy cycling. For some pathways, insufficient data prevented guideline derivation, as described below. This report presents FSQGs for quinoline for the protection of the environment only, and not for human health.

### Soil Contact

The derivation of soil quality guidelines for soil contact ($SQG_{SC}$) is based on toxicological data for vascular plants and soil invertebrates. ECCC commissioned soil toxicity testing for quinoline through Maxxam Analytics (Maxxam Analytics 2015) in order to fill data gaps and meet minimum CCME data requirements. Laboratory studies provided long-term quinoline toxicity data for two terrestrial plant species (red clover and northern wheatgrass), and three invertebrates (enchytraeid, springtail and worm) (Table 4). A total of 34 acceptable “no effects” (i.e. NOEC and $EC/LC/IC_{10}$) and “effects” (i.e. LOEC and $EC/IC_{50}$) endpoints were used in an Effects/No Effects data distribution following the weight of evidence method in CCME (2006). This approach was the most preferred method for which the data requirements were met (CCME 2006). Although plants and invertebrates demonstrated different sensitivities to quinoline, insufficient data are available to evaluate plants and invertebrates separately and still meet CCME requirements. Therefore, data are combined as per CCME protocol (2006). The 25th percentile of the estimated species sensitivity distribution ($ESSD_{25}$) was 3.1 mg/kg soil (Figure 2). The soil contact value for Agricultural and Residential/Parkland is the threshold effects concentration (TEC), which is the $ESSD_{25}$/uncertainty factor = 3.1 /2 =1.6 mg/kg. An uncertainty factor of 2 was applied because only three long-term studies were available (the minimum requirement), and more than 50% of the data were based on toxicity studies with low bioavailability conditions. The soil contact value for Commercial and Industrial land uses is the Effects Concentration- Low, which is equal to the $ESSD_{50}$ (50th percentile of the ESSD) = 9.9 mg/kg (Figure 2). Note the soil contact guidelines are based on, and applicable to, coarse soil. If the soil contact guidelines are being applied to fine soil they will be considered provisional.

Table 4: Toxicity Endpoints used for the Estimated Species Sensitivity Distribution to Derive the Soil Contact Value for Agricultural, Residential/Parkland and Commercial and Industrial Land Uses for Quinoline.

| Species | Family | Endpoint | Effect Concentration (mg/kg dry soil) | Reference |
|---|---|---|---|---|
| Red clover<br>(*Trifolium pratense*) | Plant | 14-d $IC_{10}$ Root dry mass | 1.36 | Maxxam Analytics 2015 |
| Northern wheatgrass<br>(*Elymus lanceolatus*) | Plant | 21-d $IC_{10}$ Root dry mass | 1.52 | Maxxam Analytics 2015 |
| Northern wheatgrass<br>(*Elymus lanceolatus*) | Plant | 21-d $IC_{10}$ Root length | 1.65 | Maxxam Analytics 2015 |

| **Species** | **Family** | **Endpoint** | **Effect Concentration (mg/kg dry soil)** | **Reference** |
|---|---|---|---|---|
| Red clover (*Trifolium pratense*) | Plant | 14-d NOEC Shoot length | 1.65 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $IC_{10}$ Shoot dry mass | 2.03 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d $IC_{10}$ Root length | 2.35 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $IC_{10}$ Shoot length | 2.52 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d LOEC Shoot length | 3.1 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d NOEC Shoot dry mass | 3.1 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d $IC_{50}$ Root dry mass | 4.7 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $IC_{50}$ Root dry mass | 4.96 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d LOEC Root length | 5.32 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d LOEC Shoot dry mass | 5.32 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $IC_{50}$ Shoot dry mass | 5.93 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $IC_{50}$ Root length | 7.55 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d NOEC Emergence | 9.67 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $EC_{10}$ Emergence | 9.7 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d LOEC Shoot length | 10.1 | Maxxam Analytics 2015 |
| Red clover (*Trifolium pratense*) | Plant | 14-d $EC_{50}$ Emergence | 16.5 | Maxxam Analytics 2015 |
| Northern wheatgrass (*Elymus lanceolatus*) | Plant | 21-d $EC_{50}$ Emergence | 38 | Maxxam Analytics 2015 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $EC_{10}$ Reproduction | 60.6 | Droge et al 2006 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $LC_{10}$ Survival | 69.9 | Droge et al 2006 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $EC_{50}$ Reproduction | 75 | Droge et al 2006 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $EC_{10}$ Reproduction | 118 | Kobeticova et al 2008 |
| Enchytraeid (*Enchytraeus crypticus*) | Invertebrate | 28-d $EC_{10}$ Reproduction | 181 | Droge et al 2006 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $EC_{50}$ Reproduction | 230 | Kobeticova et al 2008 |
| Enchytraeid (*Enchytraeus crypticus*) | Invertebrate | 28-d $EC_{10}$ Reproduction | 253 | Kobeticova et al 2008 |
| Enchytraeid (*Enchytraeus crypticus*) | Invertebrate | 28-d $EC_{50}$ Reproduction | 272 | Droge et al 2006 |
| Springtail (*Folsomia candida*) | Invertebrate | 28-d $LC_{10}$ Survival | 385 | Kobeticova et al 2008 |
| Enchytraeid (*Enchytraeus crypticus*) | Invertebrate | 28-d $LC_{10}$ Survival | 398.3 | Droge et al 2006 |
| Enchytraeid (*Enchytraeus crypticus*) | Invertebrate | 28-d $EC_{50}$ Reproduction | 990 | Kobeticova et al 2008 |

| Species | Family | Endpoint | Effect Concentration (mg/kg dry soil) | Reference |
|---|---|---|---|---|
| Worm<br>(*Eisenia fetida*) | Invertebrate | 28-d $EC_{10}$ Reproduction | 1641 | Kobeticova et al 2008 |
| Enchytraeid<br>(*Enchytraeus crypticus*) | Invertebrate | 28-d $LC_{10}$ Survival | 1889 | Kobeticova et al 2008 |
| Worm<br>(*Eisenia fetida*) | Invertebrate | 28-d $EC_{50}$ Reproduction | 1948 | Kobeticova et al 2008 |

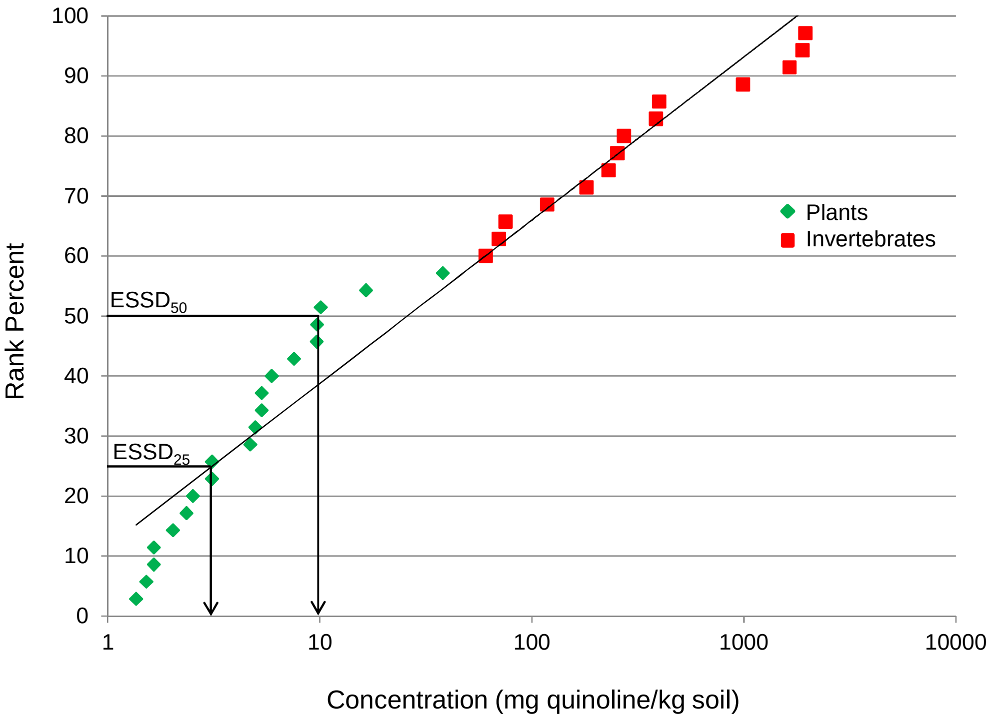

Figure 2. Estimated species sensitivity distribution (ESSD) (rank percent of Effects/No Effects data) for quinoline for terrestrial plants and invertebrates showing $ESSD_{25}$ and $ESSD_{50}$.

## Soil and Food Ingestion

Quinoline is not expected to biomagnify (GC 2011), therefore the soil FEQG for agricultural land uses only considers exposure to primary consumers in the food web; secondary and tertiary consumers are not considered for agricultural land use. Contaminant exposure to ecological receptors via soil and food ingestion is not considered for residential/parkland, commercial or industrial land uses.

CCME minimum data requirements for deriving a guideline for soil and food ingestion are three studies, including two oral mammalian studies and one oral avian study (CCME 2006). A maximum of one laboratory rodent study can be used to fulfill the mammalian species requirement. The only available oral toxicity endpoints for quinoline include two endpoints for the rat; the lowest oral $LD_{50}$ of 331 mg/kg-bw (Marhold 1986 as reported in GC 2011) and the lowest oral non-neoplastic LOEL of 25 mg/kg-bw per day (Hirao et al. 1976 as reported in GC 2011). As the data requirements for this exposure pathway are not met, no soil quality guideline for soil and food ingestion can be derived for quinoline.

## Protection of Livestock Watering and Irrigation Water

Contamination that migrates to groundwater may affect the water quality in dugouts, or water wells used for livestock watering or crop irrigation. These exposure pathways apply only for the agricultural land use. Determination of the soil quality guidelines for the protection of livestock watering ($SQG_{LW}$) and irrigation ($SQG_{IR}$) involves the application of the same groundwater model as for the $SQG_{FL}$; however transport through the saturated zone is not considered.

The guidelines are calculated by setting the allowable receptor groundwater concentration in the model equal to the livestock water and irrigation guidelines from the CCME (1999). If a livestock water guideline is unavailable, a livestock water threshold value can be developed using the following equation:

$$LWT = DTED \times BW / WIR$$

where:
LWT = calculated livestock water threshold value
DTED = daily threshold effects dose for livestock (mg quinoline/kg bw-day)
BW = livestock body weight (kg) = 550 kg for cattle (CCME 2000)
WIR = livestock water ingestion rate (L/day) = 100 L/day for cattle (CCME 2000)

A Canadian Water Quality Guideline for livestock water is not available for quinoline. Furthermore a LWT for livestock cannot be calculated as there is no information available for a DTED. Therefore, there is insufficient information available to derive a soil quality guideline for the protection of livestock watering for quinoline. As an irrigation water guideline is not available for quinoline, calculation of a soil quality guideline for irrigation water is not required.

## Protection of Freshwater Life

Contamination present in soil can migrate to groundwater. If there are surface water bodies (streams, rivers, lakes etc.) nearby, then aquatic life in these surface water bodies may be affected by the contamination, particularly if there is a permeable aquifer connecting the contamination with the surface water body. The soil quality guideline for the protection of freshwater life $SQG_{FL}$ is calculated using the model described in CCME (2006; 2015) which has four components:

1) Partitioning of contamination from soil to pore water (DF1);
2) Migration of contamination through the unsaturated zone to the groundwater surface. For generic guideline development, contamination is assumed to be in contact with the groundwater, so this component does not have an effect (DF2);
3) Dilution and mixing of the contamination in the groundwater aquifer (DF3);
4) Transport of the contamination through the saturated zone to the receptor (DF4).

The $SQG_{FL}$ is calculated by setting the allowable receptor groundwater concentration in the model equal to the freshwater life guideline. The $SQG_{FL}$ can be calculated by multiplying the allowable receptor groundwater concentration (or freshwater life guideline) by DF, where DF = DF1 x DF2 x DF3 x DF4. For generic guideline development, it is assumed the water body is located 10 m away from the contaminated soil. Chemical-specific model inputs for quinoline included a $K_{OC}$ value of 1819 (GC 2011; Schuurmann et al. 2006), Henry's Law constant of 0.169 $Pa \cdot m^3/mol$ (GC 2011; Mackay et al. 1999) which converts to a dimensionless Henry's Law Constant of 7.6E-05, and biodegradation set to 100 000 years as a conservative value in light of limited information on the half-life of quinoline in the unsaturated zone and groundwater aquifer. The saturated zone transport equation (DF4) is time-dependent, and time was determined iteratively by solving the equation until steady-state was reached, which was 1200 years. Using these chemical-specific parameters, as well as default CCME parameters (CCME 2006; 2015), the soil concentration ($FSQG_{FL}$) to prevent any quinoline that might move through soil and groundwater from exceeding the surface water quality guideline was determined to be 3.9 mg/kg for coarse soil and 2.9 mg/kg for fine soil.

### Nutrient and Energy Cycling

Soil processes such as decomposition, respiration and organic nutrient cycles are important components of the ecological function of soil. These processes may be affected by the presence of contaminants, and therefore should be considered in the development of soil quality guidelines. CCME (2006) outlines the procedures for determining the soil quality guideline for the protection of nutrient and energy cycling ($SQG_{NEC}$). The $SQG_{NEC}$ is incorporated as a check mechanism. As relevant data were not available for this pathway, no guideline for nutrient and energy cycling can be derived.

### Protection of Off-site Migration

In deriving soil FEQGs, the soil contact pathway for commercial and industrial sites considers contact of ecological receptors with on-site soil only. However, wind and water erosion of soil and subsequent deposition can transfer contaminated soil from one site to another. CCME (2006) describes a model to address this movement of soil from a commercial or industrial site to protect an adjacent, more sensitive agricultural site. Given the recognized imprecise nature of this model and the uncertainty associated with the input parameters, this pathway is considered a check mechanism.

Using the Universal Soil Loss Equation and the Wind Erosion Equation, the concentration in eroded soil from the commercial or industrial site that would raise the contaminant concentration in the receiving soil of an adjacent property equal to the agricultural guideline within a specified period of time was calculated. This concentration was applied as the soil quality guideline for off-site migration ($SQG_{OM-E}$).

$SQG_{OM-E} = (14.3 \times FSQG_{Agr}) – (13.3 \times BSC)$
where:
$FSQG_{Agr}$ = the soil quality guideline protective of agricultural land uses (mg/kg) = 1.6 mg/kg
BSC = background soil concentration of the contaminant in the receiving soil (mg/kg)

Background soil concentrations of quinoline from 34 sites with no known contamination history in Alberta, Newfoundland and British Columbia were found to be below detection (<0.05 mg/kg) (Kelly-Hooper et al. 2014, author correspondence). No further information on background soil levels of quinoline was available. Therefore, using a value of zero as the background soil concentration of quinoline, the $SQG_{OM-E}$ was estimated as follows:

$SQG_{OM-E} = (14.3 \times 1.6) – (13.3 \times 0) = 22.88$ mg/kg.

Therefore, the $SQG_{OM-E}$ is 23 mg quinoline /kg soil.

### Final Federal Soil Quality Guidelines

The final Federal Soil Quality Guideline is based on the lowest value generated by each environmental pathway for the four land uses: Agricultural, Residential/Parkland, Commercial and Industrial. The values derived using the soil contact pathway are the most sensitive for Agricultural and Residential/Parkland land uses. The values from the freshwater life pathway are the most sensitive for Commercial and Industrial land uses. Accordingly, the final Federal Soil Quality Guidelines for Agricultural and Residential/Parkland land uses are 1.6 mg/kg, and for Commercial and Industrial land uses are 3.9 mg/kg for coarse soil and 2.9 mg/kg for fine soil.

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## List of Acronyms

BCF — bioconcentration factor: the ratio of the concentration of a chemical compound in an organism relative to the concentration of the compound in the exposure medium (e.g. soil or water)
BW — body weight
CAS — Chemical Abstract Service
CCME — Canadian Council of Ministers of the Environment
CEPA — Canadian Environmental Protection Act
CMP — Chemicals Management Plan
DF — dilution factor
DNA — deoxyribonucleic acid
DTED — daily threshold effects dose
$EC_x$ — effect concentration to x% of test species
$ESSD_x$ — estimated species sensitivity distribution at x percentile of the distribution
FEQG — Federal Environmental Quality Guideline
$FGWQG_{FL}$ — Federal Groundwater Quality Guideline to Protect Freshwater Life
FSQG — Federal Soil Quality Guideline
FWQG — Federal Water Quality Guideline
$HC_5$ – concentration at the 5th percentile of an SSD plot, below which adverse effects are unlikely
$IC_x$ — inhibition concentration to x% of test species
$K_{OC}$ — organic carbon-water partition coefficient
$K_{OW}$ — octanol-water partition coefficient
$LC_x$ — lethal concentration to x% of test species
$LD_x$ — lethal dose to x% of test species
LOEC — lowest observed effect concentration
LOEL — lowest observed effect level
LWT — livestock water threshold
NOEC — no observed effect l concentration
NPRI — National Pollutant Release Inventory
PAH — polycyclic aromatic hydrocarbon
SAR — screening assessment report
SSD — species sensitivity distribution
TEC — threshold effects concentration
WIR — water ingestion rate