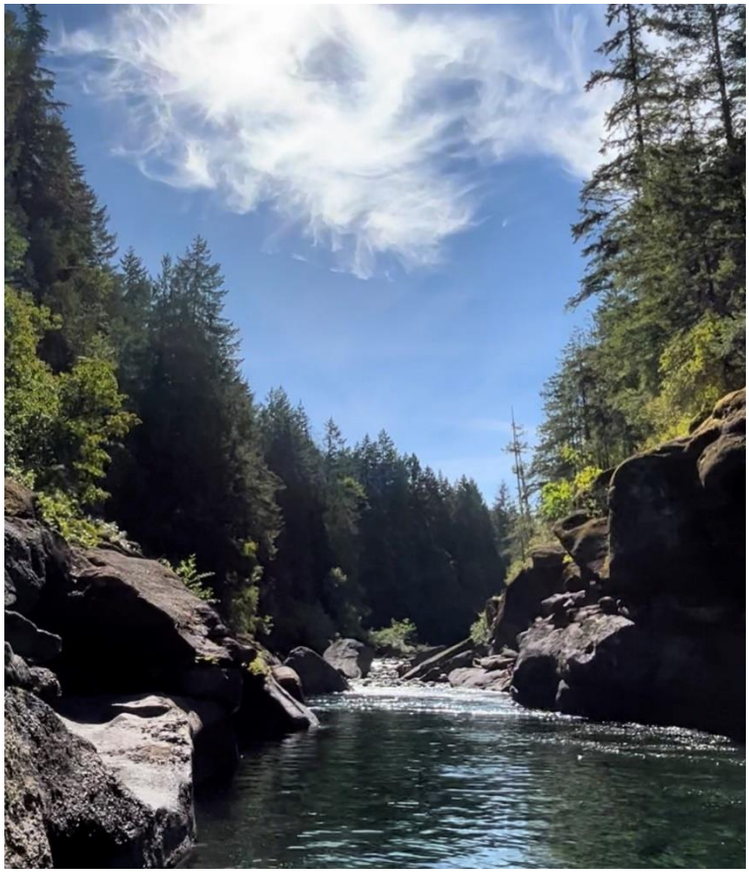
WATER QUALITY GUIDELINE SERIES

# Lead Water Quality Guidelines – Marine, Wildlife, Livestock, and Irrigation

Ministry of Water, Land, and Resources Stewardship
Water Protection & Sustainability Branch



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BRITISH COLUMBIA

The Water Quality Guideline Series is a collection of British Columbia (B.C.) Ministry of Water, Land, and Resource Stewardship water quality guidelines. Water quality guidelines are developed to protect a variety of water values and uses: aquatic life, drinking water sources, recreation, livestock watering, irrigation, and wildlife. The Water Quality Guideline Series focuses on publishing water quality guideline technical reports and guideline summaries using the best available science to aid in the management of B.C.'s water resources. For additional information on B.C.'s approved water quality parameter specific guidelines, visit:

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Location: Nanaimo River, B.C.

## SUMMARY

This document is one in a series that establishes ambient water quality guidelines, formerly known as criteria, for British Columbia (Table S1). This document is mainly based on a report prepared by the BC Ministry of Environment and Parks (1987). It sets guidelines for lead (Pb) to protect marine aquatic life, wildlife, and agricultural water (irrigation and livestock watering) uses.

Table S1. Recommended guidelines for lead.

| Water Use | 30-Day Average (µg/L Total Lead) | Maximum (µg/L Total Lead) |
|---|---|---|
| Wildlife Water Supply | - | 100 |
| Livestock Water Supply | - | 100 |
| Irrigation Water Supply (neutral and alkaline fine-textured soils) | - | 400 |
| Irrigation Water Supply (all other soils) | - | 200 |

Lead is a non-essential element for plant, animal, and human nutrition, yet ubiquitous in our environment. The most common forms of lead in our environment are oxides, carbonates, and sulphates. Anthropogenic sources of lead are atmospheric fallout originating from activities such as mining, milling, smelting, and manufacturing and production of lead and other metals. Aquatic organisms are particularly sensitive to excessive lead in water. However, this document will focus on the effects of lead on marine and estuarine aquatic life, wildlife, and agriculture. For freshwater aquatic life, please refer to the British Columbia Technical Report, Lead Water Quality Guidelines – Freshwater Aquatic Life.

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## 1. INTRODUCTION

The British Columbia Ministry of Water, Land, and Resource Stewardship (WLRS) develops province-wide ambient Water Quality Guidelines (WQGs) for substances or physical attributes that are important for managing both the fresh and marine surface waters of British Columbia (B.C.). WLRS defines a WQG as a scientifically derived numerical concentration or narrative statement considered to be protective of designated values in ambient conditions. WQGs provide a basis for water quality assessments and inform decision-making in the natural resource sector and may be derived for the protection of designated uses including aquatic life, wildlife, agriculture (livestock watering and irrigation), drinking water sources, and recreation.

In B.C., WQGs are developed to protect the most sensitive endpoint associated with a given value (e.g., aquatic life, wildlife, livestock). For substances with sufficient toxicological data, both short-term acute and long-term chronic guidelines are developed. Interim WQGs are developed when the available toxicological data are insufficient (CCME, 1999; ENV, 2019).

WQGs are typically based on toxicological studies conducted under laboratory conditions. There are several uncertainties associated with applying WQGs to field conditions, including:

- Laboratory to field differences in exposure conditions;
- Single contaminant tests in laboratories vs exposure to multiple contaminants in the field that may demonstrate additive, synergistic, or antagonistic effects;
- Toxicity of metabolites;
- Intra- and inter-specific differences between test species used to derive the WQG and those found in the field;
- Indirect effects (e.g., behavioral responses, food web dynamics);
- Laboratory studies conducted on partial life cycle studies which may not include the most sensitive life stage;
- Delayed effects which may not occur within the life stage tested, or may occur across generations; and,
- Cumulative effects of the various stressors, such as habitat loss and climate change, that organisms in the field are exposed to.

Given these uncertainties, WQGs are an estimate of a no-effect concentration (i.e., no effects are expected if exposure concentrations are below the WQG). An exceedance of the WQGs presented in this document, however, does not imply that unacceptable risks are present, but that the potential for adverse effects is increased and additional investigation and monitoring may be warranted. To that end, ongoing ecological monitoring is encouraged to ensure the WQG is indeed protective under field conditions.

Lead is a non-essential element for plant, animal, and human nutrition; yet it is ubiquitous in our environment. This document discusses the effects of lead on various water uses which include drinking water, aquatic life, wildlife, livestock water supply, irrigation, recreation and aesthetics, and industrial water supplies. Since aquatic organisms are particularly sensitive to excessive lead levels in water, a large portion of this document focuses on lead toxicity to aquatic life. Standards, objectives, and criteria from various jurisdictions are reviewed, which, in conjunction with other information available from the literature, provide a basis for criteria recommended to protect water uses in British Columbia from anthropogenic lead.

Because of the extensive amount of literature on lead, a large portion of the information presented in this document has been extracted· from recent reviews on the subject. The purpose of this document was not to re-review the original literature already addressed in recent publications, but instead, to focus on the most applicable information which could be used to formulate defensible criteria for British Columbia waters.

## 2. FORMS AND TRANSFORMATIONS IN THE ENVIRONMENT

Naturally occurring lead (Pb) has three oxidation states: metal, Pb(II), and Pb (IV). In water, lead primarily exists as Pb(II). Pb(IV) may exist only in extreme conditions, outside the environmental pH and oxidation-reduction potential (Eh) range. However, Pb(IV) compounds are produced artificially and are discharged into the environment. One such compound, tetraethyl lead, is widely used as an antiknock agent in gasoline; lead emissions from gasoline and waste oil combustion are the principal sources of anthropogenic lead (Nriagu, 1986a).

The relative abundance of Pb(II) speci.es in the aqueous environment is pH dependent. In acidic (pH 7) waters, $Pb^{2+}$, $PbSO_4$, and $PbCl^+$, are the dominant species, whereas $PbCO_3$ and lead hydroxide complexes are common in alkaline (pH>7) waters. Other forms of lead include those (a) complexed with organic matter giving soluble, colloidal, and particulate compounds, and (b) sorbed on the suspended matter in water. In acidic media, humic acid sorbs lead more strongly than clay; whereas at pH 6.5 soluble lead-humate complexes are formed and clay seems to compete strongly with soluble lead-humates for retention on the solid phase. The presence of anions such as phosphate and sulphate also reduce aqueous metal ion concentration through precipitation of lead salts of low solubility. In general terms, the solubility of lead in water decreases with increased alkalinity.

Lead forms complex molecules with organic and suspended sediment fractions of water, and therefore is rapidly removed from surface and ocean waters (Goldberg, 1976; Ter Harr, 1975), The possibility of conversions of $Pb^{2+}$ (as lead acetate), dimethyl lead, and trimethyl lead to volatile tetramethyl lead in flooded soils and lake sediments has been reported in the laboratory (Schmidt and Huber, 1976; Dumas et al., 1977; Huber et al., 1978; Wong et al., 1975, Jarvie et al., 1975; O'Hare et al., 1977; Chau and Wong, 1978). Lead methylation was dependent upon the pH, temperature, and microbial activity of the medium. Similar lead methylation in the environment is still controversial (Chau, 1986). Organolead compounds are relatively unstable and disappear rapidly from the environment through volatilization and degradation. However, alkyllead compounds are found in fish (Chau et al., 1985). Generally, organolead compounds are more toxic than the inorganic ones, and among the alkylated lead compounds the tetra-alkylated lead compounds are the most toxic (Chau and Wong, 1978; Chau et al., 1979).

Hart and Davies (1981) found that in the freshwater section of the Yarra River, Australia, about 45% of the total lead was present in particulate forms. As a comparison, 47 to 72% of the total lead was found associated with particulates in the Susquehanna River, USA (McDuffie et al., 1976) and the Rhine River, FRG (DeGroot et al., 1976). In estuaries, the particulate lead fractions could be even higher due partially to resuspension of sediments (Hart and Davies, 1981). In Buttle Lake, British Columbia, the dissolved to total lead ratio ranged from 0.01 to 1.0 (Clark and Morrison, 1982).

## 3. OCCURRENCE IN THE ENVIRONMENT

### 3.1 Natural Sources

The most common ores of lead are the oxides, carbonate, and sulphate ores. Galena or lead glance (PbS) is, however, the most important commercial ore. In general, Pb is found in all the rocks of the earth's crust. The lead content of igneous rocks ranges from 8 mg/kg (for basic rocks such as basalt and gabro) to 20 mg/kg (for acid rocks such as granite and rhyolite). Similar levels were found in sedimentary rocks; from 7 mg Pb/kg for sandstones and limestones to 20 mg/kg for shales (Aubert and Pinta 1977, Demayo et al., 1980). The average concentration of Pb in the lithosphere is about 16 mg/kg (Swaine, 1955; Vinogradov, 1959; Turekian and Wedepohl, 1961).

Soils tend to be richer in lead than the rocks from which they are derived. The usual range for Pb content in soils has been estimated at 2 to 200 mg/kg (Bowen, 1966), with an average value between 10 to 25 mg/kg. In the U.S.A., a range of <10 to 700 mg/kg was reported by Shacklette al. (1971) for the Pb concentration in soils. Agricultural soils in British Columbia had an average lead concentration in the top 16 cm of 10.4 mg/kg (John, 1975). The mean lead concentrations in various horizons of Podzols in New Brunswick ranged from 13 to 73 mg/kg, whereas the mean concentrations above a sulphide deposit varied from 752 to 1 431 mg/kg (Presant and Tupper, 1965).

Depending upon weathering rates of various rocks and their average lead content, it was estimated that 152 000 to 162 000 tonnes pe year of lead enters surface waters naturally world-wide (Eriksson, 1960). These estimates agree with those of 180 000 tonnes of Pb/year being naturally mobilized and discharged into oceans by rivers (Bryce-Smith, 1971). Bertine and Goldberg (1971) estimated that weathering mobilizes about 21 000 to 110 000 tonnes of lead each year. More recently Nriagu (1986a) concluded that about 24 500 tonnes of lead are emitted annually from natural sources, a large fraction (65%) of which is derived from wind-blown dusts. These calculations assume that the dust also contains anthropogenic lead, so that emissions in pre-technological times should have been much smaller.

### 3.2 Anthropogenic Sources

The atmospheric fallout (wet and dry) originating from such activities as: (a) mining and milling of lead ores, (b) smelting and refining of primary and secondary lead, (c) manufacturing of lead chemicals, batteries, and other products, (d) production of other metals, cement, and combustion of fossil fuel, (e) consumption of lead products, notably leaded gasoline, and (f) incineration of refuse and sewage containing trace amounts of lead, is by far the major source of the anthropogenic lead in watercourses. The atmospheric lead deposited on the land reaches watercourses via surface runoff (e.g., urban runoff). Other sources include effluent generated from lead-related operations (e.g., mining, milling, and smelting, etc.), leachate from landfills, and effluent from sewage treatment plants, agricultural runoff.

Kemp and Thomas (1976) estimated that the man-made lead input to Lakes Ontario, Erie, and Huron ranged from 47% to 93% of the total input (anthropogenic + natural) at a given location. Distribution of Pb in core samples extracted from Lake Michigan suggested that natural input into the southern basin of the lake was about 1.6 mg/$m^2$, whereas the 1972 anthropogenic input from burning of coal and leaded gasoline was estimated at 13 mg/$m^2$ (Edgington and Robbins, 1976). More recently, it was estimated that industrial activities released about 10 440 tons of lead into the Canadian atmosphere in 1980; about 80% of the lead emissions came from automobile tail pipes, and about 17% was contributed by the mining and smelting of non-ferrous metals (Nriagu, 1986a).

Lead chromate paints used on the inside of steel storage tanks or on old structures, lead pipes which may exist in some old houses and buildings, and lead solders connecting copper tubing used for distribution of water in homes and buildings may contribute significant amounts of lead to drinking water, depending upon the hardness of the water.

## 3.3 Levels in Water, Sediment, And Biota

### 3.3.1 *Water*

The lead concentration of all raw waters (rivers, lakes, wells, or groundwater) in Canada, between 1972 and 1977, was <1.0 µg/L to about 50 µg/L for dissolved lead, and from <1.0 µg/L to 100 µg/L for extractable lead. In a few cases, the results exceeded the upper limits of the test method of 50 µg/L (dissolved) and 100 µg/L (extractable) (Environment Canada, 1978). In areas where limestone and galena ores are found, waters may contain lead in solution up to 800 µg/L (Kopp and Kroner, 1967).

Most background waters in British Columbia contained lead levels ranging from <1.0 to 21 µg/L for total lead and <1.0 to 15 µg/L for dissolved lead, with median values of 3.0 and <1.0 µg/L, respectively. Less than 5% of background water samples contained total lead levels 5.0 µg/L. Elevated levels of lead in freshwater were determined in the vicinity of some mines, smelters, and landfills. In the Fraser River estuary (British Columbia), the median values for dissolved lead and total lead were 1 and 2 µg/L, respectively (Fraser River Estuary Study, 1979). The maximum levels in the Columbia River, about 0.8 km downstream from the Cominco Pb-Zn smelter, in British Columbia, were 3 µg/L for dissolved lead and 200 µg/L for total lead. The concentrations of lead in water were highest during low flow (Kootenay Air and Water Quality Study Phase II, 1979).

Neri, Schreiber, and Fortescue (1973) reported that the lead concentration in drinking water from 247 locations in Canada, ranged from 0 to 320 µg/L with a mean value of 11.8 µg/L. More recently, lead levels in drinking water in several Canadian locations were found to range from 0.25 to 71 µg/L with an average value of 8.8 µg/L (Dabeka, 1987).

Bowen (1966) and Preston (1973) estimated the Pb concentration in sea water at 0.02 to 0.03 µg/L. In British Columbia, on the west coast of Canada, the seawater lead concentrations were less than 0.05 µg/L except near large lead sources (Stukas and Wong, 1981). In some areas of the Mediterranean Sea and the Pacific Ocean, lead contents of about 0.20 µg/L and 0.35 µg/L, respectively, were found (NAS, 1972). Values up to 2.3 µg/L have been reported in the British coastal waters (Preston, 1973). The particulate matter collected from the surface of the oceans (0 to 5 m) had an average lead content of 58 µg/kg, probably largely located in plankton (Chester and Stoner, 1975).

### 3.3.2 *Sediment*

Lead forms complex molecules with organic and suspended sediment fractions of water, and therefore is rapidly removed from surface and ocean waters (Goldberg, 1976; Ter Haar, 1975). In the Saline Branch watershed, Getz et al. (1977) noted that the lead concentration in filtered (0.45 µm) water samples, unfiltered water samples, and the top 5 cm of bottom sediments in urban areas, ranged from 15 µg/L, 15 to 200 µg/L, and 2 330 to 6 300 µg/g, respectively. Lead contents of up to 3 200 µg/g, were found in the sediments from Wapato Lake (Washington), which received urban storm water with no treatment (Wisseman and Cook, 1977). The sediment lead concentrations of 390 µg/g near a sewage treatment plant, and 1344 µg/g near a snow dump exceeded by far the average concentrations in the Ottawa (26 µg/g) and the Rideau (42 µg/g) Rivers (Oliver and Kinrade, 1972). The lead concentration in sediments from the Great Lakes ranged up to 274 µg/g (Hutchinson and Fitchko, 1974).

Background concentrations of lead in most fresh and coastal water sediments ranged from <10 to <20 µg/g (Garrett, 1985). Elevated levels were, however, determined near several mines, smelters, and certain areas of the Brunette and Fraser River systems. The sediment lead content of 866 µg/g in the Columbia River, about 0.8 km downstream from the Cominco Pb-Zn smelter, was about 45 times higher than the background levels (19 µg/g, Kootenay Air and Water Quality Study Phase II, 1979). Lead levels in the Buttle Lake sediments ranged from 42 to 559 µg/g (Clark and Morrison, 1982).

The lead content in deep-sea sediments was estimated at 9 µg/g for clay and 80 µg/g for the carbonate type of materials (Turekian and Wedepohl, 1961). Chester and Stoner (1975) recorded 20 µg/g associated with nearshore sediments and 45 µg/g in deep-sea sediments.

In marine areas of British Columbia, maximum levels of lead in sediment, ranging from 2 to about 5 500 µg/g, were detected at mining operations in Alice Arm, the Alcan smelter at Kitimat, several pulp mills, in Victoria and Vancouver Harbours, certain ocean dump sites, False Creek, Comox, and the Esquimalt Harbour Armed Forces Base (Garrett, 1985). As indicated above, background lead levels in coastal water sediments ranged from <10 to <20 µg/g (Garrett, 1985).

### 3.3.3 *Biota*

Uthe and Bligh (1971) reported that fish {headless dressed fish samples ground and thoroughly mixed) from Great Lakes had less than 0.5 µg/g (wet weight). Lead concentrations in the liver of several species of fish (148 samples) from 62 British Columbia Lakes, ranged from 0.1 to 5.3 µg/g·(wet weight) with an average value of about 0.7 µg/g (Peterson et al., 1970). In another survey, the lead concentration was measured in the livers of large-scale suckers and rainbow trout upstream and downstream from a Pb-Zn smelter at Trail, B.C. on the Columbia River. The samples taken upstream from the smelter averaged 0.98 and less than 0.5 µg/g (dry weight) for four large-scale suckers and one rainbow trout, respectively; the samples taken downstream from the smelter averaged 1.5 and 1.4 µg/g for one largescale sucker and two rainbow trout, respectively (Kootenay Air and Water Quality Study Phase II, 1979). Lead levels (<0.49 µg/g wet wt.) in the livers of Fraser River fish were generally less than those taken from other British Columbia waters (Singleton, 1983).

In a more recent report (Smith, 1987), average lead levels in Columbia River fish muscle were reported to range from 0.016-0.49 µg/g-wet wt. (or 0.075-2.2 µg/g-dry wt.). Lead levels in some largescale suckers caught downstream from Cominco were elevated (average value = 0.78 µg/g-wet wt.) over the background (0.17 µg/g-wet wt.); the highest lead levels downstream were in excess of 1.0 µg/g-wet wt. Smith (1987) also noted that lead levels were higher in fish liver than in fish muscle. For instance, the average lead level in the liver of largescale suckers at the upstream (background) sites was 0.39 µg/g-wet wt., whereas at the downstream (from Cominco) sites it ranged from 2.5-2.6 µg/g-wet wt.

Brown and Chow (1977) found average concentrations of lead in fish muscle (wet weight) of 0.19 µg/g and 1.78 µg/g from Baie du Dore (Lake Huron) and Toronto Harbour, respectively. Also, there was close agreement between the distribution of metals in sediments and in non-migratory fish. Bottom-feeding fish, e.g., suckers (Catostomidae), accumulated more tissue lead in contaminated ecosystems than did centrarchids feeding in the water column at the same location; both groups were exposed to the same levels of waterborne lead, but suckers feed on organisms living in contaminated sediments (Hodson et al., 1983; Ney and Van Hassel, 1983; Czarnezki, 1985).

The transfer of lead from water and sediment into food webs (e.g., fish) is not a simple function of the lead concentration in the environment. Chemical speciation of lead in water, chemical partitioning of lead in sediments, and the nature of biota affect lead uptake. Laboratory studies have shown that lead uptake by fish is reduced when dissolved organic carbon concentrations are elevated (Wiener and Giesy, 1979),

when phosphate concentrations are increased (Freedman et al., 1980), or when pH is elevated (Merlini and Pozzi, 1977). Studies in natural systems have also shown reduced concentrations of lead in organisms where sediments are high in organic carbon (Schierup and Larsen, 1981) or high in amorphous iron oxides (Louma and Bryan, 1978; Tessier et al., 1984).

## 4. MARINE LIFE

### 4.1 Marine Algae

The saltwater species of algae are more sensitive to lead than the freshwater species. The following discussion is based on tests conducted for a duration of 2 to 12 days by various investigators.

Steele and Thurs by (1983) noted reduced growth (final dry weight) of the females, reduced tetrasporangia production, and inhibition of sexual reproduction in the saltwater alga, *Champia parvula*, at 20.3, 23.3, and 20.3 µg Pb/L of lead nitrate in water, respectively. A reduction of 65% in growth was noted in *Dunaliella salina* when exposed to a lead concentration of 900 µg Pb/L of lead nitrate (Pace et al., 1977). In tests with organolead compounds, Marchetti (1978) reported that the saltwater alga *Dunaliella tertiolecta* was ten times more sensitive to tetraethyl lead (96-h EC50 = 150 µg Pb/L) than tetramethyl lead (96-h EC50 = 1 650 µg Pb/L).

Saltwater diatoms are also quite sensitive to lead in water. The EC50 for two species of diatoms, *Ditylurn brightwelli* and *Astrionella japonica,* were noted to be 40 µg Pb/L of P bC1 2 and 207 µg Pb/L of Pb (NO3) 2, respectively (Canterford and Canterford, 1980; Fisher and Jones, 1981). In tests with *Skeletonema costatum* exposed to lead nitrate *fn* 12 days, a 50% reduction in growth rate and maximum yield of the organisms (EC50) was caused by 3.7 and 5.1 µg Pb/L in water, respectively (Rivkin, 1979). A reduction of 25-50% in photosynthetic and respiration activities was reported in *Phaedactylum tricarnutum* subjected to 100 µg Pb/L for 48 to 72 hours (Woolery and Lewin, 1976); however, Hannan and Patouillet (1972) observed no adverse effect in the growth of the same species of diatom exposed to 1 000 µg Pb/L for 72 hours.

### 4.2 Marine Invertebrates

(a) Acute Toxicity

The lead-induced acute toxicity to marine invertebrates varies with species and its life stage. An LC50 of 27 000 µg/L was noted for the adult soft-shell clam, *Mya arenaria* (Eisler, 1977); however, the acute values obtained with larvae of the blue mussel (*Mytilus edulis*), pacific oyster (*Crassostrea gigas*), eastern oyster (*Crassostrea virginica*), and quahog clam (*Mercenaria mercenaria*) were only 476, 758, 2 450, and 780 µg/L, respectively (Martin et al., 1981; Calabrese et al., 1973, and Calabrese and Nelson, 1974). The LC50 values for some other species of marine invertebrates, as reported in the literature, are: Copepod (*Acartia clausti*), 668 µg/L (Gentile, 1982); Dungeness crab (*Cancer magister*), 575 µg/L (Martin et al., 1981).

(b) Chronic Toxicity

*Mysidopsis bahia* (mysid) appears to be the only species which was subjected to chronic toxicity tests. In a life-cycle test with the mysid, lead levels ranging from 17 to 37 µg/L (with a chronic value of 25.1 µg Pb/L defined as the geometric mean of the lower and upper limits) caused reduced spawning (Lussier et al., as quoted in U.S. EPA, 1985a).

## 4.3 Marine Fish

(c) Acute Toxicity

Four species of marine fish, namely sheepshead minnow (*Cyprinodon variegatus*), mummichog (*Fundulus heteroclitus*), inland silverside (*Menidia beryllina*), and Atlantic silverside (*Menidia menidia*) have been tested for acute toxicity of lead. *Fundulus heteroclitus* was the most sensitive with an LC50 of 315 µg Pb/L (Dorfman, 1977 in U.S. EPA, 1985a). In fact, of the 11 saltwater genera (including four species of fish indicated above) for which acute values were available, the most sensitive genus, *Fundulus*, was 85 times more sensitive than the most resistant, *Mya* (*Mya arenaria* or soft-shell clam) (Eisler, 1977; U.S. EPA, 1985a). In flow-through toxicity tests with Sheepshead minnow (*Cyprinodon variegatus*) and inland silversides (*Menidia beryllina*), less than 50% of the test organisms were killed at 3 140 µg Pb/L, which is the solubility of lead in sea water under the test conditions.

(d) Chronic Toxicity

No data for marine fish were available.

## 4.4 Criteria from Other Jurisdictions

Table 4.1. Lead Criteria for Marine Aquatic Life

| Criteria Statements | Criteria Values (µg Pb/L) | Jurisdiction | Date | Reference |
|---|---|---|---|---|
| Concentration of lead in sea water should not exceed 0.02 of the 96-h LC50 for the most sensitive species, and the 24-h average concentration should not exceed 0.01 of the 96-h LC50. Concentrations of lead 0.05 mg/L constitute a hazard and levels <0.01 mg/L present minimum risk. Special efforts should be made to reduce lead levels even further in oyster growing areas | 0.02×96-h LC50<br>0.01×96-h LC50<br><br>50<br>10 | U.S. EPA | 1972 | U.S. EPA |
| Recommended criteria for marine =0.004 mg/L of total lead until more information is available on the long-term effects of lead on sensitive marine organisms | 4 | America Fisheries Society | 1979 | AFS (1979)[1] |
| Except possibly where a locally important species is very sensitive, saltwater aquatic organisms should not be affected unacceptably if 4-d average concentration of lead does not exceed 5.6 µg/L more than once every three years on the average, and if the 1-h average concentration does not exceed 140 µg/L more than once every three years on the average | 5.6<br>(4-d Average)<br>140<br>(1-h Average) | U.S. EPA | 1985 | U.S. EPA (1985a)* |

* U.S. Environmental Protection Agency

[1] American Fisheries Society

## 4.5 Recommended Criteria

(a) The average concentration of total lead in water over a 30-day period (based on a minimum of 5 weekly samples) should not exceed 2 µg/L at any time. Not more than 20% (e.g., 1 in 5) of the

values in a 30-day period should exceed 3 µg/L.

(b) The maximum concentration of total lead in water at any time should not exceed 140 µg/L.

(c) If natural levels exceed (a) or (b) above, then the increase in total lead to be allowed, if any, should be based on site-specific conditions.

### 4.6 Rationale

The criteria for the protection of marine aquatic life were based on information presented in U.S. EPA (1985a). The one-hour (acute) criterion recommended by the U.S. EPA was 140 µg/L. This value is less than half (0.44) of the lowest marine LC50 of 315 µg/L noted for the mummichog (*Fundulus heteroclitus*; Dorfman, 1977), and is accepted in this document as the maximum criterion in marine water. It is expected that this concentration would cause little or no mortality even if it persisted for four days. Research by the U.S. EPA (1985a) suggests that 0.44 of the 96-h LC50 would be ≤96-h LC1 in about 75% of cases.

The lowest level (a 12-day EC50 of 3.7 µg/L) causing long-term (chronic) effects (50% reduction in growth rate) was reported by Rivkin (1979) for the diatom *Skeletonema costatum*. In view of these results, the chronic (four-day average) criterion of 5.6 µg/L recommended by the U.S. EPA (1985a) was modified. In order to provide adequate protection from long-term effects, a 30-day average (chronic) criterion of 2 µg/L of lead (i.e., one-half of the lowest chronic effect level, based on a minimum of 5 weekly samples) is recommended in this document. Data on effects of fluctuations in lead levels in water on marine aquatic life are rare. It is believed, however, that the effects will be the same in both fresh and marine waters. It is, therefore, further recommended that no more than 20% of the samples collected over a 30-day period should exceed 1.5 times the recommended 30-day average criterion, or 3 µg/L.

Since the hardness of marine waters was assumed to be high and relatively constant, the above criteria do not vary with hardness.

The CCREM (1987) did not recommend guidelines for marine aquatic life.

## 5. WILDLIFE

### 5.1 Effects

Accidental ingestion of lead shot mistaken for seed or grit appears to be the major cause of lead poisoning in waterfowl. In hunting areas of marshlands, Bellrose (1959) estimated that the number of lead pellets per acre of marsh bottom ranged from 25 000 to over 30 000. Anderson (1975) reported that lesser scaup (a species of duck) containing 1 to 10 lead pellets in the gizzard lost an average of 30 to 35% of their body weight before dying as compared to healthy birds.

Different species of waterfowl show different tendencies to ingest lead shot. For instance, gadwall (*Anas strepera*), teal (*Amus* sp.) and shoveler (*Spatula clypeata*) show lower incidence of ingesting lead shot than redhead (*Aythya americana*), canvas back (*Aythya valisneria*), and ringnecked ducks (*Aythya collaris*). Mallards are by far the most susceptible to lead ingestion.

The toxicity of lead in waterfowl varies with species, sex, and their food intake characteristics (i.e., quantity and quality). Female waterfowl are about twice as sensitive to lead poisoning as males (Jordan, 1952). Mallards dosed with lead were less affected when maintained on a balanced diet than the birds fed on a diet low in nutrients (Finley et al., 1976). Some green plants, e.g., *Ceratophyllum demersum* (coontail), are thought to alleviate the effects of lead poisoning in waterfowl (Locke et al., 1966). Analyses

revealed that lead levels in livers of poisoned waterfowl ranged from 9 to 27 mg/kg in Canada geese (Adler, 1944), 18 to 37 mg/kg in whistling swans (Chupp and Dalke, 1964), and 6 to 20 mg/kg in mallards (Longcore et al., 1974). These levels are 6 to about 40 times higher than background, which is about 1.0 mg/kg of the wet weight of liver (Bagley and Locke, 1967).

The activity of the enzyme δ-aminolevulinic acid dehydratase (ALA-D) was inhibited by 40% after 3 and 12 weeks in mallards fed with a diet containing 25 and 5 mg Pb/kg, respectively. The inhibition of ALA-D activity by one pellet of lead was 88% (Finley et al., 1976b). Dieter et al., (1976) indicated that a blood lead level of 0.2 mg/L was dangerous for wildfowl as it caused 75% inhibition of ALA-D activity; 75% inhibition of ALA-D has been used to indicate dangerous accumulation of lead in humans.

Plants may be another source of lead for ducks. The food of ducks ranges from 10-to 100% plant material (Martin et al., 1961), and industrial and automotive lead could contribute to the lead burden of marsh plants in areas exposed to these sources.

Flynn et al. (1975) noted that the amount of lead in moose peaked in June and July and was related to the onset of new browse growth and not the levels of lead in water. However, no correlation was found between lead concentrations in plants and herbivorous muskrats (Everett and Anthony, 1976).

## 5.2 Criteria from the Literature

No water quality criteria specifically for wildlife were found in the literature.

## 5.3 Recommended Criterion

Due to the lack of sufficient relevant information in the literature, specific water quality criteria to protect wildlife from the harmful effects of lead were not developed.

The criterion to protect wildlife from harmful effects of lead in water is the same as that specified for livestock watering in section 6.3.

The concentration of total lead in water for wildlife use should not exceed 100 µg/L at any time.

## 5.4 Rationale

The use of livestock criteria for wildlife in waters devoid of sensitive or desirable aquatic life is based on the fact that, in all likelihood, the safe concentration of lead for both groups of animals is similar in magnitude. As an example, the toxic dose of 12 mg Pb/kg body weight/d for waterfowl is well within the toxic range of 2.4 to 320 mg/kg body weight/d for livestock as noted in the joint publication of Agriculture Canada and B. C. Ministry of Agriculture (Puls, 1981). The rationale for the-livestock watering criteria is presented in section 6.4.

For waters inhabited by aquatic life, the criteria recommended to protect relatively sensitive aquatic life appear more than adequate to protect wildlife.

The CCREM (1987) did not recommend criteria for wildlife; however, the livestock criterion that we are recommending for wildlife is the same as the CCREM (1987) guideline for livestock watering.

## 6. LIVESTOCK WATER SUPPLY

### 6.1 Effects

The accidental ingestion of lead-containing products such as lead-based paints (discarded surplus paint or flakes of lead paints on old walls), discarded oil, linoleum, plumber's lead, putty, discarded lead-acid batteries, and pastures contaminated by industrial lead operations are the most common causes of lead poisoning in domestic animals (Christian and Tryphonas, 1971; Hatch and Funnell, 1969; NAS, 1972; Schmitt et al., 1971). Lead in effluent from lead mining and processing may also be a hazard.

As in humans, the bone of domestic animals acts as a sink for lead thereby providing an important detoxification mechanism. However, as the bone reaches its saturation point, the level of lead in soft tissue and blood increases and leads to symptoms of lead poisoning (Hatch, 1977). In a review of lead poisoning with laboratory animals, Tornabene et al. (1977) concluded that the decrease of ALA-D enzyme (which regulates hemoglobin production) was the most significant effect of lead poisoning of rats. Another important biochemical effect of lead poisoning in chick embryos was the suppression of the production of antibodies normally caused by certain viral and bacterial agents (King et al., 1978).

Several factors determine lead toxicity to domestic animals. These include species, age (young animals are more susceptible), reproduction stage and health of the animals, quality of animal nutrition, rate of lead ingestion, and form of lead (Hatch, 1977),

Excessive amounts of lead from ingested forage were found to be the cause of a chronic debilitating disorder in six young horses near the smelter at Trail, British Columbia (Schmitt et al., 1971). Lead in oven-dried, unwashed forage varied from 6 to 264 mg/kg dry matter within 8 km of the smelter; air contained 3 to 6 µg/$m^3$ lead. Horses receiving 2.4 mg Pb/kg b.w. (body weight)/d from hay died, whereas 6 to 7 mg Pb/kg b.w./d was estimated to be the minimum lethal dose for cattle (Hammond and Aronson, 1964). Pregnant ewes fed at a rate of 3 mg Pb/kg b.w./d of lead acetate showed no adverse effects but died of severe emaciation due to lead poisoning when fed at a rate of 5.7 mg Pb/kg b.w./d (James et al., 1966). A value of 6 mg Pb/kg b.w./d was suggested as the threshold toxic level for non-pregnant ewes (Allcroft and Blaxter, 1950). The toxic cumulative and single oral doses suggested by Agriculture Canada and the B.C. Ministry of Agriculture (Puls, 1981) are as shown below:

Table 6.1. The toxic cumulative and single oral doses suggested by Agriculture Canada and the B.C. Ministry of Agriculture (Puls, 1981)

| | Cattle | Dogs | Horses | Poultry | Sheep |
|---|---|---|---|---|---|
| | | | - mg Pb/kg b.w./d - | | |
| Toxic Cumulative Dose | 5-7 | 3-30 | 2.4-7 | 320 | 3.0 |
| Toxic Single Oral Dose | 200-800 | 600-1000 | - | - | 60-80 |

In more recent studies, doses of 5 mg Pb/kg b.w./d for 7 days, or 2.7 mg Pb/kg b.w./d for 21 days were highly toxic to young calves fed a whole milk diet (Bratton et al., 1981; Zmudzki et al., 1983). *A* dose of 1 mg Pb/kg b.w./d could be lethal in approximately 60 days to calves consuming a milk diet (Zmudzki et al., 1985).

Morrison et al. (1977) reported that lambs fed 400 mg Pb/kg of a diet low in calcium and sulphur (but adequate in other minerals) died within five weeks. The diet of 400 mg Pb/kg is equivalent to about 12 mg Pb/kg b.w./d, assuming an average feed requirement for a lamb of 0.03 kg d.m. (dry matter)/kg b.w./d. However, the animals survived up to 10 months when fed a diet containing all minerals or a low phosphorus diet. A decrease in lead toxicity to lambs as a result of sulphate sulphur in the diet was

reported by Quarterman et al. (1977). Bratton and Zmudzki (1984) noted that the calves on a milk diet accumulated 12 (in bone) to 25 (in kidneys) times more lead than calves of the same age fed a diet of grain and hay.

The addition of 2 and 5 mg Pb/kg as lead acetate or lead oxide to the ration had no effect on the mortality of chickens and hatching results in a 329-d laying test. Also, in a 198-d supplementary test, the addition of 80 mg Pb/kg of feed did not increase the lead levels of the yolks and whites (Vogt et al., 1977). A decrease in growth and an increase in incidence of perosis in broiler chickens, was reported by Chah et al. (1976) at lead concentrations of 300 mg Pb/kg of diet (or ≥9.0 mg Pb/kg b.w./d, assuming average daily feed requirement for broilers = 0.03 kg dry matter/kg b.w.). Dietary lead concentrations greater than 630 mg Pb/kg of diet sharply reduced the egg production of hens (Hermayer et al., 1977).

Prenatal exposure of lambs to blood-lead levels of 0.34 mg Pb/L caused behaviour (visual discrimination) problems in the animals, while lambs exposed to blood-lead levels of 0.17 mg Pb/L did not differ from the controls. Diets of 4.5 mg Pb/kg b.w./d and 2.3 mg Pb/kg b.w./d were needed to maintain blood-lead levels of 0.34 and 0.17 mg Pb/L, respectively in the pregnant ewes (Carson et al., 1974a, b). Hapke (1973) noted that the ingestion of more than 0.5 mg Pb/kg b.w./d of lead by sheep inhibited the activity of ALA-D in blood and increased the ·excretion of δ-aminolevulinic acid (δ-ALA) in urine. Sheep with lead intake **of** up to 3 mg Pb/d did not retain any of the ingested lead (Jones and Clement, 1972).

Williams (1939) reported chronic lead poisoning among animals by 0.18 mg Pb/Lin soft water, while Pierse (1938) noted occurrence of chronic lead poisoning in cows with water containing 2.4 mg Pb/L. Chronic poisoning of horses due to lead in spring and stream water and grasses was reported by Singer (1976). The lead concentration in water ranged between 0.01 and 16 mg/L, with most of the samples having a lead concentration in the range of 0.5 to 1.0 mg/L; grasses contained 5 to 20 mg/kg (dry basis) of lead.

## 6.2 Criteria from the Literature

Lead criteria for livestock water supply from various jurisdictions are shown in Table 6.2. The lowest lead criterion of 50 µg/L was reported by Alberta and Saskatchewan, Both Alberta and Saskatchewan did not establish water use categories while setting water quality criteria but based the criteria on the most sensitive water use. Thus, it is probable that the 50 µg/L criterion is for a more sensitive water use than livestock watering, such as drinking water or aquatic life.

Considering horses to be the most sensitive animals to lead poisoning, the Inland Waters Directorate (Demayo et al., 1980) recommended two values for lead criteria in the livestock water supply; one (500 µg/L) where horses are present and the other (1000 µg/L) for other livestock. However, these criteria exceed the criterion for lead of 100 µg/L recommended by U.S. EPA (1972), Ontario Ministry of Environment (1984), and CCREM (1987).

## 6.3 Recommended Criterion

The criterion to protect livestock from lead in water is based on the susceptibility of horses to lead poisoning. Horses appear to be as sensitive, if not more, than cattle or sheep (Puls, 1981).

The concentration of total lead in livestock drinking water supply should not exceed 100 µg/L at any time.

## 6.4 Rationale

The rationale for the criteria recommended in this document for the protection of livestock was based on information presented in Singer (1976). The logic followed is shown below:

(1) Singer (1976) reported cases of lead poisoning in horses feeding on hay containing 5 to 20 mg/kg dry matter and water with lead concentrations mostly ranging from 0.5 to 1.0 mg/L (the actual lead content of water ranged from 0.1 to 16 mg/L).

Table 6.2 Lead Criteria for Livestock Water Supply

| Criteria Statement | Criteria Value (µg Pb/L) | Jurisdiction | Date | Reference |
|---|---|---|---|---|
| Recommended upper limit of 0.1 mg/L for lead in livestock waters | 100 | U.S. EPA | 1972 | U.S. EPA (1972)* |
| The derived working level for lead in stock drinking water is 0.5 mg/L | 500 | Australia | 1974 | Hart (1974) |
| Maximum concentration for lead in water = 0.05 mg/L | 50 | Saskatchewan | 1975 | SSWQO (1975)** |
| Maximum concentration for lead in water = 0.05 mg/L | 50 | Alberta | 1977 | ASWQO (1977)+ |
| Lead in water used for livestock should not exceed 0.1 mg/L | 100 | Ontario | 1984 | OME (1984)# |
| Recommended water quality objectives (as total lead) in livestock water of 0.5 mg/L where horses are present, and 1.0 mg/L where horses are absent | 500 (horses present) 1000 (horses absent) | Inland Waters Directorate | 1980 | Demayo et al. (1980) |
| Desirable annual average concentration in livestock water = 0.1 mg/L | 100 | U.K. | 1984 | Mance et al. (1984) |
| Maximum acceptable concentration of total lead in water of 0.5 mg/L | 500 | Manitoba | 1983 | MDEWSH (1983)++ |
| Maximum recommended concentration of lead in water for livestock should be 0.1 mg/L | 100 | CCREM | 1987 | CCREM (1987)## |

* U.S. Environmental Protection Agency
** Saskatchewan Surface Water Quality Objectives
\+ Alberta Surface Water Quality Objectives
++ Manitoba Department of Environment and Workspace Safety and Health
\# Ontario Ministry of Environment
## Canadian Council of Resource and Environment Ministers

(2) Assuming a dry feed requirement of 0.03 kg d.m./kg b.w./d and a water requirement of 3 L/kg d.m., the amount of lead consumed by a horse from both water and food sources collectively in step 1, is calculated to range from 200 to 700 µg/kg b.w./d.
(3) Thus, from step 2, a daily intake of 200 to 700 µg Pb/kg b.w., with an average value of 450 µg Pb/kg b.w., may be considered unsafe for horses.
(4) Lead levels in vegetation collected in the vicinity of well-travelled highways and lead-related industry in British Columbia may be well above the 20 mg Pb/kg d.m. noted in step 1, and above the normal levels of 1.0 mg Pb/kg d.m. in the diet of a horse (Puls, 1981; Garrett, 1985).

(5) In lead-affected areas, horses consuming water containing 500 µg Pb/L may, therefore, have a lead intake exceeding the critical limits as noted in step 3.
(6) The above analyses suggest that 500 µg Pb/L in livestock water supply, as recommended by the Inland Waters Directorate (Demayo et al., 1980), may not be safe for the livestock. Chronic poisoning among animals due to lead in water at a concentration of 180 µg Pb/L, has been reported in the literature (Williams, 1939).
(7) To protect livestock from lead, it is therefore recommended that the maximum concentration of lead in livestock drinking water be 100 µg/L.

Although the recommended lead level in step 7 is perhaps overprotective, especially for relatively more resistant species of livestock, it does not restrict an area to only the more tolerant species.

The recommended criterion is the same as that recommended by the CCREM (1987).

## 7. IRRIGATION

### 7.1 Effects

Lead is not an essential element for plant growth. However, it is ubiquitous in soil-water-plant systems. In general, lead is tightly held in soils by sorption and/or by forming complexes with both inorganic and organic components of the soil. As a result, only a small amount of the total lead content of soil is available to plants. A study carried out at the University of Guelph (Ontario) showed that the first crop of rye grass removed only 0.004 to 0.017 kg Pb/ha from a soil supplied with 1.5 to 116 kg Pb/ha through an application of sewage sludge (Bates et al., 1975). In British Columbia, the ratio of lead between lettuce and soil supporting the crop was 0.015; the lead concentration in lettuce was 3 mg/kg, while in the soil it was 200 mg/kg (John, 1975). Wilson and Cline (1966) estimated that only 0.003% to 0.005% of the total lead in soil was taken up by barley plants. Since lead tends to accumulate near the soil surface, shallow-rooted crops are exposed to relatively higher lead concentrations than the deep-rooted crops (Walsh et al., 1976; John, 1975).

Lead can enter the plant through the root system or the leaves. Besides the form and concentration of the metal in the environment, several factors related to soil (pH, cation exchange capacity, texture, temperature, moisture content, organic matter content, etc.), crop (species, rooting depth, anatomy, etc.), and climate (precipitation, temperature, etc.) determine lead uptake by plants.

Lagerwerff (1971) noted that the lead (also zinc and cadmium) concentration in plants was lower when the soil pH was increased from 5.9 to 7.2. A reduction in the availability of lead to plants as a result of the formation of lead compounds (e.g., organic complexes, hydroxides, phosphates, etc.) of very low solubility, was reported by MacLean et al. (1969) and Walsh et al. (1976) in response to the addition of organic matter, lime, and phosphate to soils. Foliar absorption of lead in lettuce and radish plants from foliar application of Pb $(NO_3)_2$ solution has been demonstrated by Hemphill and Rule (1975).

The total and soluble lead content of soils has been quoted to range from 2 to 200 mg/kg with a mean of 16 mg/kg, and from 0.05 to 5 mg/kg, respectively (Demayo et al., 1980). Agricultural soils in British Columbia have been shown to contain an average of 10.4 mg/kg (total lead) in the top 16 cm of soil (John, 1975). In a study concerning the lead content of vegetables and soils in British Columbia, Warren et al. (1970) found no correlation between soil (total) and plant lead contents. In this study, the vegetable (lettuce, cabbage, carrot, beet, potato, tomato, peas, spinach, etc.) lead content ranged from 0.4 to 1.9 mg/kg (dry weight), and soils supporting the crop showed a range of 6 to 230 mg/ kg. Plant lead uptake

increased little in response to an increase in total lead concentration of soils (Ter Haar, 1970; McIntyre, et al., 1977; Dowdy and Larson, 1975; Lagerwerff, 1972; John and Van Laerhoven, 1972; Andersson and Nilsson, 1972). Other investigations, however, suggested that soluble or extractable lead was a better indicator of the availability of lead to plants (MacLean et al., 1969; Kerin, 1975; Dudas and Pawluk, 1975). Although a strong positive correlation was found between total and extractable lead in heavily contaminated soils (extractable lead >90 mg/kg), this correlation was not evident in uncontaminated areas (Kerin, 1975). Cole (1977) noted that the addition of 1 800 mg Pb/kg to soil of various lead salts resulted in almost identical concentrations of soluble lead immediately after the addition of the lead salt or after 48 hours. These soluble lead levels ranged from 0.14% to 0.58% of the total lead added.

Different parts of plants accumulate lead to a different degree. In general, the fruiting and flowering parts accumulate the smallest amounts of lead. In a greenhouse experiment, Motto et al. (1970) noted that the edible parts of carrot, tomato, corn, lettuce, and potato plants grown in soils containing 76 to 164 mg Pb/kg had lead levels of 1.3 (corn kernels) to 16 mg/kg (carrots). The lead concentrations were relatively higher in the leaves (up to 74 mg/kg in corn leaves) than other parts of these plants.

When the same experiments were conducted with sand containing 1 to 4 mg Pb/kg, the edible parts of these plants contained lead levels of 0.6 to 21 mg /kg. However, the maximum levels of lead (up to 764 mg/kg) were associated with the roots of tomato, potato, and lettuce plants. Similar observations were made by Jones et al. (1973) while working with perennial rye grass in solution cultures containing 1 mg Pb/L as Pb $(NO_3)_2$; the plants removed 95% of the lead from the nutrient solution, and the roots contained 57% to 80% of the added lead.

Toxicity of lead to plants differs with the plant species. Beans grown in soil containing 820 mg Pb/kg (dry weight) showed poor growth and spotty discolouration, whereas peanuts were unaffected (Berg, 1970). A significant difference in the yield of oats and red clover grown in pots could occur at soil lead concentration above 50 mg/kg (Von Hodenberg and Finck, 1975); however, John and Van Laerhoven (1972) reported no effect on the yield of oats in response to an addition of 1000 mg Pb/kg as $Pb(NO_3)_2$, $PbCl_2$, or $PbCO_3$. Lead chloride concentrations of 125 mg Pb/kg have been reported to decrease the Ca, Mg, K, and P uptake by corn plants and reduce their growth in greenhouse experiments (Walker et al., 1977).

Cole (1977) reported that lead compounds added to soil modified soil biological activity; a reduction in amylase synthesis was initiated at concentrations of 450 mg Pb/kg (as $PbCl_2$ and PbS) of soil. Debosz et al. (1985) noted that the addition of 500 or 1 000 mg Pb/kg to natural or clay amended soils did not have an appreciable adverse effect on the extent of carbon mineralization after 16 days of incubation.

## 7.2 Criteria from the Literature

Table 7.1 shows the criteria from various jurisdictions to protect crops from harmful effects of lead in irrigation water. The limits for lead in irrigation water are strikingly similar in magnitude among most jurisdictions. This similarity in lead criteria suggests a common source and perhaps a lack of new information with regard to lead toxicity in the soil-plant-water system.

Table 7.1. Lead Criteria for Irrigation

| Criteria Statement | Criteria Value (µg Pb/L) | Jurisdiction | Date | Reference |
|---|---|---|---|---|
| Recommended maximum concentrations of lead in irrigation water are: 5.0 mg/L for continuous use on all soils; 10.0 mg/L for a 20-year period on neutral and alkaline fine textured soils | 5 000<br>10 000 | U.S. EPA | 1972 | U.S. EPA (1972)* |
| Recommended working level for lead in irrigation water = 5. 0 mg/L | 5 000 | Australia | 1974 | Hart (1974) |
| Recommended maximum concentrations of lead for irrigation water: used continuously on all soils=5.0 mg/L; for up to 20 years on fine textured soils of pH 6.0 to 8.0 = 10.0 mg/L | 5 000<br>10 000 | Ontario | 1984 | OME (1984)+ |
| Recommended maximum concentrations of lead in irrigation waters: for continuous ·use 5.0 mg/L; for intermittent use = 10.0 mg/L | 5 000<br>10 000 | Inland Waters Directorate | 1980 | Demayo et al. (1980b) |
| Maximum average concentration for the normal irrigation period = 2 mg/L | 2 000 | U.K. | 1984 | Mance et al. (1984) |
| Maximum acceptable concentration of total lead in irrigation water = 10.0 mg/L | 10 000 | Manitoba | 1983 | MDEWSH++ (1983) |
| Concentration of total lead in irrigation water should not exceed 0.2 mg/L for continuous use on all soils, and 2.0 mg/L for use on neutral and alkaline fine textured soils for up to 20 years | 200<br>2 000 | CCREM | 1987 | CCREM# (1987) |

* U.S. Environmental Protection Agency
\+ Ontario Ministry of Environment;
++ Manitoba Department of Environment and Workplace Safety and Health
\# Canadian Council of Resource and Environment Ministers

The Canadian (CCREM, 1987) and the U.K. (Mance et al., 1984) water quality, guidelines recommended much lower lead levels in irrigation water. Both these guidelines were aimed at limiting the accumulation of lead in agricultural soils to acceptable levels. The U.K. guidelines assumed an irrigation rate of 500 mm annually for 50 years, whereas CCREM based their calculations on an irrigation rate of 1000 mm/y for 100 years. Assuming soil bulk density of 1 500 kg/$m^3$ and accumulation depth for applied lead of 0.15 m, the Canadian guidelines allow a build-up in agricultural soils of about 100 (in acid soils) to 200 mg/kg (in neutral and alkaline soils), and the U.K. guidelines allow a buildup of 225 mg/kg (dry weight) in agricultural soils. It would appear that the Canadian (CCREM) guidelines were much more conservative than all other jurisdictions in Table 7.1.

The justification for safe lead levels of 5 mg/Land 10 mg/Lin irrigation water, recommended by the Inland Waters Directorate (IWD), was based upon accumulation of added lead in the top 10 cm of a soil with bulk density of 1 500 kg/$m^3$. It was assumed that 1.0 $m^3$ of water was needed to irrigate 1.0$m^2$ of agricultural

land in a year, and that losses of lead due to plant uptake or leaching through the profile were negligible. Based on these assumptions, Demayo et al. (1980, IWD) concluded that the maximum lead con centration of 5 mg/Lin irrigation water would increase the lead content of soil by 3.3 mg/kg/y. However, this increase ls in error, and instead should be 33.3 mg/kg/y as shown below:

Mass of 1 $m^2$ of 10 cm deep soil 1.0 $m^2$ × 0.1 m × 1500 kg/$m^3$ = 150 kg

Amount of Pb added to soil (1.0 $m^2$ × 0.1 m) by irrigation water (5 mg Pb/L) @ 1.0 $m^3$/ y

= 5 mg Pb/L × 1.0 $m^3$/ y × $10^3$L/$m^3$ × 1/150 kg soil

= 33.3 mg Pb/kg/y

## 7.3 Recommended Criteria

It is recommended that (a) for neutral and alkaline fine textured soils the maximum total lead concentration in irrigation water should not exceed 400 µg Pb/L at any time; (b) the concentration of total lead in irrigation water for continuous use on all other soils should not exceed 200 µg/L at any time.

## 7.4 Rationale

Criteria to protect vegetation from adverse effects of lead in irrigation water are based on information presented in CCREM (1987), Motto et al. (1970), and Tornabene et al. (1977). Laboratory experiments suggest that detrimental effects of lead on plants may occur at soil lead concentrations well below 100 mg/kg (Van Hodenberg and Finck, 1975). On the other hand it has been suggested that a concentration of at least 000 mg Pb/kg of dry weight must be present in soils (except sandy soils) before any effects of lead can be observed (Tornabene et al., 1977). On the average, lead in edible portions of plants excluding roots (Table 7.2) and in pastures (Table 7.3) grown in soils containing 1 000 mg Pb/kg (dry weight) is 24. 3 and 15.7 mg/kg (dry matter), respectively (similar values of lead in animal feed were used in establishing a lead criterion for livestock water supply in Chapter 7).

Sands containing lower lead levels (1.0 to 4.0 mg/kg) tend to contribute as much lead to the edible parts of vegetables grown in them as soils containing higher lead levels (76 to 164 mg/kg; Motto et al., 1970). This may have been the consequence of the lower cation exchange capacity (CEC) of the sandy soils (e.g., CEC of fine sandy loam = 5-10 meq/ 100 g) compared to that of fine textured soils (e.g., CEC of clay loam = 15-30 meq/100 g). In view of these facts, the critical level of lead in sandy soils must be reduced at least by a factor of 3. Further reduction in soil lead level may be desirable in acidic sandy soils, because lead uptake by plants increases at low pH's. The effects of pH and CEC factors suggest that the safe concentration of lead in soil (causing no adverse effects) should be less than 300 mg/kg as opposed to 1 000 mg/kg suggested by Tornabene et al. (1977) above.

As with the Canadian water quality guidelines (CCREM, 1987), therefore, the lead levels of 100 mg Pb/kg (dry weight) for acid and 200 mg Pb/kg (dry weight) for neutral and alkaline agricultural soils were considered to be safe levels in this document. The criterion proposed by CCREM (1987) for acidic soils was, therefore, adopted. However, the 20-year irrigation period for neutral and alkaline soils was considered too short to provide long-term protection to soils. Instead, the criterion for neutral and alkaline soils was derived for a long-term (100 years) or continuous use of land, based on assumptions specified in the CCREM (1987). Consequently, the recommended criteria are the same or consistent with the CCREM (1987) guidelines.

An example of calculations involved in the derivation of criteria in this document is shown below:

Given (i) the bulk density of a soil to be 1 500 k g/ $m^3$, (ii) the concentration of lead in irrigation water at 400 µg/L, (iii) the irrigation rate of 1.0 $m^3/m^2/y$. and (iv) the lead in irrigation water to be retained in the top 15 cm of the soil, the soil in question will accumulate lead at the rate of:

$$0.4\ \frac{mg\ Pb}{L} \times 1.0\ \frac{m^3}{m^2 y} \times \frac{1}{0.15m} \times \frac{m^3}{1500\ kg\ soil} \times 1000 \frac{L}{m^3} = 1.8 \frac{mg\ Pb}{kg - soil\ y}$$

provided there is no loss of lead from the soil. At this rate, it will take over 100 years for an alkaline fine textured soil to accumulate lead to the recommended safe level of 200 mg/kg.

In practice, lead levels of this magnitude are unlikely to be encountered in irrigation water, and for the majority of cases the much lower criteria for the protection of aquatic life will apply to waters being used for irrigation.

Table 7.2. Mean Values of Lead in Various Parts of Seven Edible Plants at Three Rates of Soil Contamination in British Columbia (John and Van Laerhoven, 1972)

| **Plant** | | **Plant Pb (mg/kg dry weight)** | | |
|---|---|---|---|---|
| **Name** | **Part** | **Control** | **200 mg Pb/kg** | **1 000 mg Pb/kg** |
| Leaf lettuce | leaves | 2.5 a[a] | 3.0 a | 54.2 b |
| | roots | 5.8 a | 84.5 b | 867.7 c |
| Spinach | leaves | 0.7 a | 7.9 b | 39.2 c |
| | roots | 4.7 a | 73.3 a | unavailable |
| Broccoli | leaves | 7.2 a | 8.4 a | 18.4 b |
| | roots | 6.5 a | 83.0 a | 745.6 b |
| Cauliflower | leaves | 5.3 a | 6.3 a | 11.8 b |
| | roots | 2.5 a | 55. 1 b | 532.2 c |
| Oats | grains | 3.2 a | 4.4 a | 4.9 a |
| | husks | 11. 1 a | 11 .8 a | 1 6.4 a |
| | leaves | 6.0 a | 6.8 a | 20. 1 a |
| | stalks | 1.6 a | 2.5 a | 9.2 a |
| | roots | 4.5 a | 82.o a | 396.6 b |
| Radish | tops | 3.7 a | 9.9 a | 1 4.3 a |
| | tubers | 6.3 a | 7.0 a | 44.6 b |
| Carrot | tops | 2.3 a | 8.0 b | 17.6 c |
| | tubers | 1.9 a | 5.3 a | 41.0 b |
| | roots | 8.9 a | 241.7 b | 561.4 c |

[a]Values within a row of means, followed by the same letter do not differ significantly at the 5% level.

Table 7.3. Pb in Herbage from Upland and Lowland Pastures in Wales (Alloway and Davies, 1971)

| **Sample Number** | **Site** | **Pb in plants (mg/kg dry matter)** | **Dominant plant species[a]** | **Soil Pb Content (mg/kg)** | **Soil pH** |
|---|---|---|---|---|---|
| 1a | Frongoch | 2.6 | R, T, M, Cl | | |
| 1b | Frongoch | 1.9 | R, T, M | 60 | 5.7 |
| 1c | Frongoch | 5.4 | Cl | | |
| 2 | Ceunant | 17.7 | R, T, C, Cl | 2 400 | 5.7 |
| 3 | Ceunant | 1. 5 | R, T, C, Cl | 630 | 5.0 |
| 4 | Ceunant | 10.2 | R, T, C, Cl | - | 4.8 |
| 5 | Cwm Ystwyth | 74.2 | Fo, S | 3 600 | 4.0 |
| 6 | Clarach | 17.0 | Fo, S | 3 680 | 5.2 |
| 7 | Parys Mt. | 66.4 | C | 890 | 5.1 |

| Sample Number | Site | Pb in plants (mg/kg dry matter) | Dominant plant species[a] | Soil Pb Content (mg/kg) | Soil pH |
|---|---|---|---|---|---|
| 8 | Parys Mt. | 40.9 | B | | |
| 9 | Parys Mt. | 6.1 | C | 220 | 5.0 |
| 10 | Parys Mt. | 2.5 | C, R, T | 340 | 5.1 |
| 11 | Llanafan | 21.1 | R, M, T, Cl | 2 050 | 5.0 |
| | | Av. = 15.7 | | | |

[a]Plant species:
R = ryegrass (*L. perenne*) M = meadow fescue (*F. pratensis*);
B = bent (*A. tenuis*);
T = timothy (*P. pralense*);
Fo = sheep fescue (*F. ovina*);
S = sedges (*Carex* spp.);
Cl = clovers (*Trifolium* spp.);
C = cocksfoot (*D. glomerata*).

## 8. RESEARCH AND DEVELOPMENT NEEDS

Several research needs, as noted below, were identified during preparation of this document.

1. Since human's lead intake comes from food, water, and air and since all intakes vary greatly and independently, it is not correct to correlate only one intake with blood lead values or other effects. A knowledge of lead intakes from all sources is lacking in detail and needs further refinement. Epidemiological studies so far have produced low correlation between, for instance, lead in water and blood-lead levels. Further studies need to define more carefully critical blood-lead levels and their relationship to lead uptake from all sources.
2. Objectives/criteria developed to date have addressed the biological effects of single compounds. This is largely due to a lack of data dealing with interactions among multiple contaminants. Research is needed to examine the significance of metal mixtures found in the environment at or less than objective/criteria levels and to correlate their toxicity with effects found in the environment.
3. Minimum daily intakes of lead causing harmful effects in livestock have not been well defined in the literature. Investigations with low doses of lead are needed to define the minimum dose causing clinical and sub-clinical toxicosis in livestock.
4. There is little information on the toxicity of lead to marine organisms. Acute and chronic bioassays are needed on marine species frequenting British Columbia coastal waters.

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