Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses (Irrigation and Livestock Water)

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Contents

Introduction

Canadian Water Quality Guidelines (CCREM 1987) was developed to provide basic scientific information on the effects of water quality variables on the uses of Canadian waters (including raw water for drinking water supply, aquatic life, agricultural uses, recreation and aesthetics, and industrial water supplies). It was designed to provide a means of assessing water quality issues and concerns and to aid in establishing site-specific water quality objectives. It contains recommendations on tolerable concentrations of a variety of inorganic, organic, and radiological chemicals as well as biological parameters. The chapter on agricultural uses includes guidelines for nearly 25 water quality chemicals or variables. Periodic amendments to the original document have resulted in guidelines for a number of priority pesticides (e.g., carbofuran, glyphosate, and atrazine) and other compounds.

Agricultural water guidelines were developed in response to a request to the CCME by organizations and jurisdictions involved in agricultural operations. The original approach adopted in deriving the agricultural water guidelines involved the review of existing guidelines obtained from many sources. If these guidelines were considered appropriate for Canadian environmental conditions, they were adopted as Canadian water quality guidelines. If the guidelines were not applicable to Canadian conditions, but additional scientific information was available, they were modified appropriately and then adopted. For many substances, however, guidelines from other jurisdictions were either not available or could not be appropriately modified. Therefore, the need for a consistent, scientifically defensible approach for the derivation of guidelines for priority substances was identified by the members of the CCME Task Force on Water Quality Guidelines.

The protocols, originally published in 1993 as an appendix to CCREM (1987), provide a consistent, scientifically defensible approach to deriving guidelines for irrigation and livestock water to protect crops and livestock from contaminants. Users of these guidelines (e.g., resource managers and farmers) are reminded that these values are recommended concentration limits on contaminants in irrigation and livestock water; above these limits, possible harm to crops and livestock may result. Remedial action to be taken in the event of water contaminated above guideline levels is beyond the scope of these protocols and is the responsibility of individual water users and/or jurisdictions. The protocols allow for site-specific objectives that are tailored to a particular farm or region for which national water quality guidelines may not be appropriate. It is recognized that combinations of chemicals are potentially toxic mixtures that must be assessed; however, an acceptable method of determining the risk of mixtures has not been developed. Thus these protocols do not account for mixtures, only individual contaminants. When an acceptable methodology for addressing the potential toxicity of mixtures is available, these protocols will be updated.

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A Protocol for Deriving Water Quality Guidelines for Irrigation Water

Introduction

Canada is a world leader in the production of many agricultural crops, especially wheat and other cereal grains. Within many regions of Canada, however, insufficient precipitation during the critical portions of the growing season may decrease productivity. In these areas, irrigation of agricultural crops is required to maintain high growth rates and yields. For the purposes of this protocol, a crop is defined as any terrestrial plant grown for economic profit or personal use.

In 1970 (the last year for which Statistics Canada collected these data), almost half (47% or ~196 000 ha) of all irrigated lands was used for the production of tame hay and pasture crops (Statistics Canada 1971). Cereals accounted for another quarter (24%), while other crops such as tobacco, potatoes, sugar beets, vegetables, and tree fruits made up the balance. In 1990, Alberta had the largest area of farmland under irrigation, with over 458 000 ha, representing almost 64% of the Canadian total (Statistics Canada 1992). British Columbia, Saskatchewan, and Ontario accounted for 85% of the remaining portion of the total area receiving irrigation.

Hess (1986) indicated that $>2.7 \times 10^9$ m^3 of water are used annually for irrigation on agricultural lands. Of this total, roughly 89×10^6 m^3 (3.3%) of water are drawn from groundwater sources. In some provinces, groundwater is more important for satisfying irrigation requirements; over 10% of the total water used for irrigation in Ontario and British Columbia comes from groundwater.

Until recently, concerns about the quality of water used for irrigation have focused largely on salinity (Environment Council of Alberta 1982). In addition, concern over the potential impacts of specific variables such as selenium, boron, chloride, and a number of metals and other trace ions (which may originate in irrigation waters) on agricultural crops has resulted in the development of irrigation water guidelines for these elements by the Saskatchewan Water Corporation (1988). The potential effects of pesticides, industrial pollutants, and other environmental contaminants in irrigation waters, however, have not been adequately addressed. The potential impact of pesticides is of obvious immediate concern to the farmer (and the consumer) since the use and re-use of irrigation water containing pesticide residues may adversely affect sensitive crop species (Davis et al. 1989).

For those contaminants that are persistent and do not degrade (e.g., heavy metals), concentrations causing adverse effects to crops may be reached due to accumulation in the soil environment. It has been the philosophy in the past to allow an accumulation of toxins in the soil from irrigation water for approximately 100 years before adverse effects would occur (CCREM 1987). However, it is no longer acceptable to merely delay the onset of toxicity. Rather, an alternate source of water free of the contaminant should be sought if accumulation is occurring. The guidelines derived from this protocol are recommended concentration limits designed to assist farmers in determining the quality of their irrigation water. They may also be used to assist local regulatory organizations in developing site-specific objectives and in implementing control measures.

Background

Since the publication of *Canadian Water Quality Guidelines* (CCREM 1987) by the Canadian Council of Resource and Environment Ministers (now the Canadian Council of Ministers of the Environment [CCME]), a number of concerns have been raised regarding the approach used to derive guidelines for irrigation. The agricultural uses chapter of CCREM (1987) indicated that interim guidelines were based on the available criteria proposed by the U.S. Environmental Protection Agency (National Academy of Sciences/National Academy of Engineering 1973). These criteria were evaluated and adopted as Canadian water quality guidelines when they were considered appropriate for Canadian conditions. The absence of accompanying rationale in the 1987 document, however, prevents a scientific evaluation of the criteria presented (i.e., key studies) and of the procedures used to derive the recommended guidelines. The irrigation water guidelines that have been derived more recently (after 1987) are supported more scientifically, but still suffer from the absence of an established and approved protocol.

The protocol recommended herein was designed to warn of possible adverse effects on crops if contaminated irrigation water from any source is used. Remedial action to be taken in cases of contamination is up to individual users and jurisdictions and is beyond the scope of this protocol. Soil organisms that may be affected (e.g., microbes and invertebrates) are also not covered by this protocol, but are considered in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* developed by the CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites (CCME 1996). Also, maximum residue limits (MRLs) of toxins (e.g., pesticides) in plant and animal tissues are developed and administered by Health Canada under the Canadian Food and Drugs Act and Regulations to protect human consumers. Users of the guidelines derived from this protocol are reminded that these values are recommended concentration limits on contaminants in irrigation water above which possible crop damage may result.

Water quality guidelines are based on two critical pieces of information: (1) the sensitivities of crops measured by acceptable application rates in kilograms of active ingredient per hectare ($kg\ a.i.\cdot ha^{-1}$) for pesticides or by acceptable soil concentrations in milligrams of contaminant per kilogram of soil ($mg\cdot kg^{-1}$) for industrial and other chemicals; and (2) maximum irrigation rates for crops in litres per hectare per annum ($L\cdot ha^{-1}\cdot a^{-1}$). Supplementary information is also required and used in the derivation process. The following sections provide the details of the protocol, including minimum data set requirements, derivation methods, and review procedures.

Guiding Principles

The following guiding principles for deriving water quality guidelines for irrigation water are based on the philosophy adopted by the CCME (CCME 1991):

- In deriving water quality guidelines, all available data on crops grown in Canada should be considered. Where data are available but limited, interim water quality guidelines are deemed preferable to no water quality guidelines.

- The sensitivities of each species and life stage of Canadian crop species should be considered in the derivation of water quality guidelines.

- A single value should be recommended as the water quality guideline for irrigation water, based on data from the most sensitive crop species. In fields that grow only less sensitive species, for which the national guideline may be too conservative, site-specific objectives more appropriate to that operation (i.e., based on the less sensitive species being grown) may be used instead. These guidelines should be based on chronic toxicological data when available.

- Unless otherwise specified, a guideline refers to the total concentration of the contaminant and its toxic transformation products in an unfiltered water sample representative of what may be applied in the field.

Overview of the Guideline Derivation Procedure

The following is a brief overview of the procedure for deriving irrigation water quality guidelines (Figure 1).

Selection of Variables

Candidate variables or chemicals for guideline derivation are selected from Canadian priority lists (i.e., CCME Task Force on Water Quality Guidelines Priority Pesticides List, Canadian Environmental Protection Act Priority Substances List). In addition, input from federal, provincial, and territorial agencies is solicited to identify regional concerns.

Literature Search

For each variable requiring water quality guidelines, comprehensive searches of the scientific literature and reviews of unpublished confidential company data (with permission) are conducted to obtain information on the following:

- physical and chemical properties
- environmental concentrations
- environmental fate and behaviour
- bioaccumulation potential
- acute toxicity to crops
- chronic toxicity to crops
- existing guidelines
- other relevant information

Data Set Requirements

In order to proceed with the guideline derivation process, certain minimum toxicological and environmental fate data set requirements must be met (see Data Set Requirements for Guideline Derivation).

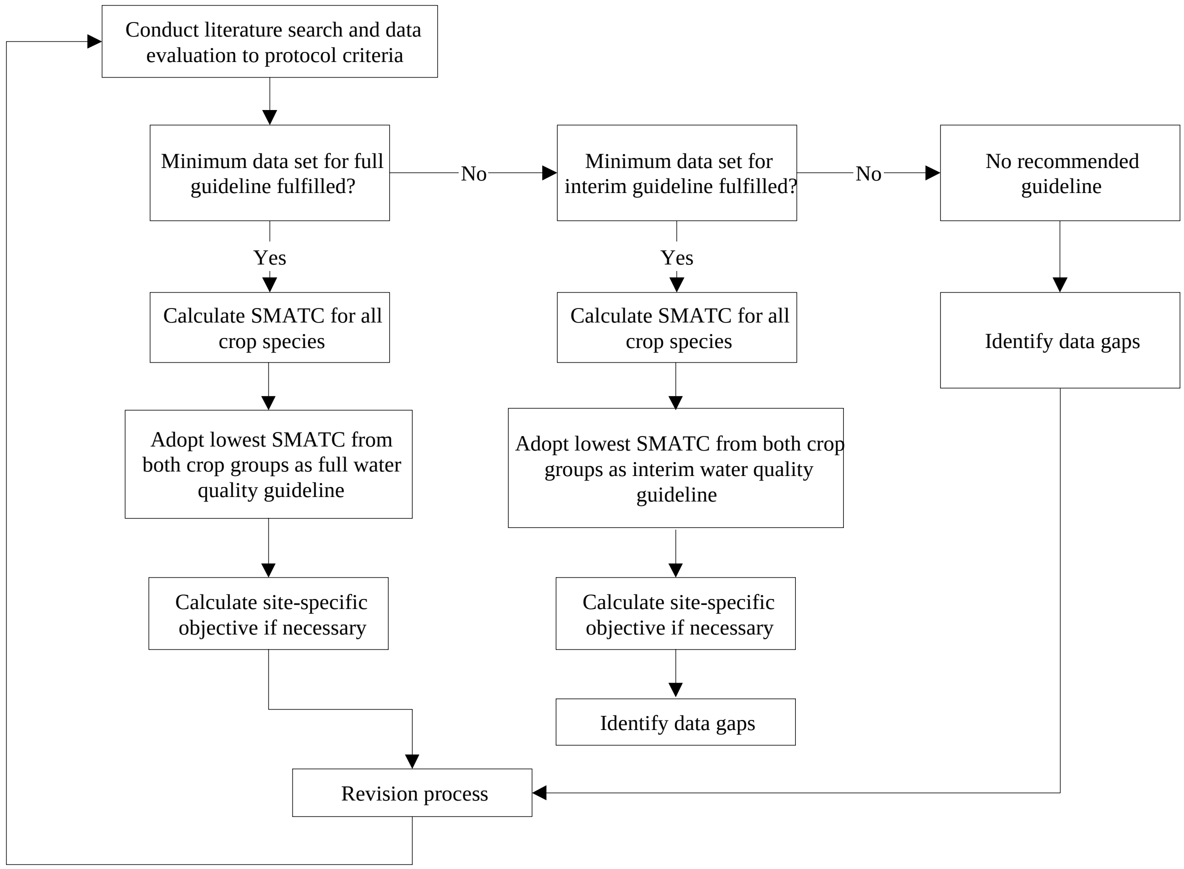

Figure 1. Procedure for deriving water quality guidelines for irrigation water.

Evaluation of Toxicological Data

Not all of the information reported in the scientific literature may be appropriate for deriving water quality guidelines for irrigation water. Each toxicological study obtained during the literature search must be evaluated to ensure that good field and laboratory practices were used in the design and execution of the experiment. Each study will be classified as primary, secondary, or unacceptable, depending on the degree to which the study fulfilled acceptable laboratory protocols.

Guideline Derivation

Water quality guidelines should be derived from dose–response data for sensitive crops grown in Canada. These data, in conjunction with an appropriate safety factor, provide the basis for calculating the acceptable soil concentrations (ASC) in milligrams of the substance per kilogram of soil ($mg \cdot kg^{-1}$) or acceptable application rates (AAR) in kilograms of active ingredient of the substance per hectare ($kg\ a.i. \cdot ha^{-1}$). The ASC is multiplied by the mass of one hectare of soil (kg), and the resulting mass (or AAR for each crop) is divided by the maximum irrigation rate ($L \cdot ha^{-1} \cdot a^{-1}$) for that species in Canada to obtain a species maximum acceptable toxicant concentration (SMATC) in micrograms per litre ($\mu g \cdot L^{-1}$). Water quality guidelines applicable to (a) cereals, tame hays, and pastures and (b) other crops may be derived by selecting the lowest SMATC in each group. Where data from irrigation studies are available, SMATCs are calculated instead by dividing the geometric mean of the lowest-observed-adverse-effect level (LOAEL) and the no-observed-adverse-effect level (NOAEL), respectively, by an appropriate uncertainty factor.

Data Set Requirements for Guideline Derivation

Minimum Toxicological Data Set Requirements: Full Guideline

Water quality guidelines for irrigation are designed to protect the most sensitive species and life stages of agricultural crops grown in Canada. It is essential that guidelines be based on data from a variety of species and preferentially consider tests in which crops were exposed to contaminants in irrigation water. For these reasons, the following minimum toxicological data set has been established:

Cereals, tame hays, and pastures (e.g., wheat, barley, sorghum, canary grass, alfalfa, clover, etc.)
- At least three studies on three or more species of cereals, tame hays, or pastures grown in Canada are required.

- Of the above studies, at least two must be chronic tests (entire growing season) that consider sensitive and biologically relevant endpoints (e.g., yield at harvest, growth rate, etc.). Long-term irrigation studies are preferred.

Other crops
- At least three studies on five or more crop species grown in Canada are required, including at least two of the following families: Leguminosae (e.g., soybeans, peas) not already included as pasture; Compositae (e.g., lettuce, sunflower); Cruciferae (e.g., cabbage); Cucurbitaceae (e.g., cucumber); Liliaceae (e.g., onion); Solanaceae (e.g., tomato); Umbelliferae (e.g., carrot); and Chenopodiaceae (e.g., sugar beet).

- Of the above studies, at least two must be chronic tests (entire growing season) that consider sensitive and biologically relevant endpoints (e.g., yield at harvest, growth rate, etc.). Long-term irrigation studies are preferred.

Minimum Toxicological Data Set Requirements: Interim Guideline

In cases where the minimum data set requirements for the derivation of full water quality guidelines are not met, interim guidelines may be derived provided that the following minimum data set requirements are met:

Cereals, tame hays, and pastures
- At least two studies on two or more cereals, tame hays, or pasture crops grown in Canada are required.

Other crops
- At least two studies on two or more plant species grown in Canada are required, including at least two of the following groups: Leguminosae, Compositae, Cruciferae, Cucurbitaceae, Liliaceae, Solanaceae, Umbelliferae, and Chenopodiaceae.

Rationale for Minimum Toxicological Data Set

Vascular plants exhibit a wide range of sensitivities to environmental contaminants. Some chemicals, such as herbicides, are produced and marketed for their toxicity to plants. The minimum data set requirements were selected to cover a range of agricultural crops that could be exposed to contaminants in irrigation water. The effects of contaminants on cereals, tame hays, and pastures are particularly important because these crops accounted for almost 71% of the total irrigated land area in 1970 (Statistics Canada 1971). (This was the last census in which Statistics Canada collected this information.)

The minimum data set requirements ensure that the resultant water quality guidelines are applicable to a variety of species under irrigation in Canada and especially those of major economic importance (i.e., crops). A preliminary investigation of the databases available on the effects of seven herbicides commonly used on crops (dinoseb, dicamba, bromoxynil, and four triazine herbicides) determined the nature and extent of information coverage with respect to the minimum data set requirements specified above. For dinoseb, toxicity data for nine species of cereals, tame hays, and pastures were found (Kent et al. 1991). In the worst-case scenario of finding data for only the three least-sensitive of these crops (as required by the minimum data set above), the protocol would still protect the most sensitive of this group. This analysis also held true when five (minimum required by protocol) least-sensitive crops of 14 from the other crops group (e.g., barley, lettuce, cucumber, alfalfa, tomato, etc.) were selected for which dinoseb toxicity data were available. Five species were required due to the wider range of responses in this group in comparison to tame hays, pastures, and cereals. Similar results were found in an assessment of the database of toxicological studies for the herbicides dicamba and bromoxynil. This analysis suggests that the protocols are likely to protect crops.

Availability of Minimum Toxicological Data Set

It is difficult to assess the availability of toxicological data on agricultural crops. The Canadian water quality guideline documents developed prior to this protocol for four triazine herbicides (atrazine, metribuzin, cyanazine, and simazine) did not provide complete summaries of the available data. The required studies for four other herbicides (dinoseb, dicamba, diclofop-methyl, and bromoxynil), however, were found, suggesting that this would probably be true for other agricultural herbicides and pesticides as well. Other compounds (e.g., industrial chemicals, pulp and paper mill effluents, heavy metals, etc.) are unlikely to have adequate information available on their effects to agricultural crops.

Minimum Environmental Fate and Behaviour Data Requirements

The environmental fate and behaviour of contaminants are influenced by factors specific to each chemical and the environment in which it is found. In order to understand the complex interactions in the environment, the major fate processes and persistence of the chemical in water, sediment, soil, air, and biota must be known. These processes include hydrolysis, oxidation, photolysis, aerobic and anaerobic degradation, sorption to organic matter in soil and sediment, leaching, volatilization, long-range transport, biotransformation, and bioaccumulation. It is not necessary to have detailed information on each of these processes. Rather, the intent is to identify the major environmental pathways and fate of the chemical in the environment, with special attention to those processes that affect the potential contamination of water sources for agricultural uses. At a minimum, the information should be collected and assessed on the following:

- the mobility of the chemical in the environment
- the environmental compartments in which the chemical will most likely be distributed
- the types of chemical reactions and biological processes that take place during transport and after deposition
- the eventual chemical forms (i.e., biotic and abiotic transformation products)
- the persistence of the chemical in water (both groundwater and surface water), sediment, soil, and biota

Where possible, the persistence of the chemical should be expressed in terms of its DT_{50} (time to 50% dissipation of original concentration) or half-life.

Additional Information

The following are not required elements of the minimum data set for deriving the water quality guidelines, but are essential in assessing the environmental impact and fate of the substance and should be included when available:

- production and uses
- physicochemical properties (and marketed formulations if a pesticide)
- methods of analysis and current detection limits
- sources to and concentrations in surface water, groundwater, sediments, atmosphere, and biota
- mutagenicity, teratogenicity, and carcinogenicity
- organoleptic effects (taste and odour)
- available guidelines, objectives, and standards from other jurisdictions

Evaluation of Toxicological Data

Because of the large variability in the quality of published studies, candidate toxicological information must be screened to ensure that experiments were conducted in a consistent and acceptable manner for each contaminant. The studies will be classified as primary, secondary, or unacceptable, based on the criteria described below.

Primary Toxicological Data

A full water quality guideline can be derived only from primary data. Toxicological studies should be designated as primary data if they meet the following criteria:

- Toxicity tests should follow generally accepted good laboratory practices of exposure and environmental controls (e.g., OECD 1992). Those tests that followed published protocols set by government agencies or standard-setting associations (e.g., ASTM) are generally acceptable. Other tests that employed more novel protocols will be critically evaluated on a case-by-case basis.

- Toxicity tests must report the concentrations in irrigation water (in micrograms per litre [$\mu g \cdot L^{-1}$]) or application rates (in kilograms of active ingredient per hectare [$kg\ a.i. \cdot ha^{-1}$] if a pesticide or in milligrams per kilogram of soil [$mg \cdot kg^{-1}$ soil] for other contaminants), test duration, formulation, and application method used in the study.

- It is preferred that concentrations of the contaminant administered to plants be measured analytically, however, calculated concentrations or measurements taken in stock solutions are also acceptable.

- Toxicity tests in which crops were exposed to the contaminant in irrigation water are preferred. Studies in which plants were exposed by foliar or soil application are also acceptable.

- Full growing season tests are preferred for deriving water quality guidelines. Desired sensitive endpoints may include effects on embryonic development, early survival, growth, reproduction, and yield at harvest.

- Responses and survival of controls must be measured and deemed acceptable and appropriate for the life stage of the species used.

- Statistical procedures used to analyze the data from the study must be reported and of an acceptable scientific standard. Studies that report both Type I errors (α = probability of rejecting the null hypothesis when it is true) and Type II errors (β = probability of failing to reject the null hypothesis when the alternative hypothesis is true) are preferred. Since most studies do not report β (also referred to as power), this criterion cannot be strictly adhered to.

Secondary Toxicological Data

Interim water quality guidelines may be based on either primary or secondary data. Secondary toxicological data are generally acceptable tests, except one or more of the criteria specified above have not been met. Studies are classified as secondary if they meet the following criteria:

- Toxicity tests may employ a wider range of methodologies (e.g., measuring toxicity while the test species is exposed to additional stresses, such as low temperature, low light, post-exposure drought, etc.) than specified under Primary Toxicological Data.

- The acceptable test endpoints include lethality, as well as those listed for primary data.

- Responses and survival of controls must be measured and deemed acceptable and appropriate for the life stage of the test species used.

Unacceptable Toxicological Data

Toxicological data are generally considered unacceptable if the studies do not meet the criteria specified for primary or secondary data. Data are also unacceptable if insufficient information was reported to assess the test design, methods, or results. Unacceptable data may be upgraded to secondary or primary if supplementary information is available from related studies or obtained from the author.

All data included in the minimum data set should be primary to derive a full guideline. For an interim guideline, a primary or secondary study may be used. Unacceptable data are reported but not used in either derivation procedure.

Derivation of Guidelines

At present, no equivalent protocols or detailed scientific approaches are employed by other jurisdictions to derive water quality criteria, guidelines, objectives, or standards for irrigation water. This protocol was developed to assess the hazards of exposing crops to contaminated surface water or groundwater used for irrigation. It relies on the results of irrigation and other related studies, in conjunction with maximum irrigation rates in Canada, to derive water quality guidelines for crop protection. (Refer to Figure 1 for an overview of the procedure.)

For those toxins (e.g., inorganics such as heavy metals) that are bioavailable and do not break down, accumulation in the soil may occur over time and reach levels sufficient to cause adverse effects. The site receiving constant loadings of toxins should not accumulate these in either the short or long term. If this is the case, all inputs of the contaminant should be stopped to prevent further degradation of the soil. Hence, this water use should cease; the contaminated water should be treated and/or alternative sources of irrigation water should be found.

Long-term studies in which crops were exposed to contaminants via irrigation water are preferred for deriving water quality guidelines. When these studies are available, the species maximum acceptable toxicant concentrations (SMATCs) for crops in each group are calculated by dividing the geometric mean of the lowest-observed-effect concentration (LOEC) and the no-observed-effect concentration (NOEC) by an uncertainty factor (UF) of 10 as follows:

$$SMATC = (LOEC \cdot NOEC)^{0.5} \div UF$$

where

SMATC = species maximum acceptable toxicant concentration ($\mu g \cdot L^{-1}$)
LOEC = lowest-observed-effect concentration ($\mu g \cdot L^{-1}$)
NOEC = no-observed-effect concentration ($\mu g \cdot L^{-1}$)
UF = uncertainty factor of 10

When the NOEC equals 0, the geometric mean may be calculated by estimating this value as NOEC = LOEC ÷ 4.5 (see Appendix), otherwise the geometric mean would be meaningless.

When suitable irrigation studies are not available, the water quality guideline is derived by an alternate method. The first step is the determination of acceptable soil concentrations (ASC) (in milligrams per kilogram of soil [$mg \cdot kg^{-1}$]) for all crops in the two groups for which acceptable data are available. The ASC is an estimate of the soil concentration that would not result in adverse effects on crops over the course of one growing season. The ASC is calculated by dividing the geometric mean of the LOEC and the NOEC by an appropriate UF as follows:

$$ASC = (LOEC \cdot NOEC)^{0.5} \div UF$$

where

ASC = acceptable soil concentration ($mg \cdot kg^{-1}$ soil)
LOEC = lowest-observed-effect concentration ($mg \cdot kg^{-1}$ soil)
NOEC = no-observed-effect concentration ($mg \cdot kg^{-1}$ soil)
UF = uncertainty factor of 10

When the NOEC equals 0, the geometric mean may be calculated by estimating this value as NOEC = LOEC ÷ 4.5 (see Appendix).

This step is simple for those compounds whose environmental concentrations are normally reported in milligrams per kilogram of soil (e.g., industrial chemicals, heavy metals, etc.). For pesticides, which normally have application rates in kilograms of active ingredient per hectare, an analogous approach is used. The acceptable application rate (AAR) is calculated in place of the ASC by dividing the geometric mean of the lowest-observed-effect application rate (LOEAR) and the no-observed-effect application rate (NOEAR) by an appropriate UF as follows:

$$AAR = (LOEAR \cdot NOEAR)^{0.5} \div UF$$

where

AAR = acceptable application rate (kg ai$\cdot ha^{-1}$)
LOEAR = lowest-observed-effect application rate (kg a.i.$\cdot ha^{-1}$)
NOEAR = no-observed-effect application rate (kg a.i.$\cdot ha^{-1}$)
UF = uncertainty factor of 10

When the NOEAR equals 0, this value is estimated as NOEAR = LOEAR ÷ 4.5 (see Appendix). The geometric mean is calculated rather than an arithmetic mean because toxicity data generally do not follow a normal distribution but rather a log-normal curve (USEPA 1985). The ASC or AAR should be calculated for all plants in the two crop groups for which acceptable data are available. These values estimate the soil concentration or application rate that would not result in adverse effects on crops if applied over the course of one growing season. The AAR should not be confused with the application rates appearing on pest control product labels for product use on crops and/or through chemigation systems.

The UF is used to account for uncertainty in the estimate of the safe concentrations of the contaminant from the toxicological data available. Uncertainty in the ASC or AAR estimate occurs from differences in sensitivity within species (e.g., genetic variability, health of individuals, sex, life stage, etc.) and among species (i.e., extrapolating from one species to others), the sensitivity of the endpoints measured, variability in soil types, and other factors. A UF of 10 is recommended in the calculation of the ASC or AAR. This choice is supported by Fletcher et al. (1990), who reported mean sensitivity ratios of 10.5 ± 3.5 for 151 plant species to 16 herbicides. The minimum database requirements ensure that sensitive and economically important crops are represented in the toxicological database. If there is a higher degree of uncertainty in the ASC or AAR for other reasons (e.g., chemical persistence, extrapolation of acute tests to chronic exposures, or site-specific considerations), the UF may be increased up to 100. Professional judgment should be exercised to make this determination.

The next step is the calculation of the maximum amount of contaminant allowed in a 1 ha (100 m × 100 m) plot of a crop. For pesticides, this is simply the AAR per hectare. For other contaminants (e.g., industrial chemicals), this requires estimates of the average density of agricultural soils and the depth of soil that is irrigated. The average bulk density of agricultural soils can be estimated as 1300 $kg \cdot m^{-3}$ (Koorevaar et al. 1983), which should be used in the absence of site-specific data. CCREM (1987) used 15 cm in the calculation of irrigation water guidelines as the depth to which trace ions would be retained in a soil. Mobile contaminants (e.g., salts), however, can leach past the root zone of crops; many cereals, tame hays, and pastures have a root zone up to 1.5 m deep (Riewe 1990). The proper soil depth to use in this calculation should be determined from the environmental fate and behaviour. The maximum depth to which the contaminant has been found to leach in Canadian soils, to a maximum of 1.5 m (root zone depth), should be used as the depth of the irrigated soil. These data are often available for pesticides but not for many industrial contaminants. Therefore, in the absence of adequate studies on the leaching depth of the contaminant in Canadian soils, 15 cm should be used as a conservative estimate. The maximum allowable mass of contaminants other than pesticides in 1 ha is calculated as follows:

allowable contaminant mass
= ASC · soil mass
= ASC · soil bulk density · soil bulk volume
= ASC $mg \cdot kg^{-1}$ · 1300 $kg \cdot m^{-3}$ · (100 m·100 m · leaching depth in soil [m])

The allowable contaminant mass per hectare (in milligrams) is then used in conjunction with irrigation rates (IR) to calculate the SMATC. The maximum irrigation rate used in Canada simulates a worst-case scenario to ensure that the water quality guideline subsequently derived is adequate for all areas. For example, some areas in the Okanagan Valley in British Columbia require up to 1200 mm of irrigation per annum (equivalent to $1.2 \cdot 10^7$ $L \cdot ha^{-1} \cdot a^{-1}$) (CCREM 1987).

$$\text{SMATC} = (\text{contaminant mass} \div \text{IR}) \cdot 10^3$$

where

SMATC = species maximum acceptable toxicant concentration ($\mu g \cdot L^{-1}$)
contaminant mass is in milligrams
IR = irrigation rate per year = $1.2 \cdot 10^7$ $L \cdot ha^{-1}$
10^3 = conversion factor from milligrams to micrograms

The SMATC for the most sensitive species in each of the two crop groups, (a) cereals, tame hays, and pastures, and (b) other crops, is adopted as the water quality guideline for that group, and the lower of the two is adopted as the water quality guideline for irrigation water. SMATC values should also be calculated for all crops to allow for site-specific objectives. The water quality guidelines may require modification to meet these objectives because certain areas may not grow the most sensitive species, or sources of the contaminant other than irrigation water (e.g., natural background levels, fertilizer, atmospheric inputs, etc.) are present. The site-specific objective is calculated by determining a new allowable contaminant mass, which corrects for background and other sources of the toxin as follows:

site-specific allowable contaminant mass
= (ASC - background - other sources) · soil mass

This new contaminant mass is then used in the calculation of the SMATC as outlined above to determine the site-specific objective.

A Protocol for Deriving Water Quality Guidelines for Livestock Water

Introduction

A wide variety of livestock are raised in Canada for both export and domestic consumption. Because of their economic importance, cattle, sheep, swine, goats, horses, and poultry receive most of the attention in evaluations of agricultural production. Viable and economically important industries are also associated with the production of less common species such as rabbit, fox, mink, elk, and buffalo. For the purposes of this protocol, livestock is defined as any terrestrial animal kept for economic profit or personal use (e.g., cattle, pigs, poultry, waterfowl, etc.). Aquatic organisms raised as livestock (e.g., fish raised in aquacultures) are more appropriately covered by the water quality guidelines for the protection of aquatic life because of the differences in route of exposure of contaminants.

Successful livestock production depends on the availability of ample supplies of good quality water (Ayers et al. 1985). Water of inferior quality may cause adverse effects on the health of animals and, consequently, economic losses to their producers (Rowe and Hymas 1954). Contamination of livestock drinking water supplies by agricultural and industrial chemicals is of particular concern and is addressed by this protocol to derive livestock water guidelines. Residues of chemicals in foods consumed by humans are controlled under the Canadian Food and Drugs Act and Regulations administered by Health Canada. A general regulation limit of 0.10 $mg \cdot kg^{-1}$ has been set as the maximum residue level (MRL) of agricultural chemicals allowed in edible plant and livestock tissues unless otherwise specified. MRLs are legislative limits intended to protect human consumers of plant and animal products. (For a precise definition of "agricultural chemical" and a listing of MRLs for specific chemicals, consult sections B.01.001, B.15.002, and Table II of Division 15 of the Food and Drugs Act and Regulations [Health and Welfare Canada 1992].) CCME water quality guidelines derived from this protocol are recommended concentration limits on contaminants in livestock water above which possible harm to livestock may result.

Background

Since the publication of *Canadian Water Quality Guidelines* (CCREM 1987) by the Canadian Council of Resource and Environment Ministers (now the Canadian Council of Ministers of the Environment [CCME]), a number of concerns have been raised regarding the approach used to derive guidelines for livestock water. The agricultural uses chapter of CCREM (1987) indicated that guidelines were adopted from various jurisdictions when they were considered appropriate for Canadian conditions. It is difficult, therefore, to establish how the key studies were selected and which procedure was used to derive the guideline. Guidelines that were developed more recently are better supported, but still suffer from the absence of an established and approved formalized protocol. These efforts provided little guidance on how water quality guidelines should be established for the protection of livestock. The adequacy of the present approach of defaulting to the drinking water quality guidelines as a surrogate livestock water guideline (intended to prevent unacceptable residue levels for the protection of livestock and subsequent consumers) must be evaluated.

In keeping with the guiding principles for the derivation of Canadian water quality guidelines, this protocol was designed to protect livestock based on the following critical information:

- tolerable daily intake rates of the contaminant (in milligrams per kilogram per day [$mg \cdot kg^{-1} \cdot d^{-1}$])
- daily water intake rates (in litres per day [$L \cdot d^{-1}$])
- body weights (in kilograms [kg])
- potential for bioaccumulation in livestock

(Bioaccumulation is defined as the concentrating of a contaminant in an organism from its environment and food. A contaminant is any chemical, element, microbial organism, etc., or mixture that adversely affects livestock.) Supplementary information is also required and used in the derivation process. The protocol applies to all substances, including those that are known or thought to be carcinogenic. For these compounds, an assessment of the available data set will determine if the guidelines for Canadian drinking water quality should be adopted as interim guidelines for the protection of livestock. The following sections provide the details of the recommended protocol, including minimum data set requirements, derivation methods, and review procedures.

Guiding Principles

The following guiding principles for deriving water quality guidelines for livestock water are based on the philosophy adopted by the CCME (CCME 1991).

- In deriving water quality guidelines, all available data on all species of livestock raised in Canada should be considered. Where data are available but limited, interim water quality guidelines are deemed preferable to no water quality guidelines.

- The sensitivities of each species and life stage of Canadian livestock should be considered in the derivation of water quality guidelines. Where data on Canadian livestock species are not available, surrogate models should be used.

- A single value should be recommended as the water quality guideline for livestock water, based on data from the most sensitive livestock species. In operations that raise only less sensitive species, for which the national guideline may be too conservative, site-specific objectives more appropriate to that operation (i.e., based on the less sensitive species being raised) may be used instead. These guidelines should be based on chronic toxicological data when available.

- Unless otherwise specified, a guideline refers to the total concentration of the contaminant and its toxic transformation products in an unfiltered water sample representative of what may be ingested by livestock.

Overview of the Guideline Derivation Procedure

The following is a brief overview of the procedure for deriving water quality guidelines for livestock water (Figure 2).

Selection of Variables

Candidate variables or chemicals for guideline derivation are selected from Canadian priority lists (i.e., CCME Task Force on Water Quality Guidelines Priority Pesticides List, Canadian Environmental Protection Act Priority Substances List). In addition, input from federal, provincial, and territorial agencies is solicited to identify regional concerns.

Literature Search

For each variable requiring water quality guidelines, comprehensive searches of the scientific literature and reviews of unpublished confidential company data (with permission) are conducted to obtain information on the following:

- physical and chemical properties
- environmental concentrations
- environmental fate and behaviour
- bioaccumulation potential
- acute toxicity to birds and mammals
- chronic toxicity to birds and mammals
- mutagenicity, teratogenicity, and carcinogenicity
- existing guidelines
- other relevant information (e.g., clinical reports)

Data Set Requirements

In order to proceed with the guideline derivation process, certain minimum toxicological and environmental fate data set requirements must be met.

Evaluation of Toxicological Data

Not all of the information reported in the scientific literature may be appropriate for deriving water quality guidelines for livestock water. Each toxicological study obtained during the literature search must be evaluated to ensure that good laboratory practices (e.g., OECD 1992) were used in the design and execution of the experiment. Each study will be classified as primary, secondary, or unacceptable, depending on the degree to which the study fulfilled acceptable laboratory protocols.

Guideline Derivation

Water quality guidelines should be derived from the results of appropriate chronic (or acute) exposure studies that consider the most sensitive life stages and endpoints. Studies in which the substance was administered via the oral route (i.e., in water, food, or by gavage) are desirable. The tolerable daily intake (TDI) is calculated by dividing the geometric mean of the lowest-observed-effect dose (LOED) and the no-observed-effect dose (NOED) by an appropriate uncertainty factor (USEPA 1985). The TDI is used, in conjunction with daily livestock water intake rates and body weights, to derive the final water quality guideline.

Data Set Requirements for Guideline Derivation

Minimum Toxicological Data Set Requirements: Full Guideline

Since water quality guidelines for livestock are designed to protect the most sensitive species and life stages of livestock raised in Canada, they are based on both avian and mammalian livestock data and preferentially consider long-term tests conducted on sensitive life stages. Because there is a wide variability in these data, the following minimum toxicological data set has been established:

Mammals

- At least three studies on three or more mammalian species are required, including at least two livestock species raised in Canada, one of which is a ruminant.
- Of the above studies, at least two must be long-term (preferably full life-cycle) tests that consider sensitive

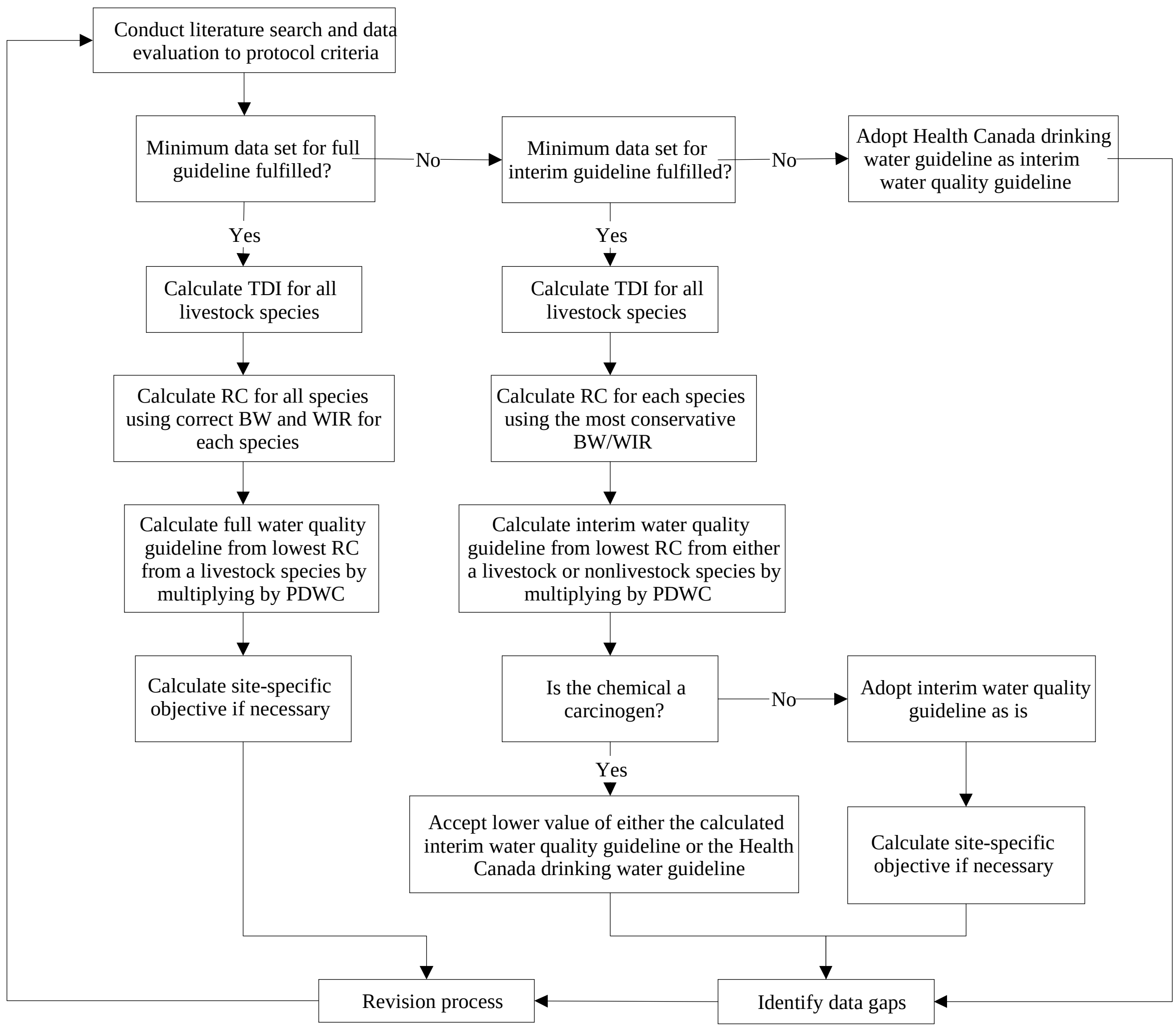

Figure 2. Procedure for deriving water quality guidelines for livestock water.

endpoints (e.g., growth, reproduction, developmental effects, and production parameters such as milk yield, litter size, feed conversion, etc.).

- At least one study on bioaccumulation in the tissues of at least one livestock species. When this information is not available, bioaccumulation studies on other biota or modeled estimates based on physicochemical properties (e.g., log octanol–water partition coefficient [log K_{ow}]) may be considered to derive a bioaccumulation factor (BAF) on a-case-by-case basis.

Birds

- At least two studies on two or more avian species are required, including at least one domestic poultry species raised in Canada.
- Of the above studies, at least one must be a long-term (preferably full life-cycle) test on a domestic poultry species that considers sensitive endpoints (e.g., growth, reproduction, developmental effects, and production parameters such as egg production, feed conversion, etc.).

In some cases, it may not be necessary to adhere rigidly to the minimum data set requirements. For example, the requirement for two chronic studies for mammals may be adjusted if acceptable information on acute-to-chronic ratios for mammals is available to convert the results of acute studies. Further, when acceptable evidence demonstrates that toxicity does not significantly increase with exposure period, or when environmental fate studies indicate that the potential for long-term exposure to the substance is highly unlikely, then the requirement for two chronic studies may not be necessary.

Minimum Toxicological Data Set Requirements: Interim Guideline

In cases where the minimum data set requirements for the derivation of full water quality guidelines are not met, interim guidelines may be derived provided that the following minimum data set requirements are met. If necessary, interim water quality guidelines may be derived from studies on nonlivestock mammals and/or poultry (e.g., rats, bobwhite quail, mallard duck, etc.), provided that the following minimum data set requirements are met:

Mammals

- At least two acute or chronic studies on two or more mammalian species raised in Canada are required, including at least one livestock species.

Birds

- At least one acute or chronic study on one or more avian livestock species raised in Canada is required.

Rationale for Minimum Toxicological Data Set

Because of the economic importance of mammalian and poultry livestock and their wide range of sensitivities to environmental contaminants, the relative toxicity of contaminants to these species must be known to ensure that they are adequately protected by the water quality guidelines. In addition, birds are known to be particularly sensitive to many environmental contaminants, such as pesticides (Hill and Camardese 1986). For most chemicals, however, the toxicological database will likely be dominated by rodent studies, which may help determine intraspecific variability in responses and mechanisms of toxicity. Variability in the toxicological data set is due to differences in the exposure route employed (e.g., oral, dermal, injection, etc.), species sensitivities, endpoints measured, life stage tested, test duration, and other factors.

The number and types of studies required for deriving the guidelines were selected by examining several typical databases on the effects of agricultural pesticides on livestock animals. These data suggest that real differences in the sensitivities of livestock to pesticides are likely to be detected if information is available for at least three mammalian and two avian species. This was empirically supported by data on dinoseb, which is representative of a commonly used herbicide. An estimate of the most sensitive LOAEL (derived from sheep, rabbit, rat, duck, and pheasant studies) was generally within one order of magnitude of the actual most sensitive LOAEL ($1.0\ mg \cdot kg^{-1} \cdot d^{-1}$ for rat reproductive toxicity).

Availability of Minimum Toxicological Data Set

A preliminary literature search found that the required number of acceptable toxicological studies was often available for pesticides but not for industrial chemicals. The water quality guidelines for livestock water (CCREM 1987) for four triazine herbicides (atrazine, cyanazine, simazine, and metribuzin) reported LD_{50} data for, on average, five mammals (including one ungulate and four rodents) and two birds. Minimum toxicological data set requirements were also met for three other herbicides (dinoseb, dicamba, and bromoxynil), suggesting that data availability for other pesticide classes (e.g., insecticides, fungicides, etc.) would be similar. Industrial contaminants, however, will likely have major deficiencies in their minimum data sets.

A major shortcoming in the minimum toxicological database is information on bioaccumulation in mammals and birds. While some studies exist, particularly on residues in milk, detailed bioaccumulation data in livestock will likely be available for only a portion of the chemicals requiring water quality guidelines. Model-derived estimates based on physicochemical properties, and studies on bioaccumulation in other biota and metabolism in livestock, may be used to fill data gaps, but will increase the level of uncertainty. Therefore, an additional uncertainty factor, the magnitude of which will be determined by the best available scientific judgment, will be required.

Minimum Environmental Fate and Behaviour Data Requirements

The environmental fate and behaviour of contaminants are influenced by factors specific to each chemical and the environment in which it is found. In order to understand the complex interactions in the environment, the major fate processes and persistence of the chemical in water, sediment, soil, air, and biota must be known. These processes include hydrolysis, oxidation, photolysis, aerobic and anaerobic degradation, sorption to organic matter in soil and sediment, leaching, volatilization, long-range transport, biotransformation, and bioaccumulation.

It is not necessary to have detailed information on each of these processes. Rather, the intent is to identify the major environmental pathways and fate of the chemical in the environment, with special attention to those processes that affect the potential contamination of water sources for agricultural uses. At a minimum, the information should be collected and assessed on the following:

- the mobility of the chemical in the environment
- the environmental compartments in which the chemical will most likely be distributed
- the types of chemical reactions and biological processes that take place during transport and after deposition
- the eventual chemical forms (i.e., biotic and abiotic transformation products)
- the persistence of the chemical in water (both groundwater and surface water), sediment, soil, and biota

Where possible, the persistence of the chemical should be expressed in terms of its DT_{50} (time to 50% dissipation of original concentration) or half-life.

Additional Information

The following are not required elements of the minimum data set for deriving the water quality guidelines, but are essential in assessing the environmental impact and fate of the substance and should be included when available:

- production and uses
- physicochemical properties (and marketed formulations if a pesticide)
- methods of analysis and current detection limits
- sources to and concentrations in surface water, groundwater, sediments, atmosphere, and biota
- mutagenicity, teratogenicity, and carcinogenicity
- organoleptic effects (taste and odour)
- available guidelines, objectives, and standards from other jurisdictions

Evaluation of Toxicological Data

Because of the large variability in the quality of published studies, candidate toxicological information must be screened to ensure that experiments were conducted in a consistent and acceptable manner for each contaminant. The studies will be classified as primary, secondary, or unacceptable, based on the criteria described below.

Primary Toxicological Data

A full water quality guideline can be derived only from primary data. Toxicological studies should be designated as primary if they meet the following criteria:

- Toxicity tests should follow generally accepted, good laboratory practices of exposure and environmental controls (e.g., OECD 1992). Those tests that followed published protocols set by government agencies or standard-setting associations (e.g., ASTM) are generally acceptable. Other tests that employed more novel protocols will be critically evaluated on a case-by-case basis.

- Toxicity tests must report the dosage rates (in milligrams per kilogram of body weight per day [$mg \cdot kg$ body weight$^{-1} \cdot d^{-1}$] for chronic tests and in milligrams per kilogram of body weight [$mg \cdot kg$ body weight^{-1}] for acute tests), exposure duration, formulation, and administration methods used in the study.

- It is preferred that concentrations of the contaminant administered to animals (dose) be measured analytically, however, calculated concentrations or measurements taken in stock solutions are also acceptable.

- Toxicity tests should administer the chemical to simulate exposures via drinking water. In general, tests that expose animals to contaminants in water and food by gavage, oesophageal cannula, or rumen fistula are appropriate. Exposure via other routes (e.g., intravascular, intramuscular, intraperitoneal, respiratory, subcutaneous, dermal, or ocular) are acceptable provided sufficient supplementary information on the pharmacokinetics (absorption, distribution, metabolism, and excretion) of the chemical is available and the dosage was measured.

- Full life-cycle tests are preferred in deriving water quality guidelines, however, partial life-cycle exposures are also acceptable. Desired sensitive endpoints include effects on development, growth, fecundity, production parameters such as milk yield, litter size, feed conversion, etc., and other significant biochemical, physiological, and behavioural parameters.

- Responses and survival of controls must be measured and deemed acceptable and appropriate for the life stage of the test species used.

- Statistical procedures used to analyze the data from the study must be reported and of an acceptable scientific standard. Studies that report both Type I errors (α = probability of rejecting the null hypothesis when it is true) and Type II errors (β = probability of failing to reject the null hypothesis when the alternative hypothesis is true) are preferred. Since most studies do not report β (also referred to as power), this criterion cannot be strictly adhered to.

Secondary Toxicological Data

Interim water quality guidelines may be based on either primary or secondary data. Secondary toxicological data are generally acceptable tests, except one or more of the criteria specified above have not been met. Studies should be classified as secondary if they meet the following criteria:

- Toxicity tests that administer the chemical via any exposure route are acceptable.
- Studies that generally do not meet acceptable laboratory practices but whose dose, duration exposure, and effects were established or can be derived without presumptions are acceptable.
- Responses and survival of controls must be measured and deemed acceptable and appropriate for the life stage of the test species used.

Unacceptable Toxicological Data

Toxicological data are generally considered unacceptable if the studies do not meet the criteria specified for primary or secondary data. Data are also unacceptable if insufficient information was reported to assess the test design, methods, or results. Unacceptable data may be upgraded to secondary or primary if supplementary information is available from related studies or obtained from the author.

All data included in the minimum data set should be primary to derive a full guideline. For an interim guideline, a primary or secondary study may be used. Unacceptable data are reported but not used in either derivation procedure.

Derivation of Guidelines

Two possible approaches to the derivation of water quality guidelines for livestock water are recommended, depending on the nature of the chemical under consideration. For both carcinogens and noncarcinogens, guidelines should be derived from a quantitative assessment of the risks to livestock. Depending on the availability of adequate studies and therefore the status of the guideline (i.e., full or interim), the actual guideline may either be derived from this protocol or adopted from the Health Canada drinking water quality guidelines (Health and Welfare Canada 1989a).

Derivation of Guidelines for Carcinogenic Substances

Many researchers believe that there is some probability of harm from carcinogens at any nonzero level of exposure (i.e., no threshold dose below which there is no effect). For this reason, derivation of guidelines requires assessment of the risks to water users associated with various exposures to carcinogens in water. This provides the scientific basis for deriving water quality guidelines by defining the concentrations of contaminants that represent negligible risks to consumers of contaminated water.

Quantitative risk assessments are conducted by Health Canada to derive drinking water quality guidelines for carcinogenic substances. These guidelines represent the probabilities of developing cancer (i.e., risks) in humans that are essentially negligible over extended (lifetime) exposure periods. Where there is no specific information indicating otherwise, it is presumed that these same guidelines should also provide adequate protection for livestock. The drinking water guidelines, however, are derived using highly conservative models, which may be too conservative for livestock purposes. Therefore, if adequate data are available for a full guideline, then the protocol for noncarcinogenic substances should be used. If only enough data are found for an interim guideline, then the lower of the interim guideline or the drinking water guideline should be adopted as an interim water quality guideline for livestock water. If not enough data are available for an interim guideline, then the drinking water guideline should be adopted as an interim water quality guideline for livestock water (Figure 2).

Derivation of Guidelines for Noncarcinogenic Substances

For noncarcinogenic substances, a hazard assessment procedure (consistent with the CCME [1991] protocol for the protection of aquatic life) is recommended for deriving water quality guidelines (Figure 2). The Canadian guidelines for drinking water may be used as water quality guidelines for livestock on an interim basis until detailed evaluations can be completed for each priority substance. Health Canada uses maximum residue limits in livestock products to protect human consumers from substances that may bioaccumulate in exposed birds and mammals (Health and Welfare Canada 1989b).

Because of improved resolution in predicting threshold toxic levels, chronic effects data are the most appropriate for deriving water quality guidelines. Therefore, chronic studies in which test animals were administered the chemical for a significant portion of their lifespan are preferred. When these data are not available, water quality guidelines may be derived from acute studies, provided that acceptable information on acute-to-chronic ratios is available (which enables the extrapolation of short-term results to long-term no-effect levels). Each study chosen for the derivation of guidelines must have a clear dose–response relationship, and the LOAEL must be statistically significant.

The first step in the guideline derivation procedure is the calculation of the tolerable daily intake (TDI) in milligrams per kilogram per day ($mg \cdot kg^{-1} \cdot d^{-1}$) for each species for which acceptable toxicological data are available. The TDI is operationally defined as “an estimate in milligrams per kilogram body weight per day of a substance which is not anticipated to result in any adverse health effects following chronic exposure to a population of livestock species, including sensitive subgroups. Adverse effects are considered as functional impairment or pathological lesions which may affect the performance of the organism or reduce its ability to respond to additional stressors” (Health and Welfare Canada 1990).

The TDI is calculated from the results of a chronic toxicity test in which sensitive endpoints were measured. It is calculated by taking the geometric mean of the LOAEL and the NOAEL from an acceptable toxicological study available on each species and subsequently dividing by an appropriate uncertainty factor:

$$\text{TDI} = (\text{LOAEL} \cdot \text{NOAEL})^{0.5} \div \text{UF}$$

where

TDI = tolerable daily intake ($mg \cdot kg^{-1} \cdot d^{-1}$)
LOAEL = lowest-observed-adverse-effect level ($mg \cdot kg^{-1} \cdot d^{-1}$)
NOAEL = no-observed-adverse-effect level ($mg \cdot kg^{-1} \cdot d^{-1}$)
UF = uncertainty factor

When the NOAEL equals 0, it can be estimated by NOAEL = LOAEL ÷ 5.6 in order to calculate a meaningful geometric mean (see Appendix).

The uncertainty factor is used to account for uncertainty in the estimate of the safe doses of the substance from the toxicological data available. Sources of uncertainty in the estimate of the TDI include differences in sensitivity that are associated with genetic variability within the species, sex, life stage, duration of exposure (i.e., to extrapolate to life-time exposures), nature and severity of the effect measured, exposure route, lab versus field conditions, and a number of other factors. A UF of 10 is recommended for livestock based on a review of the available literature on the toxicity of pesticides to mammals and birds. Gaines and Linder (1986) examined the toxicity of 57 pesticides to adult and weanling Sherman rats. Their results suggest that there are real differences in the sensitivities to contaminants based on sex and life stage. For some pesticides, females were up to four times more sensitive than males, and adults were up to five times more sensitive than weanlings. For other pesticides, weanling rats were as sensitive as, or more sensitive than, adult rats (Brodeur and Dubois 1963; Gaines and Linder 1986). It seems reasonable to presume that a UF of 10 would be adequate to account for these sources of variability under most circumstances. The UF may be increased up to 100 if there is sufficient justification. Possible reasons to increase the UF may include conditions that increase the uncertainty in the TDI, accounting for site specificity, and chemicals that bioaccumulate. Professional judgment must be exercised to determine a reasonable UF.

For those species where only acute data are available, the TDI may be calculated by an alternate method that estimates the NOAEL from the LD_{50}. In a survey of the acute-to-chronic ratios (ACR) for 17 chemicals in rats, a median ACR of 69.2 was determined (MDNR 1984). Dividing the LD_{50} by 70 estimates the median NOAEL, which harbours the least error. A UF of 10, as recommended for the calculation of the TDI from chronic data, is also applied here, but may be increased up to 100 if there is sufficient justification, as specified above. The calculation of the TDI for each species then becomes:

$$TDI = LD_{50} \div 70 \div UF$$

where

TDI = tolerable daily intake ($mg \cdot kg^{-1} \cdot d^{-1}$)
LD_{50} = lethal dose to 50% of the population ($mg \cdot kg^{-1} \cdot d^{-1}$)
70 = extrapolation factor from acute-to-chronic data
UF = uncertainty factor

The TDI is used, in conjunction with the body weight (BW) and daily water intake rate (WIR) of each livestock species, to calculate the reference concentration (RC). If the minimum data set for a full guideline is satisfied, then the BW and WIR for each livestock species, upon which the TDI is based, should be used to derive the RC (Table 1). If only the minimum data set for an interim guideline is fulfilled, then the most conservative livestock BW/WIR ratio should be used, regardless of what animal was the most sensitive species, to provide an additional uncertainty factor to compensate for the added uncertainty. The RC provides an index of relative sensitivity of the livestock species to environmental contaminants, and is calculated as follows (USEPA 1988a):

$$RC = (TDI \cdot BW) \div WIR$$

where

RC = reference concentration ($mg \cdot L^{-1}$)
TDI = tolerable daily intake rate ($mg \cdot kg^{-1} \cdot d^{-1}$)
BW = body weight (kg)
WIR = daily water intake rate ($L \cdot d^{-1}$)

Livestock may be exposed to contaminants from sources other than polluted drinking water (e.g., contaminated food, dermal exposures, inhalation, etc.). The U.S. Environmental Protection Agency (USEPA 1988a) has recommended (and Health Canada concurs) that no more than 20% of the TDI should be contributed by drinking water for humans. In the absence of specific data for livestock, this value is used as a surrogate. If evidence shows that this percentage may be inappropriate for livestock or for a particular chemical, then some modification may be warranted. If there is no indication that this is the case, a percentage drinking water contribution (PDWC) of 20% should be used. The calculation of the final guideline then becomes

$$CWQG = RC \cdot PDWC$$

where

CWQG = Canadian water quality guideline ($mg \cdot L^{-1}$)
RC = reference concentration ($mg \cdot L^{-1}$)
PDWC = percentage drinking water contribution

Table 1. Approximate body weights, daily water intake rates, and food consumption rates for livestock, poultry, and other animals.

Animal	Body weight (kg)	Water intake rate ($L \cdot d^{-1}$)	Food consumption rate ($kg \cdot d^{-1}$)	BW/WIR ratio
Livestock				
Lactating dairy cattle[1, 2]	540–862	38–137	11–26	6.3–14.2
Beef cattle[1]	730	80	—	9.1–12
Pig[3, 4]				
weaner	10–25	1–2	0.7	10–12
grower	50–100	2–6	1.92	8.3–12
finisher	50–100	6–11	2.88	8.3–9.1
dry sow, boars, and replacement	136–159	11–14	2.27	11–12
lactating sow	170-181	18–25	6.80	7.9–9.4
Sheep[1]	120	15	2.4	8.0
Goat[5]				
maintenance	59–68	3.52	2.1–2.4	17–19
lactating	59–68	6.38	3.0–3.4	9.2–11
Horse[3, 6]	500–600	15–42	13–25	10–13.3
Rabbit[7]	1.4–5	0.17–0.45	0.05–0.15	8.2–11
Poultry				
Chicken[7, 8]				
White leghorn	1.6–2.3	0.12–0.61	0.11–0.15[9]	3.8–13
Ross broiler	6.5	0.38–0.85	0.39	7.6–17
Turkey[3, 8]	7.23	1.0–1.6	—	4.5–7.2
Duck[8]	2.1–4.3	0.45–0.64	0.09–0.14	4.7–6.7
Goose[8]	5.1–7.1	0.60–0.62	0.19–0.29	8.5–11
Other Animals				
Rats[7]	0.25–0.44	0.02–0.04	0.02–0.09	11–12.5
Mice[7]	0.02–0.045	0.004–0.01	0.003–0.009	4.5–5
Fox[3, 10]				
breeders	6.5–7.5	0.312	0.22–0.23	21–24
pelters	5.5–6.5	0.170	0.17	32–38
Mink[3, 10]				
breeders	1.5–3	0.204	0.09–0.25	7.4–15
pelters	1.3–2.5	0.170	0.17–0.34	7.6–15

[1] W. Buckley 1992, Agriculture Canada, pers. com.
[2] Ensminger 1980.
[3] OMAF 1991.
[4] F. Kains 1993, Ontario Ministry of Agriculture and Food, pers. com.
[5] A. O'Brien 1993, Ontario Ministry of Agriculture and Food, pers. com.
[6] S. Koch 1993, Canadian Voltige Federation, pers. com.
[7] USEPA 1988b.
[8] Leeson and Summers 1991.
[9] Calculated from the allometric equation presented in USEPA (1988b).
[10] B. Tapscott 1993, Ontario Ministry of Agriculture and Food, pers. com.

If the minimum data set is fulfilled for a full guideline, then the water quality guideline is based on the most sensitive livestock species, even if a more sensitive nonlivestock animal was found. If only the interim guideline data set is fulfilled, then the water quality guideline is based on the most sensitive animal, livestock or nonlivestock (Figure 2).

References

Ayers, H.D., H.R. McCrimmon, and A.H. Berst. 1985. The construction and management of farm ponds in Ontario. Ontario Ministry of Agriculture and Food, Toronto.

Brodeur, J., and K.P. Dubois. 1963. Comparison of acute toxicity of anticholinesterase insecticides to weanling and adult male rats. Proc. Soc. Exp. Biol. Med. 114:509–511.

CCME (Canadian Council of Ministers of the Environment). 1991. Appendix IX—A protocol for the derivation of water quality guidelines for the protection of aquatic life (April 1991). In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers. 1987. Prepared by the Task Force on Water Quality Guidelines. [Reprinted in Canadian environmental quality guidelines, Chapter 4, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]

———. 1993a. Appendix XIV—Canadian water quality guidelines: Updates (October 1993), aldicarb and dimethoate. In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers. 1987. Prepared by the Task Force on Water Quality Guidelines.

———. 1993b. Appendix XII—Canadian water quality guidelines: Updates (April 1993), bromoxynil, dicamba, and diclofop-methyl. In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers. 1987. Prepared by the Task Force on Water Quality Guidelines.

———. 1996. A protocol for the derivation of environmental and human health soil quality guidelines. CCME, Winnipeg. [A summary of the protocol appears in Canadian environmental quality guidelines, Chapter 7, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]

CCREM (Canadian Council of Resource and Environment Ministers). 1987. Canadian water quality guidelines. Prepared by the Task Force on Water Quality Guidelines.

Davis, A.R., R.C. Pierce, and M.P. Wong. 1989. Canadian water quality guidelines: Pesticide impact on irrigation and the environment. In: Toxic substances in agricultural water supply and drainage: An international environmental perspective. Proceedings from the Second Pan-American Regional Conference of the International Commission on Irrigation and Drainage, June 1989, J.B. Summers and S.S. Anderson, eds. Ottawa.

Environment Council of Alberta. 1982. Irrigation agriculture in Alberta. ECA81-17/IB8. Edmonton.

Ensminger, M.E. 1980. Dairy cattle science. The Interstate Printers & Publishers Inc., Danville, IL.

Fletcher, J.S., F.L. Johnson, and J.C. McFarlane. 1990. Influence of greenhouse versus field testing and taxonomic differences on plant sensitivity to chemical treatment. Environ. Toxicol. Chem. 9:769–776.

Gaines, T.B., and R.E. Linder. 1986. Acute toxicity of pesticides to adult and weanling rats. Fundam. Appl. Toxicol. 7:299–308.

Health and Welfare Canada. 1989a. Guidelines for Canadian drinking water quality. 4th ed. Prepared by the Federal–Provincial Subcommittee on Drinking Water of the Federal–Provincial Advisory Committee on Environmental and Occupational Health. [6th ed. published 1996.]

———. 1989b. Maximum residue limits for agricultural chemicals. Canadian Food and Drugs Act and Regulations, Division 15, Table II. Ottawa.

———. 1990. Biological safety factors in toxicological risk assessment. Report 90-EHD-154. Environmental Health Directorate, Health Protection Branch, Ottawa.

———. 1992. Food and Drugs Act and Regulations, Division 15, B1501-B1502. Ottawa.

Hess, P.J. 1986. Ground-water use in Canada, 1981. NHRI Paper No. 28, IWD Technical Bulletin No. 140. National Hydrology Research Institute, Inland Waters Directorate, Environment Canada, Ottawa.

Hill, E.F., and M.B. Camardese. 1986. Lethal dietary toxicities of environmental contaminants and pesticides to Coturnix. Fish and Wildlife Technical Report 2. U.S. Fish and Wildlife Service, Washington, DC.

Kent, R.A., B.D. Pauli, and P.-Y. Caux. 1991. Canadian water quality guidelines for dinoseb. Sci. Ser. No. 189. Environment Canada, Inland Waters Directorate, Water Quality Branch, Ottawa.

Koorevaar, P., G. Menelik, and C. Dirksen. 1983. Developments in soil science 13: Elements of soil physics. Elsevier Science Publishing Company Inc., Amsterdam.

Leeson, S., and J.D. Summers. 1991. Commercial poultry nutrition. University Books, Guelph, ON.

MDNR (Michigan Department of Natural Resources). 1984. Support document for the proposed Rule 57 package. Environmental Protection Bureau.

National Academy of Sciences/National Academy of Engineering. 1973. Water quality criteria─1972. EPA-R3-73-033. U.S. Environmental Protection Agency, Washington, DC.

OECD (Organisation for Economic Co-operation and Development). 1992. The OECD principles of good laboratory practice. OECD Series on Principles of Good Laboratory Practice and Compliance Monitoring, Number 1, Environment Monograph No. 45. Environment Directorate, Paris.

OMAF (Ontario Ministry of Agriculture and Food). 1991. Water use by agriculture: Summary report for water efficient Ontario. Compiled by J.P. Myslik, Resources Management Branch, Guelph, ON.

Riewe, R.V. 1990. Crop rooting depth study. Irrigation and Resource Management Division, Applied Research Report 1989–90, 1990–91. Alberta Agriculture, Edmonton.

Rowe, V.K., and T.A. Hymas. 1954. Summary of toxicological information on 2,4-D and 2,4,5-T type herbicides and an evaluation of the hazards to livestock associated with their use. Am. J. Vet. Res. 15:622–629.

Saskatchewan Water Corporation. 1988. Irrigation water quality—soil compatibility: Guidelines for irrigation in Saskatchewan. Regina.

Statistics Canada. 1971. 1970 Census of Canada—Agriculture. Ottawa.

———. 1992. Census of Agriculture 91. Catalog 93-350. Ottawa.

USEPA (U.S. Environmental Protection Agency). 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. Report Number PB 85-227049. Office of Research and Development, Washington, DC.

———. 1988a. Description and use in health risk assessments. Integrated Risk Information System Background Document 1. Washington, DC.

———. 1988b. Recommendations for and documentations of biological values for use in risk assessment. PB88 179874, EPA/600/6-87/008. Cincinnati, OH.

Appendix

The Eco-Health Branch of Environment Canada conducted a preliminary survey of the pesticide databases for those chemicals for which Canadian water quality guidelines are being derived. The NOAEL and LOAEL values for various organisms for these pesticides (aldicarb, bromoxynil, dicamba, diclofop-methyl, and dimethoate) were extracted from the literature in order to determine a representative estimate of the NOAEL:LOAEL ratio for plants (Table 2) and animals (Table 3). These references are all cited in the appropriate CCME summary documents published as appendices in CCREM (1987).

The mean LOAEL:NOAEL ratio for plants (combined from the two groups for which water quality guidelines are derived) exposed to aldicarb, bromoxynil, dicamba, and diclofop-methyl was 3.09 with 95% confidence limits of (1.71, 4.47) (Table 2). Dividing the LOAEL by 4.5 (approximately equal to the upper 95% confidence limit) should then safely estimate the NOAEL approximately 95% of the time.

In the analogous situation for animals, the mean LOAEL:NOAEL ratio was 3.93 with 95% confidence limits of (2.31, 5.55) (Table 3). Therefore, dividing the LOAEL by 5.6 should safely estimate the NOAEL in approximately 95% of the cases.

Table 2. NOAEL and LOAEL values for plants exposed to various pesticides.

Species	NOAEL ($kg \cdot ha^{-1}$) [1]	LOAEL ($kg \cdot ha^{-1}$) [1]	LOAEL/ NOAEL
Aldicarb[2]			
Sweet clover*	13.5	135	10
Tobacco†	4.48	6.72	1.5
Bromoxynil[3]			
Bolley flax*	0.56	1.12	2
Sunflower†	0.07	0.14	2
Dicamba[3]			
Cotton†	0.068	0.285	4.2
	50	100	2
	0.016	0.032	2
Cucumber†	50	100	2
Soybean†	0.011	0.028	2.5
Sunflower†	0.0016	0.0032	2
Rapeseed*	1.1	0.14	1.3
White ash†	2.2	3.4	1.5
Pin oak†	1.1	2.2	2
Blue spruce†	1.1	2.2	2
Cherry†	0.3	0.85	2.8
Juniper†	0.3	0.85	2.8
Diclofop-methyl[3]			
Corn*	102.4 $\mu g \cdot L^{-1}$	1024 $\mu g \cdot L^{-1}$	10

[1] Except where otherwise specified.
[2] CCME 1993a.
[3] CCME 1993b.

LOAEL/NOAEL averages (and 95% confidence limits):

*Cereals, tame hay, and pasture crops	$\bar{x}$ = 5.82 (-1.86, 13.5)	s = 4.83	n = 4
†Other crops	$\bar{x}$ = 2.25 (1.82, 2.68)	s = 0.71	n = 13
Combined	$\bar{x}$ = 3.09 (1.71, 4.47)	s = 2.68	n = 17

Table 3. NOAEL and LOAEL values for animals exposed to various pesticides.

Species	NOAEL ($mg \cdot kg^{-1} \cdot d^{-1}$)	LOAEL ($mg \cdot kg^{-1} \cdot d^{-1}$)	LOAEL/ NOAEL
Aldicarb[1]			
Rats*	0.1	0.5	5
	0.4	0.8	2
	0.125	0.25	2
	2.5	5.0	2
	5.0	20.0	4
	2.5	5.0	2
	2.4	16.2	6.75
	5.4	16.2	3
	0.6	1.8	3
	1.8	5.4	3
	0.47	1.67	3.55
	0.5	1.8	3.6
Mice*	0.6	1.2	2
	9.6	27.4	2.85
	6	18	3
Dogs*	0.025	0.25	10
	0.25	0.5	3.23
	0.125	0.625	3.25
Bromoxynil[2]			
Rabbits*	30	60	2
Bobwhite†	11.5	37.2	3.23
Mallard†	16.6	54	3.25
Dicamba[2]			
Rats*	37.3	119	3.2
	25	40	1.6
	250	500	2
Dimethoate[1]			
Cows*	0.22	0.6	2.73
Mice*	2.6	8.5	3.27
Dogs*	0.05	1.25	25
Rabbits*	20	40	2
Rats*	6	12	2
	6	18	3

[1] CCME 1993a.
[2] CCME 1993b.

LOAEL/NOAEL averages (and 95% confidence limits):

*Mammals	$\bar{x}$ = 3.98 (2.24, 5.72)	s = 4.48	n = 28
†Birds	$\bar{x}$ = 3.24 (3.15, 3.33)	s = 0.01	n = 2
Combined	$\bar{x}$ = 3.93 (2.31, 5.55)	s = 4.33	n = 30

Reference listing:

Canadian Council of Ministers of the Environment. 1993. Appendix XV—Protocols for deriving water quality guidelines for the protection of agricultural water uses (October 1993). In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers, 1987. Prepared by the Task Force on Water Quality Guidelines. [Updated and reprinted with minor revisions and editorial changes in Canadian environmental quality guidelines, Chapter 5, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]

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