B.C. SPRINKLER IRRIGATION MANUAL

Chapter 11

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Prepared and Web Published by

BRITISH COLUMBIA
Ministry of Agriculture

2014 ISSUE

LIMITATION OF LIABILITY AND USER'S RESPONSIBILITY

The primary purpose of this manual is to provide irrigation professionals and consultants with a methodology to properly design an agricultural irrigation system. This manual is also used as the reference material for the Irrigation Industry Association's agriculture sprinkler irrigation certification program.

While every effort has been made to ensure the accuracy and completeness of these materials, additional materials may be required to complete more advanced design for some systems. Advice of appropriate professionals and experts may assist in completing designs that are not adequately convered in this manual.

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11 IRRIGATION WATER QUALITY

Farmers in British Columbia may pump their own water from a number of sources including surface water such as lakes, rivers and streams, groundwater and canals or ditch systems that are supplied by a municipality or other water purveyor. In addition there are some water purveyors that provide pressurized water in pipelines to the farm gate.

Issues with respect to water supply and irrigation include both quality and quantity. Water of poor quality may impact the operation of an irrigation system, can affect irrigation practices with respect to soil quality and may also affect food safety. The Canadian Water Quality Guidelines outline the recommended levels of waterborne chemicals and pathogens for various uses including agriculture, irrigation and livestock. Provincial jurisdictions may develop their own guidelines or criteria (e.g., British Columbia Water Quality Guidelines).

Check the internet for the most recent water quality standards in the province as the numbers shown here may change.

11.1 Water Quality Concerns

The primary activities concerning water quality are:

- Cross-connection among water supply lines carrying contaminants that pollute the water supply.
- Well construction (e.g., lack of sealing), location (e.g., down-gradient from contaminated source), or abandoned wells that cause groundwater pollution.
- Disturbances to watercourses during installation and maintenance of intake screens that may result in water pollution and habitat loss.
- Irrigation with water of poor quality that contaminates edible crops with pathogens, or causes salt build-up in the soil.
- Application of fertilizers and other chemicals that may lead to water or soil pollution.
- Water containing silt and algae or chemicals dissolved in the water that may clog micro-irrigation systems.
- Use of petroleum fuels for pumps adjacent to a watercourse.

Water Contaminants

Excessive irrigation can cause contaminants to enter the watercourse or aquifers by leaching through the soil or by overland runoff. Heavy soils that have low infiltration rates are susceptible to runoff if the irrigation system applies water at a rate greater than the infiltration rate of the soil. Contaminants from the soil or plants can be carried by the irrigation water to surface water sources or groundwater.

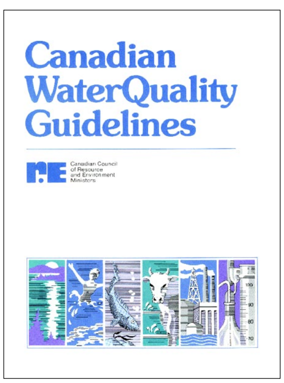
Total Ammonia

Ammonia (NH_3) plus ammonium (NH_4^+) is referred to as total ammonia, and both exist in urine, manure, fertilizer and compost. Water containing elevated levels of total ammonia may be toxic to fish and other aquatic organisms. The ammonium form is more harmful to aquatic organisms compared to ammonium.

Micronutrients and Metals

Specific metals of concern include arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc. Elevated metal concentrations can directly kill fish and other aquatic organisms, or accumulate in tissues, making them unfit for human consumption. Sources of metals include manure, waste oil, hydraulic fluids and fertilizers. Woodwaste leachate, by virtue of its acidity, can increase the rate of metal release from the soil as well.

Nitrate Ion (NO_3^-)



The total ammonia nitrogen in manure or fertilizer converts to nitrate (NO_3^-) in soil. Nitrates are easily leached from the soil because they do not attach to soil particles as ammonium does. Once nitrates are out of the root zone, they can no longer be utilized by the plant and are leached to groundwater.

Nitrates in groundwater are often an early indication of contamination by other chemicals.

Canadian Water Quality Guidelines

Nutrients

Elevated nutrient levels in a watercourse can be caused by manure or fertilizer entering a watercourse directly, by contaminated water flowing from fertilized fields, or by nutrient-rich soil being eroded from croplands. The most common effects of eutrophication in surface water are massive blooms of algae and depleted oxygen levels. Blue-green algae in sufficient quantities are toxic to livestock.

Blue-Green Algal Blooms in Lakes

Pathogens

Many organic wastes including manure contain microorganisms, such as bacteria, viruses and other parasites. Some of these microorganisms may be pathogenic (disease-causing) to animals of the same or different species. Many diseases are transmissible between animals and humans, and water can be a pathway for the transmission of infection. Pathogen contamination of shellfish beds is not uncommon, rendering shellfish unfit for human consumption.

Pesticides

Pesticides, such as fungicides, insecticides and herbicides, hold great potential to pollute both surface water and groundwater. Water polluted by pesticides can be the result of application drift, leaching, erosion of contaminated soil, spills and direct introduction. Pesticide-contaminated water can cause harmful effects on aquatic organisms, animals and humans.

Petroleum

Petroleum, antifreeze, paints, solvents, hydraulic fluids and other oil-based substances can cause direct and indirect harmful effects on watercourses and groundwater. Some negative impacts caused by petroleum products in water include destruction of fish-food organisms, such as algae and other plankton, smothering of fish spawning areas, reduced photosynthetic rate in plants, and poor stream aeration. In addition, petroleum products can taint the flavour of fish-food products.

Solids

Solids exist either in dissolved or suspended form in water. Both forms may include nutrients and metals, can elevate the biochemical oxygen demand (BOD) of water, and cause long-term damage. Some types of dissolved solids, such as ammonia, can be toxic to fish.

Suspended solids are primarily silts and clays, but can also include oils, pathogens, woodwaste components, and other materials attached to particles in the water. Suspended solids in watercourses can clog fish gills, affect fish vision and, upon settling, fill up pore spaces between pebbles; thereby, destroying spawning grounds or smothering the eggs of aquatic organisms.

Woodwaste Leachate

Woodwaste leachate from sawdust, shavings, chips, hog fuel or bark can cause negative impacts on ground and surface water. Reduced oxygen levels, due to high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), lower photosynthetic rates in aquatic plants. The colour of woodwaste leachate also reduces light transmission; thereby, photosynthesis. Woodwaste leachate is also acidic which enhances the unwanted movement of metals and nutrients from the soil into watercourses.

Oxygen in Water

Oxygen Demand

Materials with high oxygen demand (e.g., manure, silage, fruit, vegetables and composting juices) use dissolved oxygen in water directly as they decompose. Increased nutrient levels in water can also indirectly cause high oxygen demand by encouraging the growth of aquatic plants and microorganisms. After these organisms die, natural decay may accelerate the oxygen depletion to levels below that required by fish and aquatic organisms.

Dissolved Oxygen

Dissolved oxygen is a measurement of the amount of oxygen dissolved in water. The oxygen percent saturation level is a function of altitude and water temperature. If wastes with high oxygen demand or high nutrient levels are allowed to enter watercourses, dissolved oxygen levels will drop. Reduced oxygen levels are harmful to fish and aquatic organisms.

Water Temperature

Elevated water temperature has direct and indirect impacts on water quality and the organisms that live in the water. As water temperature increases, its oxygen-holding capacity decreases and can become harmful to fish and aquatic lives. The thresholds of watercourse temperature are set to protect fish. Indirectly, elevated water temperature contributes to the growth of aquatic organisms, which upon death, accelerates oxygen depletion.

11.2 Water Quality Guidelines

Irrigating with water of poor quality can not only harm or contaminate crops, but may also harm the environment. Salts, heavy metals and pathogens make their way into the soil, and may be taken up by crops or may build up in the soil to unacceptable levels. Irrigation system uniformity can also be affected by poor water quality if sprinklers or drip emitters are plugged.

The following practices should be followed when irrigating with water of poorer quality:

- know the quality of irrigation water
- ensure applications do not degrade soil quality
- ensure that food crops are not contaminated
- monitor system performance to maintain uniformity

Irrigation with poor water quality can impact soils, crops and human health.

Soil

Boron. Boron is essential for the normal growth of plants; however, concentrations greater than 2 ppm may be toxic to certain plants, especially if a large quantity of irrigation water is being used.

Nutrients. Over-application of chemical fertilizers or manure through fertigation may lead to excess nutrient concentrations in soil. An over-abundance of any one nutrient can be toxic to plants, soil and biota and can reduce crop yield. Excess nutrients not utilized by plants can leach from the root zone into the water. The application of wastes or fertilizers containing excess metals may result in an unwanted accumulation of metals in the soil.

Pathogens. Most pathogens, such as bacteria, viruses and parasites, die off rapidly when exposed to sunlight. However, some pathogens can remain infectious in soils for many years; others can be transferred among plants, soils and animals.

Pesticides. Soil can be polluted with pesticides as a result of excessive application rates and inappropriate application methods. The extent of contamination depends largely on the characteristics of the pesticide, particularly its persistence and solubility. Soil contamination can eliminate beneficial insects, inhibit crop growth, and reduce viable crop varieties. In addition, domestic animals and wildlife may be harmed when feeding on contaminated crops or when ingesting soil particles that contain pesticides. A particular risk to humans is that pesticide accumulation in plant and animal products can make foods unfit for human consumption.

Salts. The most common problems with soil resulting from the use of poor quality irrigation water are: accumulation of salts in the crop's root zone, and loss of soil permeability due to excess sodium or leaching of calcium.

Soluble salts in soil, which can impact crops, are measured by electrical conductivity (EC) in deci-siemens per metre (dS/m). Crop species vary with respect to the salt levels that they can tolerate. When the EC of soil is below 2 dS/m, they are considered to be affected by salt. Salt concentration in the root zone is influenced by the total dissolved solids in irrigation water. Applying irrigation water with high salt concentration can cause salt build-up in the root zone. Salt build-up can affect plant germination, growth, yield, and soil physical characteristics. The salt tolerance level can vary greatly among crops. Crops are generally broken into three sensitivity groups based on how well they perform for given ranges of salt concentration:

1. sensitive (0 to 4 dS/m)
2. highly tolerant (4 to 8 dS/m)
3. very highly tolerant (greater than 8 dS/m)

Soil above 4 dS/m is said to be saline, reducing yield potentials of a wide range of crops.

Salt impacts on soil are also measured by a sodium adsorption ratio (SAR). Excess sodium in irrigation water relative to calcium and magnesium or relative to the total soluble salt content can adversely affect soil structure, reduce soil infiltration rates and permeability, and reduce soil aeration. When calcium is the predominant cation of the soil exchange complex, the soil tends to have a granular structure, and be easily workable and permeable. However, when absorbed sodium exceeds 10 to 15% of the total cations, clay soil becomes dispersed when wetted, resulting in a soil that becomes puddled when wet, lowering permeability and forming a hard impermeable crust when dry.

Below the soil surface, permeability can be maintained because an increase in salinity from crop water uptake will usually be sufficient to offset the negative effects of exchangeable sodium. The magnitude of the effect of excess sodium can be related to the relative proportions of sodium, calcium and magnesium ions in the irrigation water by using the SAR. The SAR can be calculated using Equation 11.1 or is usually provided when the water sample is tested by a laboratory.

Equation 11.1 Sodium Absorption Ratio (SAR)

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \times 0.5$$

where Na^{+}, Ca^{2+}, and Mg^{2+} are expressed in milli-equivalents per litre

Table 11.1 Guidelines on SAR and EC for Irrigation Water Use for Crops and Soils

Crops[1]			
SAR	**Restrictions on Water Use Electrical Conductivity (EC) [dS/m]**		
	Low	**Slight to Moderate**	**Severe**
< 3	> 0.7	0.7 – 0.2	< 0.2
3 – 6	> 1.2	1.2 – 0.3	< 0.3
6 – 12	> 1.9	1.9 – 0.5	< 0.5
12 – 20	> 2.9	2.9 – 1.3	< 1.3
20 – 40	> 5.0	5.0 – 2.9	< 2.9
Soils[2]			
SAR < 3	EC < 0.2 sS/m		

[1] Source: Water Quality for Agriculture FAO
[2] Source: The Water Encyclopedia 2nd Ed. Van der Leeden, Fritz et al. 1990 Lewis Publishers, Chelsea Michigan, U.S.A.

When SAR exceeds 13, soil structure is generally degraded, evidenced by hard cloddy or crusted surface and reduced water infiltration (due to loss of soil particle aggregation). In addition, sodium levels begin to become toxic to plants. Table 11.1 can be used to determine if the SAR value is acceptable to the crop and soils. SAR and EC must be evaluated together. Water use should be restricted if the conditions in the table indicates a problem.

Human Health

Many water supplies may contain chemicals or pathogens that could pose a risk to human health. Testing for pesticides and herbicides are expensive and difficult to perform. If the active ingredient is known, specific tests may be done to determine if residues are excessive.

Pathogens. Pathogens are a concern for all farms that have irrigation systems or crop-washing operations. Septic fields, animal manure, milk house wastes and wildlife are all sources of pathogens that can enter surface water or groundwater. Many water supplies for irrigation and crop washing are from agricultural drainage ditches. While ditches are often prone to poor water quality, all surface water sources may contain pathogens.


Water Quality FACTSHEET

TREATING IRRIGATION AND CROP WASH WATER FOR PATHOGENS

An extensive diversity of microorganisms may be found in aquatic environments, but identifying all species is expensive. Therefore, an indicator organism or surrogate organism that is easily detectable is often used to identify fecal contamination. The two standards used for irrigation water quality with respect to pathogens are E.coli and fecal coliforms. The normal standard for measurement is colony forming units (cfu) per 100 mL.

Table 11.2 provides the water quality standards for pathogens in BC. If the tested values are higher than those in Table 11.2, the water should be treated before use.

If the level of pathogens are too high, a water treatment system may be considered to prevent contamination of food products, or alternatively consider using a drip system that does not apply water directly to the crop. The factsheet "Treating Irrigation and Crop Wash Water for Pathogens" may also be useful.

Treating Irrigation and Crop Wash Water for Pathogens

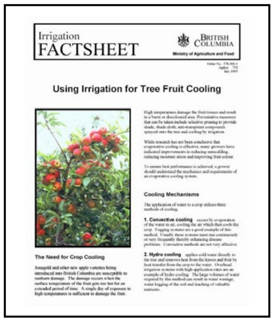
Table 11.2 Pathogen Water Quality Standards

Purpose	Pathogens	
	E.coli [cfu/100 mL]	Fecal Coliform [cfu/100 mL]
Irrigation for Crops Eaten Raw	< 77	< 200
Irrigation for All Other Crops	< 1,000	< 1,000
Crop Washing	0	0

Source: B.C. Ministry of Environment, and Health Canada

Crops

Water of poor quality can cause problems in sprinkler systems, such as plugging intakes, screens and nozzles, and depositing pathogens, chemicals or precipitates on crops.


Irrigation FACTSHEET

British Columbia

Ministry of Agriculture and Food

Using Irrigation for Tree Fruit Cooling

Cooling Mechanisms

The Need for Crop Cooling

Precipitates. Overhead irrigation may leave a calcium carbonate on fruits and vegetables if the water supply has high levels of calcium and carbonate. Iron may also stain plants and fruit products. Crops may also be sensitive to dissolved solids and other chemicals that are in the irrigation water. The guidelines for major ions and toxicity to crops are listed in Table 11.3. Refer to Tables 11.4 to 11.7 for details on crop tolerance against chloride, sodium and total dissolved solids.

Using Irrigation for Tree Fruit Cooling

Coloured Water. High levels of tannins in the water can cause discoloration of berries and fruits if applied by an overhead irrigation system. If it is not possible to find another water source or to clean up the current water supply, consider using a drip irrigation system. The drip system will require a good filtration system to prevent the system from clogging.

Insecticides and Herbicides. There are no guidelines for insecticides as there is no evidence that insecticide residue in irrigation water resulting from registered use are harmful to crops. If herbicides are applied correctly, no residues should remain in the irrigation water supply. See Table 11.9 for guidelines of irrigation water quality for some herbicide residues.

Example 11.1 Irrigation Water Quality in Armstrong

Question: A farm in Armstrong uses surface water for irrigation and crop washing. A laboratory analysis of a water sample from the water source gave the following results:

SAR = 3
Electrical conductivity (EC) = 1.2 dS/m
E.Coli = 300 cfu/100 ml
Fecal Coliform = 150 cfu/100 mL

Is the water safe to use for irrigation and crop washing?

Calculation:

Step 1. SAR Check

SAR for sprinkler system	*3*	1	
Electrical conductivity (EC) (Table 11.1)	*1.2*	2	dS/m
Restriction on water use (Table 11.1)	*Low*	3	

Using Table 11.1, if the answer in Box 3 is slight to moderate or severe, water use from this source may need to be restricted. The water is fine in this case.

Step 2. Pathogen Check

E.Coli	*300*	5	cfu/100 ml
Fecal coliform	*150*	6	cfu/100 ml

From Table 11.2, the E.Coli and fecal coliform results indicate that the water is suitable for irrigation of all crops ***except*** for crops that are eaten raw since the E.Coli level is higher than 77 cfu/100 mL. The water is ***not okay*** for crop washing as both E.Coli and fecal coliform levels are above 0 cfu/100 mL. Water treatment will be required.

Table 11.3 Summary Guidelines for Irrigation Water Quality

Parameter	Guideline [mg/L] All Soils[1]	Guideline [mg/L] Neutral to Alkaline Soils[2]
Major Ions		
Bicarbonate[3]	–	–
Chloride	100 – 700 See Tables 11.4 and 11.5	–
Sodium	Soils: determine sodium adsorption ratio (SAR) Crops: see Table 11.6	–
Total Dissolved Solids (salinity)	500 – 3,500 (may not protect some sensitive crops; see Table 11.7)	–
Heavy Metals and Trace Ions[4]		
Aluminum	5.0	20.0
Arsenic	0.1	2.0
Beryllium	0.1	0.5
Boron	0.5 – 6.0 (see Table 11.8)	–
Cadmium	0.01	–
Chromium	0.1	–
Cobalt	0.05	5.0
Copper	0.2 (Sensitive Crops) 1.0 (Tolerant Crops)	5.0 5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead[5]	0.2	2.0
Lithium	2.5	–
Manganese	0.2	10.0
Mercury[3]	–	–
Molybdenum	0.01 0.05 (intermittent for acidic soils)	0.05 –
Nickel	0.2	2.0
Selenium	0.02 0.05 (intermittent)	– –
Uranium[5]	0.01	0.1
Vanadium	0.1	1.0
Zinc	1.0 (soil pH < 6.5) 5.0 (soil pH > 6.5)	– –
Biological Parameters		
Plant Pathogens[3]	–	–
Human and Animal Pathogens[5]	100 fecal coliforms per 100 mL; 1,000 total coliforms per 100 mL	–

1 Assumes continuous irrigation unless otherwise noted.
2 Maximum time of irrigation with water containing elevated concentrations of heavy metals and trace ions is 20 years on neutral to alkaline fine-textured soils.
3 No guideline recommended at this time.
4 Guidelines expressed as total concentrations.
5 Tentative guideline.

Source: Canadian Water Quality Guidelines 1987

Table 11.4 Chloride Tolerance of Fruit and Woody Crops by Root Uptake

Root Uptake	Chloride in Irrigation Water [mg/L]
Rootstocks	
Grapes	710 – 960
Stone Fruit (peaches, plums, etc.)	180 – 600
Cultivars	
Boysenberry, Blackberry, Raspberry	250
Grapes	230 – 460
Strawberry	110 – 180
Source: Canadian Water Quality Guidelines 1987	

Table 11.5 Sodium or Chloride Concentrations in Irrigation Water Causing Foliar Damage

Sensitivity	Ion Concentration [mg/L]		Affected Crops
	Cl	Na	
Sensitive	< 178	< 115	almond, apricot, plum
Moderately Sensitive	178 – 355	115 – 230	grape, pepper, potato, tomato
Moderately Tolerant	355 – 710	230 – 460	alfalfa, barley, corn, cucumber
Tolerant	> 710	> 460	cauliflower, cotton, safflower, sesame, sorghum, sugar beet, sunflower
Source: Canadian Water Quality Guidelines 1987			

Table 11.6 Tolerance of Crops to Sodium

Tolerance	SAR of Irrigation Water	Crop	Conditions
Very Sensitive	2 – 8	deciduous Fruits	leaf tip burn, leaf scorch
Sensitive	8 – 18	beans	stunted growth
Moderately Tolerant	18 – 46	clover, oats, tall fescue	stunted because of nutrition and soil structure
Tolerant	46 - 102	wheat, lucerne, barley, tomatoes, beets, tall wheatgrass, crested wheatgrass	stunted because of soil structure
Source: Canadian Water Quality Guidelines 1987			

Table 11.7 Tolerance of Selected Crops to Total Dissolved Solids in Irrigation Water[1], as Determined by Research in California, U.S.A.

Degree of Tolerance	Fruits and Berries	Vegetables	Field Crops	Forages
Not Tolerant				
EC_w < 0.7	strawberry	bean	bean	
TDS < 500	raspberry	carrot		
Slightly Tolerant				
EC_w < 1.2	boysenberry	onion	cowpea	clover (alsike, ladino red
TDS < 800	currant	parsnip	broadbean	and strawberry)
	blackberry	radish	flax	berseem clover
	gooseberry	pea	sunflower	forage corn
	plum	pumpkin	corn	
	grape	lettuce		
	apricot	pepper		
	peach	muskmelon		
	pear	sweet potato		
	cherry	sweet corn		
	apple	potato		
		celery		
		cabbage		
		kohlrabi		
		cauliflower		
Moderately Tolerant				
EC_w < 2.2		spinach		brome, smooth
TDS < 1,500		cantaloupe		alfalfa
		cucumber		big trefoil
		tomato		beardless
		squash		wildrye
		brussel sprout		vetch
		broccoli		timothy
		turnip		crested wheatgrass
Tolerant				
EC_w < 3.6		beet	rape	oat hay
TDS < 2,500		zucchini	sorghum	wheat hay
				brome, mountain
				tall fescue
				wweet clover
				reed
				canarygrass
				birdsfoot
				trefoil
				perennial
				ryegrass
Very Tolerant				
EC_w < 5.0		asparagus	soybean	barley hay
TDS < 3,500			safflower	tall wheatgrass
			oats	
			rye	
			wheat	
			sugar beet	
			barley	

1 *Assumptions and Definitions:*

1. The crops within each "tolerant" grouping are listed from least to most tolerant. Actual tolerances will be modified by management, climate and soil conditions.
2. EC_e means electrical conductivity of saturation extract (mS/cm or mmhos/cm). EC_w is the electrical conductivity of the irrigation water. EC_{sw} is the electrical conductivity of the soil solution. $EC_{sw} = 3EC_w$ for a leaching fraction of 0.15.
3. TDS means total dissolved solids in units of mg/L. the conversion factor of 1 EC = 700 mg/L has been used to transpose data.
4. A leaching fraction of approximately 15% is maintained. The tolerance tables can be adjusted by increasing or decreasing the leaching fraction.
5. Soil texture ranges from sandy loam to clay with good internal drainage and no uncontrolled shallow water table.
6. Rainfall is low and does not play a significant role in meeting crop demands. The guidelines may be too restrictive for wetter areas.
7. Assume the use of gravity and sprinkler irrigation systems where water is applied infrequently as needed. The crop utilizes 50% or more of the stored available water before the next irrigation. Guidelines are too rstrictive for frequent or drip irrigation systems.
8. Each irrigation leaches the upper root zone, and sale accumulation increases with depth. The crop responds to the average salinity in the root zone, and the salt content of the soil solution (EC_w) is about three times that of the irrigation water (EC_w) because of evapotranspiration.

Source: Canadian Water Quality Guidelines 1987

Table 11.8 Relative Tolerance of Agricultural Crops to Boron

Tolerance[1]	Concentration of Boron in Soil Water[2] [mg/L]	Agricultural Crops
Very Sensitive	< 0.5	blackberry
Sensitive	0.5 – 1.0	peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean
Moderately Sensitive	1.0 – 2.0	red pepper, pea, carrot, radish, potato, cucumber
Moderately Tolerant	2.0 – 4.0	lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 – 6.0	sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet
Very Tolerant	6.0 – 15.0	asparagus

1 Tolerances will vary with climate, soil conditions and crop varieties; values are to be used only as a guideline.
2 Maximum concentrations tolerated in irrigation water without reductions in yield or vegetative growth are approximately equal to soil water values or slightly less.

Source: Canadian Water Quality Guidelines 1987.

Table 11.9 Tolerance of Crops to Herbicides in Irrigation Water

Herbicide	Application Rate[1]	Maximum Residues in Irrigation Water [mg/L]	Concentrations Known to Injured Crops [mg/L]		References
Applied to Water:					
Acrolein	1.5 mg/L	1.5	60 20	beans, corn, sugar beets soybeans	Bruns (1969) Yeo (1959) Bruns et al. (1964)
Chlorofenac	14 – 20 kg/ha	Traces	10 0.1 0.1 – 10	corn alfalfa sugar beets	
Diquat	2 – 10 kg/ha	< 0.1	125 5	corn beans	
Paraquat	1 – 2 kg/ha	No data	No data		
Simazine	0.9 g/m^3	0.25 and 0.7	0.15	alfalfa, brome grass (eradicated)	Anderson et al. (1978) Korven (1975) Smith et al. (1975)
Applied to Dry Ditches:					
Dalapon	20 – 33 kg/ha	< 0.2	> 7.0 > 0.3	beets corn	Bruns and Dawson (1959)
Diuron	18 – 88 kg/ha	0.2 and 0.8	No data		Bowmer and Adeny (1978)
Chlorofenac	18 – 88 kg/ha	0.2 and 0.8	No data		Grover et al. (1982)
Applied to Banks Only:					
2, 4-D amine	0.8 – 3.2 kg/ha	0.10	10 > 1.0 0.7 > 0.2 > 0.02	corn field beans, cucumbers, potatoes, sorghum, alfalfa, peppers grapes sugar beets soybeans	Bruns (1954, 1957) Bruns and Clore (1958)
MCPA	0.9 – 2.2 kg/ha	No data	No data		

1 Application rates are registered in Canada for use in ditches or reservoirs and on banks of ditches.