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WATER QUALITY AND AGRICULTURAL IRRIGATION: A CANADIAN PERSPECTIVE

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I. INTRODUCTION

Canada is a diverse nation, varying in climate, water quality and agricultural capability from region to region. Surface water quality in Canada is generally good when viewed in the light of water quality guidelines, but dramatic regional differences exist in some parameters, particularly in the closed basin areas of the Interior Plains of Canada (Inland Waters, 1977). National water quality guidelines were summarized in 1979 (McNeely et al, 1979) but it was felt, by experts in various water quality disciplines, that some of the guidelines were outdated. Consequently, a task force on Water Quality Guidelines under the auspices of the Canadian Council of Resource and Environment Ministers (CCREM) initiated a study to collect and compile an inventory of Provincial, Federal and Territorial water quality objectives and guidelines (CCREM, 1985). Subsequently, a number of activities were launched and are now nearing completion which will result in the development of an updated and comprehensive set of Canadian Guidelines for Water Quality (Thibault, 1985).

The purpose of this study is to review and update the water quality guidelines for irrigation. At present water quality guidelines for agricultural irrigation vary from region to region and are altered as new knowledge is gained or to compensate for regional/local conditions. The proposed study will examine irrigation water quality guidelines for agriculture across Canada and delineate regions for purposes of establishing guidelines more useful to each region. In addition to establishing guidelines, a separate text will examine the issue of the impact of irrigation on surface and groundwater (Thomson and Neufeld, 1983).

II. EXTENT OF IRRIGATION IN CANADA

Canada has approximately 922 million hectares of land of which only about 66 million hectares (7.1 %) is classified as farmland (Table 1; Statistics Canada, 1981). The arable land area in Canada occupies the southern portion of Canada (Figure 1, dashed lines) and essentially all of Canada's irrigated land areas are within this region.

A breakdown of the irrigated areas by province is presented in Table 1. The 1980 values were obtained from the 1981 Census of Canada Agriculture statistics. The 1985 estimates were derived from the latest available provincial data and expert opinions. No attempt was made to separate intensive irrigation (water available all year) from less intensive, usually individual projects, where one application of spring melt waters may be available. As a rough guideline, approximately 70% or more of the 1985 irrigation development in Western Canada is intensive, particularly in British Columbia, Alberta and Manitoba.

In Eastern Canada, irrigation provides a supplementary source of water. Water is often applied at a critical growth or stress stage, particularly in dry years. Almost all of the irrigation in Eastern Canada is by some form of sprinkler system.

Table 1. Land areas and irrigated hectares for each of the Provinces in Canada.

Province	Total Land Area(ha)	Total Area of Farms	Improved Land Area	Irrigation[1] 1980	Irrigation[2] 1985	% of Improved	% of Canada's Irrigation
B. C.	89,307,183	2,178,596	946,330	100,475	109,000	11.52	14.9
Alberta	63,823,257	19,108,513	12,525,481	393,696	454,000	3.62	62.0
Sask.	57,011,330	25,947,086	19,683,855	55,913	101,000	0.51	13.8
Man.	54,770,472	7,615,926	5,503,980	6,935	11,330	0.21	1.5
Ont.	91,743,326	6,039,237	4,518,552	32,127	40,000	0.89	5.5
Quebec	135,780,889	3,779,169	2,360,339	5,989	14,700	0.62	2.0
N. B.	7,156,913	437,888	191,931	346	400	0.21	0.1
N. S.	5,284,093	466,023	177,982	605	1,400	0.79	0.2
P. E. I.	566,171	284,024	202,688	23	80	0.04	-
Nfld.	37,163,735	33,454	10,452	9	20	0.19	-
	992,097,312	65,888,916	46,121,591	596,118	731,930	1.29%	100%

1. Taken from 1981 Census of Canada, Agriculture

2. Professional estimates.

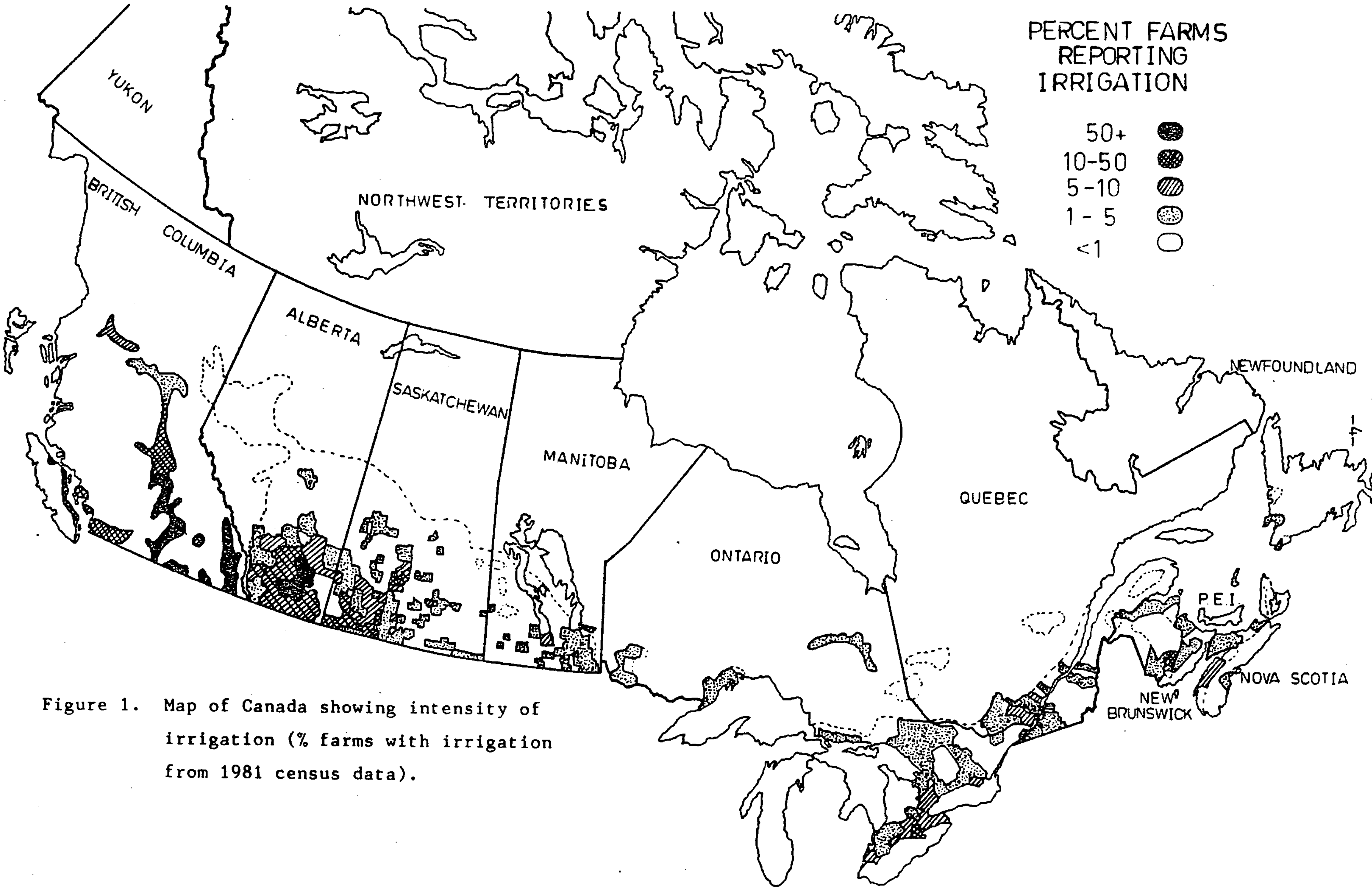

Figure 1. Map of Canada showing intensity of irrigation (% farms with irrigation from 1981 census data).

Some of the most intensive irrigation is practised in British Columbia where 11.5% of the improved farmland is irrigated. A measure of the degree of regional intensity across Canada was obtained from the 1981 Census of Agriculture by calculating the percent of farms within various Census sub-divisions reporting irrigation. The results are depicted in Figure 1 by shaded areas with the dark area representing regions with 50% or more of the farms reporting irrigation and the white areas with less than 1% of the farms reporting irrigation. Areas of B. C. and Alberta show fairly dense irrigation.

Alberta contains the largest acreage of irrigated land with 454,000 hectares, about 62% of the total irrigated land in Canada (Table 1). British Columbia and the Prairie Provinces account for 92% (675,330 ha) of the irrigated land in Canada. Ontario and Quebec account for 97% (54,700 ha) of the irrigated land in Eastern Canada.

III. IRRIGATED CROPS

A fairly detailed breakdown of irrigated crops by province was obtained from the census in 1970 (Table 2, Statistics Canada, 1971). Irrigation of tame hay and forages (and some pasture) accounted for almost half the irrigated area in Canada. About 1/4 of the irrigated land area was seeded to cereal crops. The remaining land area was more or less evenly divided between tobacco, sugar beets, vegetables, and tree fruits. The large irrigated acreage for Quebec in 1970 (compared to 1980) was due to misinterpretation of the census questionaire resulting in the inclusion of tile drained areas. The actual irrigated area in Quebec would have been much smaller.

Table 2. Percentages of types of irrigated crops in Canada by Province (1970).

	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec*	Atlantic Provinces	Canada
Total Irrigated Area, 1970 (ha)	89,440	217,660	31,370	2,970	40,256	37,592	2289	421,577
Tame Hay and Pasture	65.8	41.8	74.4	16.5	5.6	53.3	19.4	46.6
Cereals	2.7	38.9	16.2	37.0	2.5	21.1	9.5	24.3
Tobacco	-	-	-	-	63.8	7.0	11.5	6.8
Potatoes	1.6	4.2	2.5	14.5	4.4	5.4	30.8	3.9
Sugar Beets	-	6.9	-	2.0	-	1.2	-	3.7
Vegetables	4.2	1.2	0.7	21.3	10.8	4.8	13.8	3.2
Tree Fruits	14.2	some	some	0.3	3.4	1.2	1.7	3.5
Strawberries	0.5	some	-	1.3	1.8	2.0	10.8	0.5
Other	11.0	7.0	6.2	7.1	7.8	4.0	2.5	7.5

* The statistics for Quebec were incorrect as the questionaire was interpreted to include both irrigated and drainage lands.

Since 1970, there has been a change in irrigated crop patterns, particularly in Western Canada. A comparison between irrigated crops in Alberta in 1970 and 1984 is illustrated in Table 3 below:

Table 3. Irrigated crops in Alberta: 1970 versus 1984

	1970	1984
Total Area	217,660 ha	380,000 ha*
Tame Hay & Forage	41.8 %	28.6 %
Cereals	38.7	54.7
Potatoes	4.2	1.6
Sugar Beets	6.9	3.3
Vegetables	1.2	1.7
Corn	-	2.5
Oilseeds/Special Crops	-	6.8
Other	7.0	0.8

* Information derived from fact sheet by A. G. N. Van Deurzen, Economist, Alberta Agriculture. Only includes data from those irrigation districts reporting.

Since 1970 the roles of cereals and forages have reversed with cereals taking the dominant role. The potato and sugar beet share of the irrigated area has decreased, while acreage of oilseeds, specialty crops, and corn have increased. In Saskatchewan cereal irrigation has increased, but irrigated hayland still accounts for an estimated 60% of the irrigated land. In Manitoba, corn has become a major irrigated crop (25-30%) similar to cereals (35%) while forages (12%) make-up an important tertiary role. The remaining acreage is primarily vegetables with some oilseeds, special crops and strawberries.

Figure 2 shows the approximate location of the major irrigated crops in Canada.

The trends in Eastern Canada have not changed appreciably since 1970. In Ontario, tobacco is still the major irrigated crop, although with recent depressions in the market, there is a shift towards the irrigation of vegetable crops. Strawberries, vegetables and small fruits are major irrigated crops in the rest of Eastern Canada.

IV. IRRIGATION WITHIN REGIONS OF CANADA

1. British Columbia

Physiographically, British Columbia is located in the Cordilleran region. The agricultural land in British Columbia is located in mountain valleys and interior plateaus. The dominant soil types include Chernozems (Dark Brown to Black, and Dark Grey) which extend through the Kelowna, Kamloops, and Williams Lake area in central B. C. (Canada Department of Agriculture, 1977). Brunisolic soils in the extreme south of B. C. and along the eastern edge of Vancouver Island

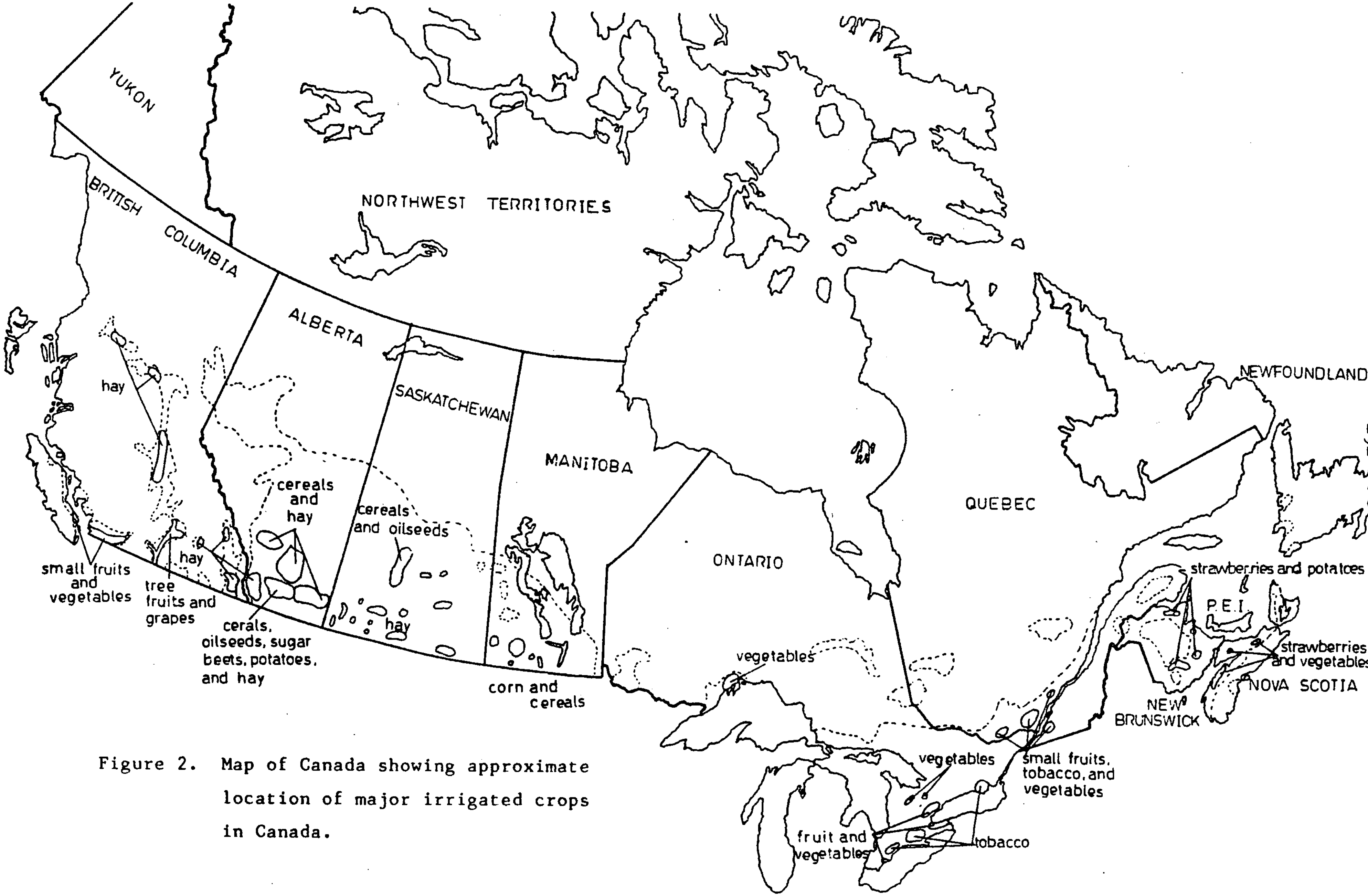

Figure 2. Map of Canada showing approximate location of major irrigated crops in Canada.

are also irrigated. The Fraser Valley near Vancouver has Gleysolic soils.

Annual precipitation in the irrigated areas of the Okanagan and Kamloops averages less than 40 cm as does a small area south of Cranbrook. The Fraser Valley near Vancouver and the east coast of Vancouver Island usually average 160 cm.

The Okanagan basin is the key source of fruit production in the province. Annual precipitation in the basin varies from 38 cm at Vernon towards the north end of the valley to 20 cm at Osoyoos near the U.S. border. Almost 70% of agricultural land in the basin is irrigated.

North of the Okanagan, the major irrigated crops are forages and pastures. In the lower Fraser and Vancouver Island hay, pasture, market gardens, vegetables, strawberries and specialty crops are the mainstay (Figure 2).

An approximate breakdown of the types of irrigation used in British Columbia is flood 26%, handmove 24%, wheelmove 20%, solid set 19%, travelling guns 4%, center pivots 4%, and trickle 3%. Flood systems are used for hay production in central British Columbia. Wheelmove and center pivots are primarily used for alfalfa production. Solid sets are used in tree fruit and small fruit orchards. Trickle is becoming more prominant in orchards, grape vineyards, and raspberry plantings. Handmove systems are used on all types of crops and travelling guns are used primarily for pasture and hayland irrigation.

The crop water demand in British Columbia varies from 30 cm to 120 cm, depending upon the soil texture, crop type and weather conditions (B.C. Irrig. Comm., 1983). In a dry year on a sandy soil near Osoyoos, an orchard or alfalfa crop might require 120 cm of irrigation water. However, application rates of 50 cm to 75 cm are more representative for the area.

Natural surface waters are the major source of irrigation water. The suitability of British Columbia's lakes and streams for irrigation is excellent (Wilcox and Mason, 1963). Groundwater from both shallow and deep wells is also used for irrigation to a limited extent. Water quality from these wells is good. The use of secondary effluent waters and industrial wastewaters for irrigation is not widespread in British Columbia. Cranbrook, Vernon, and Osoyoos dispose of the municipal effluent by irrigation, and some small food processing plants do likewise (Oldham, 1979). Irrigated acreage from municipal and other effluents in British Columbia might total 1,500 hectares.

2. Prairie Provinces

The major irrigation areas within Alberta, Saskatchewan and Manitoba lie within the physiographic region known as the Interior Plains of Canada. Although the Manitoba lowlands (around Winnipeg) and the Regina Plains represent sections of prairie consisting of flat to gently rolling landscape with little relief, a larger portion of the prairies consist of a more rolling topography occasionally dissected with old glacial meltwater channels. The rolling nature of the topography creates thousands of closed drainage basins. It has been estimated that the runoff from two-thirds of the prairie area terminates in closed basins (PFRA, 1982). Spring runoff waters in these basins can often be trapped or diverted for irrigation. The dominant soils irrigated in the Prairie Provinces are Chernozems with occasional inclusions of Solonetzic soils.

The climate of the Prairies is classed as semi-arid with an overall average precipitation of 37 cm. Southern Saskatchewan and southeastern Alberta might average near 28 cm, 56 cm in eastern Manitoba, 41 cm in the northern fringe of the Prairies and 64 cm along the foothills in Alberta.

Irrigation on the Prairies began in the late 1800's by individual ranchers who diverted small streams on to adjoining haylands to improve yields and assure hay supply for livestock. Although, private irrigation projects still account for over 20% of the irrigated acreage (mainly in Saskatchewan), most of the irrigation in Western Canada has been organized into larger Irrigation Districts, Irrigation Projects, or Water User's Districts where large storage reservoirs and canal systems have been constructed and are operated to provide releases on a controlled basis. Often these projects have involved joint Provincial-Federal funding (PFRA, 1983).

The major source of water for irrigation in the Prairies comes from rivers and streams dammed or diverted at some point to provide on-stream or off-stream storage. Although water quality of the major rivers on the Prairies is considered good, there are a number of situations where the use of certain waters has been of concern because of their high salt content. In the Prairies, some of the smaller river systems will naturally exceed a total dissolved solid concentration of 1,000 mg/L (Prairie Provinces Water Board, 1984; Inland Waters Directorate, 1985). Of larger concern, are smaller group projects and private irrigation projects where water quality can deteriorate rapidly with summer evaporation, particularly in drought years when it is most needed. In southern Saskatchewan, permanent lake and slough areas tend to be very saline and are usually not considered suitable for irrigation (Hammer, 1978 and Cameron, 1985).

Irrigation with groundwater plays a major role in Manitoba where about 60% of the land is irrigated from water pumped from various aquifers, the Carbury aquifer southeast of Brandon being the major one. In the rest of the Prairies most of the known aquifers with sufficient water supply for irrigation are considered too highly mineralized (saline) for irrigation (Bachman et al, 1980 and Environment Canada, 1978). Irrigation from two deep wells having EC's of 3.2 and 4.1 ds/cm is presently being field tested on sandy soils in Saskatchewan (Gillies et al, 1985).

There is increasing pressure in the Prairie Provinces to utilize agricultural land for the disposal of wastewaters. Irrigation of effluent wastes is becoming both economically and environmentally acceptable and several successful projects utilizing effluent waters with TDS concentrations up to 2,000 mg/l have been established (Environment Canada, 1984; Jame et al 1984; and Bole and Bell, 1978). It is estimated that approximately 4,000 ha are presently being irrigated with secondary lagoon effluents. Disposal of industrial wastewater (fertilizer plants, rendering plants, canning wastes, cheeze processing, gas plants, etc.) by irrigation is being monitored.

Irrigation cropping patterns in the Prairie Provinces have changed since 1970 (Table 2). In Alberta, cereals and to a lesser extent oilseeds and specialty crops have replaced hay. In Saskatchewan, hay production accounts for 60% and cereal and oilseeds account for over 30% of the irrigated acreage. In Manitoba, irrigated corn and cereal acreage are similar and account for about 65% of the irrigated acreage.

Types of irrigation systems have also changed. Various forms of flood and gravity systems, prominant 20 years ago, now comprise less than 30% of the irrigated acreage in the Prairie Provinces. Wheel roll and center pivot sprinklers are most common in intensive irrigation systems. Some spring backflood projects are now utilizing volume pumps to obtain their floodstage water alotment rather than using gravity diversions.

Crop water demand is dependant upon weather, crop type, and crop growth stage, but many producers have been using 30 cm of applied irrigation water over and above average seasonal precipitation as a general guideline for alfalfa irrigation (Pohjakas et al, 1967). Cereal crops and vegetables generally require less irrigation water, but potatoes and sugar beets often require as much as perennial forage crops.

3. Central Canada and the Maritimes

In Ontario and Quebec, the larger divisions of irrigated lands are in the physiographic region known as the St. Lawrence Lowlands which includes southern Ontario and the portion of Quebec adjoining the St. Lawrence River. The Gaspe Penisula and the Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland) are part of the Appalachian region of Canada.

Gray Brown Luvisols are the dominant soil in much of the St. Lawrence Lowlands, particularly in southern Ontario. In the Appalachians, Podzolic soils dominate. Small areas of Brunisolic soils are also present. Some of the Podzolic soils contain indurated (dense) or cemented layers (fragipans) which have caused percolation, runoff and erosion problems. This is being overcome by irrigation designs that yield lower application rates.

Average annual precipitation in the drier areas of Ontario is around 80 cm increasing to 100 cm over most of Central and Atlantic Canada. In parts of Nova Scotia, New Brunswick and Newfoundland an average annual precipitation of 140 cm is common (Environment Canada, 1978). Because of the generally favorable moisture conditions in Eastern Canada, (greater than 80 cm) relative to Western Canada (less than 40 cm) irrigation has been considered supplementary. Adequate drainage is often considered more of a problem than sufficient irrigation.

Since the droughts of the early 1950's, Ontario has experienced a considerable growth in irrigation, particularly in the tobacco-growing areas situated on coarse textured soils. The demand for flue cured tobacco and the value per hectare of this crop coupled with the incidence of summer moisture deficiencies on the sandy tobacco soils provided on initial impetus for irrigation development. About 2/3 of the total irrigated area of 40,000 ha is in tobacco. Vegetables and potatoes occupy the next largest area of 6,000 ha, followed by some 1,500 ha of fruit trees (International Commission on Irrigation and Drainage, 1975).

Throughout the Eastern Provinces, irrigation of market gardens, vegetables, strawberries, and fruit trees has helped intensify production while providing a more uniform product and a more reliable supply. Recently irrigation systems have also been used for frost protection (Irwin and Armitage, 1981).

Most natural sources of water in Eastern Canada are of good quality for irrigation (OME, 1980). Exceptions are saline groundwaters which may be encountered in some bedrock formations

(Ayers, 1980). Lakes, large ponds, and streams, provided they do not dry up, are all used for irrigation. Farm holding ponds or small reservoirs, which may be spring-fed or may collect waters from stream diversions or runoff, are popular in Eastern Canada. In the tobacco lands of Ontario a common practice is to excavate into the shallow sand deposits to a depth of two or three meters to establish a groundwater fed pond. In effect these ponds act as larger diameter shallow wells. Deep groundwater wells as a source of irrigation water are not as extensive as other water sources.

Gravity flow systems of irrigation are virtually non-existent in Eastern Canada. A variety of sprinkler systems are used, mainly portable systems with some solid set. There are very few wheel roll and center pivot systems. Gun sprinklers are becoming common, particularly for tobacco and some vegetables (Walker and Watson, 1980). Trickle irrigation for tree fruit and grapes is limited, but gaining acceptance (Cline, 1981).

Irrigation water requirements in Eastern Canada are fairly low relative to the rest of Canada. Application rates of 10 cm or so per season are common. Irrigation is sometimes used in small fruit production (strawberries) as a means of frost protection.

V. CROP SALT TOLERANCE

The salinity or total soluble salt concentration of an irrigation water is an extremely important water quality consideration. An increase in salinity causes an increase in the osmotic pressure of the soil solution resulting in a reduced availability of the water for plant consumption. Consequently, plant growth may be severely retarded.

Salt accumulation in the soil can be controlled by irrigation management, or more specifically the rate of application of the water. If the combined application of irrigation and rainfall is lower than plant consumptive use, an accumulation of salts in the main root zone will result. A properly managed irrigation will allow for application of sufficient excess water (called leaching fraction) to move a portion of the salts out of the root zone.

Plants vary in their tolerance to soil salinity. As a general rule, most fruit crops are sensitive followed by vegetable, field, and forage crops. Within a crop species, there is often variation in salt tolerance. In addition, tolerances vary with different stages of growth; usually the germinating seedling is the most sensitive stage (Millington et al, 1951 and Hart, 1974).

There is a large collection of world-wide literature available that deals with the relationship of the salt tolerance of plants to the salinity of irrigation water (Ayers and Westcot, 1976; Bernstein, 1964; Bernstein 1965; Bernstein, 1974; Bernstein et al, 1972; Francois, 1981; Kearney and Scotfield, 1936; Maas, 1985; Maas and Hoffman, 1977; Westcot and Ayers, 1984). Most of the data has been derived from artificial field plots where high leaching fractions were maintained to obtain a uniform salt distribution throughout the root zone. Experience has confirmed that such data are reproducible and reliable and have the advantage of being transposed to field situations. Over the years, salt tolerant tables showing the relationship between plant sensitivity and irrigation water salinity have been derived from the data.

A salt tolerance table for some irrigated Canadian crops has been compiled taking into account the previously published literature (Table 4). The assumptions used to derive the salt tolerance ratings are presented at the bottom of the table. There have been several concerns about the use of the data in Table 3 for Canadian conditions.

1. The crop varieties used to derive the salt tolerances for Table 4 are not the same as our Canadian varieties and differences have been observed (MacKenzie et al, 1983). Canadian wheat and barley varieties do not appear as salt tolerant as those used to derive Table 4 and alfalfa might be more salt tolerant than suggested by Table 4.
2. The derivation of the table is based on maximum tolerance without yield reduction of growing (established) plants but does not account for germination and seedling tolerance. Although barley and wheat are shown as very tolerant crops, actual soil electrical conductivities (ECe) should not exceed 4 to 5 mmhos/cm (mS/cm) during the germination and seedling stages. ECe should not exceed 3 mmhos/cm for garden beets and sugar beets during germination.
3. There is concern by researchers that the data in Table 4 is more representative of California conditions than Canadian conditions. The climate in Canada is cooler and moister, suggesting a higher natural leaching fraction may be more appropriate.

Table 4. Salt tolerance of selected crops.

Degree of Tolerance	Fruits and Berries	Vegetables	Field Crops	Forages
Not Tolerant				
ECw < 0.7	Strawberry	Beans	Beans	
TDS < 500	Raspberry	Carrots		
Slightly Tolerant				
ECw < 1.2	Boysenberry	Onion	Cowpea	Clover
TDS < 800	Currants	Parsnips	Broadbean	(alsike,
	Blackberry	Radish	Flax	ladino
	Gooseberry	Pea	Sunflower	red, &
	Plum	Pumpkin	Corn	strawberry)
	Grape	Lettuce		Berseem
	Apricot	Pepper		clover
	Peach	Muskmellon		Corn
	Pear	Sweet Potatoes		forage
	Cherry	Sweet Corn		
	Apple	Potato		
		Celery		
		Cabbage		
		Kohlrabi		
		Cauliflower		
Moderately Tolerant				
ECw < 2.2		Spinach	Rice	Brome,
TDS < 1500		Cantaloupe	(paddy)	smooth
		Cucumber		Alfalfa
		Tomato		Big Trefoil
		Squash		Beardless
		Brussel Sprouts		wildrye
		Broccoli		Vetch
		Turnips		Timothy
				Creasted
				wheatgrass
Tolerant				
ECw < 3.6		Beets	Rape	Oat Hay
TDS < 2500		Zucchini	Sorghum	Wheat Hay
				Brome,
				mountain
				Tall Fesure
				Sweet Clover
				Reed
				canarygrass
				Birdsfoot
				trefoil
				Perennial
				ryegrass

Table 4 (con't)

Degree of Tolerance	Fruits and Berries	Vegetables	Field Crops	Forages
Very Tolerant				
ECw < 5.0 TDS < 3500		Asparagus	Soybean Safflower Oats Rye Wheat Sugarbeet Barley	Barley Hay Tall wheatgrass

Assumptions

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. ECe means elctrical conductivity of saturation extract (mS/cm or mmhos/cm). ECw is the electrical conductivity of the irrigation water. ECsw is the electrical conductivity of the soil solution. ECsw=3ECw for a leaching fraction of 0.15.

3. TDS means total dissolved solids in units of mg/L or ppm. The conversion factor of 1EC=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 demand 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 appplied infrequently as needed. The crop utilizes 50% or more of the stored available water before the next irrigation. Guidelines are too restrictive for frequent or drip irrigation systems.

8. Each irrigation leaches the upper root zone and salt accumulation increases with depth. The crop responds to the average salinity in the root zone and the salt content of the soil solution (ECsw) is about three times that of the irrigation water (ECw) due to evapotranspiration.

4. Much of the data has been derived using sandy soil or sand cultures, while the irrigated soils in Canada range from sands to clays. It has been felt that some compensation or adjustments for soil texture should be made.

VI. SODIUM ADSORPTION RATIO, BICARBONATES AND PERMEABILITY

Excess sodium in the irrigation water relative to calcium and magnesium or relative to the total salt content can adversely affect soil structure and reduce the rate at which water moves into the soil (permeability, infiltration) as well as reduce soil aeration. When calcium is the predominant cation on the soil exchange complex, the soil tends to have a granular structure, easily worked and permeable. However, when adsorbed sodium exceeds 10 to 15% of the total cations then the clay becomes dispersed and this results in a soil that becomes puddled when wet, lowering permeability and forming a hard impermeable crust when dry.

The magnitude of the effect of excess sodium can be related to the relative proportions of sodium ions and calcium plus magnesium ions in the irrigation water. The sodium adsorption ratio (SAR) can be calculated as follows:

SAR = .275 (Na)/SQRT [(Ca) + 1.64 (Mg)]

where concentrations of Na, Ca, and Mg are expressed as mg/L (ppm).

Most researchers agree that when the SAR approaches 10, the probability for soil permeability problems increases. However, the potential permeability effects of SAR can often be counter-acted by high salt levels. Quirk and Schofield (1955) and Quirk (1971) have shown that there is a clear advantage in increasing the salinity in the irrigation water to maintain soils in a flocculated, and hence permeable condition. As discussed previously, irrigation with water relatively high in sodium and low in total salt content may result in poor soil physical conditions, however, high sodium waters with high salinity provide stable conditions. The generalized boundary between stable and unstable soil conditions is shown in Figure 3 (from Oster and Rhoades, 1984). Combinations of salinity and SAR values that lie above the solid line are not expected to cause dispersion or clay swelling. The values that lie below the line can create permeability problems.

If the SAR in the topsoil is greater than 10, then large reductions in permeability (puddling, crusting) can occur if rainfall reduces soil salinity to levels less than 1 mS/cm (Figure 3). In Canadian climates this becomes important, particularly in spring when snowmelt infiltration and rainshowers can temporarily dilute the surface salt concentration without affecting the exchangable sodium percentage. It may be realistic under these situations to provide some degree of protection by extending the zone of potentially unstable conditions upward, particularly for more saline waters. Thus, the dashed line in Figure 4 might be more representative of conditions in Canada where irrigation waters with EC's of 1 mS/cm and SAR's of 8 or less would create stable conditions and waters with EC's near 3 should not cause permeability problems if SAR's were limited to less than 20 as opposed to 30.

With regard to soil permeability below the soil surface, the increased level of salinity due to crop water uptake will usually be sufficient to offset the effects of exchangeable sodium.

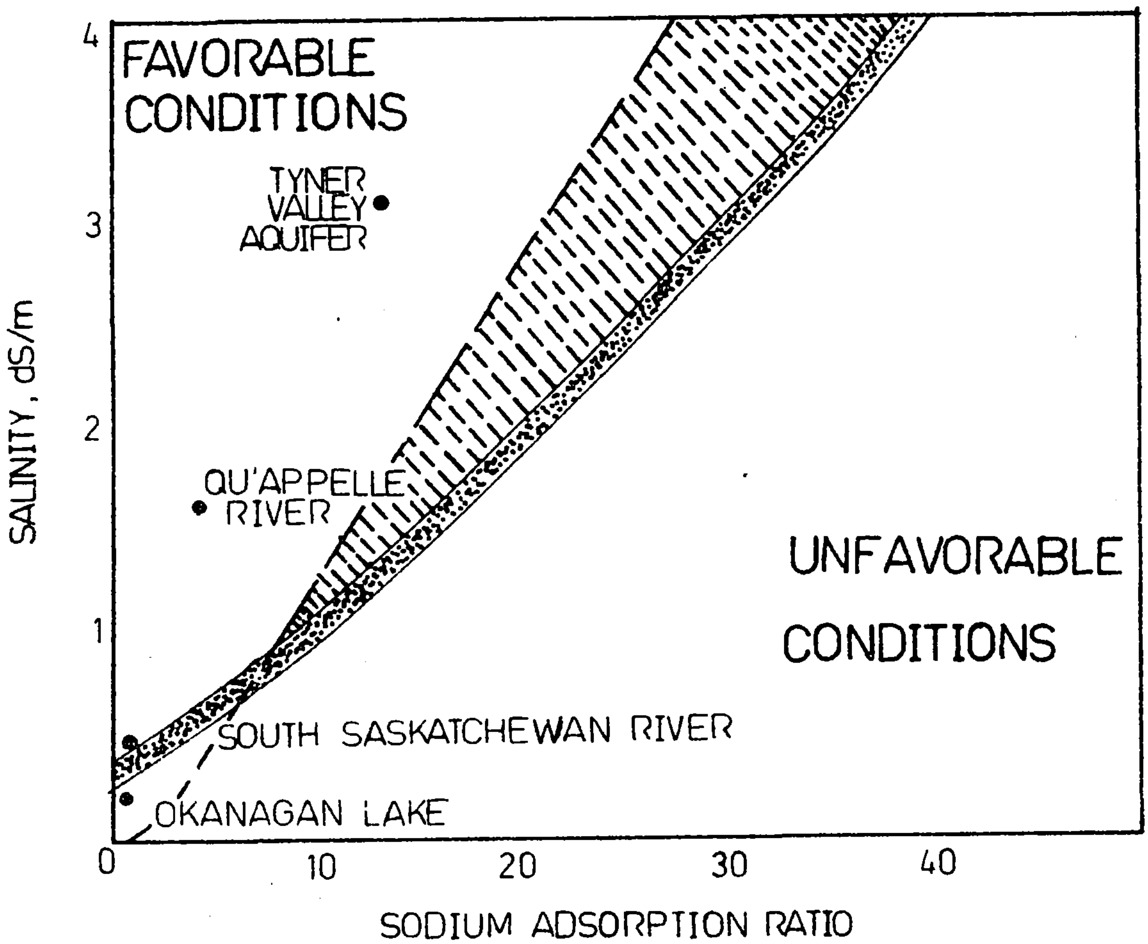

Figure 3. Relationship between salinity and sodium adsorption ratio showing combinations that promote good permeability and those which do not.

There is a tendancy to emphasize the effect of SAR on water infiltration. Of importance, but not well documented are problems associated with tilth, seedbed preparation and reduced germination. Increased cultivator shovel wear and horsepower requirements also play a role (McMullin, 1985).

The bicarbonate hazard discussed by Eaton (1950) refers to long term use of irrigation waters containing high concentrations of bicarbonate. As the bicarbonate becomes concentrated in the soil water due to evapotranspiration, there is an increased tendency for calcium and magnesium to be precipitated as insoluble carbonates. Over time this will result in an increased SAR and the appearance of sodium problems that previously did not exist.

Several researchers over the past decade have made attempts to quantify the potential bicarbonate hazard ranging from calculating residual sodium carbonate (RSC) values (Eaton, 1950; Wilcox, 1959) to calculating adjusted SAR's (Bower et al, 1968; Rhoades, 1968 and Rhoades, 1971). Canadian experience has shown that the adjusted SAR calculations are often 2 to 3X the SAR for many waters. It was felt that the calculated adjusted SAR's might tend to over compensate for a potential HCO_3 hazard (Environment Canada, 1984). The approach of Suarez (1981) for estimating SAR has been adopted by Westcot and Ayers (1984), and appears to yield SAR values similar to the standard SAR calculation.

VII. ROLE OF SOIL TEXTURE IN GUIDELINES

Soil texture plays a major role in irrigation. It is closely related to the ability of a soil to percolate water (permeability, infiltration), to store water (available water holding capacity) and to adsorb-desorb chemical ions (exchange capacity). Soil texture has been used extensively in irrigation design and scheduling, but has not received the attention it may merit in setting irrigation water quality-soil suitability guidelines.

Most researchers, field advisors and farmers know that poorer quality water used to irrigate sandier soils will sometimes cause problems on heavier soils. Several state and local agencies have attempted to include texture as part of their general irrigation water quality guidelines (A&L Laboratories, 1978; Anonymous, 1975; Soil Conserv. Serv., 1982; and Schafer, 1984). Not only texture, but the types of clays present can influence soil reaction. Ayers and Wescot (1976) indicated that the sodium permeability problems may be greatest in soils with montmorillonite type clays than in soils with illite-vermiculites clays, and least in kaolinite-sesquioxides clays. However, this same criteria was deleted from their recent guidelines for municipal wastewaters (Westcot and Ayers, 1984).

Although it is felt by some researchers that soil texture should be included as a part of the guidelines, particularly in determining combinations of SAR and salinity that afford permeability and salt tolerance protection, it is also a fact that insufficient rationale has been published in the scientific literature to include texture categories as a standard part of the EC-SAR guidelines. Likely within the next decade, texture categorizations and other soil related categorizations including depth to impermeable or permeable layers and depth to water tables will form integral parts of water quality-soil suitability guidelines.

At this stage it would be premature to include textural categorization within national water quality guidelines without an adequate data base and/or general peer concensus. However, categorization by texture on a Provincial level as deemed necessary is supported.

VIII. SPECIFIC ION TOLERANCES

In addition to the effect of total salinity on water-soil-plant relations, some individual ions can have varying effects on plant growth. The ions considered to be of most concern are sodium, chloride, and boron. Toxicity problems from these ions often accompany and complicate a salinity problem, although toxicity occasionally occurs even if salinity is low.

1. Boron

Boron is one of the essential elements for plant growth but is needed in relatively small amounts. If excessive, boron then becomes toxic. A boron toxicity problem in irrigation waters is often associated with groundwaters or secondary wastewaters rather than surface streams (Ayers and Westcot, 1976).

A major portion of the plant B toxicity criteria used for evaluating irrigation waters is based on sand culture work performed in California (Eaton, 1944). In a fairly comprehensive general review on boron Gupta et al (1985, in press) have concluded that there is confusion in the interpretation of Eaton's data as to whether the "B concentration" is that of the irrigation water or the soil solution and, also, because of the lack of replication in Eaton's work, precision cannot properly be assessed. The authors emphasized the need to establish criteria for evaluating B in irrigation water. Boron adsorption also plays a role in determining soil solution concentrations. Jame et al (1982) have developed a theoretical model to aid in predicting B concentrations.

Despite possible shortcomings of Eaton's data, it has provided reasonable guidelines in the past (U.S. Salinity Laboratory Staff, 1954; Wilcox, 1960; Allison, 1964; Bingham, 1973; NAS/NAE, 1973; Bernstein, 1974; Hart, 1974) and these guidelines have been extensively utilized in the last decade (Ayers and Westcot, 1976; U.S. EPA, 1976; Ayers, 1977; Shainberg and Oster, 1978; Westcot and Ayers, 1984; Environment Canada, 1984; and Maas, 1985 in press). Using data taken from Maas (1985, in press), the relative boron tolerance of agricultural crops has been tabulated (Table 5, from Westcot and Ayers, 1984).

The results compiled in Table 5 show that most fruit trees, small fruits, and berries are sensitive to boron levels of irrigation waters that exceed 1.0 mg/l. The cereal crops, wheat and barley and such field crops as sunflowers and potatoes are categorized as sensitive, although field crops such as oats, corn, tobacco, mustard, sorghum, and sugar beets are tolerant (irrigation water concentrations ranging from 2.0 to 6.0 mg/l). Vegetable crops vary in their tolerance: onions and beans are sensitive; peas, carrots, cucumbers, lettuce, and celery are moderately affected; and tomatoes, parsley, beets, and asparagus are tolerant.

Table 5. Relative boron tolerance of agricultural crops.[1]

Tolerance	B (mg/L) soilwater	Agricultural Crops
Very Sensitive	< 0.5	lemon, blackberry
Sensitive	0.5-1.0	avocado, grapefruit, orange, peach, cherry, plum, fig, grape, walnut, pecan, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupine, strawberry, Jerusalem artichoke, kidney bean, lima bean, peanut
Moderately Sensitive	1.0-2.0	red peper, pea, carrot, radish, potato, cucumber
Moderately Tolerant	2.0-4.0	lettuce, cabbage, celery, turnip, Kentucy bluegrass, oats, 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	cotton, asparagus

1. Assumptions used to derive Table 5 were:

   (a) Boron concentrations are maximum concentrations tolerated in water without yield or vegetative growth reductions.

   (b) Boron tolerances will vary depending upon climate, soil conditions and crop varieties, i.e. the table is only a guideline.

   (c) Maximum concentrations tolerated in the applied irrigation water are aproximately equal to soil-water values or slightly less.

2. Chloride

Chloride is essential to the growth of plants; however most woody plant species (stone fruits, citrus, avocados) are sensitive to low concentrations of chloride while most vegetable, grain, forage and fibre crops are not (Chapman, 1966; Oster and Rhoades, 1984).

Chloride damages can occur in two ways. First the Cl ion can be taken up by the roots and moved upward to accumulate in the leaves, similar to sodium. Excessive accumulation causes leaf burn, chlorosis, and twig die-back. Second, direct foliar absorption of chlorides from sprinkler irrigation can also cause damage, particularly on hot, windy days (Bernstein, 1967).

The degree of tolerance to chloride ions is summarized in Tables 6 and 7 for root uptake and foliar injury from sprinkler absorption, respectively (data taken from Maas, 1985, in press as summarized by Westcot and Ayers, 1984). In Canada, such stone fruits as apricots, cherries, peaches, and plums; and some berry plants including strawberry, raspberry, boysenberry, and blackberry may be sensitive to concentrations of chlorides in irrigation waters ranging from 110 to 250 mg/L. Often, the overall salinity tolerance of the crop (see Table 4) will be exceeded and cause yield reduction prior to chloride ion toxicity.

Foliar damage by sprinkler irrigation due to excessive absorption of chloride or sodium directly by the leaves is most likely to occur on fruit trees as they are most sensitive, but grapes, peppers, potatoes, and tomatoes are also sensitive. Generally the effects of leaf burning can be minimized by night-time sprinkling and water applied at a rapid continuous rate.

Table 6. Chloride tolerance of fruit and woody crops by root uptake.

Rootstocks	Cl (mg/L) in Irrigation water	Cultivators	Cl (mg/L) in Irrigation Water
Avocado	110-180	Boysenberry Blackberry Raspberry	250
Citrus-			
grapefruit	600		
rough lemons	355		
sweet oranges	250		
Grapes	710-960	Grapes	230-460
Stone Fruit (peaches, plums, etc.)	180-600	Strawberry	110-180

Table 7. Sodium or chloride concentrations in irrigation water causing foliar damage.

	Sensitive	Moderately Sensitive	Moderately Tolerant	Tolerant
Na or Cl (meq/L)	<5	5-10	10-20	>20
Cl (mg/L)	<178	178-355	355-710	>710
Na (mg/L)	<115	115-230	230-460	>460
	Almond	Grape	Alfalfa	Cauliflower
	Apricot	Pepper	Barley	Cotton
	Citrus	Potato	Corn	Sugarbeet
	Plum	Tomato	Cucumber	Sunflower
				Safflower
				Sesame
				Sorghum

Tobacco plants absorb chloride rapidly and excess chloride in the tobacco leaf reduces its smoking qualities. In Australia, excessive chloride has occured in the tobacco leaf where irrigation water concentrations exceed 30 mg/L (Hart, 1974). In Wisconsin, Wedin and Struckmeyer (1958) found that chloride levels near 35 mg/L in nutrient solution lowered the burning quality of the tobacco leaf. Peele et al (1960) found that, in South Carolina, most farm ponds used as supplementary irrigation for tobacco had chloride contents ranging from 5 to 54 mg/L and averaging about 12 mg/L. In a test where extra chloride was added to bring concentrations up to 25, 75, and 225 mg/L and the amount of irrigation water applied was 4 to 6 cm/year (there was adequate rainfall during most of the growing season), it was found that the 225 mg/L adversely affected the smoking flavor.

In Ontario, Quebec and the Maritimes, rainfall generally provides 60 to 70% (more in the Maritimes) of the plants' water requirements for optimum yield. If an irrigation system were providing most of the water then a limit of 35 mg/l would be in order. However, with supplementary irrigation a concentration of 70 mg/l will be diluted by rainfall and should not cause losses in tobacco quality.

3. Sodium

Sodium can affect plants through five different avenues:

(a) direct root uptake and plant accumulation of toxic levels of sodium.

(b) direct foliar absorption from sprinklers (already discussed for chloride, see Table 7).

(c) nutritional imbalance due to insufficient concentrations of calcium and magnesium to prevent the uptake and accumulation of sodium.

(d) impairment of soil physical conditions (already discussed in section VI of this report).

(e) sodium often a major cation contributing to osmotic stress on the salinity effect on plants.

It is often difficult to separate the various direct and indirect toxic effects of sodium and usually these are coupled with an overall osmotic or "salinity" effect. However, some plants are sodium sensitive and can be affected by low exchangable sodium percentages. A broad grouping of crop tolerances to sodium is presented in Table 8 (from Hart, 1974).

Sodium absorption ratio (SAR) and exchangable sodium is often used interchangeably to express tolerance levels to sodium toxicity. The reason for this is sodium toxicity is often modified and reduced if calcium is also present. Moderate amounts of calcium may prevent it. Thus, a reasonable evaluation of the potential toxicity is possible using SAR.

Sodium sensitive crops include deciduous fruits, nuts, citrus, avocado, and beans. In their recent guidelines, Westcot and Ayers (1984) have categorized the sodium effects as follows:

SAR	Restriction on Use
<3	none
3-9	slight to moderate
>9	severe

For most annual crops which are not as sensitive, they suggest that the salt tolerance tables (Table 4) be used as a guide.

Table 8. Tolerance of crops to sodium.

Tolerance	SAR of Irrigation Water	Crop	Conditions
Very Sensitive	2-8	Deciduous fruits Avocado Nuts	leaf tip burn, leaf scorch
Sensitive	8-18	Beans	stunted growth
Moderately Tolerant	18-46	Clover, oats tall fescue	stunted due to nutriton and soil structure
Tolerant	46-102	wheat, cotton lucerne, barley, tomatoes, beets, tall wheatgrass, crested wheatgrass	stunted due to soil structure

IX. PROPOSED IRRIGATION GUIDELINES FOR CANADA

The proposed irrigation water quality guidelines for Canada are presented in Table 9. The guidelines were compiled taking into account the diverse nature of agriculture in Canada including major regional differences in types of crops irrigated, climatic differences, and the inherent variability in quality of water sources from one region to the next. The major regions included British Columbia, The Prairies, and Eastern Canada.

The philosophy behind the establishment of the guidelines for each region was to provide maximum crop and soil protection for the major economical crops of each region, keeping in mind the natural climate and water quality of the region. Thus, tree fruits and grapes were considered as sensitive crops in British Columbia. In the Prairie region, hay and cereal production were highlighted at the expense of much smaller areages of specialty crops and vegetables. In Eastern Canada, tobacco, fruit trees, small fruits, and vegetable production were all considered important.

The "desirable" water quality guideline in Table 9 represents a figure which should provide complete protection of the crops and soils for the major crops while maintaining optimum yields. The "maximum" guideline was set to a level which would allow maximum irrigation use of poorer quality water while minimizing yield reductions and soil deterioration. Setting a "maximum" level required some degree of subjective evaluation and as such this guideline should be considered flexible. Where there was controversial or insufficient data, such as with boron, then the guideline was set close to what the majority of researchers consider reasonable (i.e. previously set guidelines).

Table 9. Proposed Irrigation Water Quality Guidelines for Canada.

I. Salinity (TDS)	Desirable	Maximum	Rationale
1. British Columbia	500 mg/L	800 mg/L	Water quality is excellent, guidelines provide protection for fruit crops and vegetables.
2. Prairie Provinces	1000	1500	Water quality is variable. The guidelines provide ample protection for the major crops of hay and cereals. Some specialty crops and vegetable crops will be set-back. Market gardens near Regina are presently irrigating with 1200 TDS waters.
Waste Disposal	1000	3000	Water quality greater than 1000 is not desirable, but can be utilized for disposal of effluents on hay crops in special situations. Well drained sandy soils and high leaching rates are desirable.
Manitoba	800	-	This guideline provides protection for Manitoba's growing corn acreage and for most of the vegetable production. A 10 % reduction in yields can be expected for strawberries, raspberries, beans, and carrots.
3. Central Canada and the Maritimes	500	800	Water quality is very good. Guidelines protect all major crops (tobacco, potatoes, vegetables, fruits and berries)

Table 9 continued.

	Desirable	Maximum	Rationale
II. Sodium Adsorption Ratio (SAR)			
EC (mS/cm)			SAR guidelines provide protection against soil structure deterioration. Desirable guidelines allow some protection for snowmelt/rainfall dilution effect. Guidelines can be less restrictive on sandy soils.
<0.5	<3	4	
0.5-1.0	3-8	4-10	
1.0-2.0	8-14	10-21	
2.0-3.0	14-22	21-30	
3.0-4.0	22-28	30-38	
III. Specific Ions			
1. Boron (mg/L) Canada	1.0	3.0	The guideline provides reasonable protection for a large number of vegetable, fruit, and cereal crops. Crops such as oats, corn, tobacco, beets, alfalfa, clover, celery and cabbage can tolerate higher concentrations. More research on relative crop tolerance under Canadian conditions is required.
2. Chloride (mg/L)			
British Columbia	110	180	The guideline provides protection for the most sensitive crops including tree fruits, grapes, and berries from both root uptake and foliar absorption.
Prairie Provinces	350	700	Hay crops and cereals are the major irrigated crops on the Prairies and are not chloride sensitive. Fruit trees and berry production can be reduced at these levels. Effects on potatoes and tomatoes will be noticed at the maximum level.

Table 9 continued.

	Desirable	Maximum	Rationale
Central Canada and the Maritimes	35	70	Tobacco is a major crop in Eastern Canada. The guideline provides for protection against deterioration of the smoking quality of flue-cured tobacco. Chloride sensitive crops (fruits, berries, and woody ornamentals) are also well protected by this guideline.
3. Sodium			
British Columbia and Eastern Canada	70 mg/L 3 SAR	120 8	The sodium ion guideline (mg/L) provides protection from foliar absorption and the SAR criteria provides protection from sodium toxicity for fruit and berry crops. Most vegetable, cereal, and hay crops have higher tolerances.
Prairie Provinces	No specific guidelines		Sodium levels will be controlled by the salinity and SAR guidelines. The major irrigated crops in the Prairies (hay and cereals) are relatively sodium tolerant.

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