Reclamation of saline soils adjacent to rehabilitated irrigation canals

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Bennett, D. R. 1990. **Reclamation of saline soils adjacent to rehabilitated irrigation canals.** Can. Agric. Eng. **32**: 1–9. A 3-yr study was conducted at eight locations in southern Alberta to monitor changes in soil salinity and groundwater conditions adjacent to rehabilitated irrigation canals. Monitoring activities included: measurement of water-table depths, soil moisture content and irrigation or precipitation amounts; and annual soil sampling and analysis to evaluate changes in soil salinity and sodicity. Soils were classified as to their present suitability for irrigation according to current land classification standards. A general decrease in the level of the water table was observed in only about half of the affected areas. Improvement in the salt-status of some soils was detected when water-table levels were maintained at depths greater than 1–1.5 m throughout most of the growing season. Irrigation and major precipitation events promoted some leaching of excess salt below the upper portion of the root zone. However, only two of the land units improved sufficiently to permit reclassification into an irrigable category. Major precipitation events, combined with irrigation events, contributed to the persistence of shallow groundwater levels at several plot locations because soils were nearly saturated to the ground surface. Additional surface or subsurface drainage will likely be required within most of the land units investigated, to permit adequate control of the water table and leaching of soil salts within a reasonable time frame.

INTRODUCTION

Approximately 70% of the salinized and waterlogged land within the irrigated areas of southern Alberta has been attributed to seepage (Sommerfeldt and Rapp 1982). Canal seepage was recently recognized as the most important cause of soil salinity problems in three irrigation districts (Chang et al. 1985). Salinity levels were found to vary from one location to another and relationships with clay content, distance from canals and water-table levels were observed. Groundwater migration from upslope recharge areas, inadequate surface drainage and inappropriate irrigation practices may further aggravate existing salinity problems (Paterson and Harker 1980).

A variety of rehabilitation methods have been used in southern Alberta over the past 20 yr to curtail salinization of land due to seepage from leaky canals. More than 250 million dollars were spent by the 13 irrigation districts from 1969 to 1987 under the Irrigation Rehabilitation Cost-Sharing Program, with another 50 million dollars allocated for the same program until 1990. These expenditures have been defended on the basis of increased capacity and efficiency of water distribution systems and enhanced productivity of salt-affected land through reclamation.

Attempts to reclaim salt-affected land through canal rehabilitation have had mixed success. Some land units have reportedly been reclaimed within one or two years, whereas others have shown little change in persistently high water table and salinity conditions for several years after canal rehabilitation (unpublished data). Detailed soil investigations and sampling are required to determine whether sufficient amelioration has occurred after canal rehabilitation to permit reclassification of salt-affected land units into an irrigable category (Alberta Agriculture 1983). A documented record of the reduction in seepage-affected land through the existing canal rehabilitation program does not currently exist in Alberta (Coopers and Lybrand Consulting Group 1987).

Maintenance of a favorable salt balance in most irrigated soils has been observed in southern Alberta for as long as 60 yr (Oosterveld et al. 1978; Chang and Oosterveld 1981; Pohjakas 1983). In the absence of canal seepage, internal drainage of glacial till soils appears to be adequate for sustained crop production with judicious irrigation management (Sommerfeldt and Chang 1980; Hendry 1982; Doering et al. 1986). Monitoring the fluctuation of the water table following rehabilitation is necessary to evaluate the potential for leaching of excess salt from saline soils by irrigation. Management recommendations for enhanced reclamation of salt-affected land may then be considered, provided drainage conditions improve within the short term.

The objective of this study was to determine changes in soil salinity and groundwater conditions within salt-affected areas and to ascertain whether sufficient improvement had been achieved after canal rehabilitation to permit reclassification of land units into an irrigable category. Monitoring prior to rehabilitation was not emphasized in the study because the irrigation suitability of a given saline or waterlogged land unit is rated on the basis of groundwater and soil salinity levels at the time of a land classification investigation.

MATERIALS AND METHODS

Site Description

Eight sites, located within four irrigation districts in southern Alberta, were selected in 1984 (Fig. 1). These sites represent a variety of soil types and four principle rehabilitation methods (Table I). These sites were originally rehabilitated between 1976 and 1985. Four of the study sites were rehabilitated using buried polyvinylchloride (PVC) or concrete pipelines. Two of the laterals, LNID 62H and TID 1, were lined with nonreinforced concrete lining. Both of these laterals have experienced some cracking and horizontal displacement. Polyethylene lining, covered with gravel armour, was installed on LNID 62K. Excavation to a deeper depth (1 m), for drainage as well as water conveyance purposes, was the rehabilitation method used on TID 20.

Glacial till (CL-C) is encountered within 1–2 m of the soil surface at five of the eight study sites (Fig. 2). Three of these five sites (LNID 62K, SMRID 12 and TID 20) have till consistently within 1 m. Till is also within 1.5–2 m of the surface in plot C — RID R-8-1.

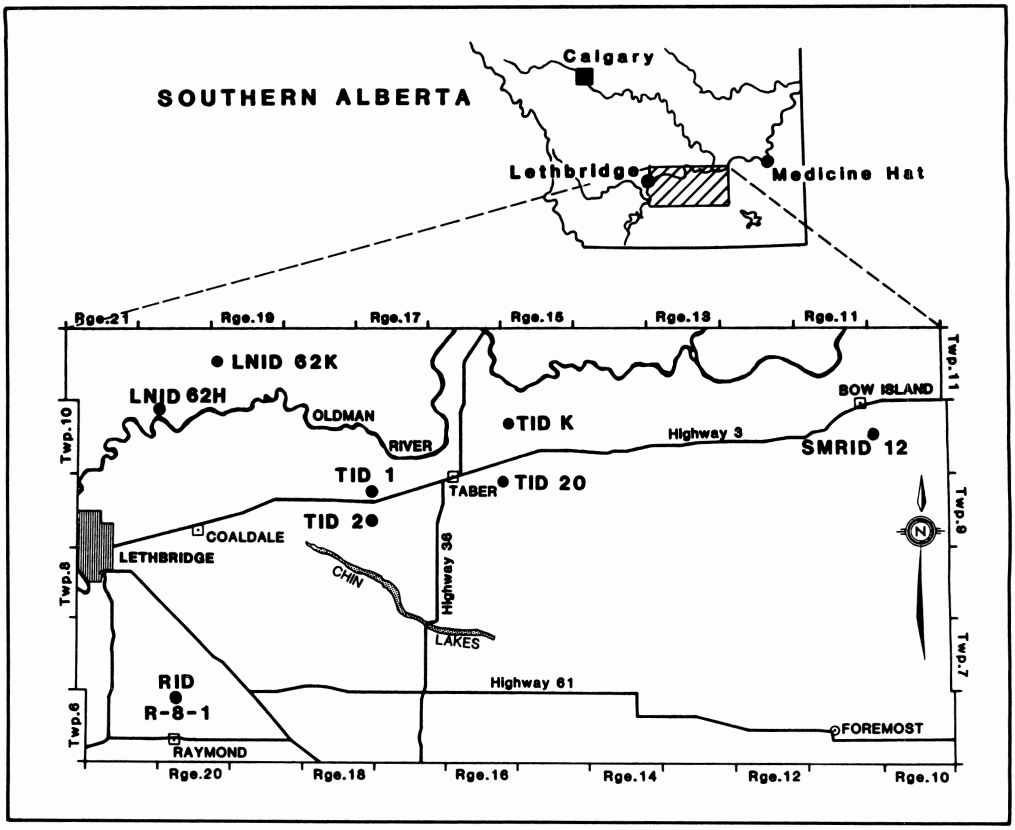

Figure 1. Location of study sites in southern Alberta.

Table I. Method and timing of rehabilitation at each site

Site†	Rehabilitation method	Year of rehabilitation
LNID 62H	Concrete lining	1978
LNID 62K	Polylining	1985
RID R-8-1	PVC pipe	1984
SMRID 12	PVC pipe	1983
TID 1	Concrete lining	1976
TID 2	PVC pipe	1983
TID K	Concrete pipeline	1985
TID 20	Canal deepening	1984

†LNID, RID, SMRID and TID = Lethbridge Northern, Raymond, St. Mary River and Taber Irrigation Districts, respectively.

Soils at six of the sites have developed within a veneer (less than 1 m) to blanket (1 m or more) of medium- to moderately fine-textured fluvial-lacustrine parent material (Fig. 2). The other two study sites, LNID 62K and TID K, have a sandy loam veneer underlain by fine-textured till and coarse-textured fluvial sediments containing a lacustrine layer, respectively.

Monitoring

Three 10 × 10-m plots were established along a 1- to 2-km length of rehabilitated lateral at each location. Plots were situated in lower to depressional slope positions within affected areas adjacent to original canal locations. One plot along TID 20 was abandoned in 1986 due to the deposition of approximately 0.3 m of fill material to the affected area. Plot A on TID K was not established until the fall of 1985 due to disturbance of an original plot by rehabilitation activities.

Site characterization and initial sampling were conducted in the fall of 1984. Soils within each plot were characterized to a 1.8-m depth at five locations — the four corners and center of each plot. Soil profiles were sampled at depths of 0–0.15, 0.15–0.30, 0.30–0.60, 0.60–0.90 and 0.90–1.20 m. Composite soil samples were obtained for each depth interval by bulking samples from three cores taken at each of the five sampling locations. These cores were obtained randomly from within each third of a 1-m-diameter circle surrounding the sampling location. Soils were subsequently sampled in the fall of 1985, 1986 and 1987 at the same depths and locations.

Soil samples were analyzed for saturation percentage, soil reaction (pH), electrical conductivity (ECe) and sodium adsorption ratio (SAR) of the saturated paste extract (Rhoades 1982). The irrigation suitability of the soils within each site was evaluated on the basis of current land classification standards (Alberta Agriculture 1983).

Neutron probe access tubes 1.8 m long, water table wells 3 m long and rain gauges were installed near the center of each plot in the fall or after crops were seeded in the spring. Probe readings and water-level measurements were gathered at 10-d intervals throughout the growing season. Soil moisture measurements were taken at depths of 0.3, 0.6, 0.9 and 1.2 m. Farming operations permitted access to at least half of the 24 plots for monitoring during the winter. Samples obtained during installation of access tubes were used for particle-size analysis (Bouyoucos 1962) and estimation of field capacity and wilting point (Oosterveld and Chang 1980). The amount of irrigation water applied, amount of precipitation and irrigation frequency were monitored at each site.

A split-plot analysis of variance (split by time) and protected least significant difference test were conducted for each parameter to determine whether significant changes in ECe and SAR had occurred from 1984 to 1987 within each sampling depth (Box 1954; Gomez and Gomez 1984).

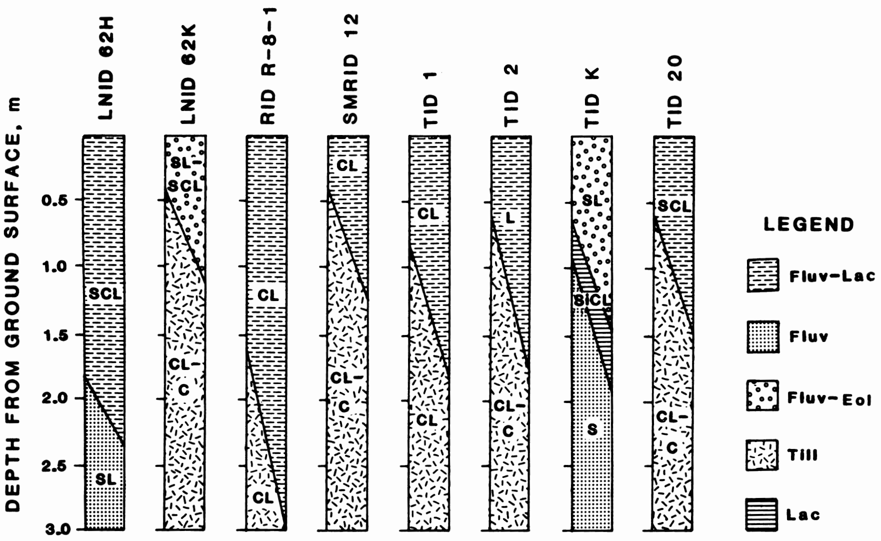

Figure 2. Parent geological material and texture of soils investigated at each site.

Table II. Monthly precipitation summary for the 1985 to 1987 growing seasons

		Precipitation (mm)							
Location	Year	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Total
Lethbridge	1985	39.3	31.5	2.0	21.8	83.5	106.9	22.1	307.1
(Agriculture Canada)	1986	18.0	71.3	52.2	16.4	19.0	97.0	39.0	312.9
	1987	19.0	20.3	63.8	93.3	62.8	33.6	9.6	302.4
	30-year mean†	41.3	48.5	78.1	39.5	47.4	36.5	17.8	309.1
Medicine Hat	1985	37.8	47.0	8.7	7.7	46.6	63.9	23.0	234.7
(Environment Canada)	1986	5.7	84.0	82.9	57.2	12.3	197.6	25.2	464.9
	1987	18.5	18.6	21.9	40.4	91.9	9.4	8.6	209.3
	30-year mean†	30.2	40.1	63.5	40.4	36.4	32.4	16.2	259.2
Brooks	1985	79.9	13.2	22.0	38.8	53.4	65.4	26.8	299.5
(Alberta Agriculture)	1986	10.8	54.3	30.5	62.9	12.8	140.6	25.3	337.2
	1987	11.6	26.8	22.1	43.2	102.6	15.7	6.8	228.8
	30-year mean†	26.0	38.3	65.7	32.2	40.1	33.8	13.4	249.5

†Environment Canada (1982).

Table III. Summary of irrigation water applied to the sites from 1985 to 1987

	Irrigation amount (mm) (number of irrigation events)								
	Plot A			Plot B			Plot C		
Site	1985	1986	1987	1985	1986	1987	1985	1986	1987
LNID 62H	0	0	0	118(4)	167(2)	180(3)	124(4)	107(2)	114(2)
LNID 62K	42(2)	105(4)	157(5)	0	0	55(3)	23(2)	197(5)	120(5)
RID R-8-1	70(3)	72(1)	137(2)	60(1)	98(1)	60(1)	170(2)	48(1)	123(1)
SMRID 12	288(8)	98(3)	218(6)	183(3)	143(2)	0	193(5)	259(8)	107(6)
TID 1	98(1)	124(1)	137(2)	106(2)	127(2)	0	10(1)	0	44(1)
TID 2	200(2)	131(2)	0	169(2)	60(1)	0	336(4)	210(2)	277(3)
TID K	0	132(1)	171(2)	0	64(1)	65(2)	0	0	0
TID 20	13(1)	-	-	126(4)	187(5)	170(5)	68(2)	0	170(3)

RESULTS

Precipitation and irrigation amounts

Precipitation throughout the growing seasons of 1985 to 1987 varied considerably among years and sites. Rainfall amounts (May through August) were less than 50% of long-term monthly averages about half the time during 1985, 1986 and about a third of the time during 1987 (Table II). Due to above-normal rainfall at other times, however, rainfall totals for the 7-mo period of April to October were usually near or above long-term normals. Abnormally high rainfall was received during August to October of 1985 and during September and October of 1986. The greatest amounts of precipitation during 1987 were received in July and August at most sites.

Amounts of irrigation water applied from 1985 to 1987 were also variable among sites (Table III). All but one plot (plot C — TID K) received at least one application of irrigation water during the three-year study. Several plots were irrigated only

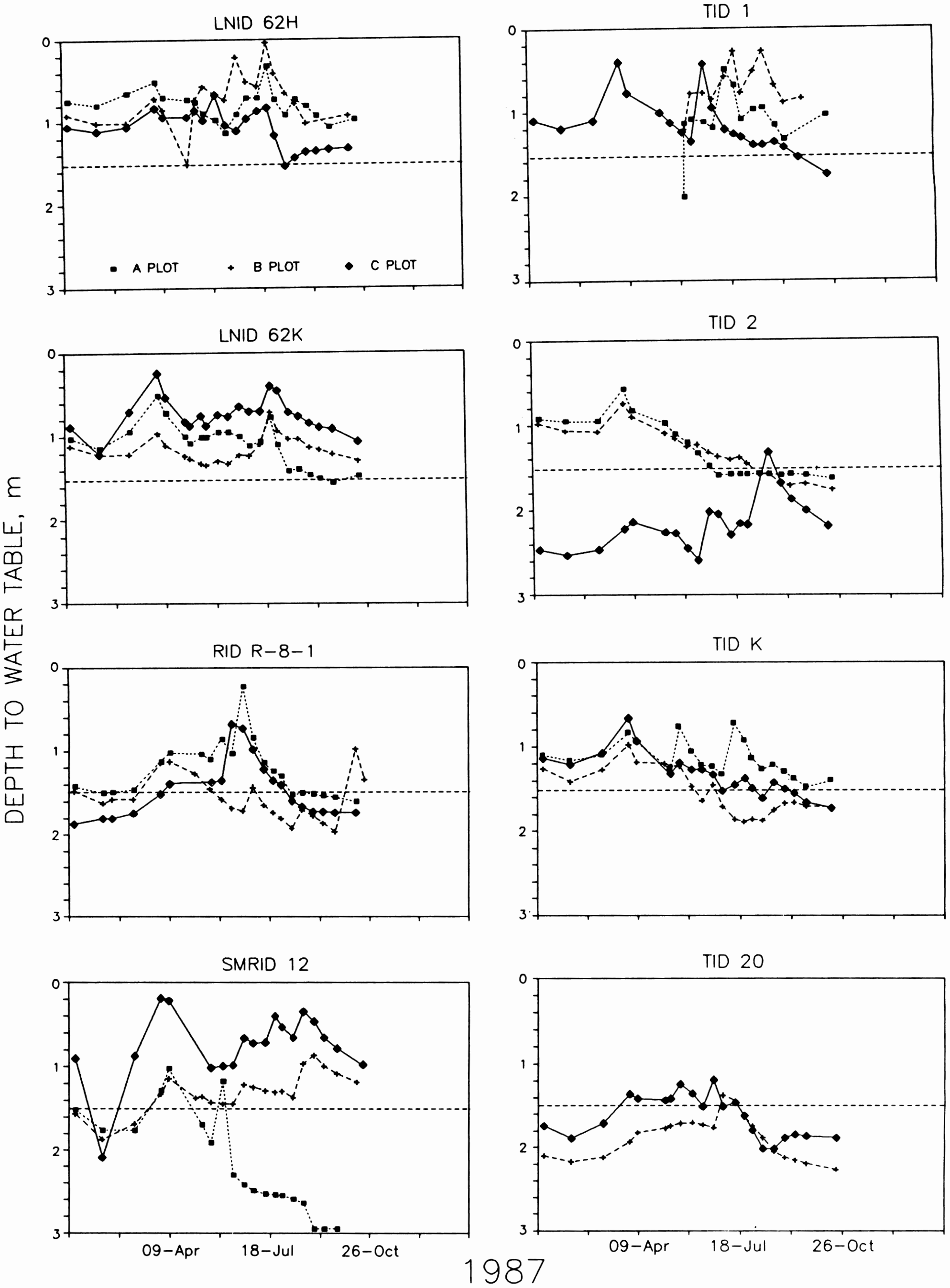

Figure 3. Water-table hydrographs for eight study sites during 1987.

once in a given year. The total amount of irrigation water applied and natural precipitation received was generally far less than the potential consumptive use requirements of crops grown at the different sites.

Water table responses

Water-table hydrographs for each of the sites in 1987 indicate that shallow groundwater levels persist at depths less than 1.5 m at a number of sites (Figure 3). This trend was also observed in water-table hydrographs for 1985 and 1986 (Data not shown). Persistently high water-table levels (less than 1.5 m) were observed in 1987 on all of the plots at three sites — LNID 62H, LNID 62K and TID 1. Water tables were above 1.5 m over half the time on at least two of three plots for the remaining sites, with the exception of TID 20. A lower water-table level in 1987, as compared to the two previous years, was apparent at about half the sites. This included all three plots on RID R-8-1 and TID K, on two plots of SMRID (plots A and B) and TID 20 (plots B and C), and only one plot of TID 2 (plot C).

A general increase in the water-table level was evident in late March to early April on plots monitored over the winter (Fig. 3). Responses in groundwater depth associated with turning water into canals in mid- to late-May were not detected at any of the sites over the 3-yr monitoring period. Surface ponding was observed on several plots because of irrigation, major precipitation events and spring runoff. Surface ponding was noted at least once in the three years on two plots (A and

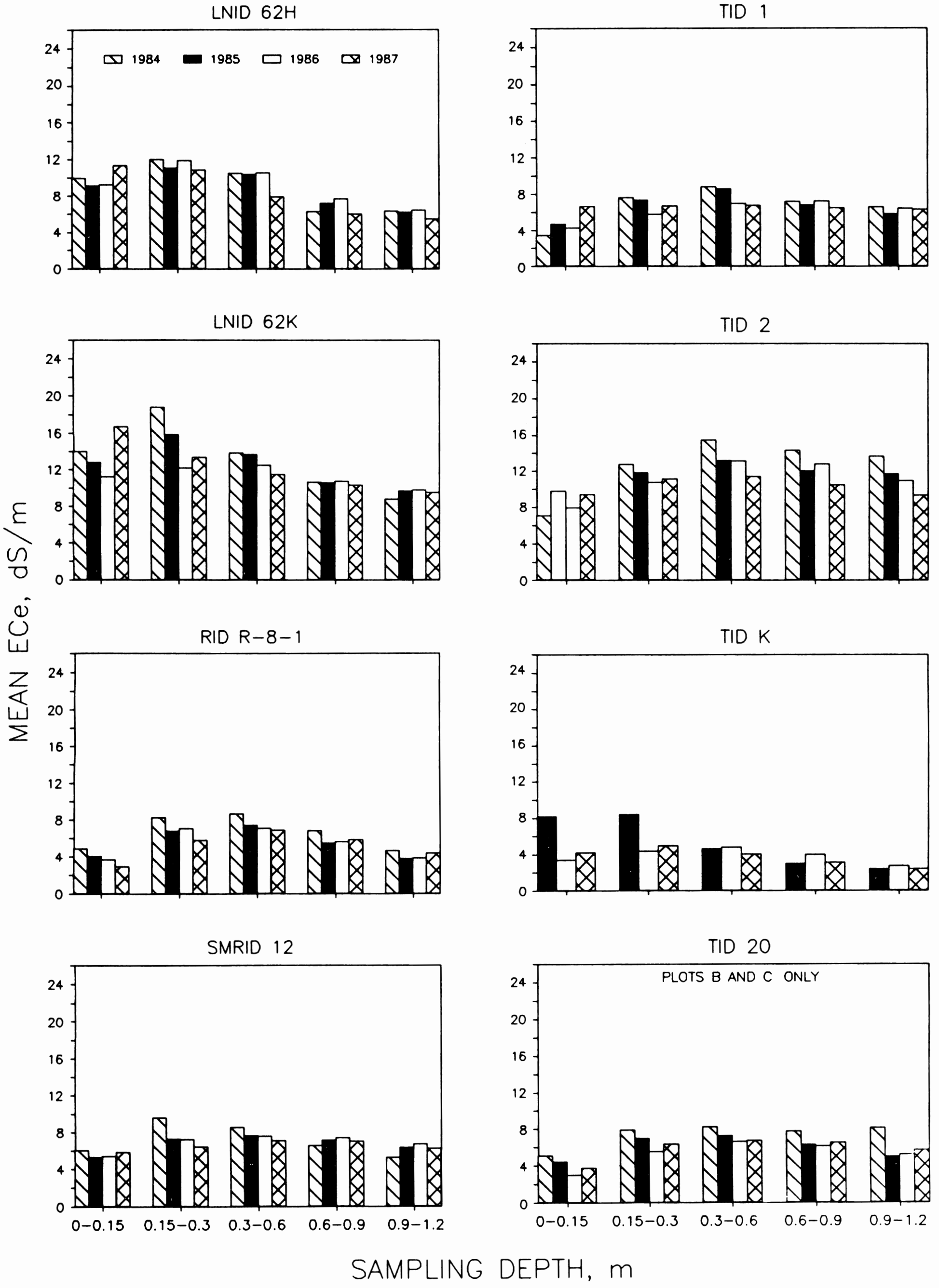

Figure 4. Mean soil salinity levels at eight study sites from 1984 to 1987.

B) of LNID 62H, TID 1 and TID 20; and on only one plot (C) of LNID 62K and SMRID 12. There is only one site (TID 20) where plots subject to surface ponding had a declining water table in 1987.

Soil moisture content

Fluctuations in soil moisture content were evident within the upper 0.5 m of soils for most of the plots; however, near-saturated conditions were prevalent throughout the remainder of the profile at all sites (data not shown). Soil moisture content was maintained within the range of 35-45% by volume throughout the study period, except in the coarser-textured soils on TID K and TID 20 where moisture content near the surface was reduced to 30% or less. Plots that were not irrigated in a given year also experienced reductions in moisture content to less than 30% by volume within the upper portion of the profile.

Soil salinity and sodicity

Mean salinity and sodicity levels in the upper 0.6-m portion of the soil profile generally exhibited an increase in 1987 as compared to levels observed in 1986 at all sites, except RID R-8-1 (Figs. 4 and 5). Specific reductions in soil salinity and sodicity levels within the upper profile of individual plots were only noted for plot A of SMRID 12 and TID K, and plot C of TID 2.

Comparison among years of annual mean values of ECe and SAR (1984–1987) indicated significant reductions in ECe and

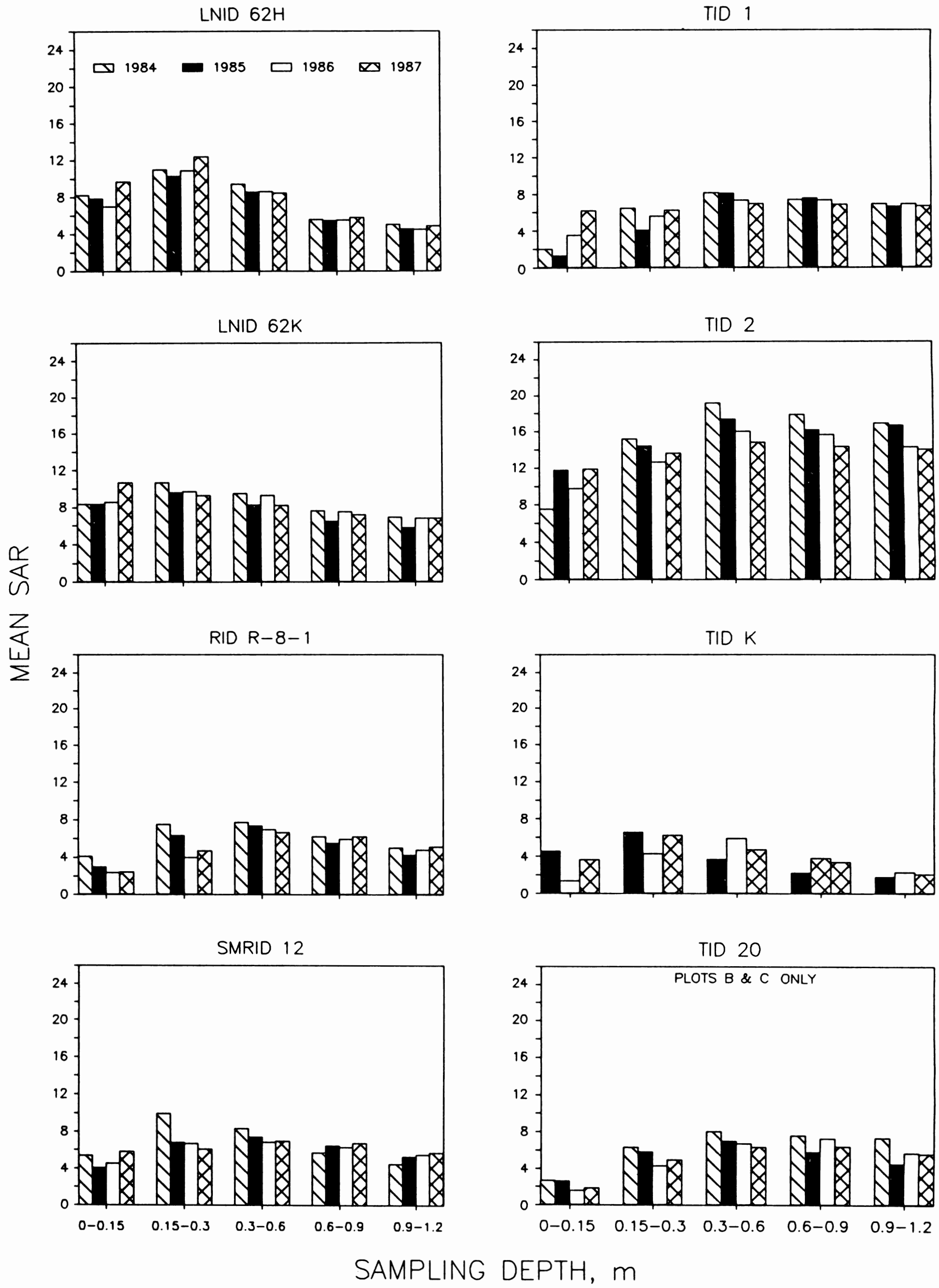

Figure 5. Mean sodicity levels in soils at eight sites from 1984 to 1987.

SAR within 0.15- to 0.6-m depths when means over all eight sites were considered (Table IV). Significant differences were detected for ECe at the depths of 0.15–0.30 and 0.30–0.60 m and for SAR at all depth intervals to 0.60 m. General reductions in salinity and sodicity within the 1.2-m root zone were also apparent from annual weighted mean values for ECe and SAR. The leaching of excess salt was also evidenced by the significant decrease in weighted total ECe for the 1.2-m profile.

A significant site-by-year interaction was apparent for ECe at the 0- to 0.15-m depth (data not shown). This interaction indicates that trends over time were not consistent at all sites.

DISCUSSION

Factors affecting soil reclamation

The water-table depth required to prevent salinization of soils in southern Alberta varies from 1 to 1.5 m, depending on the salinity of groundwater, soil characteristics, local climatic conditions and type of crop (Van Schaik and Milne 1962, 1963; Van Schaik and Stevenson 1967). Capillary rise of groundwater from a shallow water table will inevitably result in further salinization of soils unless the water table is maintained below this critical depth and sufficient irrigation water or natural precipitation can be applied to promote the net downward movement

Table IV. Comparison of annual mean salinity and sodicity values at the eight study sites from 1984 to 1987

Parameter	Sampling interval (m)	Annual mean values†				
		1984	1985	1986	1987	LSD
ECe ($dS\ m^{-1}$)	0 - 0.15	7.01	7.42	6.10	7.69	NS
	0.15 - 0.30	10.49*a*	9.46*b*	8.12*c*	8.22*c*	0.67
	0.30 - 0.60	9.88*a*	9.05*b*	8.64*b*	7.76*c*	0.70
	0.60 - 0.90	7.81	7.28	7.66	6.93	NS
	0.90 - 1.20	6.83	6.35	6.44	6.08	NS
Weighted mean	0 - 1.20	8.32*a*	7.78*ab*	7.46*bc*	7.18*c*	0.55
Weighted total	0 - 1.20	33.27*a*	31.13*b*	29.84*c*	28.73*d*	1.10
SAR	0 - 0.15	5.41*a*	5.64*ab*	5.00*a*	6.68*b*	0.78
	0.15 - 0.30	9.34*a*	8.04*b*	7.32*c*	7.99*b*	0.70
	0.30 - 0.60	9.46*a*	8.43*b*	8.43*b*	7.87*b*	0.70
	0.60 - 0.90	7.57	6.93	7.36	7.05	NS
	0.90 - 1.20	6.65	6.18	6.29	6.29	NS
Weighted mean	0 - 1.20	7.76	7.09	7.06	7.14	NS

†Mean of eight sites.
a-d Values followed by the same letter are not significantly different ($P=0.05$) using Box's correction (Box 1954).

of water (Van Schaik and Stevenson 1967; Van Schaik and Rapp 1970).

The water table response observed in late March to early April at most of the plots (Fig. 3) may be attributed to recharge resulting from thawing of frozen soil near the ground surface. Van Schaik and Stevenson (1967) noted significant upward migration of moisture from a shallow water table during the winter, in response to a freezing front gradient. This excess moisture is released as the frozen zone thaws, resulting in a rise in the water-table level. This phenomenon has also been detected by other workers (Gray and Granger 1986; Fullerton and Pawluk 1987).

Seepage from rehabilitated canals or pipelines was not apparent at any of the sites during the 3-yr monitoring period, regardless of the method of rehabilitation. Persistence of a high water table and associated salinity, at most of the plots investigated (Figs. 3 and 4), may be attributed to the internal drainage characteristics of the soil and parent material, natural groundwater flow from upslope recharge areas and surface ponding in depressional areas as a result of spring runoff and major precipitation or irrigation events.

Irrigation and major precipitation events, in particular, contributed to dramatic fluctuation of the water table throughout the growing season (Fig. 3), resulting in a rise in the groundwater level to within 1-1.5 m of the soil surface at all sites and most plots. A rapid rise in the water-table level with each irrigation or major precipitation event was predictable because of the minimal available moisture storage capacity in any of these nearly saturated soils.

Increases in soil salinity and sodicity levels in the upper soil profile during 1987 may be attributed to two main factors. These are: the persistence of a high water table within 1-1.5 m of the soil surface throughout most of the growing season; and the relatively warm, dry weather experienced in the fall of 1987. High moisture conditions associated with several major precipitation events during the 2-mo period prior to sampling in the fall of both 1985 and 1986 may have contributed to some previous leaching of excess salt.

Leaching of excess salt from the soil is impossible to achieve unless adequate internal or artificial drainage is available to maintain the water table at sufficient depth to prevent the capillary rise of groundwater into the root zone. The net downward movement of salt may be readily achieved within these moist soils, with very small amounts of water, when soil drainage is adequate. On the other hand, insufficient internal drainage will inevitably result in an increase in water-table levels and the further salinization of soils. Adequate control of the water table in the future could well necessitate the installation of drainage within these salt-affected areas.

Implications for Soil Reclassification

Reclamation of soils at the majority of the study sites has not been achieved within the varied times (2-11 yr) since rehabilitation activities were completed (Table V). Soil salinity must be reduced to ECe values less than 6 $dS\ m^{-1}$ within the upper 0.5 m and to less than 12 $dS\ m^{-1}$ from 0.5 to 1 m for an irrigable rating to be applied (Alberta Agriculture 1983).

Two nonirrigable land units in which plots were situated, plot A on SMRID 12 and plot C — TID 2, could be reclassified into an irrigable category as a result of sufficiently improved groundwater and salinity conditions. Mean water-table levels have been lowered to more than 2 m below the surface and soil salinity levels have been substantially reduced within the upper 0.6 m. (Average salinity values presented for plot A — SMRID 12 reflect the somewhat higher salinity levels within the 0.3- to 0.6-m depth (7.8 $dS\ m^{-1}$).) Irrigation with additional quantities of water to enhance leaching of salts would promote faster reclamation of soils within this land unit.

Reclassification of land units for 11 of the remaining plots is dependent upon continued leaching of excess salt below the 0.5-m depth. Careful irrigation management must be applied to the latter soils to minimize the presence of groundwater at a critically shallow depth within the root zone. Application of irrigation water is, nevertheless, essential to promote net downward movement of water for salinity control.

The other plots did not show signs of reclamation and would retain nonirrigable ratings due to excessive salinity and shallow groundwater. Successful reclamation of soils in these 10 plots will be unlikely unless greater control of the water table and a reduction in the moisture content of the soil profile can be achieved through implementation of additional reclamation procedures.

In conclusion, installation of measures to eliminate seepage from leaky canals does not guarantee rapid reclamation of adjacent saline or waterlogged soils. Recession of the high water

Table V. Average soil salinity and groundwater levels in relation to the irrigation suitability of each plot in 1987

Site	Plot	Mean ECe (dS m^{-1}) (0 - 0.6 m)	Mean water table depth (m) (1 May - 31 Oct.)	Irrigation suitability†
LNID 62H	A	4.81	0.83	NI-I
	B	17.15	0.67	NI
	C	6.36	1.11	NI-I
LNID 62K	A	9.73	1.18	NI
	B	17.34	1.16	NI
	C	12.61	0.75	NI
RID R-8-1	A	5.36	1.20	NI-I
	B	6.67	1.61	NI-I
	C	4.74	1.37	NI-I
SMRID 12	A	6.24	2.41	I
	B	6.89	1.24	NI-I
	C	6.65	0.70	NI
TID 1	A	1.31	1.10	NI-I
	B	6.65	0.70	NI
	C	12.04	1.21	NI
TID 2	A	13.30	1.47	NI
	B	15.52	1.45	NI
	C	3.44	2.10	I
TID K	A	3.43	1.18	NI-I
	B	5.80	1.62	NI-I
	C	3.53	1.45	NI-I
TID 20	A	–	–	–
	B	6.81	1.83	NI
	C	4.87	1.62	NI-I

†Where NI = nonirrigable; I = irrigable; NI-I = nonirrigable, but could be upgraded to an irrigable class with continued leaching and/or better water-table control.

table in these affected areas is dependent on local and regional groundwater levels, surface drainage and the internal drainage characteristics of the soils and underlying geological materials in the affected land units. Additional drainage may be required in many of the salt-affected land units to facilitate the reclamation of these soils in a more reasonable time frame.

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