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CHAPTER 11

Saline Seeps in the Northern Great Plains of the USA and the Southern Prairies of Canada

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11.1 INTRODUCTION

In about 1945 saline seeps were recognized as a potential problem in non-irrigated agricultural areas of the semi-arid Northern Great Plains and Southern Prairies of the USA and Canada (Figure 11.1). Seeps were rare, however, in non-cultivated rangeland. During the last 10–15 years saline seeps have grown rapidly in cultivated areas and have been intensively investigated by numerous organizations (Van der Pluym, 1978). This report attempts to summarize and evaluate some of the work that has been published and is available to the reader in a large university library. Some of the works cited have not been read by the author (indicated by an asterisk) but are included because they have been extensively cited by individuals working in the area and indicate the large amount of literature that is now readily available.

Saline seeps are defined as areas of saline soils that have formed in non-irrigated areas within the last 30–40 years. This is to differentiate them from the saline soils that were present earlier, many before the areas were settled by Europeans. The seeps are wet some or all of the time, may or may not have a saline water discharge, and commonly have white salt crusts. Vegetative production ranges from abundant to almost nil, depending on the vegetation salt tolerance and the amount of salt collected at or below the surface (Miller *et al.*, 1981). The seeps develop near the shoulders, backslopes and footslopes, usually accompanied by a distinct change in topography (Halverson and Black, 1974). The seeps do not always occur at the low point in the landscape.

The degradation produced by saline seeps, formerly called north slope

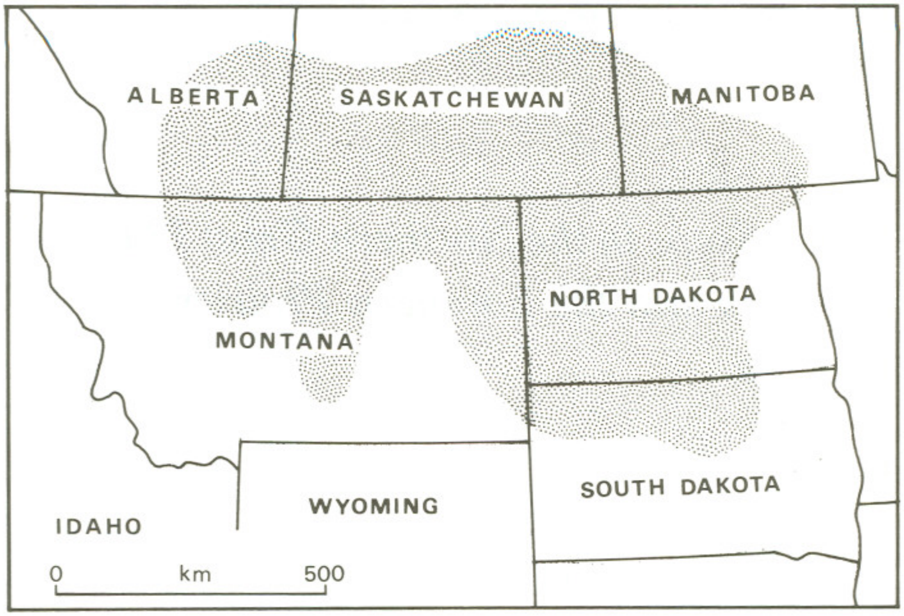

Figure 11.1 Areas (shaded) of potential saline seep development on the Northern Great Plains (Miller *et al*., 1981)

alkali (Thacker, 1976), was hardly recognized in the early 1940s, but since then has taken approximately 0.8 million hectares out of crop production. Saline seeps and the factors leading to their development have degraded the surface and shallow groundwater supplies in many areas that are the only or primary source of potable water (Miller *et al*., 1981). The high salt, particularly nitrogen, and metal content of the saline water is believed responsible for a number of livestock, wildlife and fish kills.

11.2 GEOLOGICAL SETTING

The dryland saline seeps in the prairie provinces of Canada and Great Plains of northern USA are underlain by dark, salt-laden, Cretaceous marine shales, and to a lesser extent the non-marine Tertiary sediments derived from the shales (Figure 11.2). The Colorado and Bearpaw shale in Montana and their equivalents elsewhere have a high amount of gypsum and other elements with lesser amounts of calcium. The Judith River–Claggett–Eagle (JCE) unit includes marine and non-marine units, but saline seeps are not widespread in its outcrop area. The groundwater of the JCE unit has a large salt load (Miller *et al*., 1981). The soluble salt load contained within each unit is believed to be a reflection of the total dissolved solids (TDS) in the groundwater (Table 11.1).

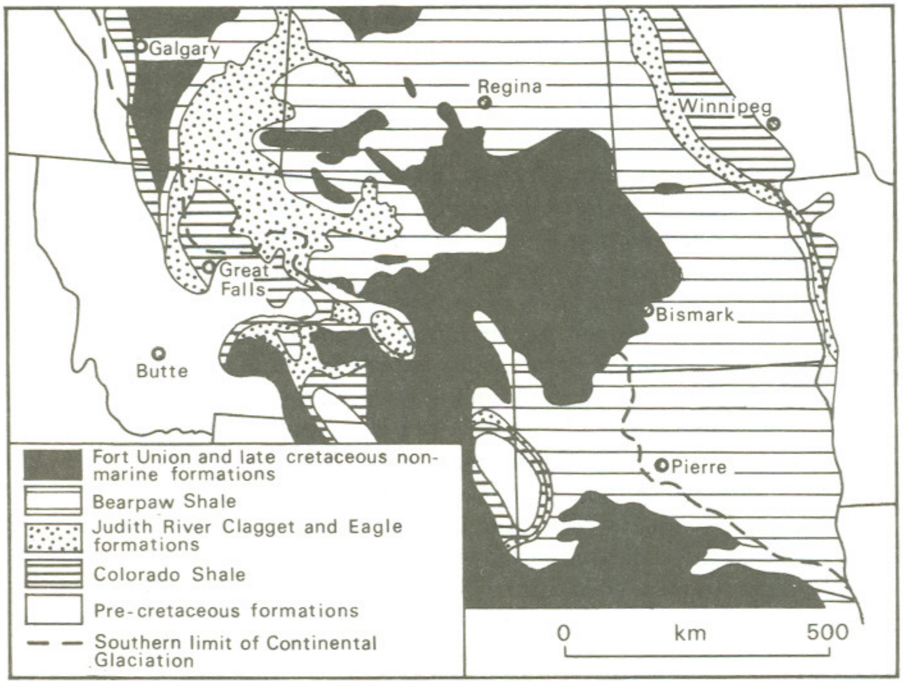

Figure 11.2 Generalized geological map of the Northern Great Plains Region (Miller *et al*., 1981)

The bedrock is overlain by till in much of the saline seep area (Figure 11.2). In the Colorado or Bearpaw shale area, a weathered zone at the till–shale contact is 1–10 m thick. The underlying shale is dry, suggesting the shale is an aquiclude (Miller *et al*., 1981). The Judith River–Claggett–Eagle unit has more silt and sand beds than the Colorado or Bearpaw units, but does have numerous bentonite, shale and mudstone beds that perch water. The widespread saline groundwater in the JCE unit suggests permeable materials and a

Table 11.1 Total dissolved solids (TDS) in major bedrock units (Miller *et al*., 1978[a], 1981)

Geological unit	TDS (g/l)
Colorado and Bearpaw shale	20–50
Judith River–Claggett–Eagle	10–25
Fort Union	3–15

[a]Literature cited but not seen by author, but included to indicate the large amount of literature on the subject that is not readily available to the average reader.

deep flow system. Within the non-marine Fort Union unit, water that escapes the root zone moves down through permeable materials until it perches on the dense underclay beneath a coal seam. The perched water can move laterally and in places breaks out at the surface (Halverson and Black, 1974; Doering and Sandoval, 1976).

The glacial drift covering much of the saline seep area (Figures 11.1 and 11.2) has a swell-and-swale topography, with numerous potholes that pond water for extended periods during the spring months (Miller *et al*., 1981). Post-glacial erosion has cut a drainage system into the drift plain, resulting in an increased local relief and increased local hydraulic gradient. The till has extensive vertical joints and fractures. The till and the underlying weathered shale have low horizontal permeability, so lateral drainage is slow (Miller *et al*., 1981). In Montana, along the major streams, the till is 1–25 m thick but may exceed 100 m in Canada. Below 1 m it has abundant calcium and sodium salts. Laboratory data by Sanderegger *et al*. (1978) indicate that enough sodium is available in the aquifer systems within the upper 6 m to maintain existing saline seeps for the next 25–100 years; carbonate and sulphate minerals control the alkaline earth content of the leachate; and total leachable dissolved constituents make up 2–23% by weight of the original sample.

Nearly 95% of the saline seeps are in the glaciated region (Miller *et al*., 1981), but several have developed in the unglaciated areas. The unglaciated areas in Montana with saline seeps have shallow soils developed from the Colorado, Bearpaw and Fort Union units (Figure 11.2). In both glaciated and certain unglaciated areas a large reserve of soluble salts is available for movement in the groundwater. Weathering and leaching during the Holocene era apparently have modified only the upper 1 or 2 metres.

Adding to the problem of high soluble salts in the till is the relatively high nitrogen content of the shale. Power *et al*. (1974) found very little nitrate nitrogen in the upper 2 m of the soil (apparently lowered by plant uptake), but from 2 to 10 m the NO_3^-N increased to 20–40 ppm (parts per million), with only 2–5 ppm NH_4^+N. Below 10 m the shale had 300–500 ppm N by Kjeldahl analyses, 10–40 ppm NH_4^+N exchangeable with 2N KCl and 150–300 ppm NH_4^+N released by HF treatment. Below 10 m, NO_3^-N was only 1–3 ppm. Power *et al*. believe the large store of NH_4^+N is readily nitrified when moisture, temperature and oxygen supply are favourable. In some shales, at least, a large reservoir of potentially available NO_3^-N exists to be added to the soluble sodium and calcium when conditions are right.

11.3 CLIMATIC FACTORS

Saline seeps occur in an arid to semi-arid climate with a precipitation range of 250–450 m a year. Winters are cold but snow cover is seldom more than 0.1 m. Strong winds usually remove snow from the cultivated upland areas and deposit it on the north and north-east facing slopes. About one-half the annual precipitation falls during April, May and June, when water use by crops is low. Crop yields are directly related to the spring rainfall. The largest outbreaks of saline seeps are in areas with more than 350 mm of annual precipitation, but there are many exceptions (Miller *et al*., 1981).

11.4 HYDROLOGY

Several authors have studied the hydrology of saline seeps, and while each area is somewhat different there is a general similarity (Miller *et al*., 1981; Halverson and Black, 1974; Doering and Sandoval, 1976a and b; Ballantyne, 1963; Luken, 1962). The till mantles an irregular eroded topography (Figure 11.3) and locally contains silt or sand lenses that are more permeable than the till matrix (Figure 11.4). A dense clay occurs at the top of the shale, or in other sediments permeable lignite or sandstone layers overlie dense clays (Halverson and Black, 1974). The aquitards perch water moving down below the root zone, and the water then moves towards the low areas of the buried landscape (Figure 11.5). Saline seeps develop wherever the saline groundwater comes within about 1.5 m or less of the surface, and evaporation during

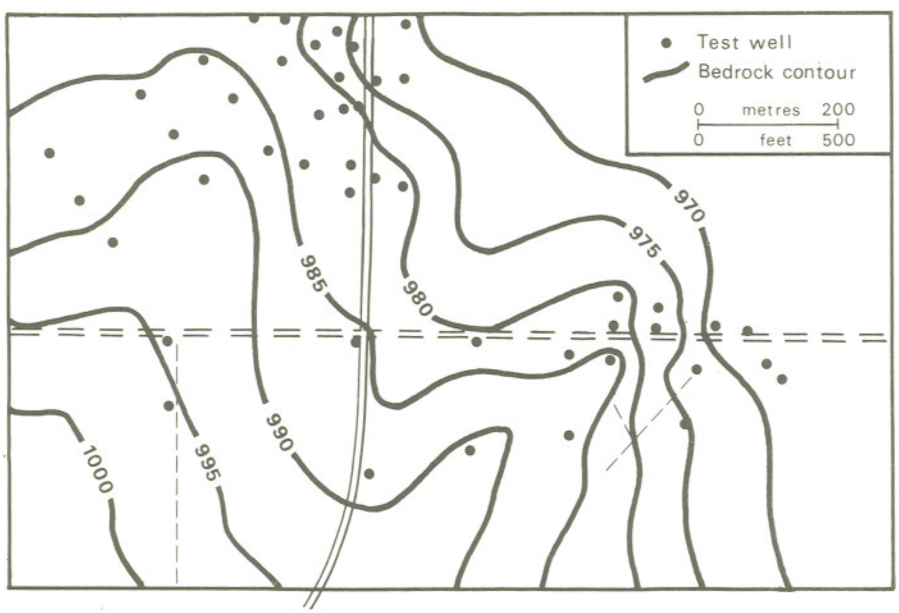

Figure 11.3 Configuration of eroded surface of the Colorado Shale underlying the Hanford–Bramlette test area (Miller *et al*., 1981)

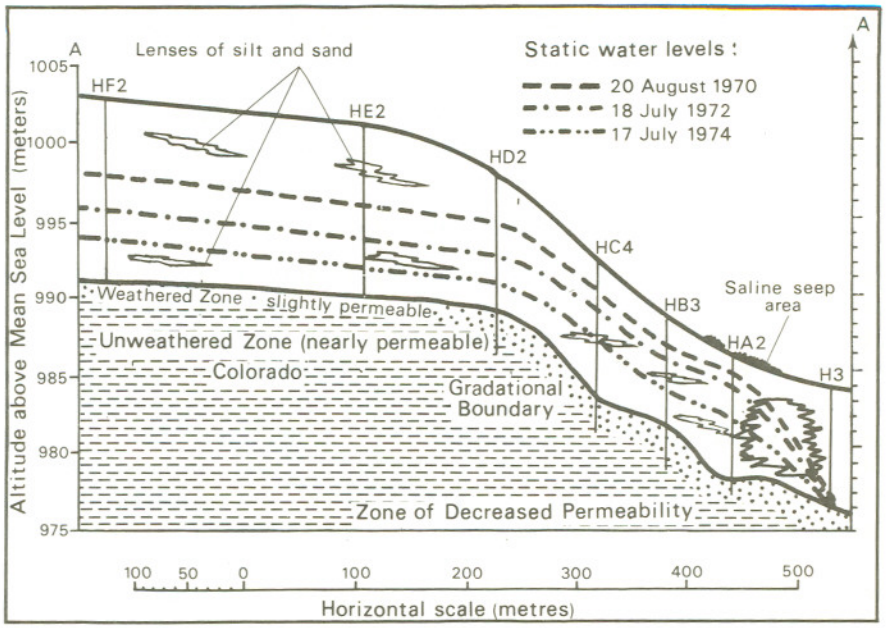

Figure 11.4 Geological section A–A′ across the Hanford–Bramlette test area showing change in static water level from 1970 to 1974

the dry summer months produces a net upward movement of water and salts (Rhoades and Halverson, 1976). Most of the seeps investigated have a local recharge area that is responsible for the salt load at the discharge (seep) area (Doering and Sandoval, 1976a and b; Halverson and Black, 1974; Miller *et al*., 1981). Paul Brown (personal communication) believes that the upland areas with slopes of 0–2% are the major recharge area for the adjacent seep.

Data from a test area in Montana (Figure 11.5) indicate transmissivity values of 0.52 m^2 a day and a seepage rate of 1.6 m^3/ha/day (Miller *et al*., 1981). Water in the weathered zone is commonly under artesian pressure in the discharge areas. Miller *et al*. estimate that 1–4% of the annual precipitation reaches the shallow groundwater flow system under native sod, but about 7–15% under an alternate crop–fallow system. Under 350 mm precipitation, 3.5–14 mm would be added to the shallow groundwater flow under sod and 2.45–52.5 mm under a crop–fallow system.

11.5 WATER QUALITY

Several investigations have quantified the salt load of the seepage and groundwaters in areas with saline seeps (Miller *et al*., 1981; Halverson and

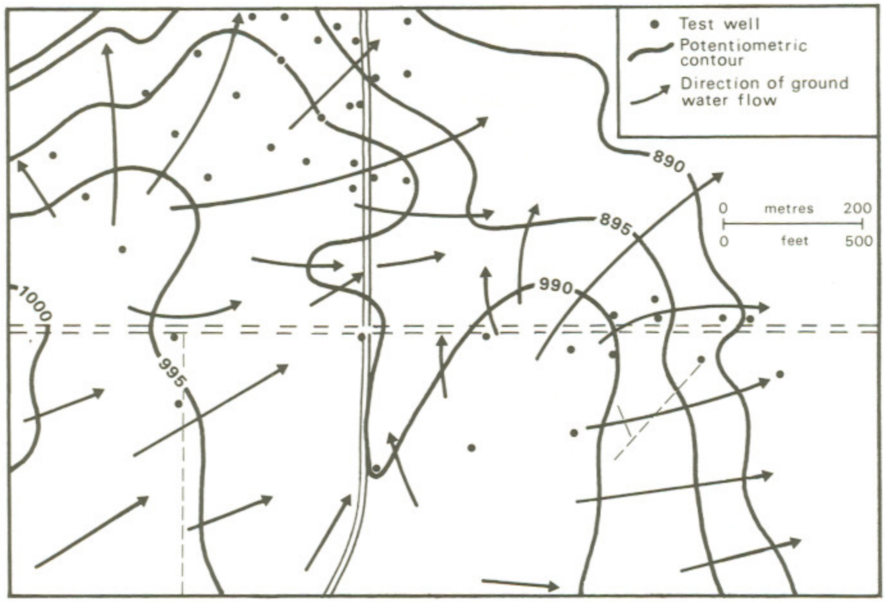

Figure 11.5 Configuration of the potentiometric surface and direction of groundwater flow on the Hanford–Bramlette test area (Miller *et al.*, 1981)

Black, 1974; Doering and Sandoval, 1976a; Sanderegger *et al.*, 1978; Power *et al.*, 1974; Ballantyne (1963); Luken, 1962; Rhoades and Halverson, 1976). Sodium and magnesium are the major cations, and sulphate and bicarbonate are major anions (Tables 11.2 and 11.3). In Montana significant concentrations of trace elements occur, particularly selenium (Miller *et al.*, 1981). Nitrate concentration is variable, but concentrations as high as 1829 ppm have been reported (Halverson and Black, 1974), and it is not uncommon for nitrate values in reservoirs to exceed 100 mg/l. The influence of bedrock on salt concentration is shown in Table 11.2, where the mean total dissolved solids (TDS) is greater than 9000 mg/l in the Colorado shale compared with about 3000 mg/l in the Judith River–Claggett–Eagle unit. Total dissolved solids greater than about 7000 mg/l usually result in fish kills. Detailed discussions of saline seep chemistry have been given by Oster and Halverson (1978) and St. Arnaud (1978).

Shallow groundwater in the saline seep areas is not a desirable source for either livestock or human consumption, and reservoirs are receiving an increased salt load. But the detailed historical data are lacking to quantify the effects of saline seep development on surface and groundwater. However, some authors believe there has been a significant deterioration in ground-

Table 11.2 Mean concentration of groundwater in Montana Plains (Miller *et al*., 1981)

	Colorado shale unit (mg/l)	Judith River–Claggett Eagle unit (mg/l)
Ca	275	120
Mg	866	71
Na	1317	670
K	17.7	6.1
Fe	0.3	0.3
SiO_2	12	12
HCO_3	534	722
Cl	141	177
SO_4	6041	1143
NO_3	57	6
Se	0.308	0.028
Sr	4.6	2.0
TDS	9262	2928
pH	7.62	7.89

water quality in the glaciated portions since the crop–fallow system of farming began (Miller *et al*., 1981).

In areas the shale contains relatively large amounts of NH_4 that can be oxidized to nitrate (Power *et al*., 1974), but most of the $NO_3^{-1}N$ occurs in the upper 10 m of the shale. Because the shallow-water flow system involves the upper weathered part of the shale, it is reasonable to assume that at least some—and possibly a large part—of the $NO_3^{-1}N$ is from the shale. Custer (1976) disagrees. In his study of a cultivated and fertilized and native sod area, Custer found that water below non-cultivated sod has no nitrate, but below a similar cultivated area the summer fallow land had 33–55 ppm

Table 11.3 Chemical analysis for water samples from five seeps in Hettinger County, North Dakota (Doering and Sandoval, 1976a)

Seep	EC (mmhos/cm)	Cations Ca, Mg, Na (meq/l)			SAR	NO_3	Anions Cl (meq/l)	SO_4^2
1	7.2	15	18	47	12	–	1	70
2	6.5	18	40	21	4	–	1	77
3	8.2	16	25	52	11	–	1	86
4	9.6	14	76	59	9	6	2	139
5	7.2	15	58	36	6	5	2	100

nitrate. The nitrate values were largest in the spring. Within the upper 7.6 m there is 3 times more nitrate below cultivated land than below non-cultivated sod. The nitrate profile suggests a source near the surface. All the fertilizer, rainfall and manure nitrogen added during the cultivation history of the site do not account for the excess nitrate below the cultivated land. Custer concluded that only oxidation of organic matter in the soil is quantitatively large enough to produce the excess nitrogen observed in his study area. Later Custer (1978) sampled the groundwater beneath a native sod and again the following year after the area had been cultivated for one season. About 68 kg/ha of 18% nitrogen was applied in fertilizer. The nitrogen in the groundwater after one season's cultivation increased nearly 7.7 times the amount of nitrogen available from the fertilizer, but was still considerably below the nitrogen in the groundwater of adjacent sites cultivated for at least 60 years. Apparently the oxidation of organic matter is releasing large amounts of nitrate nitrogen that escapes uptake by cultivated crops. However, the first year's cultivation of a native sod probably released more nitrogen than similar areas that have been cultivated for some time.

11.6 DETECTION OF SALINE SEEPS

Several methods, including visual, remote sensing and soil resistance measurements, have been used to detect saline seeps (Rhoades and Halverson, 1976; Brown, 1976; Horton and Moore, 1976). Early detection is important if counter-measures are to be effective. Brown (pp. 59–60) gives the following visual criteria:

(*a*) Prolonged soil surface wetness following a substantial rain. Surface wetness is easily observed in a fallow field but can also be observed on cropland, especially in late spring and summer. There will nearly always be uneven surface drying in a field following a rain but if wetness persists over a localized area for more than two or three days, it may indicate a shallow or perched water table. Sampling with a soil moisture probe may reveal that the soil is much wetter than field capacity and a film of free water may show on the end of the probe. Tractors 'bog down' or cut deep ruts in these areas. Water often seeps into the ruts and remains there for a period of time. Salt crystals form on the surface as the disturbed area dries.

(*b*) Rank wheat or barley growth is sometimes accompanied by lodging in an area that was normal in previous years. Farmers sometimes report that the crop of grain on these areas was not only their best but their last. The areas are sub-irrigated by a rising water table, however, the salt content was not yet high enough the first year to reduce growth. Following the bumper grain crop, the spot may become so wet and salty that the next crop either can't be seeded, or if seeded, doesn't survive. Such wet and saline areas usually expand rapidly.

(*c*) Scattered salt crystals on the soil surface or localized cloddiness are the other indications of a pending saline-seep outbreak.

(*d*) Rank *Kochia scoparia* growth after grain harvest in small areas where the soil would normally be too dry to support weed growth. Probing these areas may reveal that the surface and subsoils are wet.
(*e*) New foxtail barley (Hordeum jubatum) infestations indicate possible saline-seep outbreaks. The foxtail usually increases with time.
(*f*) Stunted or dying trees in a shelter belt or windbreak. Leaves may be light green or yellowish before stunting or death.
(*g*) Other early warning signs are delayed small grain germination, abnormally mellow soil and darker colored surface soil on lower slopes. The color change may be caused by dispersed organic matter or lignite fractions mixed with the surface soil. Another indication of saline seep is a sloughed hillside covered by native vegetation—and located next to a cultivated field.

After crop failure there is a typical sequence of vegetation (Custer, 1976):

(1) Kochia thrives vigorously for a year or two followed by stunted growth. Stunting results from salt build-up and lack of nitrogen.
(2) Kochia dies out and foxtail barley increases to a pure stand. Kochia probably is still present around seep perimeter.
(3) Bare soil, especially in the center of the seep, is too salty to support plant growth. Not all saline seeps reach this stage.

Rhoades and Halverson (1976) proposed the diagnostic criteria in Table 11.4 for distinguishing between unaffected, encroaching and developed saline seeps using extensive soil resistance measurements.

Other methods used to detect saline seeps are remotely sensed data (Horton and Moore, 1976) and rural assessment data used primarily for taxation but containing information on soil salinity on an individual quarter section basis (Crosson and Ballantyne, 1976).

11.7 DISTRIBUTION AND GROWTH RATES

The dryland saline seeps are most abundant in areas with greater than 350 mm of annual precipitation but occur within a precipitation range of

Table 11.4 Diagnostic criteria for distinguishing between unaffected soil sites, encroaching and developed saline seeps

Site type	Salt content	Water content
Unaffected	Low, increasing with depth	Low, increasing with depth
Encroaching saline seep	Intermediate, increasing to a peak at a relatively shallow depth, then decreasing with further depth	Moist surface becoming wet with depth
Saline seep	High, decreasing with depth	Relatively uniformly wet to the water table

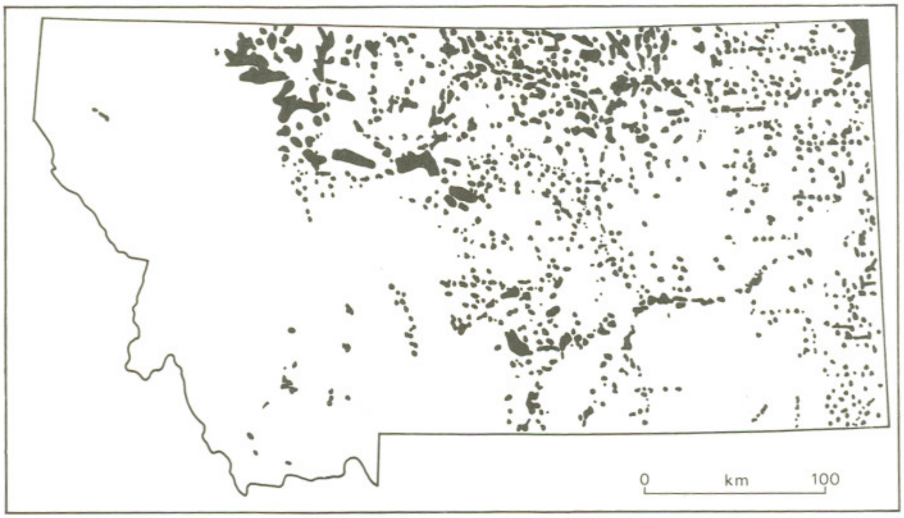

Figure 11.6 Distribution of saline seeps in Montana (1978)

250–450 mm. They are closely associated with Cretaceous saline shale bedrock and some of the Tertiary sediments derived from the saline shales (Figures 11.1 and 11.2). Within an area, the saline seeps are unevenly distributed (Figures 11.2 and 11.6), but regionally they occupy 0.8 million hectares or more (Van der Pluym, 1978). Within an affected area the seeps seldom develop in rangeland but are common in cultivated land. The seeps were essentially unknown before the early 1940s and apparently did not develop rapidly or attract much attention until the 1960s. Seeps expand very little during dry cycles but grow by 20% to 200% after wet cycles; a growth rate of about 10% is commonly cited (Miller *et al*., 1976). Figure 11.7 is an example of how rapidly saline seeps can grow in an area. The growth rates indicated in Figure 11.7 cannot be maintained because a balance between recharge and discharge areas is maintained.

11.8 SOILS

The soils affected by dryland saline seeps have not been carefully described in the symposiums held on the problem. Conversations with pedologists from North Dakota suggest there may be some morphological clues that can be used to delineate potential problem areas, but published documentation cannot be offered. It is, in some ways, odd that hundreds of person hours have been spent on the hydrology, geology, chemistry and detection of dryland saline seeps, but apparently little time has been spent documenting the soil morphology of active or potential saline seeps. Eight recently published US

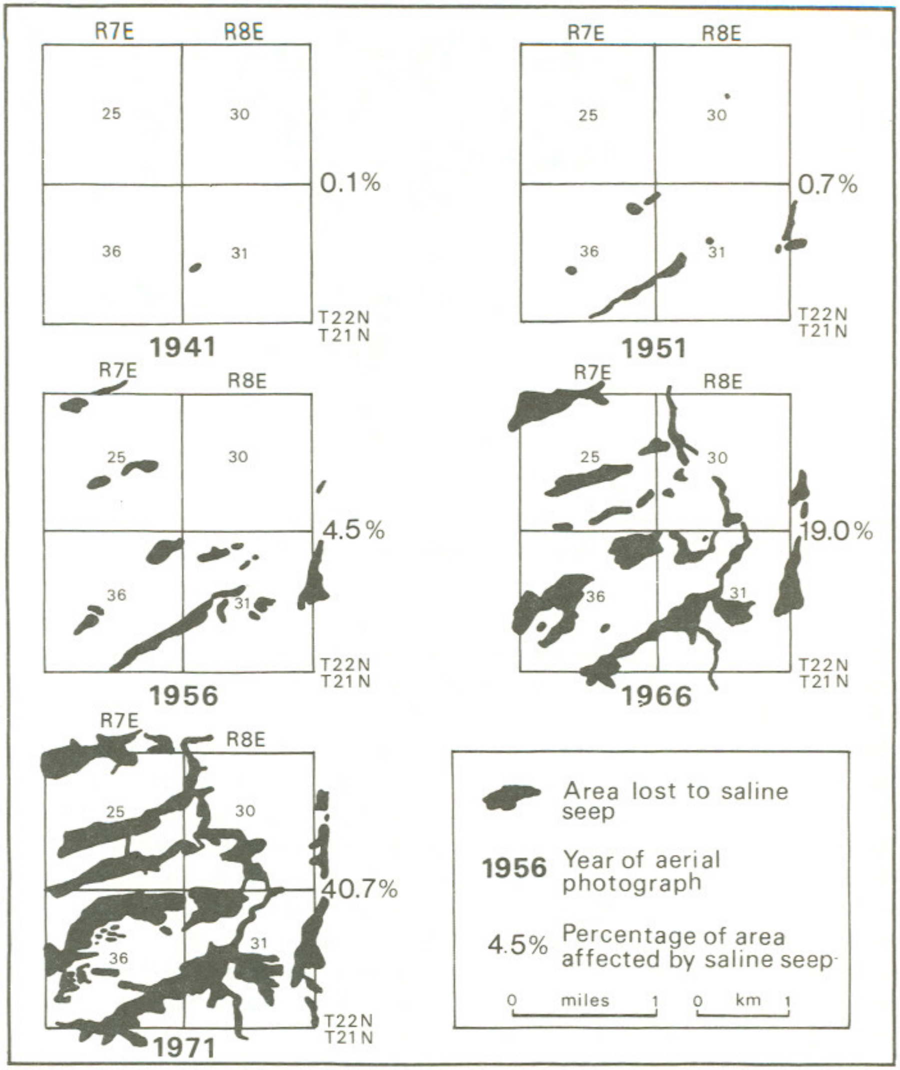

Figure 11.7 Rate of growth of a saline seep in a 10 km^2 area of Montana (1841 to 1971)

Department of Agriculture Soil Conservation Service soil surveys from North Dakota were examined (Benson, 1979; Emmons, 1980; Mercer, 1978; Oliver, 1975; Pierce, 1978; Pembina, 1977; and Slope, 1978). All counties were within the area of saline seeps (Figure 11.1) but no mention of saline seeps were noted. About one-half the maps of Benson County were examined for saline and wet spot symbols. Fifteen map units had a few too many saline spot symbols, but wet spot symbols were not found. There was no discussion either in the series or map unit descriptions of the significance of the saline spot symbols, although the need for intensive cropping and limiting fallow was mentioned in the saline phase descriptions. The other county surveys were similar to Benson County and little descriptive material that related to saline seeps could be found. Possibly saline seeps did not occur in these areas, but this seems unlikely in view of other evidence. Few modern soil surveys were found within the saline seep area of Montana. After spending several hours looking for information on the distribution of saline seeps and the properties of the affected soils, the author concluded that only someone well acquainted with the area could interpret the soil survey. Insufficient information is given for less-informed individuals.

It is highly unlikely that the soil survey party did not map saline seeps in the area and have considerable knowledge about the soil characteristics. Most of that knowledge, unfortunately, will remain with those individuals.

11.9 MAJOR FACTORS LEADING TO OUTBREAKS OF DRYLAND SALINE SEEPS

Most authors agree that saline seeps are produced when excess water over evapo-transpiration moves below the rooting zone through salt-laden material and eventually reappears at the surface. The area affected depends upon the local stratigraphy and geomorphology since the saline water must be within 1.5 m of the surface (Figures 11.3, 11.4, 11.5) (Rhoades and Halverson, 1976). Dryland saline seeps are rare under native sod and an estimated 1–4% of the annual precipitation moves below the rooting zone to the groundwater (Miller *et al*., 1981). Under an alternate crop–fallow system, 7–15% of the precipitation reaches the groundwater. Anything that allows water to be lost below the rooting zone, including farm ponds, water-filled potholes, accumulation of snow on north-east slopes (Miller *et al*., 1981; Thacker, 1976), or tillage techniques that increase snow cover and water intake (Greb *et al*., 1970; Sommerfeldt, 1976), can speed and aggravate the development of dryland saline seeps. The excellent evidence presented by Miller *et al*. (1981), Haas and Willis (1962), Fergerson (1963) and Doering and Sandoval (1976b), show that summer fallow is the major cause of dryland saline seep growth during and following the wet years of favourable precipitation of the 1940s and 1960s.

The dryland saline seep is a problem inherited from the geology and hydrology of the area. Marine shales high in gypsum and carbonate are overlain in large areas by a glacial till that also has a large amount of salt, derived primarily from the underlying marine shales. Groundwater becomes saline as it moves through the saline till below the rooting depth of the crop or native vegetation. The till–shale contact and the underclay of lignite beds are aquitards and perch water. Shallow valleys have been eroded in the till, so the water perched above the aquitard moves towards the valley under a local hydraulic gradient. Where the aquitards are close enough the saline groundwater appears at the surface. Evaporation concentrates the salt and a saline seep develops. Agriculture has increased the amount of water moving to the shallow groundwater system and increased the area of saline seeps by using a fallow–cropping system and building ponds. In some cases the increase in area of saline seeps has been dramatic.

Although agriculture has aggravated the situation, the potential for dryland saline seeps was always there, and even under natural conditions a slight change in factors that would allow more water to move to the shallow groundwater flow system would result in the development of saline seeps. Saline and saline–alkali soils are common in the saline seep area, and the same factors responsible for their characteristics and distribution are responsible for the saline areas produced by agricultural use. The problem and major causes have been clearly defined, but now what can be done to alleviate or control the situation?

11.10 SALINE SEEP CONTROL

Most saline seeps develop from local shallow groundwater systems and therefore their control can be local. Two major control methods are used. The agronomic approach attempts to use all or nearly all the precipitation in growing crops. By reducing or eliminating water loss to the groundwater in the recharge area, the amount of water moving to the seep is reduced. If groundwater tables can be lowered, many seep areas will disappear. The engineering approach attempts to intercept the saline groundwater before it reaches the surface. Both approaches have advantages and disadvantages.

The agronomic approach uses deep-rooted crops and several combinations of crops and cropping systems to reduce the volume of water in the rooting zone and still maintain enough for economical crop production. The amount of water lost below the rooting zone in the recharge area is kept to a minimum. By drying out the deeper subsoil a storage reservoir is established during the periods of higher rainfall or when crops that use less water are grown. The water use and rooting depths of various crops have been intensively studied (Brown *et al*., 1976; Black *et al*., 1981). Deep-rooted perennials such as alfalfa remove large amounts of water from the soil (Tables 11.5 and 11.6). The soil-water depletion and rooting depth over a 5-year period of several crops are shown in Figure 11.8. In one test, alfalfa grown on the recharge area lowered the water table 2.9 m in the discharge area and 2.0 m in the recharge area in six years (Brown and Miller, 1978). The alfalfa used current precipitation and reduced the volume of water in the deeper subsoil. At the seep area the deeper water table allowed leaching of the salts and

Table 11.5 Cumulative soil-water depletion and rooting depths for perennial crops and biennial sweetclover (Brown *et al*., 1976)

Crop	1971		1972		1973		1974		1975	
	Soil water used (in)	Root depth (ft)	Soil water used (in)	Root depth (ft)	Soil water used (in)	Root depth (ft)	Soil water used (in)	root depth (ft)	Soil water used (in)	root depth (ft)
Vernal alfalfa	7.0	7	11.3	10	20.2	14	22.2	18	30.9	19
Eski sainfoin	5.9	5	10.3	9	17.9	11	22.1	13	22.2	13
Cicer milkvetch	4.2	5	8.9	9	15.6	13	21.5	15	22.6	15
Russian wildrye	–	–	–	–	12.5	7	16.1	9	18.7	10
Tall wheat	7.6	6	11.1	7	14.0	8	17.1	9	17.3	9
Sweetclover	–	–	10.9[a]	6[a]	13.9[b]	8[b]	–	–	15.9[b]	9[b]

[a]First-year sweetclover.

[b]Second-year sweetclover.

Table 11.6 Soil water use and rooting depths for annual crops seeded on fallow or annually cropped (Brown *et al*., 1976)

Crop	1971 Soil water used (in)	1971 Root depth (ft)	1972 Soil water used (in)	1972 Root depth (ft)	1973 Soil water used (in)	1973 Root depth (ft)	1974 Soil water used (in)	1974 Root depth (ft)	Average Soil water used (in)	Average Root depth (ft)
Fallow–wheat	9.6	6	6.1	6	8.6	7	10.1	8	8.6	6.8
Fallow–barley	6.1	4	5.4	5	6.7	5	7.6	6	6.4	5.0
Proso millet	5.3	5	2.0	3	10.4	7	2.3	4	5.0	4.8
Corn	3.2	4	2.3	2	6.2	4	3.2	5	3.7	3.8
Kochia	–	–	8.2	5	7.7	4	4.6	5	6.8	4.7
Safflower	–	–	5.6	5	16.7	8	10.5	8	10.9	7.0
Sunflowers										
Mingren M	–	–	–	–	12.0	6	8.2	9	10.1	7.5
Mingren L	–	–	–	–	9.6	6	9.2	6	9.4	6.0
Krasnodarets	–	–	–	–	9.1	5	5.4	8	7.2	6.5
Peredovik	–	–	–	–	9.0	6	4.4	8	6.7	6.8
Annual cropping:										
Barley after WW	–	–	–	–	6.9	4	–	–	–	–
WW after Barley	–	–	–	–	–	–	8.3	8	–	–
									7.6	6.0

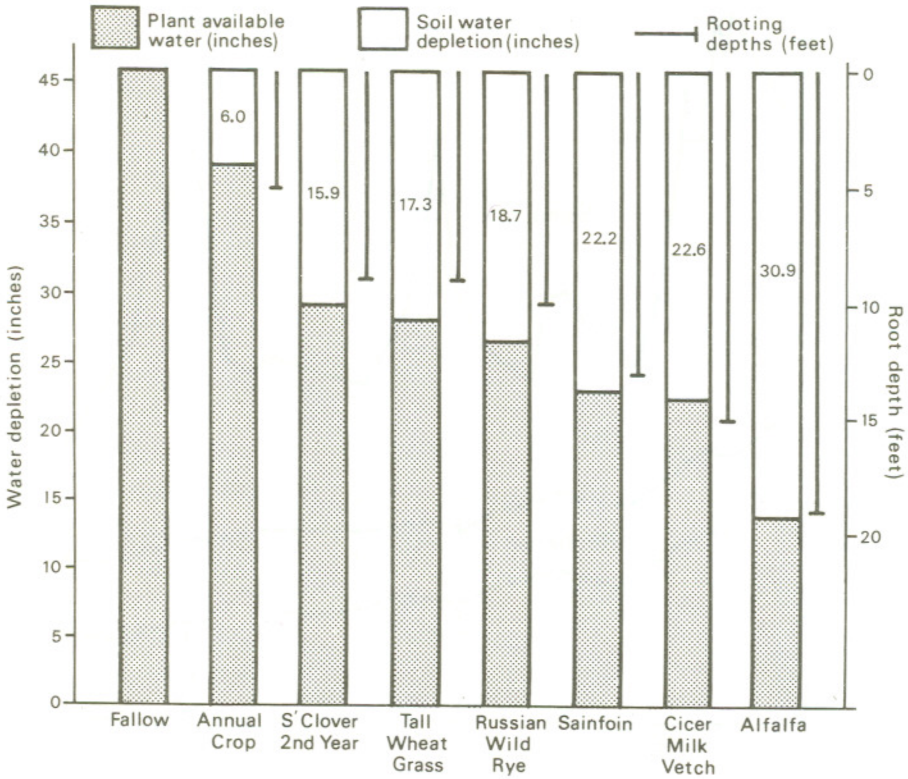

Figure 11.8 Soil-water depletion and rooting-depth measurements in 20 ft (6 m) soil profile after 5 years (1971 to 1975)

reduction of the surface soil electrical conductivity, enough for barley and winter wheat to produce 70% of the normal yield.

Halverson and Reule (1976) used alfalfa on about 80% of the recharge areas of two saline seeps and a 46 m wide alfalfa buffer strip (about 15% of the recharge area) to study the effect of deep-rooted crops on groundwater levels. Annual precipitation was above average for most of the three years of their study and for the two years before the study started. Groundwater levels decreased at the seep (J3) and the wells in the recharge area, J1 and J10 (Figure 11.9), where alfalfa occupied about 80% of the recharge area. The salinity at the seep decreased slightly, the salt crust disappeared, and farm equipment could cross the seep most of the year. Groundwater levels at the seep with only 15% alfalfa in the recharge area—buffer strip alfalfa—changed little if any and the seep was wet most of the time.

The success in controlling many saline seeps by agronomic means has spurred the development of flexible cropping systems to use most of the

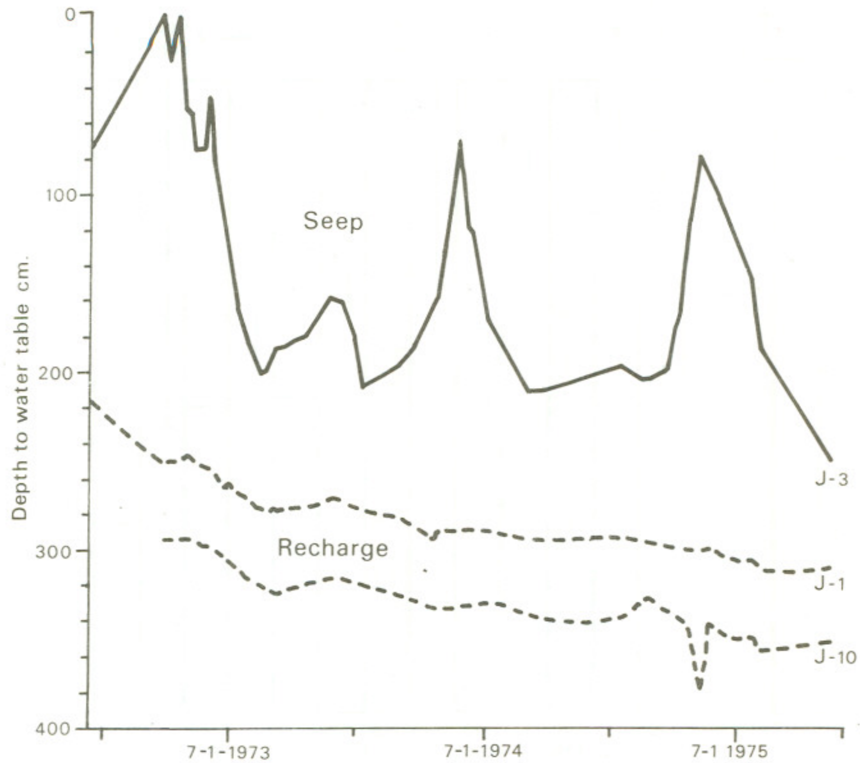

Figure 11.9 Seasonal changes in depth to water table from the soil surface in observation wells located in the seep (J-3) and in the recharge area seeded to alfalfa (J-1 and J-10) at the Jones study site east of Froid, Montana (Halverson and Reule, 1976)

rainfall in the recharge areas and to retain as much water as possible within the crop rooting system (Miller *et al*., 1981; Brown *et al*., 1976; Black *et al*., 1981; Brown and Cleary, 1978; Brown and Miller, 1978; Halverson and Reule, 1976; Jackson and Kroll, 1978; Duff, 1976; Black and Siddoway, 1976). In general the cropping systems eliminate fallow if possible, but do not rule out its use if stored moisture and expected precipitation are not large enough to insure a crop (Table 11.7). Although the dramatic growth of saline seeps influenced the move into flexible cropping systems, there was considerable earlier information that suggested fallow was not necessary in most years over much of the affected area (Greb *et al*., 1970; Haas and Willis, 1962; Fergerson, 1963; Ford and Kroll, 1979).

The engineering approach to saline seep control intercepts the saline water before it comes close enough to the surface to develop into a seep. Tile or mole drainage systems are installed, where possible, to intercept the water-

Table 11.7 Types of cropping strategies needed, based on effective soil root-zone depth, crop rooting, and precipitation (Black *et al*., 1981)

Precipitation (mm)	Cropping strategies for three effective depths of soil root zone				
	<1.5 m	1.5–3.0 m		3.0–6.0 m	
250–380	Winter wheat	Alfalfa (3 to 4 years)[a]		Alfalfa (4 to 5 years)	
	Barley	Fallow[b]		Fallow[b]	
	Winter wheat	and/or	and/or	and/or	and/or
	Fallow[b]	Barley	Winter wheat	Wheat[c]	Spring wheat
	or	Fallow[b]	Barley	Safflower	Winter wheat
	Spring wheat	Wheat[c]	Fallow[b]	Barley	Fallow[b]
	Winter wheat	Safflower	or	Fallow[b]	
	Barley	Barley	Spring wheat		
	Fallow[b]	Fallow[b]	Winter wheat		
			Fallow[b]		
380–500	Spring wheat	Alfalfa (3 to 4 years[a]		Alfalfa (4 to 5 years)	
	Oilseed (sunflower)	Fallow[b]		Fallow[b]	
	Barley or oats	and/or		and/or	
	Fallow[b]	Sunflower		Spring wheat	
	or	Spring wheat		Sunflower	
	Barley	Barley or oats		Barley or spring wheat	
	Spring wheat	Fallow[b]		Fallow[b]	
	Sunflower	Spring wheat		Spring wheat	
	Barley or oats	Sunflower		Sunflower	
	Fallow[b]				

[a]Sweet clover could be substituted for clover (2 years).
[b]Fallow is optional.
[c]Spring or winter wheat.

Table 11.8 Total drain outflow and dissolved salt load for drains A and B (Doering and Sandoval, 1978)

	Outflow		Dissolved salt	
	(ft^3)	(m^3)	(lb)	(kg)
1971[a]	110 410	3 127	63 500	28 800
1972	836 460	23 689	483 600	219 300
1973	205 860	5 830	101 400	46 000
1974	36 580	1 036	19 200	8 700
1975[b]	31 780	900	12 600	5 700
Totals	1 221 100	34 582	680 300	308 500

[a]September to December.
[b]January to June.

bearing strata (Doering and Sandoval, 1976b, 1978; Sommerfeldt *et al.*, 1978). The combined flow and dissolved salt load from two drains in North Dakota are shown in Table 11.8. The probable recharge area for the seeps was about 125 acres (50 ha). Combined outflow from the drains was equivalent to 2.7 inches (68 mm) over the recharge area. About 1.8 inches (46 mm) of the drainage occurred in 1972. The dissolved salts (Table 11.8) amounted to about 5440 pounds per acre (6100 kg/ha) and about 44 pounds of nitrogen per acre (49 kg/ha) of recharge area. The chemical composition of water from seeps (Table 11.9) is somewhat different from the chemistry of the drainage

Table 11.9 Chemical composition of water samples from three seeps in south-western North Dakota (Doering and Sandoval, 1978)

	#1	#2	#3
Electrical conductivity (mmhos/cm)	9.5	9.9	6.1
Calcium (meq/l)	11.4	25.3	21.9
Magnesium (meq/l)	22.4	42.8	38.2
Sodium (meq/l)	95.8	80.2	31.5
Ammonium (meq/l)	0.2	0.2	1.1
Sodium adsorption ratio[a]	23.3	13.7	5.7
pH	7.8	7.9	3.7
Bicarbonate (meq/l)	4.3	7.9	
Chloride (meq/l)	0.4	2.8	0.9
Nitrate (meq/l)	0.2	0.3	1.4
Sulphate[b] (meq/l)	125.0	138.0	90.0

[a]Sodium adsorption ratio = $Na/[(Ca + Mg)/2]^{\frac{1}{2}}$ when chemical compositions are in meq/l.
[b]Sulphate = (sum of cations) − (sum of determined anions).

water (Table 11.10) that has not yet passed through several feet of calcereous soil. The low pH of the drainage water is from the acidic nature of the lignite layers that conduct the water toward the seep area.

The mole drain systems (Sommerfeldt *et al*., 1978) were designed to remove temporary excess water and control the water table at a safe depth through a combination of practices including plant use, surface and subsurface drainage, and natural drainage. The mole drains and associated practices appear to be functioning properly, but how long they will function is not known. However, mole drains have been used in England for the past 200 years and some have been operating in Canada for more than 20 years (Sommerfeldt, 1976b). Their low cost and ease of installation may give them a place in saline seep reclamation.

The most effective methods of controlling saline seeps are deep-rooted perennial crops, surface drainage of upland recharge areas, and flexible cropping systems (Miller *et al*., 1981). Problems encountered with these methods are economic and cultural. Many farming operations have little use

Table 11.10 Average chemical composition of the drain waters and the standard deviation of the determinations for the intial drainout period and for the remainder of the study (Doering and Sandoval, 1978)

	Drain A				Drain B			
	9/71–4/73		4/73–6/75		9/71–4/73		4/73–6/75	
	Avg	σ	Avg	σ	Avg	σ	Avg	σ
	$n = 19$		$n = 27$		$n = 20$		$n = 32$	
Electrical conductivity (mmhos/cm)	8.1	0.9	7.3	0.3	10.1	1.0	9.0	0.3
Calcium (meq/l)	17.0	2.9	21.1	2.9	15.8	3.1	20.1	1.7
Magnesium (meq/l)	62.4	7.8	53.1	5.6	76.6	11.7	63.6	3.9
Sodium (meq/l)	42.5	6.5	36.1	1.8	64.4	8.1	52.0	2.5
Ammonium (meq/l)	0.8	0.3	0.6	0.3	1.3	0.3	1.5	0.3
Sodium absorption rainfall[a]	6.7	–	5.9	–	9.5	–	8.0	–
pH	4.6	0.4	4.8	0.7	3.6	0.1	3.8	0.2
Carbonate (meq/l)	0	–	0	–	0	–	0	–
Bicarbonate (meq/l)	0	–	0	–	0	–	0	–
Chloride (meq/l)	2.7	0.3	2.3	0.8	2.3	0.5	1.8	0.1
Nitrate (meq/l)	4.7	0.7	4.3	0.9	6.2	2.1	3.9	1.2
Sulphate[b] (meq/l)	115.0	15.0	104.0	6.0	150.0	18.0	132.0	5.0

[a]Sodium adsorption ratio = $Na/[(Ca + Mg)/2]^{\frac{1}{2}}$ when chemical compositions are in meq/l.

[b]Sulphate = (sum of cations) – (sum of determined anions).

for alfalfa without radical changes; the recharge areas do not always fall within one operating unit, and the needed degree of water control in the recharge area cannot be exercised by the operator of the affected area; the recharge area can be dried out by deep-rooted crops, but a crop–fallow rotation soon refills the soil moisture reservoir reduced by the deep rooted crops; the deep-rooted crops may concentrate salts in the soil profile over a period of time; a high level of management is required to monitor soil moisture levels, so changes in cropping sequence can be timely; and weed, fertility and mulch control also require a high level of management (Jackson and Kroll, 1978; Duff, 1976).

Drainage is a necessary part of the control of saline seeps, especially surface drainage of potholes and some farm ponds. Again problems arise: the potholes are excellent wildlife breeding areas; disposal of saline waters from the subsurface is difficult because high nitrate and salt contents contaminate surface waters and are marginal if not dangerous drinking water for livestock; and fish kills may result from allowing drainage waters to contaminate surface reservoirs.

11.11 SUMMARY

The work conducted by numerous investigators on the origin and control of dryland saline seeps is, in general, excellent. The geology and hydrology of saline seeps have been well documented, and the most probable causes are now understood. As a result methods to control the seeps have been developed that alleviate the primary cause of seeps—water moving below the rooting zone to a shallow groundwater flow system. The effects of various cropping systems on the control and reclamation of saline seeps has been well documented, and some authors believe that 60–70% of the seeps can be controlled and reclaimed by agronomic practices alone. The remaining 30–40% will require a combination of agronomic and engineering practices. The reclamation of saline seeps can be relatively rapid; within 5 years wheat and barley production have reached 70% of normal and was 100% within 7 years using agronomic techniques. The reclamation process is not without problems, but considerable progress has been made on overcoming the difficulties of various cropping systems and the educational needs to put the systems into effect. There are, however, a few areas of investigation or interpretations that seem questionable.

Published reports by pedologists on the morphology of saline seep areas are rare except for those of the early Canadian workers. Soil scientists, including pedologists, have published on the properties of saline seeps, but a recent strictly pedological study has not been found. Although other disciplines within the broad fields of soil science, engineering, agronomy and geology were used in the multitude of investigations, the one apparently missing team member has been an experienced field pedologist. One strongly suspects that much more is known about the morphology of soils in potential and active seep areas than can be found in published literature, including published soil surveys. The pedologist, working with other scientists, has an opportunity to delineate potential seep areas if there have been past events of saline seeps that left some morphological clue. Yet the published literature leads one to believe that each area must be investigated by deep drill holes, water table studies, and detailed field examination using various techniques that can be described as research tools, not production mapping tools. It would be an exception if a soil survey party leader in a county did not quickly develop a 'feel' for the areas where potential saline seeps may occur and their maximum size based upon geologic, morphologic, and topographic inference. But this information is not readily available in the published literature, and apparently not even in recently published soil surveys from saline seep areas. Part of the reason is that the drive for uniformity in published soil surveys have forced the party leader to publish in a standard format that may almost preclude any direct discussion of saline seeps. Many of seeps initially occupy relatively small areas, and spot symbols are very easy for high authority to eliminate. The soil survey party seldom publishes their findings in national or local journals because this is not always encouraged or even deemed to be of any importance by their immediate supervisors. The journal reviewers usually are dominated by laboratory-oriented scientists who frequently frown on publication of field observations. These reviewers are used to volumes of laboratory data from one or two points, not hundreds or thousands of field observations that describe the relations of several natural bodies. Frequently, the 'real world' does not fit the provincial theories developed by laboratory-oriented scientists.

The inference is strong in many published articles on saline seeps that the seeps are a first-time phenomenon produced by cultivation. The glacial till in much of the saline seep area (Figure 11.1) apparently was deposited about 20 000 years ago, and since that time there have been several climatic fluctuations. Unless the landscape of the saline seep spots were developed only in the mid- to late-Holocene, there may have been several periods of saline seep development even under the native vegetation. Even the late-Holocene may have had short periods favourable for seep development.

Another inference from published papers is that agriculture has polluted the shallow groundwater supplies by allowing more water to escape to the groundwater table (Miller *et al*., 1981; Doering and Sandoval, 1976a, 1978; Ballantyne, 1963; Black *et al*., 1981; Botz, 1976). There can be little doubt that agriculture has contributed to the nitrate loading of the groundwater, but how has the non-irrigated agriculture contributed to groundwater pollution? Any water moving below the root zone must pass through salt-rich till or shale to reach the groundwater. The leachable salt content of the material above the groundwater reservoir is from 2.2% to 23.5% (average of 8.1%) by weight. How could the water moving below the rooting zone in pre-agriculture times, estimated at 1–4% of precipitation under current grassland conditions, have a lower salt load than water now moving through the same material? Has there been an interval in pre-agricultural time when the water-soluble salt content of the till and shale was less than present, or when there was no water escaping the rooting zone? If the latter is true, is the present salt load a flush of soluble salt released by earlier weathering but not moved into the groundwater? These questions need to be answered before an increase in the groundwater salt load on a unit volume basis (a possible exception is nitrogen) can be attributed to agriculture.

Although there is considerable evidence supporting the statements that agronomic and engineering methods can control and reclaim saline seeps, will they be controlled? The control methods require a high level of management using techniques new to the land operators. Will the land operators apply the needed technology to control saline seeps? Can they afford to control the seeps under the future economic conditions, especially when control measures call for crops such as alfalfa on a grain farm? Will the control of saline seeps be like the control of erosion—the control technology is available but for several reasons it is seldom applied. Time will tell.

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