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Saline-Seep Diagnosis, Control, and Reclamation

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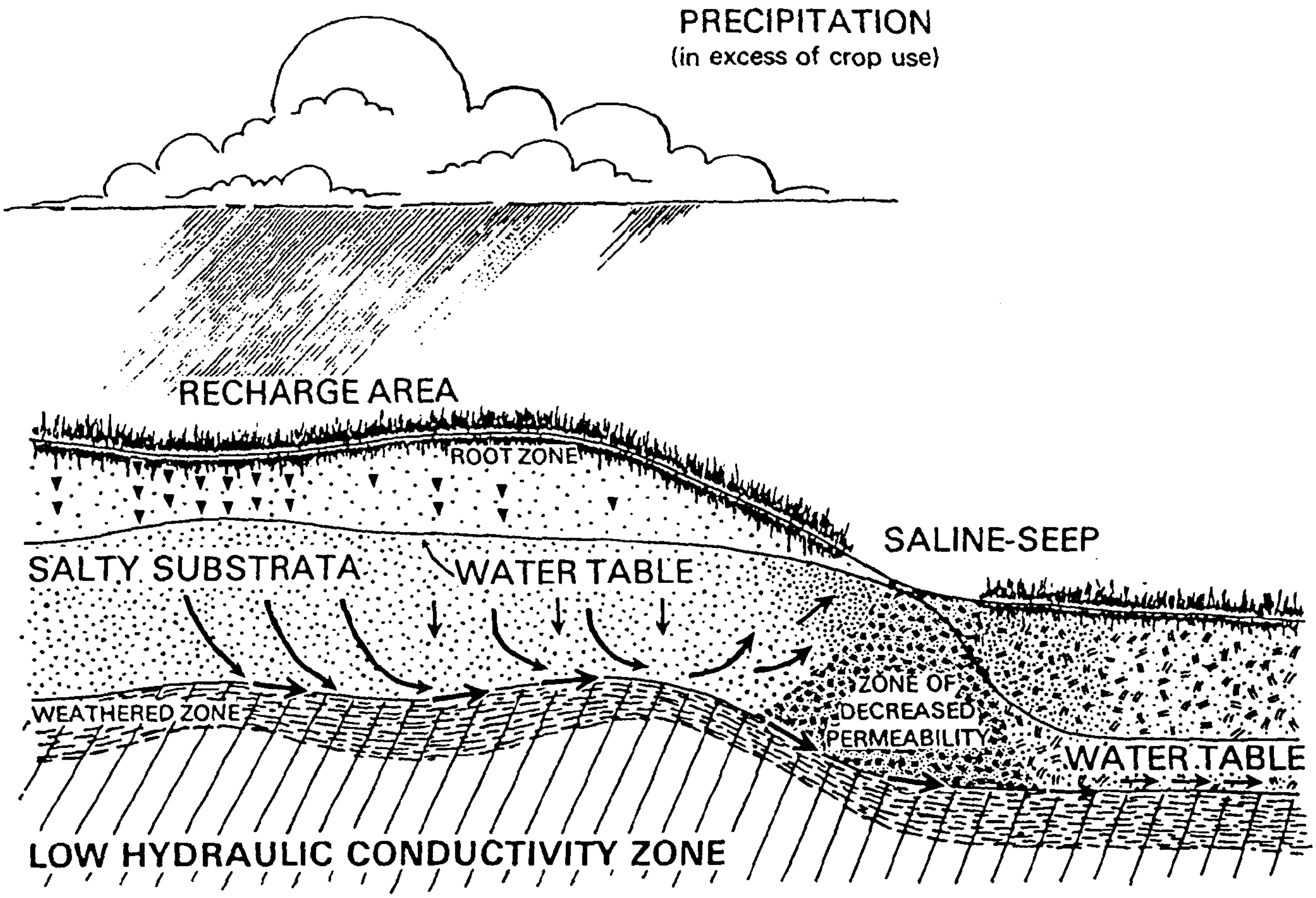

Frontispiece.—Generalized diagram of saline seep, recharge area, and the substrata formation that contributes to a saline seep.

Abstract

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Changes in land use from native rangeland to dryland grain production, improved farming technology, and periods of high precipitation have contributed to a dryland salinity problem termed "saline seep" in the northern Great Plains. The geology of the area, water moving through the soil profile as a result of farming systems, and climate are responsible for the development of saline seeps.

The purpose of this publication is to provide (1) a general description of extent and history of the saline-seep problem, (2) methods for identifying saline-seep recharge areas, (3) methods for controlling saline seeps, (4) information on reclamation of saline-seep areas that have been controlled, and (5) information on the environmental and economic factors affecting saline seeps. This publication summarizes 10 years of research and experience on the saline-seep problem and serves as a guide for public service agencies, farm consultants, and farmers who are concerned with the saline-seep problem.

Keywords: discharge area, dryland salinity, fallow, flexible cropping, ground water, recharge area, saline seep, saline soil, seeps, soil salinity, water pollution, water table.

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Saline-Seep Diagnosis, Control, and Reclamation[1]

P. L. Brown, A. D. Halvorson, F. H. Siddoway, H. F. Mayland, and M. R. Miller[2]

Introduction

The term "saline soils" is used to characterize soils containing sufficient soluble salts to adversely affect the growth of most crop plants. The adverse effects of salts in depressing plant growth are caused by at least one of three factors: First, direct physical effects of salt in preventing soil water uptake by plant roots because of increased osmotic tension; second, direct chemical effects of salt in disrupting the nutritional and metabolic processes of plants; and third, the indirect effect of salt in altering soil structure, permeability, and aeration (Thorne and Peterson *1954*).[3]

Plants vary in their tolerance to salt. When the electrical conductivity (EC) of the saturation extract reaches 4 mmhos per cm, the growth of many plants is reduced by the salt; however, salt-sensitive plants are affected at 2 mmhos per cm and highly tolerant plants can withstand 8 mmhos per cm. EC is proportional to the salt content of a soil and is the common method of measuring and expressing salinity.

Saline seep describes a salinization process accelerated by dryland farming practices. A saline seep is defined as follows: Intermittent or continuous saline water discharge, at or near the soil surface downslope from recharge areas under dryland conditions, that reduces or eliminates crop growth in the affected area because of increased soluble salt concentration in the root zone. Saline seeps can be differentiated from other saline soil conditions by their recent and local origin, saturated root zone profile, shallow water table, and sensitivity to precipitation and cropping systems.

Two other salinity conditions, which may occur in the same locality as saline seeps, are sometimes mistakenly classified as saline seeps (Malcolm, undated; Soil Survey Staff *1951*; Stoneman *1978*).

1. Saline areas associated with shallow water tables in low-lying areas underlain by an impermeable base. Over geologic time, runoff and seepage waters have contributed salt. Since outflow is restricted, the salt concentration has increased with time.

2. Sodium-affected areas. These areas appear as barren, shallow depressions, locally called "slick-spots" or "pan spots." Most of these soils are Natrargids, formerly called Solodized-Solonetz. The leached surface of these soils is commonly blown away during extended drought, exposing the hard clay of the subsoil. Affected areas are usually just a few yards in diameter; however, they may occupy a fourth of some landscapes and are scattered throughout millions of acres of the glaciated northern Great Plains and elsewhere in the world. The northern Great Plains includes Alberta, Saskatchewan, and Manitoba in Canada, and Montana, North and South Dakota, and Wyoming in the United States.

These two salinity conditions must be carefully distinguished from saline seeps because their amelioration and control differ from those for saline seeps.

Types of Saline Seeps

There are several types of saline seeps in the northern Great Plains. Worcester et al. (*1975*) described six types they identified in western North Dakota. In Alberta, T. S. Sommerfeldt (personal communication) listed four distinct types of seeps and four combinations, which included two or more types. In Saskatchewan, J. L. Henry (personal communication) listed four types of dryland saline seeps. Based on field investigations in Montana and elsewhere in the northern Great Plains, there appear to be seven fairly common types of saline seeps, which are shown in figure 1.

Type 1. Geologic Outcrop Seep. The recharge area is underlain by geologic material of low hydraulic conductivity (HC) such as shale, dense till, or clay. The upper surface of the geologic material may or may not conform to the soil surface topography. The soil material above the low HC layer varies in texture from sand to silty clay, and the depth varies from less than 2 feet to more than 30 feet. There may be a weathered zone above the HC zone. Seepage area expansion is lateral and downslope with limited upslope extension.

Type 2. Coal Seam Seep. The recharge area is underlain by coal, lignite, or clinker, which overlies a dense clay. The soil material above the coal seam varies from sandy loam to silty clay loam. There is no glacial till mantle. Lateral water movement, through the coal-related material, is more rapid than with the type 1 seep. The seep occurs where the coal material outcrops at the surface or is truncated by the landscape. Seepage area expansion is lateral and downslope. There is normally no upslope expansion.

Type 3. Glaciated Fort Union Seep. The recharge area is glacial till underlain by sandstone, siltstone, lignite, and dense clay strata of the Fort Union Formation. Water from the recharge area passes through the glacial till and enters the more per-

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[1] The results and information presented in this report were obtained from the northern Great Plains but are generally applicable to the southern Great Plains where saline seeps are also a serious problem. See, Lowrey, J. C. 1980. Saline seep problem in the Great Plains. Unpublished report. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 35 p.

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[3] The year in italic, when it follows the author's name, refers to Literature Cited, p. 16.

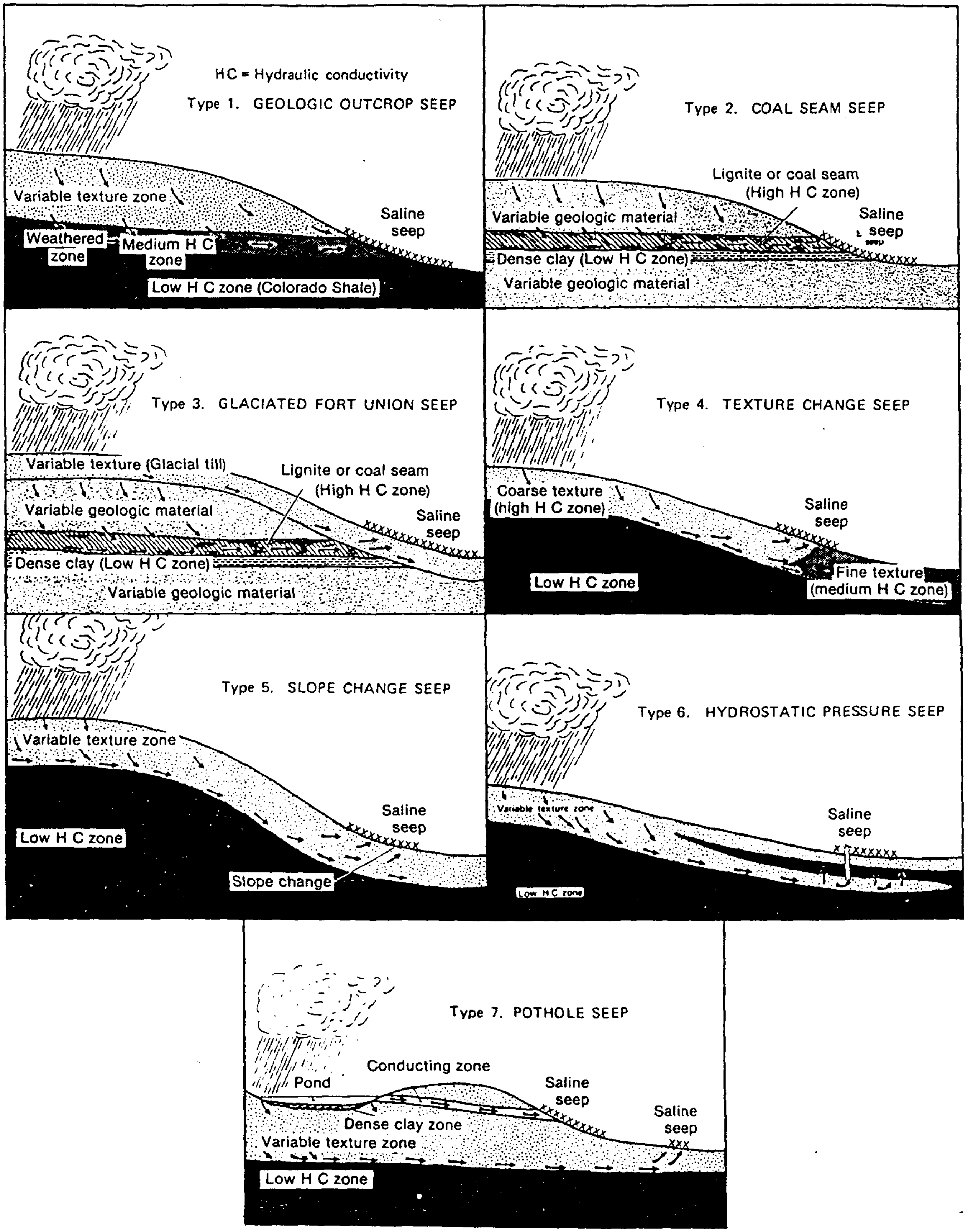

Figure 1.—Schematic diagrams illustrating seven saline-seep conditions.

meable strata of the Fort Union Formation to form a water table above the low HC zone. Water from the water table moves downslope to a point where the glacial till of lower HC truncates the permeable zone. This causes the water table to rise to the surface forming a saline seep. Expansion of the seep area is generally upslope, with some downslope and lateral expansion.

Type 4. Textural Change Seep. The recharge area is underlain by geologic material having a low HC. The soil material above the low HC zone is coarse to medium textured. Water moves through the root zone to the low HC zone and laterally downslope where it encounters a soil zone of lower HC, which slows movement and causes the water table to rise to the soil surface, producing a saline seep. Such seeps are most common in toeslope positions on the landscape. Most expansion is lateral and downslope, but some upslope expansion occurs.

Type 5. Slope Change Seep. The recharge area is underlain by geologic material of low HC. The soil material above the low HC zone is variable in texture. Water moves through the root zone to the low HC zone and laterally downslope to a point where the slope gradient decreases. The reduced gradient causes the water movement to slow and the water table to rise to the soil surface where it produces a saline seep. Types 4 and 5 may be combined in certain seep outbreaks. Most expansion is lateral and downslope, but some upslope expansion occurs.

Type 6. Hydrostatic Pressure Seep. The recharge area is underlain by geologic material of low HC. The soil material above the dense layer is variable in texture. Water moves through the root zone to the low HC zone and laterally downslope to a point where it becomes confined by a low HC zone located above the saturated zone. The confined water is under hydrostatic pressure, which often forces the water through a fracture to the surface to cause a saline seep. Expansion is primarily lateral and downslope. The recharge area may be located at a greater distance and at a higher elevation than for the other seep types.

Type 7. Pothole seeps. The recharge area has potholes or poorly drained areas underlain by slowly permeable material, typically dense clay. Water moves through the slowly permeable material in the pothole to a low HC zone. The water then moves downslope where it may encounter a zone of higher HC, which outcrops at or near the soil surface to form a saline seep. This water is often under hydrostatic pressure. Expansion is primarily lateral and downslope. This type of seep expands during high precipitation periods, particularly when ponded water rises above the normal shoreline and contracts during dry periods.

Combinations of the seven types may occur under field conditions.

Control measures must be applied to the recharge area. They will vary according to the folowing criteria: (1) texture of the soil and underlying geologic material, (2) water table fluctuations, (3) depth to the low HC zone, (4) occurrences of potholes and poorly drained areas, and (5) annual precipitation and frequency of high precipitation periods. Control measures for types 1 to 5 are primarily agronomic with limited drainage and land leveling. Control measures for types 6 and 7 are both mechanical (drainage and land leveling) and agronomic. Control measures will be discussed in more detail in a later section.

Description and Extent

The saline-seep problem of the northern Great Plains is caused by the geology of the region, high precipitation periods, and farming practices that allow water to move beyond the root zone and into the subsoil of saline geologic formations (Bahls and Miller *1973*; Black et al. *1974*; Halvorson and Black *1974*).

Under native vegetation, grasses and forbs used most of the precipitation and little percolated below the root zone. Water table measurements at the time of settlement were not documented, but more recently, farmers and ranchers report that water levels in their wells have risen during the past 40 years. In many wells, the water has become too salty for livestock and humans.

According to Cole and Mathews (*1939*), plowing the native sod in the Great Plains increased the quantity of water in the subsoil. They found that, where land was periodically fallowed, the subsoil was wetter than under sod. The effect of summer fallow on subsoil water on land plowed in 1915 was studied at Havre, Mont., from 1916 to 1936 The 5- to 7-foot section of soil profile under a spring wheat-fallow rotation remained dry (below wilting coefficient) until 1927 when rainfall moistened the soil to a depth of at least 7 feet. The 5- to 7-foot section remained moist from 1927 to 1936. Results of a study at Mandan, N. Dak., on a fine sandy loam soil, indicated that with alternate crop-fallow some rainfall probably infiltrated to depths below the spring wheat root zone (Cole and Mathews *1939*).

Before 1940, soil water storage during fallow was less efficient than thereafter. Frequently, tillage tools provided less than optimum weed control, tractor power was minimal, and fallow operations were often not timely. After 1940, more effective tillage tools became available, tractor power was adequate, and fallow operations became much more timely. The widespread use of 2,4-D since its introduction in the forties has reduced weed populations in crops and during subsequent fallow periods, which has helped improve water storage efficiency (Greb et al. *1979*). The increased water storage contributed to saline-seep outbreaks, which began in the forties and continue to the present.

Saline-seep formation begins with a root-zone filled to its water-holding capacity. During a 21-month fallow period, precipitation exceeds the storage capacity of the soil. Some of this water runs off the surface, some evaporates, and the rest moves into the soil. Once the soil is filled to field capacity, any additional water that moves through the root zone may contribute to saline seepage (fig. 2). Water percolating through salt-laden strata dissolves salts and eventually forms a saline water table above an impermeable or slowly permeable layer. The underground saline water moves downslope and dissolves more salts, until it eventually discharges at the soil surface.

As a general rule, in the glaciated region underlain by Colorado shale, water dissolves 10 times more salt per foot of vertical movement as compared with salt dissolved during horizontal movement.

The discharge water evaporates, concentrating salt on or near the soil surface. As a result, crop growth in the affected area is reduced or eliminated and the soil is too wet to be farmed. Bahls and Miller (*1973*) and Veseth and Montagne (*1980*)

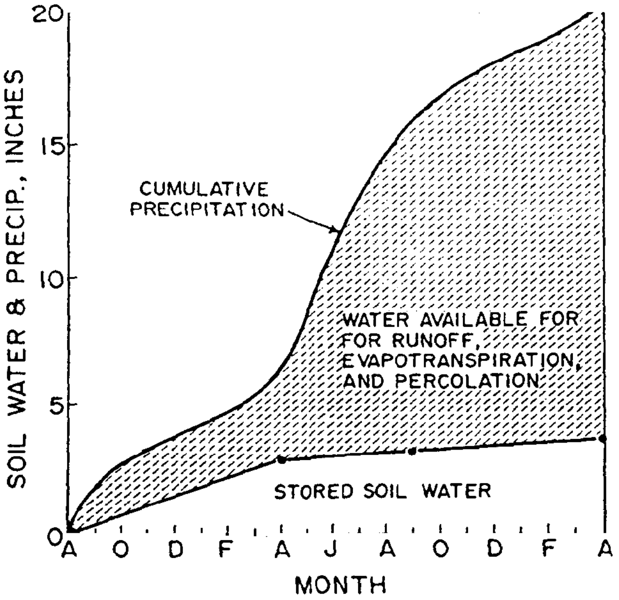

Figure 2.—Cumulative precipitation, in excess of soil water storage, is available for runoff, evapotranspiration, and deep percolation during 21-month fallow period at Sidney, Mont.

described two geologic formations in the northern Great Plains that are associated with saline seeps. The first is the thick sequence of gray-black marine shale typified by the Colorado, Bearpaw, and Claggett Formations in north-central Montana and the Provinces of Alberta and Saskatchewan. Second are the nonmarine sediments of the Fort Union Formation, a sequence of siltstone, sandstone, shale, and coal covering most of eastern Montana, western North Dakota, and southern Saskatchewan. The marine shales are salty and nearly impermeable to water. Dense clay layers generally underlie coal seams and sand and silt layers of the Fort Union Formation. Any water that percolates to the shale or clay layer (low HC) forms a water table. In many places, these shale and clay layers are close to the surface (5 to 60 ft), and the ground water is moderately to highly saline. In galciated areas, glacial till caps both geologic units, which cover about 228,000 mi^2 (fig. 3) in Montana, North Dakota, South Dakota, Alberta, Saskatchewan, and Manitoba.

Seep development in glaciated areas is most pronounced where the till is less than 20 feet thick or where clay layers or dense layers of low HC occur only a few feet below the surface. Where substrata are permeable or where most of the precipitation is used for plant growth, saline seeps do not form. Except for the surface 3 to 6 feet, the entire till profile contains abundant solubilizeable calcium, magnesium, and sodium sulfate salts with some nitrates, chlorides, and bicarbonates (Ferguson *1976*; Halvorson and Black *1974*; Oster and Halvorson *1978*; Sonderegger et al. *1978*). Average water quality data from selected shallow wells associated with saline seeps (table 1) show that salt concentrations in seepage waters are much higher in the Colorado shale areas than in the Fort Union areas (Bahls and Miller *1973*; Doering and Sandoval *1976a, 1976b, 1978*; Halvorson and Black *1974*).

Many areas of the northern Great Plains contain saline seeps that significantly reduce crop production and inconvenience farming operations on adjacent areas. Vander Pluym (*1978*) estimated that about 2 million acres are affected in the northern Great Plains Region of Alberta, Saskatchewan, Manitoba, Montana, North Dakota, and South Dakota. Vasey (*1976*) reported that soil surveys made in the thirties in North Dakota showed the presence of saline seeps in a few counties. Warden (*1954*) reported that saline seeps were becoming evident in north-central Montana as early as 1941. Saline seeps occur on all classes of land. A 1981 soil survey report of Adams County, N. Dak., showed the distribution of saline seeps by land classes as follows: 27 percent were on class II land; 65 percent on class III land; 5 percent on class IV land; and 3 percent on class V, VI, VII, and VIII land (USDA *1981*).

Doering and Sandoval (*1976a, b*) estimated that saline seeps and their associated downslope wet areas occupied 100,000 acres of cropland in North Dakota.

Bahls and Miller (*1973*), using aerial photographs of the Nine Mile watershed near Fort Benton, Mont., documented the proliferation and rapid growth of saline seeps in a 19-mi^2 watershed as follows: 1941, 0.1 percent of land was occupied by seeps; 1951, 0.4 percent; 1956, 2.2 percent; 1966, 9.1 percent; and 1971, 19.4 percent. No control measures were applied to the land before 1971. These data illustrate how rapidly the problem can expand if remedial measures are not applied.

Miller et al. (*1978, 1981*) prepared a map of Montana showing the distribution of saline-seep areas. The map (fig. 4) was based on aerial and field reconnaissance and surveys completed in 1977. This survey indicated that about 200,000 acres of Montana land were affected by saline seeps. The area lost to saline-seep development will continue to increase until such time as adequare controls are implemented.

During the seventies, reported acreage of saline seep in Montana increased dramatically from 51,000 to 200,000 acres. Much of this reported increase may have resulted from the increased awareness of the saline-seep problem. Loss of land to new and untreated saline seeps is continuing at a greater rate than the amount of saline-seep land being controlled and returned to production. Under a wheat-fallow system, salinization of 200,000 acres amounts to an estimated annual loss of 3 million bushels of wheat and an estimated gross income of $12 million.

Dryland salinity problems are widespread in many parts of the world where geology, climate, and farming systems combine in such a way as to enable the salinization process to occur. Olson (*1978*) reported saline seep problems in India, Iran, Turkey, Latin America, and Australia. The Australian seepage problems appear to be similar to those in the northern Great Plains [Stoneman *1978*; Malcolm (not dated)].

In 1979, Bown and Krall (*1979*) prepared a brief publication describing the process of saline-seep formation, control, and reclamation. Much additional information has become available since that time.

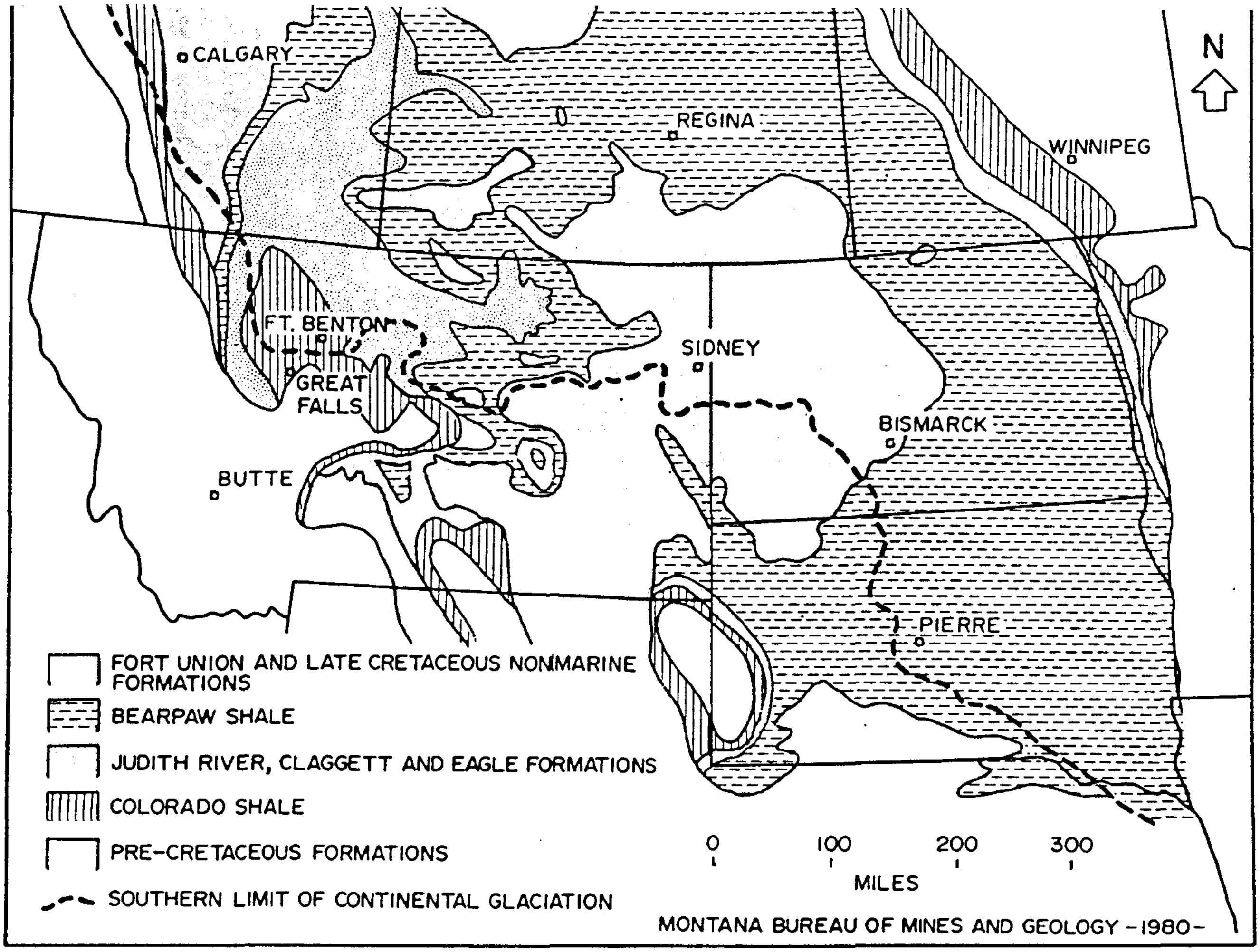

Figure 3.—Geological formations associated with saline seeps in the northern Great Plains.

Table 1.—*Water quality data associated with saline seeps in the Colorado shale and Fort Union geologic formation areas* [1]

Salt	Colorado shale	Fort Union
	Mg/L	
Sodium (Na)	5,200	1,500
Magnesium (Mg)	5,500	750
Calcium (Ca)	400	330
Sulfate (SO_4)	32,000	6,000
Nitrate (NO_3)	1,600	600
Chloride (Cl)	200	70
Bicarbonate (HCO_3)	700	500

[1] Adapted from: Bahls and Miller (*1973*); Doering and Sandoval (*1976a, 1978*); Halvorson and Black (*1974*).

Factors Contributing Water to Saline Seeps in Northern Great Plains

Changes in land use, brought about by plowing the native range and subsequent introduction of the crop-fallow system, disrupted the original hydrologic balance and caused the saline-seep problem. Several conditions or combinations of conditions contribute water that causes saline seepage.

1. *Fallow.* During the fallow period, the 3 to 8 inches of soil watered by the previous crop is replenished. Many deep subsoils in the crop-fallow areas of the northern Great Plains are wet to near field capacity below the root zone. When the amount of water used by the previous crop has been recharged by precipitation, any additional water entering the soil moves to the water table and often resurfaces downslope as a saline seep.

2. *High Precipitation Period.* Infiltration and subsequent percolation may exceed the water holding capacity of the root zone during periods of high rainfall. For example at Fort Benton, in 1975, rainfall totaled 15 inches in April, May, and June. Assuming that 75 percent of this water entered the soil, the fallow land would have been completely recharged and a considerable quantity of water would have moved below the root zone to the water table.

3. *Poor Surface Drainage.* Runoff water collects in shallow land depressions. Over time, some of this water infiltrates into the soil, raising the water table and causing the water to flow downslope to eventually resurface as a saline seep.

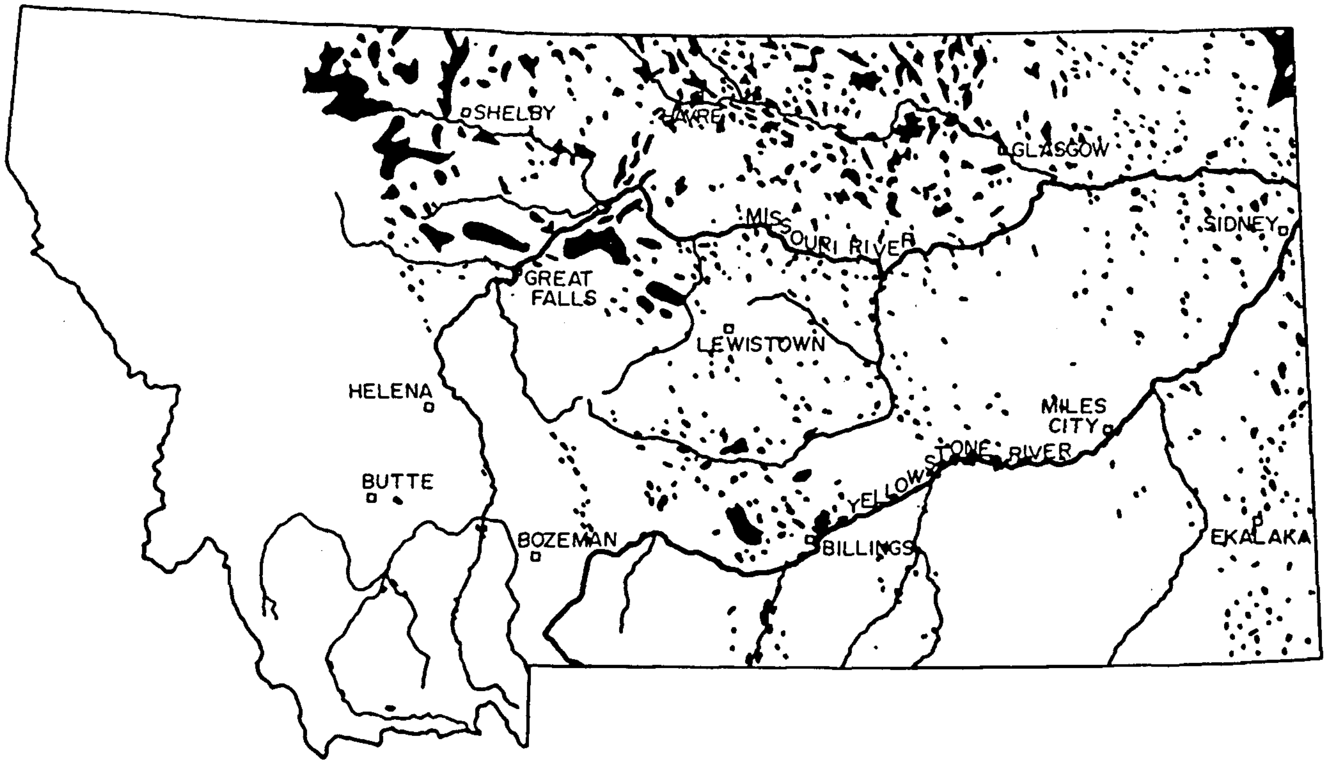

Figure 4.—Distribution of salinized areas in Montana as determined by aerial and field reconnaissance surveys completed in 1977 (adapted from Miller et al. *1978* and *1981*).

4. *Snow Accumulation.* Windbreaks, roadways, railroadways, and wind-protected areas collect deep snowdrifts (Sommerfeldt *1976a*). Under some conditions, these drifts contribute significant amounts of water to the water table. If these barriers are found to contribute water to discharge areas, the cropping system should be altered to use the additional water or the barrier should be modified or removed.

5. *Gravelly and Sandy Soils.* Water infiltrates rapidly on these soils, which have limited water holding capacities. Such soils often serve as recharge areas for saline seeps. These areas should be cropped annually or seeded to a perennial crop.

6. *Drainageways.* Surface and subsurface water flow patterns along drainageways may be disrupted by soil texture changes (clay dikes), topography, or geology, causing the buildup of saline ground water that eventually surfaces as saline seeps. The relatively fresh water carried by natural drainageways keeps the area wet, perpetuating the saline seeps. Improving the natural drainage channel will help alleviate this problem.

7. *Constructed Ponds and Dugouts That Leak Water.* Saline seepage is often severe downslope from such structures. If the stored water is salty, these structures should be removed.

8. *Artesian Water.* Drilling through consolidated material or shale layers may encounter confined saline water systems under hydrostatic pressure. The holes may release artesian water that flows to the surface to form and/or contribute to a saline-seep problem. These holes should be carefully plugged.

9. *Roadbeds across Natural Drainways.* Construction of roadways may disrupt or restrict the normal underground lateral waterflow. Improperly installed or plugged culverts may cause the water table to build up or rise to the surface, causing a salinized area. Gravel fills to a depth of at least 5 feet below the roadbed will preserve and enhance subsurface flow.

10. *Crop Failure.* Crop loss as a result of poor stand establishment, hailstorms, winterkill, diseases, insects, and low fertility may cause incomplete use of stored soil water. If this land is fallowed, the water storage capacity is limited. This will cause extra water to move below the root zone to aggravate the saline-seep problem.

Identifying Saline Seeps

Early detection and diagnosis of a saline-seep problem are important in designing and implementing control and reclamation practices to prevent further damage. Any delay in implementing control practices can lead to a much larger and more difficult-to-manage problem. By early detection, a farmer may be able to change his or her cropping system to minimize the damage.

Visible Detection

Some visible symptoms of impending saline-seep development are listed as follows (Brown *1976*):

1. Kochia (*Kochia scoparia* [L.] Roth,) dominant indicator plant on cultivated land. Kochia growing vigorously after grain har-

vest, in small areas where normally the soil would be too dry to support weed growth, is an indicator. Examine these areas to see if the subsoil is wet.

2. Scattered salt crystals on a dry soil surface.

3. Prolonged soil surface wetness in small areas following a substantial rain. Surface wetness is easily observed in a fallow field but can also be observed on cropped land in late spring or early summer after seeding. There will normally be uneven surface drying following a rain, but if a local area remains wet 2 to 4 days longer than the rest of the field, it may indicate a shallow water table. A soil moisture probe (Brown et al. *1981*) may show that the soil is unusually wet or that there is free water present.

4. Tractor wheel slippage or tractor bog-down in certain areas. Water often seeps into the wheel tracks and remains for a period of time. Salt crystals form on soil surface as the discharge areas dries.

5. Rank wheat or barley growth accompanied by lodging in localized areas that produced normal growth in previous years. Farmers report that crop yields on such areas are unusually high. This may be the last crop before the area becomes too wet to farm. Such areas may be subirrigated by a rising water table, but the salt content is not yet high enough to reduce growth. These wet areas soon become salinized and often expand rapidly.

6. Foxtail barley (*Hordeum jubatum* L.) infestations that increase with time. In a normally developed seep, the sequence of vegetation going from the center to the perimeter is bare soil, foxtail barley, and kochia. After several years, the kochia may move inside the foxtail barley area.

7. Trees stunted or dying in a shelterbelt or windbreak. Leaves often turn light green or yellow.

8. Sloughed hillside, covered by native vegetation, adjacent to a cultivated field.

9. Other symptoms, including poor seed germination and abnormally mellow, dark-colored surface soil on lower slopes. The dark color could be caused by dispersed lignite or organic matter mixed with surface soil.

Electrical Conductivity Detection

Soil EC, which is proportional to soil salinity, can be determined in the field, using resistivity (Halvorson and Rhoades *1974, 1976*) or electromagnetic inductive (Cameron et al. *1981*) techniques. The resistivity technique is referred to as the four-probe electrode method of measuring soil salinity. These methods do not require soil sampling and laboratory analysis. Figure 5 shows typical EC curves for a saline seep, an encroaching saline-seep site, and an unaffected site for a glacial till clay loam soil near Sidney. The four-probe resistivity technique of measuring soil salinity or electromagnetic inductive techniques (discussed in detail on p. 8) can be used to identify and confirm an encroaching or developing saline seep. Soil salinity may be low near the soil surface, but increases considerably in the 1- to 3-ft soil depth (fig. 6). Calibration curves relating four-electrode soil conductivity to soil texture are show in figure 7 (Halvorson et al. *1977*). A USDA publication (Rhoades and Halvorson *1977*) describes how to use the resistivity equipment to measure soil salinity and identify saline seeps.

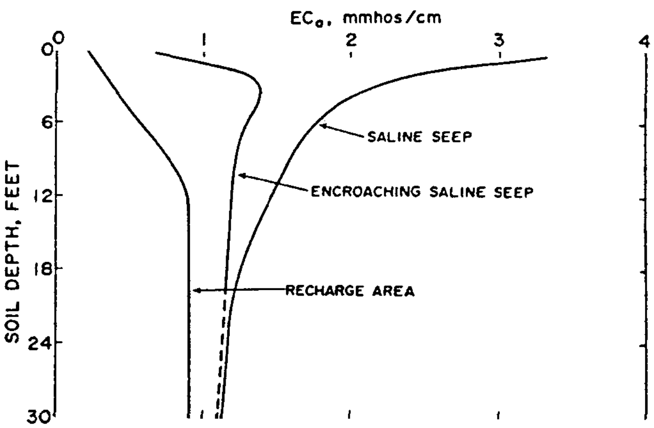

Figure 5.—Typical four-probe electrical conductivity (EC_a) as a function of soil depth in recharge, encroaching saline seep, and saline-seep areas.

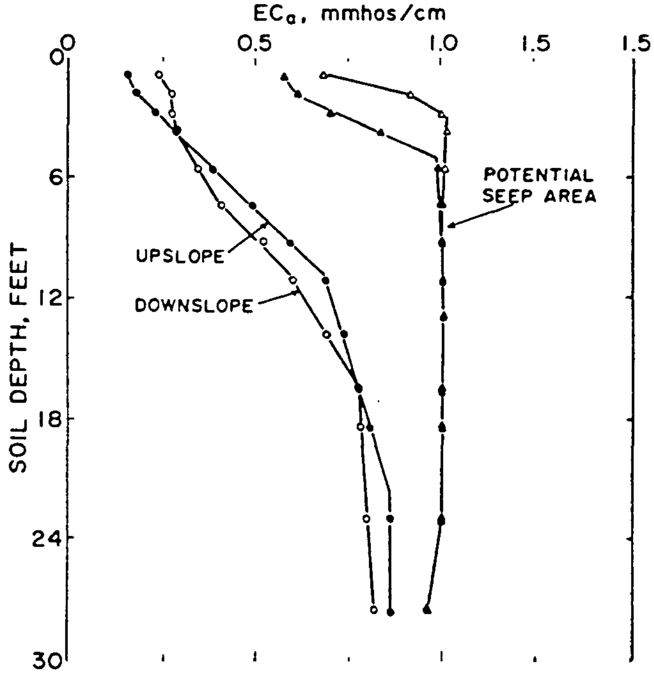

Figure 6.—Four-probe electrical conductivity (EC_a) as a function of soil depth upslope and downslope, and in the potential seep area.

Identifying the Recharge Area

The first indication of saline-seep development is the observation of one or more of the previously identified symptoms. The next step is to locate the recharge area. Most remedial treatments for controlling the seep must be applied in the recharge areas, which will always be at a higher elevation than the discharge area. The approximate size of the recharge area must

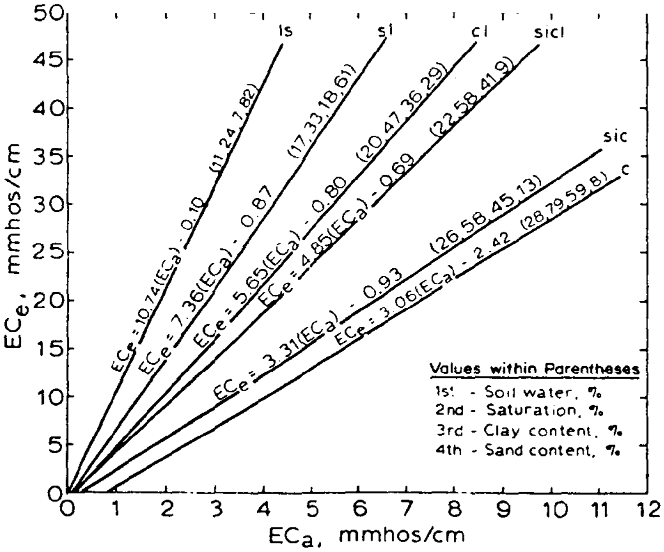

Figure 7.—Calibration curves to calculate electrical conductivity of saturation soil extract (EC_e) as a function of apparent electrical conductivity (EC_a) determined by the four-probe.

be determined if treatment is to be successful. Most recharge areas are within 2,000 feet and many within 600 feet of the discharge area. Where gravel beds and sandy soil are involved, the recharge area may be within 100 feet. The recharge area may be located directly upslope or at an angle across the slope from the discharge area. Methods used for determining the location and size of recharge areas are only approximate. Following are some methods of recharge area identification that have been used.

Soil Survey

Soil surveys, generally available from the local Soil Conservation Service Office (SCS), are helpful in locating the recharge area. Using survey maps, locate all gravelly and sandy soil areas upslope from the saline seep. These areas usually serve as recharge areas and should be examined carefully to determine their extent. Areas of 0 to 2 percent slope and poorly drained areas (depressions and closed basins) may also be recharge sites.

Soils with very low HC contribute little water to saline seeps because most water runs off or evaporates. The Kobar silty clay loam (fine montmorillonitic Borollic Camborthid) is an example of a soil with very low HC.

Soil Probe Procedures

Recharge areas can often be located by probing the area upslope from the seep with a soil probe (Brown et al. *1981*) in late winter or early spring. Upslope areas with soil wet to more than 40 inches are potential recharge areas. Deeper probing to 6 feet or more provides further assessment of the extent of the recharge area. If the upslope area is uniformly wet to more than 40 inches, the probe procedure should not be used to detect recharge areas during that particular season.

If a seep is surrounded by higher topography on several sides, the soil probe can be used to identify direction of recharge area from the seep. For example, if the soil is abnormally wet in one direction, this indicates the potential recharge area.

Four-electrode Resistivity Method (Four-Probe)

Halvorson and Rhoades (*1974, 1976*) and Halvorson et al. (*1977*) used the four-electrode resistivity technique to measure soil sailinity and identify established saline seeps, potential saline seep, and recharge areas (fig. 5). This method measures apparent soil electrical conductivity (EC_a). Existing saline seeps generally have a high level of salinity at the soil surface, which decreases with soil depth. Encroaching or developing seep areas generally have low to medium levels of salinity at the soil surface, with a rapid increase in soil salinity in the 1- to 3-foot soil zone, and then decreasing salinity at deeper soil depths. Soil salinity generally increases gradually with increasing soil depth in the recharge area.

Maps of EC_a isolines (Halvorson and Rhoades *1976*) can also be drawn of the seep areas. These maps used in relation to surface topography often show the direction that the recharge area is located from the seep area. Direction of water flow through the seep can also be estimated using these EC_a isoline maps.

With a knowledge of soil texture, the four-probe electrical conductivity measurements (EC_a) of soil salinity can be converted to the approximate electrical conductivity (EC_e) obtained by using saturated soil paste extracts (standard laboratory method of measuring soil salinity) (fig. 7).

The method requires a minimal amount of time to make a soil salinity measurement. Uniform soil physical properties to the depth of EC_a measurement are not essential, but make data interpretation easier. Soil moisture should be near field capacity for most accurate results. Generally, soil moisture does not limit the use of the method in saline seep or developing seep areas.

The four electrodes used with the resistivity meter can be mounted on a board, plastic, or any other nonelectrical conducting material, or they can be used without mounting. The only requirement is that the four electrodes be equally spaced in a straight line. A commercially built, single EC probe in which four electrodes are mounted on a shaft as spaced rings is also available (Rhoades and van Schilfgaarde *1976*). This probe can measure soil salinity within discrete soil depth intervals.

The four-electrode resistivity technique can also be used to estimate depth to the water table and impermeable layer where two known geologic strata are present. A good example of this condition would be the glacial till areas underlain by the Colorado or Bearpaw shales (Rhoades and Halvorson *1977*). A good knowledge of the area's geology is necessary to prevent inaccurate interpretation of the measurements made. The depth to water table or impermeable layer is determined by plotting EC_a measurements vs. electrode spacing. A change in the slope of the plotted curve generally corresponds to some change in the geologic profile, such as water table, abrupt texture change, or impermeable layer.

Inductive Electromagnetic Soil Conductivity Method

Cameron et al. (*1981*) compared the Wenner array (four-probe) resistivity method with two inductive electromagnetic conductivity meters (EM31 and EM38) for mapping field scale salinity. Both methods gave a clear delineation between areas of high and low salt content.

The main advantages of the EM31 meter for mapping are: (1) it can be used to map a saline area rapidly because it continuously registers as the operator traverses a field without requiring soil-to-instrument contact, and (2) it senses to a maximum depth of 20 feet and provides correlations of 0.81 to 0.96 with EC_e for the 0- to 11-foot depth. The disadvantages of the EM 31 are (1) that it does not distinguish salt distribution with respect to depth; (2) only 50 percent of the conductivity response is within the 0- to 9-foot depth, and the rest is below; (3) the instrument may not give a good indication of expected plant response; and (4) it weighs 20 pounds, making it cumbersome to carry for extended periods.

The main advantage of the Wenner array, four-probe system is that it can be used to measure discrete increments in salt distribution in the root zone at each grid point. The Wenner array readings takes about 2 minutes to complete, compared with less than 5 seconds for the EM31.

The shallower (2.5- to 5-ft) sensing EM38 gives a rapid response, but the prototype used requires frequent scale adjustment (Cameron et al. *1981*). Rhoades and Corwin (*1981*) evaluated the EM38 instrument and reported the device to be well suited for field investigations of soil salinity.
Continued improvement in instrumentation for the electromagnetic detection of soil conductivity is expected.

Drilling Procedures (Auger or Core)

Based on field observations and aerial photographs, several holes are drilled in both the discharge and suspected recharge areas. Prior knowledge of the soils and the geology of the area is most helpful in deciding where to drill. Most drilling will be with auger bits, but core samples are needed at times. Wells are carefully logged noting depths to dense (clay and shale) and highly permeable (sand, gravel, silt, and lignite) zones. Depth to free water should be noted. The depth of wells will vary but should be deep enough to identify the water transmission zone. Perforated plastic pipe (preferably greater than 2 inches in diameter) is installed in selected wells for periodic monitoring of water table depths. Depth to the water table should be determined when the well is drilled and 24 to 72 hours after drilling. (See appendix for added details.) Information from well logs, water table levels, and topography is then used to delineate the recharge area. A combination of probing and drilling is an excellent way to locate the recharge area.

Farmers are encouraged to take part in the drilling operation and to periodically measure water levels to determine the effect of cropping systems on water levels. The drilling experience demonstrates the nature and seriousness of the saline-seep problem.

Visual Approximation of Recharge Area

Sometimes, soil survey maps, drill rigs, and four-probe or electromagnetic equipment are not available to assist in identifying the recharge area. A farmer can still do certain things to solve his or her problem. A visual approximation of the recharge area (that is, upslope area, sandy or gravelly soils, areas of temporary water ponding, shelterbelts, fallowed land) can be made and strategies implemented to correct the saline-seep problem. Some recharge areas can be visually estimated using the information presented earlier. Some facts to remember are: (1) recharge areas are higher in elevation than the seep or discharge area; (2) recharge areas are generally within 2,000 feet of the discharge area; (3) saline seeps in glacial-till areas generally tend to expand downslope, laterally, and upslope *toward* the recharge area; (4) saline seeps in the nonglaciated Fort Union Formation areas tend to expand downslope *away* from the recharge area; (5) before the saline-seep area can be reclaimed, ground water flow from the recharge area must be reduced or eliminated; and (6) if the seep does not show signs of drying up within 2 or 3 years after implementing control measures (such as planting alfalfa or grasses, or annually cropping the suspected recharge area), the recharge area boundary was incorrectly identified, it was larger than anticipated, or the water in the seep area may be coming from an artesian source.

Control Measures for Saline-Seep Problems

Since seeps are caused by water moving below the root zone in the recharge area, there will be no permanent solution to the saline-seep problem unless control measures are applied to the recharge area. There are two general procedures for managing seeps: First, by agronomically using the water before it percolates below the root zone; second, by mechanically draining ponded surface water where possible before it infiltrates, and/or by intercepting lateral flow of subsurface water before it reaches the discharge area. Subsurface drainage is generally not satisfactory. The water is salt contaminated, and disposal without downstream surface or ground water pollution is difficult because of physical and legal constraints.

Prior to application of saline-seep control measures, the land capability class should be determined by examining a soil survey report or having a qualified person classify the land. If the land is class V or greater, it is generally not suited for cultivation (Klingebiel and Montgomery *1961*). All control measures should be compatible with the land class involved.

Concurrent with the application of control measures to the recharge area, the seep area and the immediate surrounding area may be seeded to an alfalfa-grass mixture such as:

	Pounds per acre
Beardless wildrye	4
Altai wildrye	3
Tall wheatgrass	3
Tall fescue	2
Alfalfa	2

Crop establishment on the discharge area will be difficult unless ground water flow to the seep is reduced. The choice of seed mixture, seeding rate, and planting frequency should be at the discretion of the land manager.

Agronomic Measures

Annual Cropping or Flexible Cropping

Flexible cropping is defined as seeding a crop when stored soil water and rainfall probabilities are favorable for a satisfactory yield or fallowing when prospects are unfavorable (Black and Siddoway *1980*; Black et al. *1981*; Brown et al *1981*; Halvorson and Kresge *1980, 1982*). Available soil water can be estimated by measuring moist soil depth with a soil moisture probe or other soil sampling equipment. The USDA, SCS (*1980*), has shown how the flexible cropping system works on a field during a 10-year period. Black et al. (*1981*) suggested cropping strategies for efficient water use to control saline seeps in the northern Great Plains. They suggested using two precipitation regimes, 10 to 15 inches and 15 to 20 inches, and three soil rooting depths, less than 5 feet, 5 to 10 feet, and 10 to 20 feet. For the 10- to 15-inch rainfall area, suggested crops were winter wheat, spring wheat, barley, and oats for the 5-foot root zone; winter wheat, spring wheat, barley, safflower, and alfalfa (3 to 4 years) for the 5- to 10-foot root zone; and winter wheat, spring wheat, barley, safflower, and alfalfa (4 to 5 years) for the 10- to 20-foot root zone. For the 15- to 20-inch rainfall areas, the same crops were listed for each root zone delineation except that sunflower was substituted for safflower. Use of a flexible cropping system was recommended for all cropping strategies. Proper fertilization, weed control, variety selection, and seeding time are necessary to maximize rooting depth, water use, and yields.

Brown et al. (*1981*) have developed soil water guidelines and precipitation probabilities for barley and spring wheat in flexible cropping systems in Montana and North Dakota. Barley and spring wheat can be seeded on stubble land having 3 to 4 inches of available soil water at seeding time provided there is a good probability of receiving an additional 5 to 6 inches of precipitation during the growing season. A soil texture guide showing plant-available water per foot of moist soil depth is presented in table 2. Each inch of plant-available water used by these crops above a minimum of 4 inches will increase spring wheat yields 4 to 7 bushels per acre and barley yields 7 to 10 bushels per acre. In North Dakota, Schneider et al. (*1980*) showed that with adequate fertilization, recrop spring wheat yields increased by 16 bushels per acre and water use by 1.3 inches.

When fall soil moisture conditions are sufficient to obtain a stand of winter wheat, the practice of no-till seeding directly into standing spring wheat or barley stubble without tillage has been successfully demonstrated (Black and Siddoway *1980*; Halvorson et al. *1976*). Research (Black and Ford *1976*) and farmer experience have shown that 6 inches of moist soil at seeding usually ensures a good stand of winter wheat. Each inch of plant-available water used by winter wheat above a minimum of 4 inches increases yields 4 to 7 bushels per acre.

Safflower and sunflower are oilseed crops that may be seeded every 3 to 4 years to use deep subsoil water not used by cereals. In most years, safflower roots to about 7 feet and used about 10 inches of soil water. Sunflower roots to about 6 feet and uses about 7 inches of soil water (table 3). For comparison, winter wheat roots to about 6 feet and uses about 7 inches of soil water, and barley roots to about 5 feet and uses about 6 inches of soil water. For seeding oilseed crops on recrop land, there should be at least 4 inches of plant-available soil water. Safflower will often root through a moderately dry root zone, left by the previous year's small grain crop, to reach available soil water at deeper depths. Other benefits from growing oilseed crops are improved weed control and disruption of disease and insect cycles associated with cereal grain production.

Table 2.—*A soil texture guide*[1] *showing available water-holding capacities by foot depths*

Group	Basic soil textural class	Available water per foot of moist soil depth[1]
		Inches
Sandy soils		
Coarse textured	Sands	0.40–0.75
	Loamy sands	0.75–1.25
Loamy soils		
Moderately coarse textured	Sandy loam Fine sandy loam	1.25–1.75
Medium textured	Very fine sandy loam Loam Silt loam Silt	1.50–2.30
Moderately fine textured	Clay loam Sandy clay loam Silty clay loam	1.75–2.50
Clayey soils		
Fine textured	Sandy clay Silty clay Clay	1.60–2.50

[1] U.S. Department of Agriculture, Soil Conservation Service. 1964. SCS National Engineering Handbook.

Average yields, rooting depth, soil water depletion, and oil contents of eight oil-yielding crops seeded on fallow at Fort Benton are shown in table 3.

Computer Evaluation of Flexible Cropping Decisions (FLEXCROP)

In considering a flexible cropping system, one should evaluate the amount of plant-available soil water at seeding time; growing season precipitation; and management factors, such as crop to be grown, variety, crop rotation, weed and insect problems, soil fertility, and planting date. Halvorson and Kresge (*1982*) developed a dryland cropping systems computer model called FLEXCROP, which estimates yield potential of a given field after considering the above factors. This model was designed to help farmers evaluate the effects of their crop and soil management decisions on potential crop yield and to help them decide whether to recrop or summer fallow a given field. Winter wheat, spring wheat, barley, oats, and safflower are the current crops covered in the model.

FLEXCROP is available to Montana and North Dakota farm managers through the AGNET computer system (a multi-State computer network), which is operated by the USDA Cooperative

Table 3.—*Average yields, oil contents, rooting depth, and soil water depletion for 10 crops seeded on fallow from 1976 to 1979 at Fort Benton, Mont., where the mean May through August precipitation was 7 inches*

Crop	Yield	Oil content	Root depth	Soil water depletion	Yield range
	Lb/acre	*Percent*	*Feet*	*Inches*	*Lb/acre*
Safflower	1,560	42.0	7	10	1,140–2,300
Sunflower	1,210	48.0	6	7	1,020–1,480
Oriental mustard	1,140	36.0	5	7	720–1,970
Flax	890	41.2	5	7	770–960
Yellow mustard	860	26.2	4	6	560–1,390
Turnip rape	800	37.0	5	7	450–1,140
Brown mustard	790	30.9	5	7	560–1,230
Argentine rape	570	38.2	4	7	290–1,110
For comparisons:					
Winter wheat	3,000	n.d.	6	7	2,060–3,700
Barley	2,910	n.d.	5	6	2,050–3,660

NOTE: n.d. = not determined.

Extension Service. Use of this model for evaluating management decisions involved in flexible cropping systems should help reduce the risk of an uneconomical return. FLEXCROP should be useful to most county agent, SCS, and other action agency and farm service personnel in helping farmers develop successful flexible cropping systems to control saline seeps. The computer program is designed for use with microcomputers.

Copies of the current program are available to those persons wishing to use the program on their own computers (Halvorson and Kresge *1982*). A users' manual is also available (Kresge and Halvorson *1979*), which discusses the type of information needed for the computer.

Perennial Cropping (Alfalfa and Grasses)

Seeding alfalfa in the recharge area of a saline seep is often the quickest, most effective way to dry the deep subsoil and stop waterflow to the saline seep (Brown et al. *1976*; Brun and Worcester *1975*; Brown and Cleary *1978*; Brown and Miller 1978; Halvorson and Reule 1980). Alfalfa roots penetrate deeply into the soil and extract large amounts of water, which permits the storage of additional water that might otherwise percolate to the water table. Soil water data presented by Halvorson and Reule (*1980*) demonstrate why alfalfa is effective in reducing the loss of water to deep percolation (fig. 8). From the fourth through the eighth foot, the soil water content under alfalfa was much lower than under sod or grain stubble. Brown and Miller (*1978*) reported rooting depths and soil water depletion of three legumes and two grasses after a 6-year growth period (table 4). After 6 years, Vernal alfalfa was the deepest rooted and showed the greatest soil water use.

Alfalfa cultivars differed markedly in rooting depth, soil water extraction, and yields (table 5). After 5 years, Beaver alfalfa was the deepest rooted (24 ft) and used the greatest amount of water (41 in). In contrast, Kane was shallow rooted (16 ft) and a low water user (21 in).

Halvorson and Reule (*1976, 1980*) found that alfalfa growing on about 80 percent of the recharge area effectively controlled

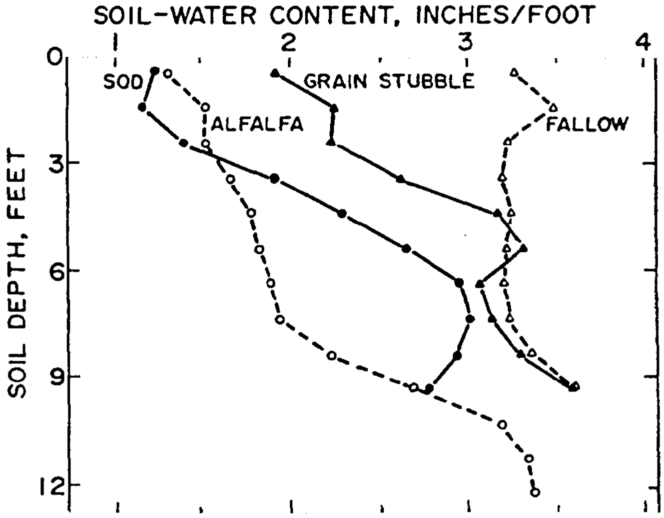

Figure 8.—Soil water contents under native sod, alfalfa, and grain stubble compared with those of fallow.

Table 4.—*Rooting depth and net soil water depletion for 5 adequately fertilized forage crops grown for 6 years near Fort Benton, Mont.*[1]

Crop	Root depth	Net soil water depletion
	Feet	*Inches*
Vernal alfalfa	20	31
Eski sainfoin	14	23
Cicer milkvetch	15	23
Russian wildryegrass	9	18
Tall wheatgrass	9	17

[1] Cumulative precipitation in 6-year period was 80 inches. The soil was Gerber silty clay loam, a fine, montmorillonitic frigid Udorthentic Chromusterts. Depth to the water table was 49 feet, and depth to Colorado shale was 50 feet.

Table 5.—*Rooting depth, net soil water depletion, and average hay yield after 5 years for 10 adequately fertilized alfalfa cultivars grown near Fort Benton, Mont.*[1]

Cultivar	Root depth	Net soil water depletion	Average hay yield
	Feet	*Inches*	*Lb/acre*
Beaver	24	41	4500
Roamer	24	39	4600
MS 243	24	37	4300
Grimm	16	28	3700
Ladak 65	22	26	4400
Ladak 75	20	28	4500
Drylander	17	25	4700
Vernal	17	23	4600
Kane	16	21	5400
Rambler	17	19	4800
Average	20	28	4600

[1] Net soil water depletion from 1976 through 1980 does not include yearly precipitation, which was 12.8, 14.3, 19.2, 10.5, and 16.3 inches for 1976, 1977, 1978, 1979, 1980, respectively. For soil characteristics, see footnote 1 in table 4.

several saline seeps. They also found that a narrow alfalfa buffer strip (occupying less than 20 percent of recharge area) on the immediate upslope side of a seep did not effectively control the water in the discharge area. Alfalfa is being used by an increasing number of farmers in Montana and North Dakota to bring saline-seep areas under control.

Grasses may also be seeded in the recharge area. They are most effective where the depth to a low HC zone is less than 15 feet. When adequately fertilized, several grass species roots penetrated to 15 feet and depleted stored soil water by more than 20 inches in 5 years (table 6) (P. L. Brown, unpublished data).

Table 6.—*Rooting depth and net soil water depletion for 8 grass species after 5 years' production near Fort Benton, Mont.*[1]

Species	Rooting depth	Net soil water depletion[1]
	Feet	*Inches*
Intermediate wheatgrass	15	29
Basin wildrye	18	26
Kenmont tall fescue	15	25
Green needlegrass	15	23
Slender wheatgrass	15	22
Pubescent wheatgrass	15	22
Western wheatgrass	11	20
Crested wheatgrass	13	16

[1] Net soil water depletion from 1976 through 1980 does not include yearly precipitation, which was 12.8, 14.3, 19.2, 10.5, and 16.3 inches for 1976, 1977, 1978, 1979, and 1980, respectively.

Stubble and Vegetative Snow Trapping

Grass barriers, standing stubble, and the two combined are excellent ways to trap and hold snow on the land and provide uniform snow distribution (Black and Siddoway *1976*). These practices reduce snow blowing from the fields and increase soil water storage in the root zone, providing a greater opportunity for successful recropping. At Sidney, Black et al. (*1981*) used tall wheat grass barriers spaced at 50-foot intervals to store 3.1 inches of water during the first winter as compared with 2.1 inches in an undisturbed stubble field. Total soil water storage for the entire fallow period within the barrier system was 4.2 inches compared with 3.5 inches outside the system. Controlling fall weeds and volunteer grain growth after harvest is another important method for conserving soil water supplies. Efficient water conservation during the period between crops is necessary to improve the opportunity to successfully recrop. The additional water storage resulting from grass barriers and standing stubble should be utilized by more intensive cropping. If not utilized, it may increase water movement through the soil and contribute to saline seep.

Drainage

Brown and Miller (*1978*), Vander Pluym (*1978*), and Worcester et al. (*1975*) have shown that undulating, nearly level land with poor surface drainage (potholes) can be recharge areas for saline seeps. Prior to sod plow-up, these areas were sealed by natural accumulations of layered silt and clay. Cultivation, including deep chiseling, disrupted the layers and increased infiltration and percolation. Following heavy rain and rapid snowmelt, these poorly drained areas fill with water. In 1975, water infiltration measurements at three such sites, south of Fort Benton, averaged 0.07 inch per day (Brown and Miller *1978*). The water level in observation wells at the pothole sites continued to drop after the surface water disappeared, indicating that these poorly drained areas continued to supply water to the discharge area. Procedures for determining leakage through the bottom of the potholes and expected water volume contribution to the discharge site are described by Shjeflo (*1962*). Where possible, surface drains should be installed to prevent the temporary ponding of surface water. Drainageways under roadbeds should be kept clear of debris and sediment so that the site does not serve as a contributing or recharge area.

Doering and Sandoval (*1976a, 1976b, 1978*) and Hanson (*1976*) found that interceptor drains (tile drain) installed immediately upslope from the seepage area, reduced the amount of water flowing to the seepage area and permitted the seep to dry. Disposal of the saline drainage water, however, was a severe problem because of its salt and nitrate content.

A few scattered ephemeral and permanent salt lakes exist in the northern Great Plains. These are closed basins with no natural outlets. The salt content of this water may exceed that of ocean water. Such lakes may be used to dispose of salt water drainage.

Mole drains have been installed at Claresholm, Magrath, and Sterling, Alberta, to drain temporary excess water and maintain the water table at safe depths (Sommerfeldt et al. *1978*). Satisfactory results were obtained when drains were installed on proper grade and in moist and cohesive fine-textured soils where shallow water tables (<40 in) occurred. This drainage technique may not be successful in noncohesive soils and where the water table is below 40 inches (Sommerfeldt *1976b*). Drainage procedures are site specific.

Water Table Monitoring

Water tables fluctuate seasonally and annually. Fluctuations can be measured in observation wells and, when recorded, can provide accurate assessment of the water table hazard in potential saline-seep or discharge areas. Measurements in 1981 from one observation well are recorded in table 7 and indicate a sharp rise, followed by a recession in water table. This well is located in a former seep that has been reclaimed by seeding alfalfa in the recharge area. The rise in water table was caused by 11.4 inches of rain during March 1 to May 19. Subsequent recession was due mostly to slow subsurface water movement through the clay dike at the lower edge of the former saline seep. The barley crop also used some of the water. Fortunately, the saline seep was not reactivated by the sudden rise in water table. Halvorson and Reule (*1980*) reported similar water table fluctuations in a former seep area at Sidney in 1975. Such fluctuations can be expected during high precipitation periods with certain soils. Reclaimed saline seeps may be reactivated by a significant rise in water table, which persists for several weeks or months.

Table 7.—*Precipitation and depth to water table as measured in an observation well located in a reclaimed seep area at Fort Benton, Mont., in 1981*

Date	Depth to water table	Interval	Precipitation
	Feet		*Inches*
Mar. 1	6.5		
May 19	.4	Mar. 1 to May 19	11.4
June 4	1.3	May 20 to June 4	.6
June 27	2.2	June 5 to June 27	1.7
July 18	4.0	June 28 to July 18	.7
Aug. 27	4.9	July 19 to Aug. 27	.8
Oct. 14	5.3	Aug. 28 to Oct. 14	1.5

If a saline water table is less than 3 feet below the soil surface, saline water can move to the surface by capillary rise and create a salt problem. The severity of the problem depends on the size of the recharge areas, and depth and salinity of the water table, as well as soil physical and chemical properties, climate, and management. The degree of salinity hazard in the root zone is related to the depth to the water table. Based on research experience, this may be classified as follows:

Salinity Hazard	*Depth to water table*
Severe	<3 feet
Moderate	3 to 5 feet
Mild	5 to 6 feet
None	>6 feet

The above water table depths are approximate and will vary with soil, climate, and management. Water table depths often vary during the year, being shallower in spring and early summer than during the rest of the year. The relationship between water table depth and soil salinity in the surface foot of soil is further documented in figure 9 (Halvorson and Rhoades *1974*). Perforated plastic pipe (2- to 4-in. diameter) should be installed at strategic locations on farms with saline-seep problems to allow monitoring of water tables. The drilling of deep wells will require a power drill, but a tractor-mounted posthole auger can be adapted to install shallow wells. Bucket augers can be used to install wells down to 10 feet. These wells should be located in *discharge areas, along drainageways, and in recharge areas.* Ideally, the water table should be at least 6 feet deep. Water table levels should be monitored monthly, especially during and after snowmelt and rainy seasons. A rising water table that persists into the summer months indicates that cropping practices should be intensified to increase soil water use.

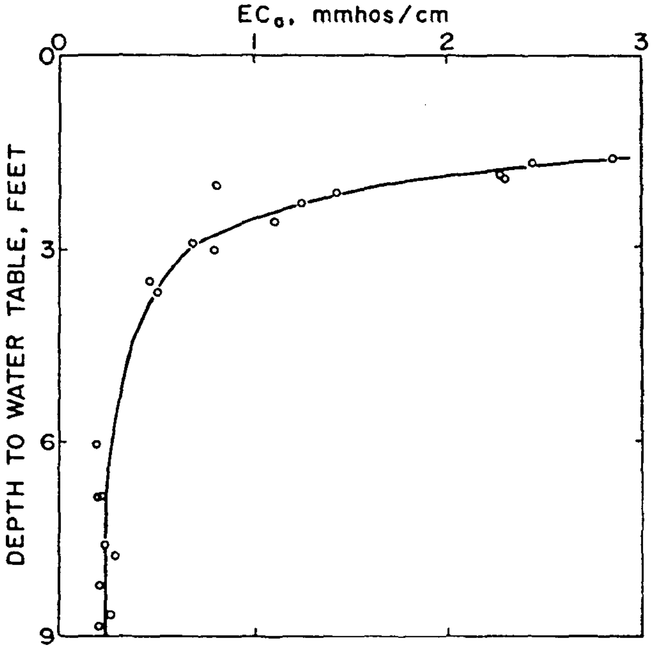

Figure 9.—Four-probe soil electrical conductivity (EC_a) as a function of water table depth in a saline-seep area.

Reclamation of Saline Seep

After the flow of water from the recharge area has been controlled to the extent that the water table in the saline seep has been lowered or eliminated, reclamation can proceed. Research and farmer experience show that reclamation occurs quite rapidly (Brown and Miller *1978*; Halvorson and Reule *1976*; *1980*). With the water table in the seep area at 5 feet or deeper, the surface of the seep dries enough for tillage and seeding. Bole and Wells (*1978*) found that cereal grain production on a saline soil (8.8 mmhos per cm) relative to nonsaline soil was as follows: Oats, 25 percent; wheat, 41 percent; two-row barley, 40 percent; and six-row barley, 62 percent. Since six-row barley is the most salinity-tolerant cereal available, it normally should be the first crop seeded. Reclamation progress can be monitored by comparing yields within and outside the former seep area. Two or more successive barley crops can be grown if necessary. The water table depth should be closely monitored during the reclamation period.

Another approach that can be used on severe seep areas is to seed salt-tolerant grasses such as tall wheatgrass and beardless wildrye. If the water table is above 4 feet, mow and remove all vegetation in the fall to prevent excess snow accumulation and water table rise. If the water table is below 4 feet, weeds and grass can be left to catch snow. The resulting snowmelt will leach the salt downward in the soil and thereby improve grass growth. Water table level should be monitored closely. Halvorson (unpublished data) found that application of gypsum or a straw mulch did not hasten the movement of salts from a surface-dry saline-seep area. Due to the type of the salts involved (Ca, Mg, and Na sulfates), permeability does not appear to deteriorate as the salts are leached out.

The rate of reclamation is dependent on the amount of precipitation received to leach the salts. Therefore, applying practices, such as snow trapping or summer fallowing, which enhance water movement through the profile on the salt-affected area, will hasten the reclamation procedure. These practices will not be effective until hydrologic control is achieved in the recharge area and the water table is significantly lowered in the seepage area.

To prevent a reclaimed seep area from recurring, the recharge area should be managed to control the amount of water moving through the profile. The recharge area shold be cropped more intensively than is done with a crop-fallow system. Fallow may be used on occasion when needed. The water table in the recharge area should be monitored. Even with intensive cropping, alfalfa may need to be reseeded periodically in certain recharge areas.

Two examples of control and reclamation are given as follows:

Example 1: In 1971, an 80 acre field of the Norris Hanford farm near Fort Benton had seep outbreaks totaling 10 acres. The entire field was seeded to 'Ladak 65' alfalfa. Observation wells were installed in the recharge and discharge areas to monitor water tables. In 1971, the water table was 1 foot below the soil surface in the monitored discharge area and 19 feet below the soil surface in the recharge area. Six years later, the water table had dropped to 10 feet in the discharge area and to 28 feet in the recharge area (fig. 10). The alfalfa roots had penetrated to 15 feet, and there was a net depletion of 19 inches of soil water. The lowering of the water table in the discharge area resulted from reduced flow from the recharge area and slow subsurface drainage through the weathered zone of low HC downslope from the seep area. Changes in EC's in the saline-seep area from 1971 to the spring of 1977 are shown in table 8.

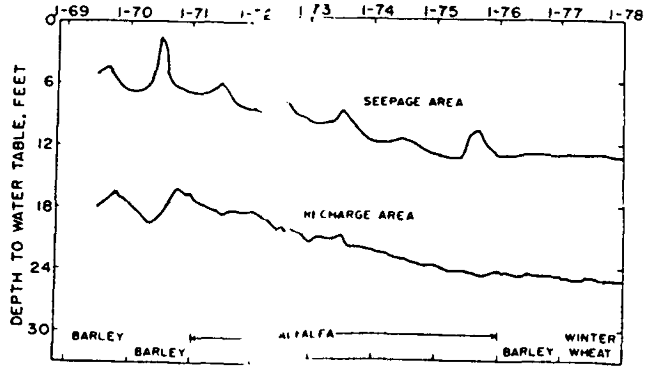

Figure 10.—Effect of alfalfa on lowering water table levels in the recharge and seepage area on the Hanford farm near Fort Benton, Mont.

Table 8.—*Electrical conductivities in the Hanford saline-seep area in 1971 and 1977*

Depth (feet)	Electrical conductivities	
	1971	1977
	Mmhos/cm	*Mmhos/cm*
0–1	21.3	4.3
1–2	13.9	6.3
2–3	13.6	12.2
3–4	12.9	15.0
4–5	15.8	17.3
5–6	12.2	14.9
6–7	13.1	12.5
7–8	14.0	12.4

With the drop in the water table in the seep area, salts had been leached below 2 feet and the land again supported acceptable crop growth. In 1977, winter wheat in the former saline-seep area produced 70 percent of the yield in the surrounding area. By 1978, barley yield in the former seep equaled yields in the surrounding area.

Example 2: In 1971, a saline seep on the Larry Tveit farm near Sidney developed in a field where the recharge area was in a crop-fallow system (Halvorson and Reule 1980). Observation wells were installed in the recharge and seepage area during the summer of 1971, and 'Ladak 65' alfalfa was planted on about 80 percent of the recharge area in 1973. Water table levels were monitored for 7 years (fig. 11).

The water table in the recharge and seepage areas began receding shortly after alfalfa was seeded. Except for a brief period in the spring of 1974 and 1975, when the water table was close to the soil surface, the surface of the seepage area was dry enough to cross with farm machinery. By 1977, the water table had dropped to about 8 feet in the seepage area. In the

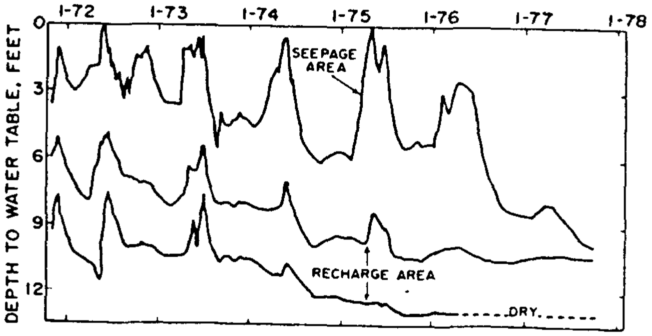

Figure 11.—Effect of alfalfa, seeded in summer 1973, on the net lowering of water tables in the recharge and seepage area on the Tveit farm near Sidney, Mont. Note the sensitivity (rise and lowering) of water table levels to seasonal precipitation.

recharge area, one observation well was dry by 1977, and the water level in the other well had dropped from 6 to 11 feet. Salinity (EC) in the surface 1 foot of soil in the seep area had decreased from 20 mmhos per cm in 1972 to about 5 mmhos per cm in 1978. In 1978, spring wheat planted in the center of the Tveit seep area yielded 37 bu per acre; barley, 85 bu per acre; oats, 94 bu per acre; flax, 9 bu per acre; and alfalfa, 2.6 tons per acre. These encouraging results show that once a seep area is controlled, the salt-affected area will support economical crop production after a period of natural leaching.

These examples of reclamation are impressive, but saline seeps would reappear if the drop-fallow system were to be reinstated. Data from experimental plots on the Hanford farm indicate that 6 years of crop-fallow have recharged the 15-foot soil profile to field capacity and that continued crop-fallowing on the whole field would reactivate the former saline-seep area. The rate of soil water recharge after alfalfa depends on: (1) cropping system, (2) quantity and distribution of precipitation, (3) soil type, (4) depth to impermeable strata, (5) recharge infiltration rate, and (6) depth to which the alfalfa had dried the soil profile.

Institutional Aids and Constraints

Except for small, uncomplicated seeps, most farmers and ranchers need help in diagnosing their saline-seep problem and in developing cropping systems and other control measures to combat the problem. An example of an uncomplicated saline seep would be a half-acre outbreak downslope from an easily identifiable 5-acre gravelly soil area. Farmers need help when the recharge area is on an adjacent farm. This situation requires the cooperative participation of both landowners. Wide recognition of the saline-seep problem and an understanding of its cause are essential to solving the problem on a watershed basis. Competent individuals or agencies, such as SCS, Extension Service (ES), or a specialized team, can assist by characterizing the problem and by recommending necessary control measures.

Saline seepage is not just an individual farmer problem. Any loss of farmland decreases the Nation's food and tax base. Furthermore, unless this salinization process is controlled, the salty water from seeps can pollute fresh surface waters and add to the salinity of ground water.

In recognition of the potential impact of the problem on the natural resource base, State and Federal agencies have funded research aimed at understanding and controlling saline seepage. The research agency of the U.S. Department of Agriculture, the Agriculture Research Service, along with the State experiment stations of the northern Great Plains States, and other State agencies have, since about 1970, conducted research that has defined the cause and extent of saline seeps and developed methods for their control. SCS, ES, and specialized State programs use this methodology for direct on-farm assistance in applying control practices. The Agriculture Stabilization and Conservation Service provides cost-sharing subsidies and other incentives to assist farmers in applying these practices. Programs similar to those in the United States are being employed in the affected Provinces of Canada.

Saline seeps do not respect property lines. A recharge area on one farmer's property can supply water to a discharge area on a neighbor's farm or the seep discharge can contaminate a stream or a neighbor's natural drainageway and farm pond. State and Provincial legislation may provide procedures for farmers to form salinity control districts and a means of achieving collectively what cannot be done individually. A notable example is the Triangle Conservaton District (TCD), which encompasses a nine-county area in north-central Montana. Through the joint efforts of farmers with county, State and Federal Governments, this district has instituted an active on-farm program to combat saline seepage. The TCD provides a technical field team to assist landowners in diagnosing saline problems on their own land and make control measure recommendations. Background information on the formation of the district and its operation is given in the appendix.

Such Federal legislation as the Rural Clean Water Act of 1977, the Great Plains Conservation Program, and the Agricultural Conservation Program, among others, all impinge on the saline-seep problem in terms of technical and financial assistance. It is not our intention to provide a detailed discussion of the institutional factors affecting saline-seep problems; however, local conservation districts and the Soil Conservation and Extension Services can provide information that can help coordinate the approaches and methodology to curb further damage from saline seepage.

The saline-seep problem has political implications, involving such questions as subsidies, crop-acreage allotments, and landowners' rights. Federal farm programs have sometimes adversely affected progress in controlling seeps by restricting the acreage that could be planted to small grains and thereby increasing the summer fallow acreage—one of the main contributors to the problem. There is the additional legal factor of water pollution. Saline pollution may violate the Water Quality Act of the State of Montana and Federal water pollution regulations (Harlow *1974*).

Summary

Saline seep is defined as: Intermittent or continuous saline water discharge at or near the soil surface downslope from recharge areas under dryland conditions, which reduces or eliminates crop growth in the affected area because of increased soluble salt concentration in the root zone. It is differentiated from other saline soil conditions by its recent and local origin, saturated root zone profile, shallow water table, and sensitivity to precipitation and cropping systems. The salts are primarily sodium, magnesium, and calcium sulfates. In the recharge area, water percolates to zones of low HC at depths of 2 to 60 feet below the soil surface and flows downslope to emerge at the point where the transport layer approaches the soil surface or soil permeability is reduced.

Crop production has been reduced or eliminated by saline seeps on about 2 million dryland acres in the northern Great Plains. This translates to $120 million of lost annual farm income. The saline-seep problem stems from surface geology, above-normal precipitation periods, and farming practices that allow water to move beyond the root zone. Most of the area is underlain by thick sequences of marine shale of Cretaceous age and nonmarine sediments of the Fort Union Formation. The marine shales and dense clay layers (Fort Union Formation) are nearly impermeable to water. Glacial till covers a considerable portion of both formations. The till carries a variable salt load depending on the point of origin. In the Colorado shale areas, percolating water picks up about four times the concentration of soluble salts as compared with that in the Fort Union areas.

Under native vegetation, grasses and forbs used most of the water before it had a chance to percolate to the water table. Many deep subsoils were comparatively dry. With sod plow-up, subsoils became wetter. Fallow kept the land relatively free of vegetation for months at a time. Beginning in the forties, soil water storage efficiency during fallow improved with the advent or large tractors, good tillage equipment, effective herbicides, and timely tillage operations. This extra water filled the root zone to field capacity and allowed some water to move to the water table and downslope to emerge as a saline seep. This process usually required several years. By the sixties, many deep subsoils and substrata were wet to field capacity and shallow (6 to 20 ft) water tables existed under large areas of cultivated land. Much of this water is salty, and water tables are rising. Certain soils with low infiltration rates may not serve as recharge areas.

Several factors that may individually or in combination contribute water to shallow water tables include: (1) fallow, (2) high precipitation periods, (3) poor surface drainage, (4) gravelly and sandy soils, (5) drainageways, (6) constructed ponds and dugouts, (7) snow accumulation, (8) roadways across natural drainageways, (9) artesian water, and (10) crop failures resulting in low use of stored soil water.

Several procedures for identifying the recharge area include: (2) visual, (2) soil probing, (3) drilling, (4) soil resistivity and electromagnetic techniques, and (5) soil survey. After the recharge area has been located, a management plan should be designed to control the saline-seep problem.

The most effective solution to the saline-seep problem is to use as much of the current precipitation as possible for crop or forage production before it percolates beyond the root zone. Forage crops, such as grasses and alfalfa, use more water than cereal grains and oil crops because they have deep root systems, are perennial, and have longer growing seasons.

For many saline-seep areas, the quickest and best way to solve the problem is to seed alfalfa in the recharge area. Where water and growing season are not limiting, alfalfa will use about 25 inches of water per year. The average yearly precipitation in the saline-seep susceptible areas of the northern Great Plains ranges from 10 to 18 inches. Alfalfa can use all current precipitation plus a substantial amount of water from the deep subsoil. On a deep soil with the shale layer at 50 feet, 'Beaver' alfalfa rooted to 24 feet in 5 years and used 41 inches of stored soil water plus cumulative precipitation. This permits storage of additional water that might otherwise percolate to the water table. After terminating alfalfa production, the recharge area should be farmed using a flexible cropping system. Fallow should be used sparingly because a return to the crop-fallow system will recharge the soil profile and reactivate the seep.

Where poor surface drainage in the recharge area is contributing to the saline-seep problem, surface drainage and land shaping should be performed to remove standing water. As a general rule, all water that stands in a recharge area more than 24 hours should be removed by surface drainage and land shaping. Once the waterflow from the recharge area to the seep has been stopped or controlled and the water table in the seep has dropped enough to permit cultivation, cropping in the seep area can begin. Research and farmer experience have shown that yields will generally return to normal in 3 to 5 years. Precipitation leaches the salts into the subsoil.

In saline-seep areas, observation wells are useful for monitoring water table levels during the control, reclamation, and post-reclamation periods.

In saline-seep susceptible areas, saline-seep control should be integrated into farm management along with fertilizer applications, weed, disease, and erosion control plans. Assistance can be obtained from the Soil Conservaton Service and the Cooperative Extension Service. In some areas, a saline-seep diagnostic team may be available to provide assistance.

The size of the saline-seep area and the recharge area on each farm will determine the magnitude of the control plan. On many farms, the saline seep-recharge area may be less than 5 percent of the total farm. This acreage should be set aside to be farmed more intensively than the rest of the farm. If the saline seep-recharge area includes a large percentage of the farm, the control measures should be expanded. In some cases, the whole farm may need to be included in the plan.

In any case, the affected area should be investigated in some detail. This investigation may include drilling wells and installing plastic pipe for water table monitoring. Based on saline-seep outbreaks and water table levels, a crop and land management plan can be devised to control saline seeps. The system should include flexible cropping, seeding alfalfa and grasses, and the use of drainage and land shaping where needed.

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Appendix

Triangle Conservation District

Prior to 1979, farmers in north-central Montana recognized the need to solve the increasingly serious problem of saline seepage, but lacked required knowledge and expertise. In 1979, 10 Soil Conservation Districts joined together to form the Triangle Conservation District (TCD). With help from the Conservation Districts Division of the Montana Department of Natural Resources and Conservation, the TCD drew up the necessary documents to become a legal entity under Montana codes. At that time, the TCD also received a grant of $241,000 from the Montana Renewable Resource and Development Program to fund the early work. This included purchase of a pickup truck, hydraulic truck-mounted soil sampler, and necessary supplies and equipment.

A three-person technical field team was hired to locate recharge areas, gather data, and furnish information to assist the farmer in controlling and reclaiming saline seeps. The headquarters office was located in Conrad, Mont. The program was set up for 2 years to serve as a pilot project to demonstrate the feasibility of using a trained field team to provide on-farm assistance. M. R. Miller, hydrogeologist with the Montana Bureau of Mines and Geology, and P. L. Brown, soil scientist, USDA-ARS, provided initial training of the team.

Each Soil Conservation district within the TCD receives farmer applications (fig. 12) and establishes priorities based on seep severity, access to recharge areas, and the probability of implementing a control plan once the recharge areas were identified. These applications are sent to the TCD office.

The field team procedure is outlined as follows: After examining the TCD Application for Assistance and locating the farm on available aerial photographs, SCS soil survey maps, and U.S.

TRIANGLE CONSERVATION DISTRICT
APPLICATION FOR ASSISTANCE

OWNER ______ **NO. OF SHEETS USED FOR THIS OPERATOR** ______

OPERATOR ______ **ADDRESS** ______

1. ARE THERE SALINE SEEPS OR OTHER SALTY OR ALKALI AREAS ON YOUR FARM OR RANCH? Yes ___ No ___ Suspected ___

IF YES OR SUSPECTED:

(1) ON FARMLAND: Use one sheet per SECTION
(2) Trace salty areas on aerial photos if possible

2. LOCATION OF SALTY AREAS: County ______ Twp ______ Rge ______ Sec ______

3. TYPE OF LAND AND ACREAGES OF SALINE SEEPS OR OTHER SALTY AND ALKALI AREAS:

A. Dry cropland ______ A.

B. Range & grass ______ A.

1. Recharge area on range, seep area on crop ______ A.
2. Recharge area on crop, seep area on range ______ A.

4. HOW LONG HAS AREA BEEN AFFECTED AND ACREAGE?

A. More than 25 yrs. ______ A.

B. More than 10 yrs. ______ A.

C. 5 to 10 yrs. ______ A.

D. Less than 5 yrs. ______ A.

5. GROWTH STATUS OF AFFECTED AREAS:

A. GROWING:
(1) Acreage in seep area 5 yrs. ago ______ A.
(2) Acreage in seep area 2 yrs. ago ______ A.
(3) Total acreage in seep area now ______ A.

B. Receding ______ A.

C. Stationary ______ A.

6. VEGETATIVE CHANGES IN AFFECTED AREAS (check):

A. Areas too wet to farm in most years ______

B. Wet soils and little affect on normal vegetation ______

C. Wet and decline of normal vegetation ______

D. Wet soils & normal vegetation dies while small or barren areas ______

7. CROPPING HISTORY OF SALINE SEEP AREAS (Include grass or hay in tons/a) Years from ______ to ______

A. Cropping sequence and yield/acre before SALINE SEEPS developed e.g. W. Wheat (30) fallow barley (45):

______

B. Cropping sequence and yield/acre on this SEC during SALINE SEEP development:

1. Seep Area ______
2. Non Seep Area ______

8. IN YOUR ESTIMATION WHERE IS THE RECHARGE AREA (check): ☐ On your land ☐ On your neighbors land

9. OTHER COMMENTS (observe effects - water quality, livestock, fish, greasewood, etc.)

______

______

Figure 12.—Triangle Conservation District, Application for Assistance form.

Geological Survey maps, the field team contacts the owner-operator. Together they examine the site and discuss cropping history, seep development, surface water accumulation, and cropping possibilities. Information is collected on the growth of the seep, location of ponded and flowing water, and plant growth patterns. Soils and topography, including gravelly and sandy areas and drainage patterns above the seep, are also noted. Road cuts are examined for shale, lignite, and gravel outcrops. Then with the aid of the aerial photographs and soil survey maps, in conjunction with the field examination, drilling sites are selected.

Drilling Procedure

Most drilling is done with auger bits, but core sampling drilling tools are used when needed. The wells are carefully logged with special attention given to sand, gravel, shale, clay, and lignite layers, and depth to water table. Most well depths range from 10 to 30 feet. Farm owner-operators are asked to assist with the drilling and logging activity to help them understand the problem. Not all sites require drilling. On sites with shallow soils, where the recharge area is evident, pickup-mounted equipment is used to sample to 5 feet.

Perforated plastic pipe is installed in wells selected for subsequent water table monitoring. Water table depth is measured immediately after the water table stabilizes, generally within 24 to 72 hours, and thereafter at monthly intervals. Wells are identified by operator and number.

Each owner-operator is supplied with a metal conduit-measuring pipe (1/2 inch by 10 feet) marked in one-foot increments, a 6- by 9-inch spiral notebook, and a foot rule. The operator measures and records depth to water table to the nearest one-half inch. This information is then sent to the TCD office on preaddressed postcards.

A team member later returns with well logs and water table information to specifically locate the recharge area. Agronomic and mechanical control measures are discussed with the farm operator. Based on the accumulated information, a comprehensive plan is written for controlling and reclaiming the seepage. This plan includes (1) a map showing recharge area and well location and (2) a situation statement listing the cause of the seepage and suggested solutions.

Copies of the plan are given to the farmer-operator, extension agent, and SCS district conservationist and reviewed with each. These key people are instrumental in implementing the plan. Because the operator is involved in both the investigative drilling and planning process, this helps ensure his or her understanding of the problem and willingness to implement the plan.

The team works closely with ARS, SCS, Montana Bureau of Mines and Geology, and the SCS Plant Materials Center at Bridger, Mont., to provide landowners with up-to-date recommendations on saline-seep control measures. The SCS field staff provides soil maps, aerial photographs, and technical assistance in implementing each plan. Other agencies cooperate in various phases of the TCD project as follows:

The Agricultural Stabilization and Conservation Service (ASCS) provides cost sharing for establishing alfalfa and grass on the recharge-discharge areas, as recommended by the TCD team. Adjustments are made in the Normal Crop Acreage (NCA) to allow county committees to grant an increased NCA so that farmers can recrop the recharge areas using the TCD plan and still remain in the Federal farm program.

Montana Department of State Lands provides a cost-share program to assist State land lessees in controlling and reclaiming saline seeps. The program requires lessees of State school trust lands to cooperate with the program when asked to do so by the TCD, subject to cancellation of the lease.

Montana Agricultural Experiment Station staff was involved in initial planning of the TCD and subsequent team training. Maps were provided that indicate recommended alternate crops for specific areas in north-central Montana that were suitable for intensified cropping.

Montana Cooperative Extension Service provides technical assistance through its county agents. A cropping system specialist helps develop intensive cropping system plans.

Accomplishments of Triangle Conservation District. Based on responses from the 10 Soil Conservation Districts, in the nine-county area, the TCD estimated there are 76,610 acres of saline seep in the District. There is a total 6,100,000 acres of dryland cropped area in the District. During the first year of operation, 178 requests were submitted for assistance, totaling 10,580 acres of seeps.

The field team began operation in January 1980 and by September 30, 1981, the TCD reported the following accomplishments:

	Number
Plans completed	103
Sites	171
Saline-seep acres	4,389
Recharge acres	20,250
Total acres planned	24,639

The 1981 Montana Legislature provided additional funding for operation of the TCD during fiscal years 1982 and 1983.

Glossary

Apparent electrical conductivity (EC_a)...A term used to express soil salinity as measured by the four-electrode resistivity or inductive electro-magnetic methods. The values are generally expressed millimhos per centimeter at 25°C.

Dryland...Land areas in low rainfall regions where crops are produced without irrigation.

Electrical conductivity (EC)...A method of expressing salinity. The EC values are proportional to salt concentration in the soil solution and are usually expressed in units of millimhos per centimeter at 25°C.

Fallow...Farming practice in which no crop is grown and plant growth is controlled by cultivation and/or herbicides.

Flexible cropping...A nonsystematic rotation of fallow and growing adaptable crops in a sequence. Decisions to crop or fallow are based on available soil water and expected growing season precipitation at prospective date of planting a crop.

Four-electrode method...Use of a resistivity meter with a Wenner array of four electrodes to measure apparent electrical conductivity (EC_a). Electrodes are inserted into the soil and equally spaced in a straight line. The electrode spacing and resistance measurements are used to determine changes in soil salinity with depth and geologic strata. The spacing between electrodes is approximately equal to depth of soil measurement. Also referred to as four-probe method.

Hydraulic conductivity (HC)...Capacity for transmitting water.

Inductive electromagnetic soil conductivity method...Use of an instrument to remotely measure bulk electrical conductivity (inverse of resistance) of the soil as a function of soil salinity. Some instruments provide continuous conductivity readings as they are transported over the terrain.

Infiltration...The downward entry of water into the soil.

Percolation...The downward movement of water through the soil, subsoil, and substratum.

Permeability...The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil.

Recharge area...A land area with permeable soils through which water percolates below the root zone, contacts a zone of low hydraulic conductivity, flows laterally, and eventually contributes to saline seepage.

Root zone...The depth of soil occupied by roots. This may be up to 10 feet for annual crops and up to 25 feet for some perennial crops.

Saline seep...Intermittent or continuous saline water discharge, at or near the soil surface downslope from recharge areas under dryland conditions, that reduces or eliminates crop growth in the affected area because of increased soluble salt concentration in the root zone. It is differentiated from other saline soil conditions by its recent and local origin, saturated root zone profile, shallow water table, and sensitivity to precipitation and cropping systems.

Water table...The upper surface of ground water or that level in the ground where water is at atmospheric pressure.

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