Saline-Seep Development on Upland Sites In the Northern Great Plains

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Summary

Saline seeps and their downslope wet areas cover several hundred thousand acres in the northern Great Plains; more seeps are appearing each year. Soil borings, hydraulic head measurements, chemical analyses, and climatic data show that seeps are caused by a combination of geologic, climatic, and cultural conditions—geologic because seeps occur where highly permeable, nearly horizontal, layers are truncated at shallow depths on the hillsides; climatic because recharge is from precipitation that infiltrates adjacent upslope land; and cultural because the prevailing small grain-fallow system of farming increases the opportunity for soil water to percolate past the root zone.

When the profile contains several highly permeable layers, two or more seeps can occur at different elevations on one hillside. Percolating water is salinized as it passes through the soil system, principally with sodium and magnesium sulfate salts. Nitrate concentrations are often so high that seep waters are unsuitable for domestic use. Calcium and chloride concentrations are characteristically low.

The seep problem can be solved either by intercepting the water above the seep and conducting it to a suitable outlet, or by using the soil water before it percolates past the root zone.

Introduction

Saline seeps are becoming increasingly prevalent in western North Dakota and other areas of the northern Great Plains. For saline seeps and their associated downslope wet areas to develop on nonirrigated upland sites in semiarid regions seems anomalous; salinity and seepage problems are usually associated with irrigated agriculture. Recently, seeps appeared on hillsides in fields that have been farmed for years (fig. 1).

The eventual outbreaks of some seeps could have been predicted from differences in crop growth that were visible from a distance; other seeps have appeared quite suddenly as unsuspecting farmers broke through the apparently dry surface soil with their machinery. The insidiousness of seeps can also be a problem for contractors. Figure 2 shows how easily machines mire down when the dry surface mantle is broken.

Regardless of whether seep outbreak is triggered naturally or mechanically, the seep usually remains untrafficable for months and often discharges so rapidly that water flows over the surface. Farmers have reported flows as great as 100 gallons per minute. Discharge water is usually saline, so the affected areas are progressively salinized. Seeps not only remove agricultural land from production because of wetness and soil salinity but also interfere with farming operations by dividing fields into small and usually odd-shaped parcels. As a consequence, farmers suffer direct financial losses because of seeps.

After initial surveys in 1968, the Agricultural Research Service began studies in 1969 with cooperation from Soil Conservation Service, the Agricultural Stabilization and Conservation Service, and the North Dakota Cooperative Extension Service to (a) determine the extent of the seep problem, (b) gain an understanding of the geology, hydrology, and chemistry of seeps, and (c) find ways by which existing seeps can be reclaimed and new seeps prevented. This paper deals primarily with objective (a) and general aspects of objectives (b) and (c).

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FIGURE 1.—A saline seep on a hillside site.

Extent of the Seep Problem

Saline seeps occur in land resource areas known as the Brown Glaciated Plain, Dark Brown Glaciated Plain, Rolling Soft Shale Plain, Black Glaciated Plain, Northern Rolling High Plain, Northern Smooth High Plain, Pierre Shale Plain and Badlands, and Rolling Pierre Shale Plain in North Dakota, South Dakota, Montana, and Wyoming. The general boundaries for these eight land resource areas (*1*)[2] are shown in figure 3. Saline seeps also occur in the provinces of Alberta and Saskatchewan, Canada. The normal climate for the region is semiarid (*21*).

FIGURE 2.—Nothing warned the operator that a potential saline seep existed beneath the surface.

Precipitation events and amounts are irregular, and more than half of the normal annual precipitation is received from April through July. As Norum and others (*16*) stated, "The climate, topography, soil, and native vegetation together encourage an agriculture broadly devoted to the production of spring wheat and range livestock." Cropland acreages for each of the eight land resource areas are listed in table 1. Land not in cropland is primarily in grassland and small acreages in forest and urban or public developments.

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[2] Italic numbers in parentheses refers to Literature Cited, page 9.

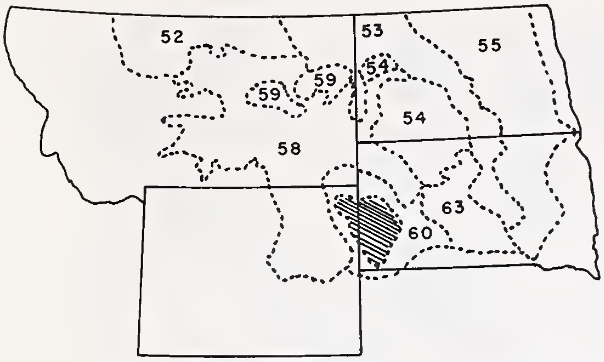

FIGURE 3.—Land resource areas of the four northern Great Plains states in which saline seeps are known to occur (*1*).

Estimates of the total amount of land actually occupied by seeps vary considerably. To broaden the base for an understanding of the extent of the seep problem, an extensive survey of Hettinger County in southwestern North Dakota was undertaken early in 1969. Hettinger County is near the center of the Rolling Soft Shale Plain land resource area (54 in fig. 3). A questionnaire was sent to each farmer in the county along with an aerial photograph of his farm. Each farmer was requested to provide the location of each seep on his farm by marking the photograph, an estimate of acreage affected by each seep and whether the affected area was increasing or decreasing in size, and the year when the seep first became evident.

Of the farmers who responded, 80 percent reported that they had seeps on their farms (table 2); of the 899 seeps that were listed, one seep was affecting 80 acres and 84 were affecting 10 acres or more. Hence, most seeps in Hettinger County were affecting less than 3 acres each. The farmers recorded the affected areas to be increasing for 57 percent of the seeps and decreasing for only 3 percent.

TABLE 1.—*Total area and approximate cropland area for land resource units in the Northern Great Plains (1)*

Land resource unit			
Number	Name	Total	Cropland
		Millions of acres	
52	Brown Glaciated Plain	12.6	6.3
53	Dark Brown Glaciated Plain	18.6	10.2
54	Rolling Soft Shale Plain	13.9	4.9
55	Black Glaciated Plain	26.5	18.5
58	Northern Rolling High Plain	42.5	2.1
59	Northern Smooth High Plain	5.8	1.2
60	Pierre Shale Plains and Badlands	8.6	.6
63	Rolling Pierre Shale Plain	8.8	1.8
	Total	137.3	45.6

Areas represented by the returned questionnaires were shaded on a county map, and reported seep sites were marked (fig. 4). The map shows that seeps are randomly distributed throughout the county. A plot of reported seep locations on the Hettinger County General Soils Map (*17*) indicated that the seeps were associated with several different soil types but about 60 percent of the seeps were associated with the Morton (TYPIC ARGIBOROLL) and Vebar (TYPIC HAPLOBOROLL) soil series. Both of these soils developed from the Tongue River and Cannonball formations of the Fort Union Group of Paleocene Age (*9*). The Tongue River formation, younger of the two, is a continental (nonmarine) deposit and commonly displays alternate layers of lignite, shale, and sandstone or siltstone (*15*). The Cannonball is the oldest geologic formation within the Fort Union Group and was deposited in tertiary seas. It interfingers with the lignite-bearing Tongue River formation (*13*).

In 1968, seeps occupied about 1 percent of the land reported in the Hettinger County survey (table 2); however, seeps are primarily associated with cropland rather than natural grasslands. Approximately 234,000 acres of cropland were represented by the questionnaires and the 3,165 acres of seeps represent 1.4 percent of that cropland. Seeps are a problem primarily in the northwestern corner of the Black Glaciated Plain

TABLE 2.—*Summary of information obtained from the Hettinger County, N. Dak., survey*

Questionnaires sent	701
Questionnaires returned	311
Percent of farmers reporting seeps	80
Total acreage of Hittinger County	710,872
Acreage reported	338,300
Cropland reported	233,580
Number of seeps reported	899
Estimated acreage covered by seeps	3,165
Percentage of affected areas that are increasing	57
Percentage of affected areas that are decreasing	3
Percentage of seeps appearing since 1960	51

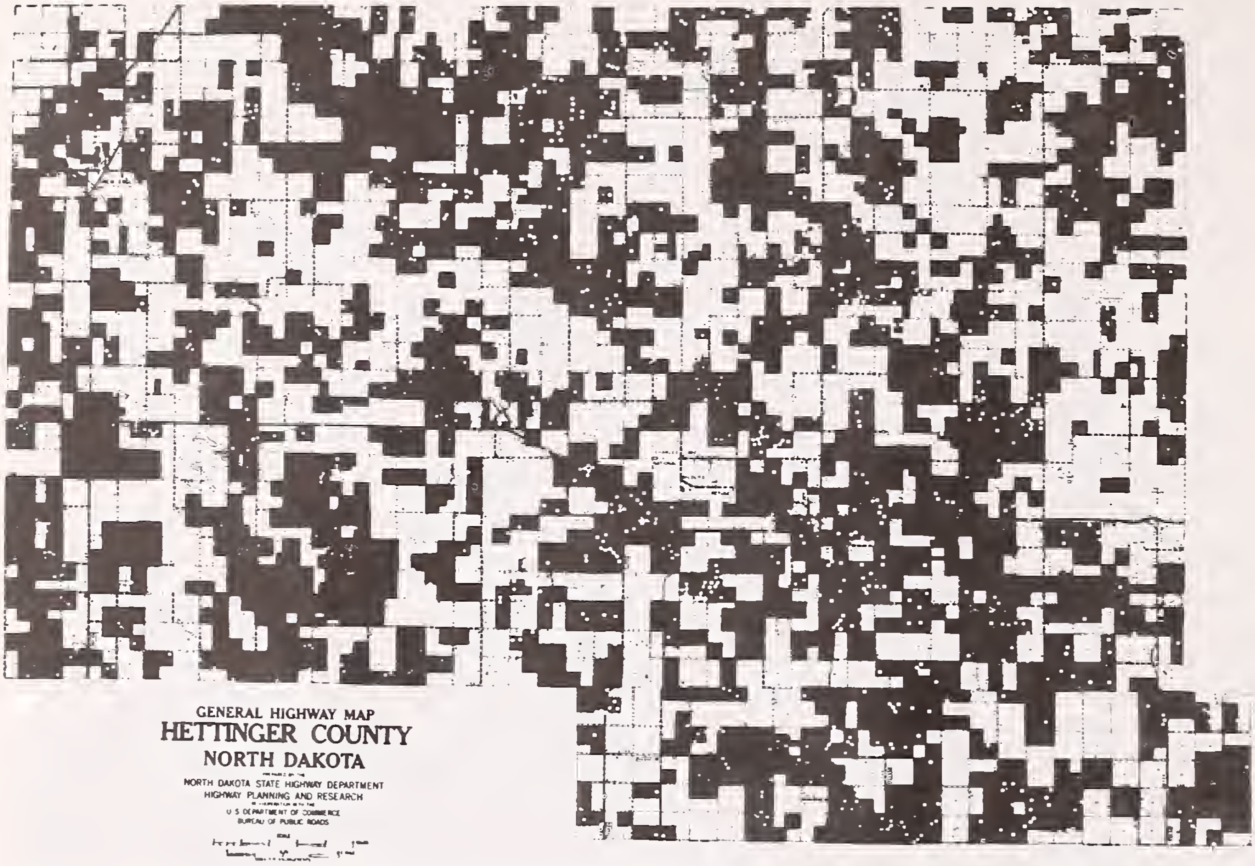

FIGURE 4.—Map of Hettinger County, N. Dak. showing, in black, the lands represented by returned questionnaires. The location of each seep is shown by a white dot.

(land resource area 55). To avoid possible bias, the Black Glaciated Plain is excluded from the following considerations, leaving a cropland base of 27,100,000 acres in the other land resource areas (table 1).

Assuming that Hettinger County data are representative for the 7 remaining land resource areas of the region, more than 380,000 acres (1.4 percent of 27,100,000 acres) of agricultural land probably were affected by saline seeps in 1968. This estimate may even be conservative because other surveys have indicated as much as 3 percent of the landscape was affected by seeps in Montana (*6*). More seeps have developed since 1968, but the increased acreage has not been evaluated in North Dakota. Surveys in Montana indicate that seep-affected areas are increasing at a rate of about 10 percent per year.[3] Loss of crop production from 380,000 or more acres represents a loss of farm income of millions of dollars annually. In addition, disruption of field boundaries by seeps increases production costs on the remaining cropland.

Physical Characteristics

Numerous seeps in western North Dakota were discharging saline water where nearly horizontal layers of lignite coal or lignitic materials were truncated near the hillside surface. Several seeps were sometimes found along a contour, indicating that a given lignite layer may have several discharge points. Occasionally, two or more seeps were found at different elevations on the landscape; this indicated the truncation of two or more different lignite layers.

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[3] A comprehensive plan for the control and reclamation of saline seep in Montana—A report to the governor of Montana. The Governor's Emergency Committee on Saline Seep—Robert Anderson, Chairman. December 1973.

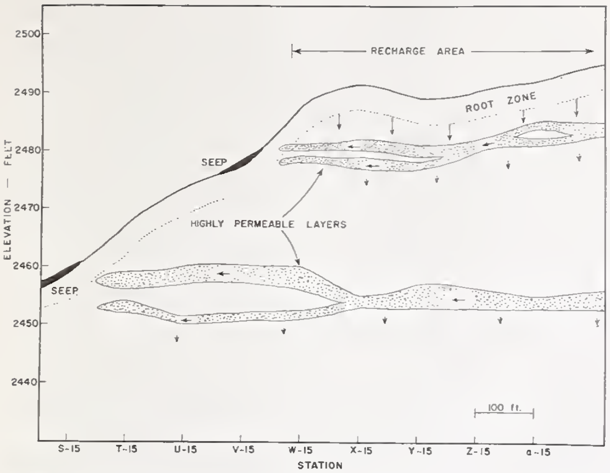

FIGURE 5.—Landscape cross section through two saline seeps in Hettinger County, N. Dak. showing truncated layers that conduct saline water to the hillside surface.

The flow system must be known before either the physical or the chemical characteristics of the saline seep problem can be understood. Ground water flow systems can be either regional or local. Regional flow implies that the water discharged from a particular seep entered the ground water at a point many miles from the seep. Local flow implies that water discharged from a seep entered the ground water at a point on the landscape adjacent to, but at a higher elevation than, the seep. In other words, with a local flow system, the recharge area may be only a few hundred yards upslope from the seep.

A site in Hettinger County that encompassed several seeps was selected for detailed study in 1969. Soil borings showed that the profile contains several nearly horizontal layers of lignite coal or lignitic material. A landscape cross section with two seeps at different elevations is presented in figure 5. The lower seep has been discharging for several years. The upper seep appeared in 1969. Both seeps discharge so rapidly that water flows over the soil surface.

Hydraulic head data showed that the seeps are sustained by local recharge. The process starts when precipitation falls on adjacent upslope land surfaces and infiltrates into the soil. When this soil water is not used by plants or evaporated from the soil surface, it remains stored in the root zone or percolates downward. Downward percolating soil water is intercepted by permeable lignitic layers underlain by less permeable layers and is conducted horizontally to the discharge point to cause a seep.

At other locations in the northern Great Plains, the horizontal conducting layers are clinker, fractured shale, and sometimes sand and gravel lenses. In northeastern Montana, Halvorson and Black (*14*) found that even though the soil profile sometimes contained lignitic and sandy layers, seep water was often conducted along the more permeable contact layers between glacial till and more dense clay substrata. In such cases, seeps occurred where those permeable contact layers were either truncated or dammed near the hillside surface by less permeable glacial till to cause a perched water table. They concluded, as we did, that seeps are sustained by local recharge.

The Hettinger County Survey (table 2) indicated that discharge areas or seeps directly occupied about 1.4 percent of the cropland in 1968. Of the remaining cropped landscape, some parts probably are more effective recharge areas than others because they are coarser textured, have greater infiltration capacities, or occupy a favored position on the landscape for infiltration. However, this recognition of differences in recharge effectiveness does not negate the possibility of deep percolation beneath parts of the landscape occupied by fine-textured soils.

Halvorson and Black (*14*) report seep and recharge areas are present in landscapes dominated by clay loam soils. Large amounts of deep percolation are not required for seeps to develop. For example, assuming that each acre of seep is sustained by 40 acres of effective recharge area and that only 0.5 inch of water per acre per year percolates past the root zone in the recharge area, the net result is an addition of 20 acre-inches of water per year at the discharge site. Addition of 20 inches of water to precipitation certainly provides enough water to create a seep problem.

Chemical Characteristics

Soil parent material releases soluble salts during normal weathering and soil-forming processes. As the downward percolating water moves through soils and underlying strata, its burden of dissolved salts increases; therefore, seep discharges are saline.

TABLE 3.—*Chemical analyses for water samples collected from five seeps in Hettinger County, N. Dak.*

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

[1] SAR=Sodium-adsorption-ratio$=Na/\left(\frac{Ca+Mg}{2}\right)^{1/2}$. Chemical concentrations are in meq/liter.

[2] SO_4=(Sum of cations)—(sum of determined anions).

[3] Not determined.

Chemical analyses of water from five seeps are presented in table 3. Salinity levels of the seeps varied considerably but the principal salts in all samples were sodium and magnesium sulfates. Nitrate concentrations were high, and chloride concentrations were low. Similar results were obtained in Montana (*14*). Three types of salinity hazard are evident from the data in table 3—those related to soluble salt concentrations, to high sodium concentrations, and to ion toxicity. Each type has a different significance to agriculture and deserves a brief discussion.

The electrical conductivity (EC) of a water or soil solution, commonly expressed in millimhos per centimeter (mmhos/cm), is proportional to the concentration of dissolved salts in that solution. Salts dissolved in a soil solution increase the osmotic concentration of that solution and make the soil water less available to plants. When the salt concentration is great enough, desirable plants cannot survive even with their roots in an essentially saturated soil.

Crops differ in their tolerance to salinity. For example, wheat and oat yields are reduced when EC of the saturation extract for root-zone soil (equivalent to EC of the soil solution in the saturated root zone) exceeds about 7 mmhos/cm (*4*); corn and alfalfa yields suffer when the EC exceeds about 5 mmhos/cm; but barley can tolerate an EC of 10 or 12 mmhos/cm (*3, 4*). Yields of even salt-tolerant crops are reduced appreciably when the EC of the saturation extract is greater than 12 to 16 mmhos/cm (*22*). Evaporation and transpiration concentrate salts in the soil solution by removing water and leaving the salts behind; therefore, affected areas quickly become barren when seep discharges have electrical conductivities as high as 6.5 mmhos/cm.

High sodium concentrations in waters applied to soils are of concern because the soil-exchange complex reacts chemically with the cations in the soil solution (soil water) it contacts. The principal cations involved in the chemical reaction are calcium (Ca), magnesium (Mg), and sodium (Na). The equilibrium condition for the soil-exchange complex depends on the relative concentrations of these cations in the soil water.

Soils that have more than 15 percent of their exchange sites occupied by sodium are called sodic soils. Sodic soils characteristically have poorer tilth and lower permeability than nonsodic soils. The sodium-adsorption-ratio (SAR) for a water indicates the sodium hazard associated with the application of that water to soils (*22*). High sodium waters are called "soft" waters and high calcium and magnesium waters are called "hard" waters, but "hard water makes soft land and soft water makes hard land" (*20*). Although the SAR's shown in table 3 are not dangerously high, the SAR of a solution increases as water is removed by evaporation (*19*). Therefore, sodic soil conditions could develop in seep-affected areas.

High nitrate (NO_3) concentrations in some seep water represent a potential health hazard to people and livestock. The maximum nitrate concentration recommended for human consumption is 45 p/m or 0.7 meq/liter (*10*). Maximum concentrations recommended for livestock use have not been established, but cases of possible nitrate poisoning have been reported. Five and 6 meq/liter of NO_3 equal 310 and 370 p/m, respectively.

The source of the nitrate in seep waters has not yet been established, except that the nitrate is leached from within the local recharge system. As such, it can come either from the oxidation of exchangeable ammonium in the geologic materials below the root zone or from the mineralization of organic nitrogen in the root zone. Power and others (*18*) have shown that the underlying geologic materials contain considerable exchangeable ammonium that is readily oxidized to nitrate. They report nitrate-N concentrations ranging from essentially zero near the surface to 30 to 40 p/m below the root zone of mixed prairie grasses. Assuming 30 p/m of NO_3-N and a bulk density of 1.3 g/cm^3, the volumetric water content of the substrate would be about 46 percent if the NO_3-N concentration of the soil solution were 6 meq/liter. Such a water content is feasible with fine-textured materials.

Mineralization of organic nitrogen in the root zone is also a possible source of nitrate for seep waters. If only 10 pounds of N per acre were leached from the root zone each year by an equivalent surface depth of 0.5 inch of water, the NO_3-N concentration of that solution would be approximately 6 meq/liter. The same NO_3-N concentration would prevail in the percolating soil solution if 30 pounds of N per acre were leached by 1.5 inches of water during a fallow year. Both leaching combinations are reasonable.

Climatic and Cultural Influences

Why are seeps occurring now where they have not been before? There are two probable answers: one is related to the natural precipitation cycles of semiarid regions, and the second is related to prevailing agricultural practices. Long-term (66-year) and recent precipitation data for Mott in Hettinger County are summarized in table 4. Particularly note the difference between average precipitation for the 11 years from 1962-72 as compared with the long-term average. Not only has this area received above-normal precipitation during this period, but approximately 80 percent of that increased precipitation has occurred during April, May, and June.

Precipitation averages do not necessarily tell the full story because they do not give information about storm intensities and runoff or infiltration; however, increased precipitation could result in increased infiltration into the soil system and thereby increase the opportunity for percolation past the root zone. This is particularly true if precipitation is high during spring months when the land is fallowed and the water storage capacity of the root zone is most likely to be satisfied by recent snowmelt. With generally above-normal precipitation in many areas of the northern Great Plains during the past decade, the seep problem is understandably widespread; questionnaire responses indicated that 51 percent of the seeps in Hettinger County had developed since 1960 (table 2).

The second answer to why seeps are now occurring is found in the prevailing agricultural system. Spring wheat and other small grains are the principal crops grown in this region. Crop success often depends on whether enough water is stored in the soil profile to supplement precipitation received during the growing season. Greater supplies of stored water at planting have consistently produced greater yields of wheat (*8*). Therefore, fallow was adopted many years ago as a standard practice for small grain production over most of the northern Great Plains.

Cole and Mathews (*7*) showed that fallow permits the wetting of the entire root zone more often than continuous cropping, and increases the number of times when water reaches the underlying subsoil. Most cropland is fallow every other year, and some fields have occasionally been fallowed 2 consecutive years. Frequent cultivation of fallowed land for weed control maintains soil and residue mulches that are effective evaporation barriers (*24*). As a consequence, plants are actively transpiring water only 2 or 3 months out of each 2 years. During those 2 or 3 months, spring wheat can effectively extract soil water from only the top 3 to 5 feet of the soil profile.

Bauer and Young (*2*) found that when more than 6 inches of available soil water were stored to a depth of 5 feet at seeding time, significant amounts of available water remained in the soil on both well-drained and poorly drained sites when the spring wheat was harvested. When available soil water is present within the root zone at the end of the crop season, the probability of deep percolation during the following fallow season is enhanced.

TABLE 4.—*Precipitation data for Mott in Hettinger County, N. Dak.*[1]

	Annual	April, May, June
	Inches	*Inches*
1906–72 average	14.4	6.7
1962–72 average	17.5	9.4
1970	19.5	10.9
1971	19.1	11.0
1972	20.3	9.7

[1] From Climatological Data, North Dakota, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Although fallow does increase the probability of increased grain yields during the cropped year, it is an inefficient conserver of precipitation (*5, 11, 12, 23*). In fact, Haas and Willis (*12*) found that fallow conserved only about 20 percent of the precipitation that was available at Mandan, N. Dak., during the fallow period. The opportunity for water to percolate past the root zone is certainly increased by the use of fallow. The authors state, however, that it is the judicious use, not the categorical elimination, of fallow that this analysis suggests. Cropland should not be fallowed if stored available soil water at seeding time and expected growing season precipitation would probably result in water loss by deep percolation.

Conclusions

Saline seeps and their associated downslope wet areas occupy an estimated 100,000 acres of cropland in North Dakota and several hundred thousand acres of cropland in the northern Great Plains.

The development of saline seeps on hillside sites depends upon the proper combination of geologic, climatic and cultural conditions. Seeps occur where highly permeable, nearly horizontal, layers of lignite, clinker, gravel, fractured shale, or other suitable material are truncated at a shallow depth on a hillside. Local precipitation is the source of water. Seep recharge results from precipitation that infiltrates adjacent upslope portions of the landscape, percolates past the root zone, is intercepted by the permeable layer, and then is conducted laterally to a discharge point. The effects of cultural practices are expressed in the grain-fallow system of farming that increases the opportunity for water to percolate past the root zone because the crop is actively transpiring only 2 or 3 months of each 24 months.

Seep waters are generally saline, with electrical conductivities greater than 6 mmhos/cm. The predominant salts are sodium and magnesium sulfates; calcium and chloride concentrations are characteristically low. Nitrate concentrations in seep waters are frequently too high for domestic use.

The seep problem can be solved by either collecting the water immediately above the discharge point and conducting it to a suitable outlet or eliminating the source of recharge. If the water is intercepted above the seep, an outlet must be available. Outlet considerations must include not only easement for transport of drainage water across intervening lands, but also the effect that those drainage waters might have on the quality of streams or reservoirs that they might subsequently enter.

Elimination of the source of recharge requires that evapotranspiration, or infiltration, or both, be managed on the recharge area to reduce or eliminate water percolation past the root zone. Beneficial use of all available water in the recharge area is an idealistic goal because of the climatic variability in the northern Great Plains. For complete use of water, the root zone must have enough storage capacity to hold all precipitation that infiltrates through the surface until the crop can use that water. The more realistic goal would be to reduce average percolation to the level that the subterranean system can absorb. Thus, horizontal flow would be eliminated and seeps would not develop.

Reduction or elimination of percolation past the root zone of recharge areas requires that recharge areas be identified so they can be treated agronomically and that those treatments be compatible with uses that society imposes on adjacent land. Many combinations of land use and farming practices might be effective. The following is an example based on available crop choices: continuous annual cropping uses more water beneficially than does a crop-fallow rotation, many introduced perennial grasses use available soil water longer in the growing season than do cereal crops, and alfalfa uses water the entire growing season and has a deep root system that can extract water from greater depths. Therefore, alfalfa would intercept and use more of the infiltrated water than any other agricultural crop common to the region, except possibly for well-managed natural grasslands.

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